Rijkswaterstaat
Ministry of Infrastructure and the Environment

Sustainable Development

Energy & Materials

MSc. thesis

The Optimum Between Solar Energy Production and The Ecological Function Directly Next to Highways

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A case-study of the Dutch highway A37 from intersection Hoogeveen to the German border

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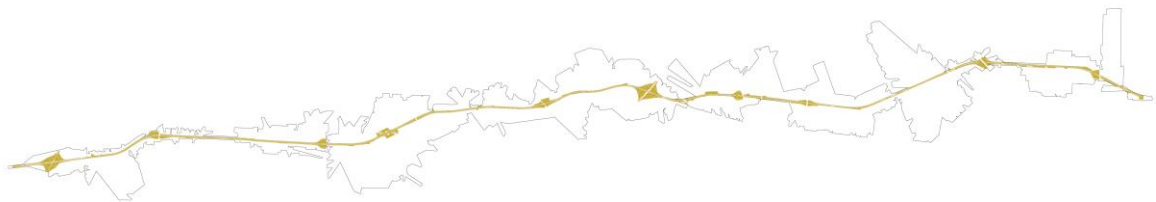
Nederlandse samenvatting

Introductie

Klimaatverandering is iets van alle tijden en zal ook in de toekomst voorkomen. Echter gaat de huidige klimaat verandering op een zeer hoog tempo en bovendien is het veroorzaakt door menselijke activiteiten. Aan de andere kant wordt het besef dat een energietransitie, naar een meer duurzame samenleving, nodig is steeds groter. De Europese Unie heeft in 2010 het 10-jaren plan 'Europa 2020' opgesteld. In dit jarenplan staan verschillende duurzaamheidsdoelen vastgesteld, aan welke door elk lidstaat moet worden voldaan. Voor Nederland betekent dat onder andere dat het in 2020 14% van haar energie duurzaam moet opwekken. Echter wekte het in 2015 pas 5,8% van haar energie duurzaam op en het ziet er op dit moment niet naar uit dat Nederland haar doelen gaat behalen.

Rijkswaterstaat (RWS) herkent de urgentie van het probleem en wil graag een steentje bijdragen. Om deze redenen heeft de organisatie haar eigen duurzaamheidsdoelen opgesteld. Het uitvoeringsorgaan van het ministerie van infrastructuur en milieu is van plan om in 2020 20% minder broeikasgassen uit te stoten t.o.v. 2009, bovendien wilt het in 2030 100% duurzaam zijn. Een progressief plan, maar haalbaar als er genoeg stappen op tijd gezet worden. Eén van die eerste stappen is het plaatsen van zonnepanelen op het areaal van RWS. RWS beheert o.a. de snelwegen in het land en ziet de berm van sommige snelwegen als een potentieel interessante locatie voor het opwekken van zonne-energie. De A37 van Hoogeveen tot aan de Duitse grens is zo'n snelweg. Echter zijn er nog een hoop vraagtekens bij dergelijke projecten. Enkele voorbeelden zijn: Hoe gaan de zonnepanelen de verkeersveiligheid beïnvloeden? Wat zijn de kosten en baten van het project? Hoe beïnvloeden de zonnepanelen die ruimtelijke kwaliteit? Hoe wordt de natuur en de ecologische functie van de berm beïnvloedt? Dit laatstgenoemde is nog niet onderzocht en daarom is er besloten om dat te onderzoeken en te beschrijven in deze scriptie.

Zoals eerder beschreven is de A37 een snelweg met een hoog potentieel voor de productie van zonne-energie (fig. 1). Dit komt mede door de brede bermen, open karakter en de oost-west oriëntatie van de snelweg. Om deze redenen is het besloten om deze snelweg als zogenaamde 'case-study' te gebruiken. Aan de hand van de gebruikte onderzoeksmethode kunnen dan vergelijkbare onderzoeken gedaan worden bij andere snelwegen. Voor de case-study had RWS al drie architectenbureaus ingeschakeld om een eerste ontwerp te maken. Een daarvan van Studio Marco Vermeulen (SMV). Het ontwerp van SMV heeft een hoge elektriciteitsproductie en zorgt voor het behoudt van de hoge ruimtelijke kwaliteit van de A37. Om deze redenen is ervoor gekozen om dit ontwerp als startpunt te gebruiken. Gebruikte oppervlakten, rendement van de panelen, grootte per paneel en andere factoren zijn op dit ontwerp gebaseerd.



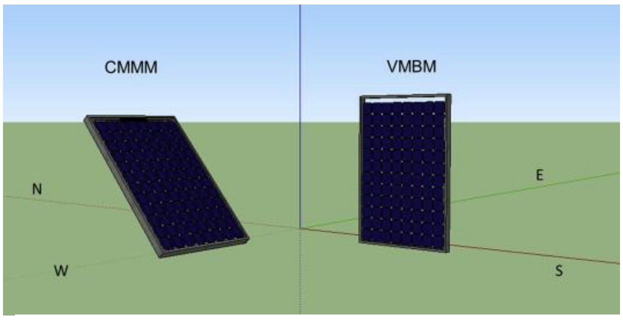
Figuur 1: A37, inclusief areaal grenzen. Totale oppervlak = 313 ha. (bron: Studio Marco Vermeulen, 2016)

Om voldoende duidelijkheid te verkrijgen is de volgende onderzoeksvraag opgesteld:

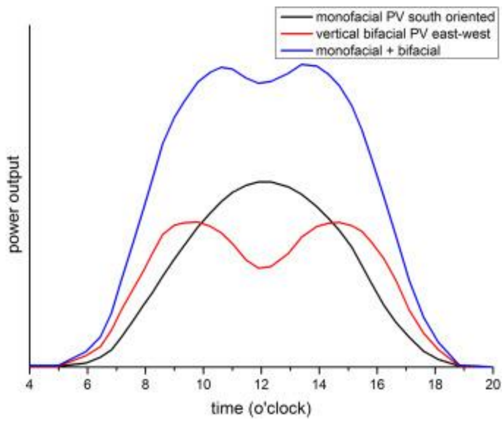
Hoe wordt de ecologische functie van bermen beïnvloedt door zonne-energie productie en welke aanpassingen zijn er mogelijk om de ideale middenweg te vinden tussen elektriciteitsproductie en de ecologische functie in bermen?

Om antwoord te vinden op deze vraag wordt er allereerst bekeken wat de huidige ecologische functie is. Vervolgens wordt er bepaald hoe deze functie wordt beïnvloed door de zonnepanelen. Daarna worden er verschillende aanpassingen aan het zonnepark of aan de panelen zelf voorgesteld die ervoor zorgen dat de impact op de ecologische functie verkleind wordt. De vierde stap in het onderzoek is om te bepalen wat deze aanpassingen voor gevolgen hebben voor de elektriciteitsproductie en wat de financiële consequenties zijn van de aanpassingen. Als laatste is de elektriciteitsproductie afgezet tegen de ecologische functie, waarna er een optimum bepaald kan worden op basis van de prioriteiten van het ontwerp. Dit alles is samengevat in een conceptueel raamwerk dat bijgesloten zit bij dit document (bijlage A (NL)).

Het onderzoek vergelijkt in haar zoektocht naar het optimum twee typen zonnepanelen. Een type daarvan is de bekende conventionele platliggende mono-faciale zonnepanelen (CMMM). Zoals de naam al doet vermoeden zijn dit platliggende zonnepanelen die aan één zijde van de module energie opwekt. Het andere type is de rechtopstaande bifaciale zonnepanelen (VMBM) (fig. 2). In tegenstelling tot de CMMM staat dit type verticaal, beschikt het over een transparant frame en kan het aan beide zijden energie opwekken. De afkortingen zijn gebaseerd op hun Engelse namen; Conventional Mounted Monofacial Modules en Vertical Mounted Bifacial Modules. De CMMM heeft een hoge piekproductie rond het middaguur, waar de VMBM eerder op de dag een hoger rendement kan behalen, echter kent de productie een kleine afname rond het middaguur (fig. 3). De dagelijkse elektriciteitsproductie van de VMBMs is enkele procenten langer t.o.v. de CMMM, echter heeft de lagere piekproductie als voordeel dat er minder stress op het net komt, wat de kosten van elektriciteit doet afnemen.



Figuur 3: Beide vergeleken zonnepanelen.



Figuur 2: Opbrengstcurve voor beide typen zonnepanelen

De ecologische functie

Op basis van interne documenten binnen RWS en gegevens van de Nationale Databank voor Flora en Fauna is er een overzicht gemaakt van welke natuur er voorkomt in de berm van de A37. Hieruit is gebleken dat er 14 vegetatietypen en 67 verschillende diersoorten voorkomen. De 67 verschillende diersoorten zijn vervolgens in zes fauna-groepen onderverdeeld.

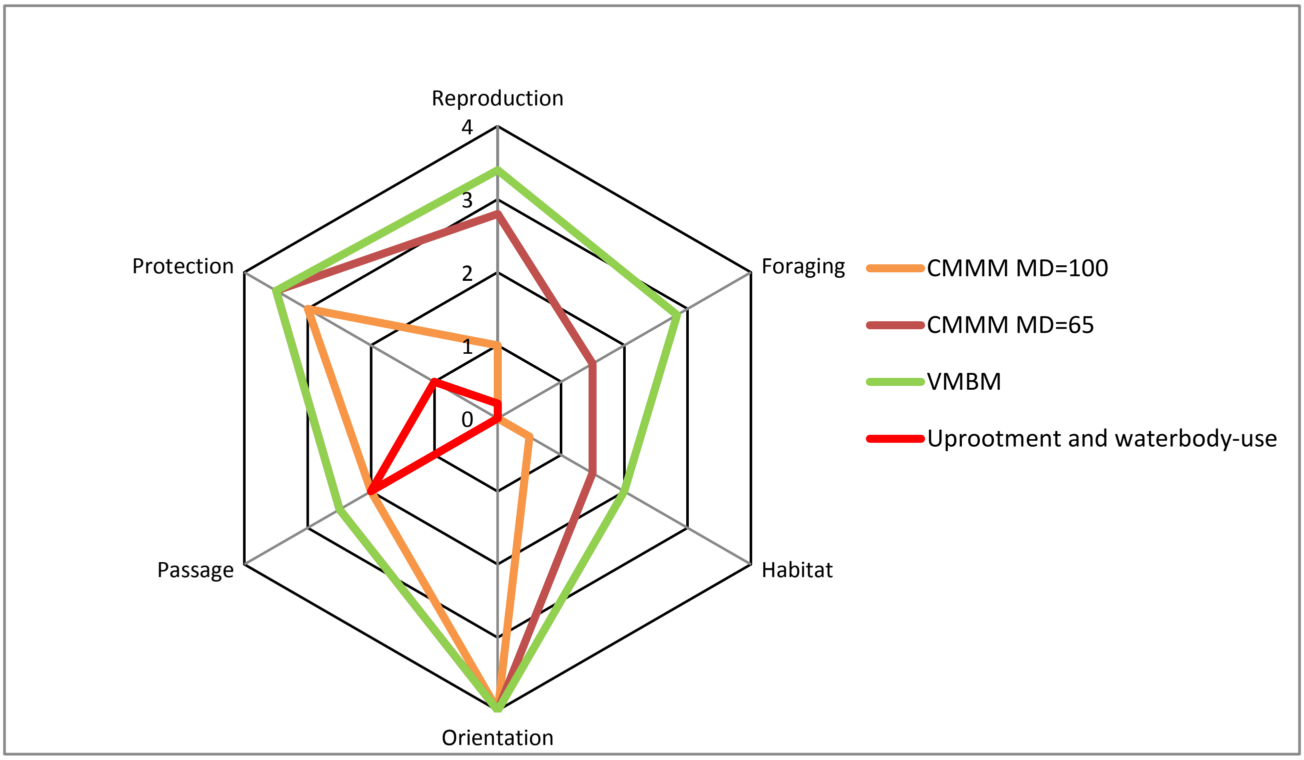
Verreweg het grootste deel van de berm wordt bedekt door schrale graslanden (74,4%). Een ander prominent vegetatie-type is ‘loofbos op zand’, wat ruim 14% van het areaal bedekt. Het overige deel wordt bedekt door water-gerelateerde vegetaties, heide, plant-specifiek vegetatie en taluds. De zes gevormde fauna-groepen zijn: Zoogdieren (kleine en grote zoogdieren), Vogels (zang, roof en watervogels), Vleermuizen, Amfibieën, Reptielen en Vlinders.

Vervolgens is er op basis van interviews, met ecologen en andere experts, en wetenschappelijke literatuur een overzicht gemaakt van de ecologische functies die de berm biedt aan de fauna. Dit is alleen gedaan voor de fauna, omdat vegetatie aan de basis staat van elk ecosysteem op land, dus ook die van de bermen. Dit wil zeggen dat zodra er een volwaardige ecologische functie is voor fauna, er automatisch ook een ecologische functie aanwezig moet zijn voor flora. De onderscheiden ecologische functies voor fauna zijn: foerageergebied, habitat, migratie-corridor, oriëntatie, protectie en voorplantingsgebied. Voor de specifieke ecologische functies per fauna-groep, raadpleeg bijlage B (NL). Verder hebben de bosachtige gebieden nog een extra ecologische functie in relatie met het achterliggende grootschalige akkerlandschap. Voor veel fauna levert de oplopende vegetatiehoogte de ideale overgang van foerageergebied op de akkers tot aan bescherming in de bosachtige gebieden.

De invloed van zonnepanelen

Voor het bepalen van de invloed op de ecologische functie van zonnepanelen is er een evaluatie gedaan van beide types. Deze kwalitatieve evaluatie is gebaseerd op de mening van experts en ecologen en op gevonden informatie in de wetenschappelijke literatuur. Alle functies kregen per gebruikmakende fauna-groep een score variërend van 0 tot 4. 0 betekent dat de functie volledig verdwenen is en 4 houdt in dat de functie onaangetast blijft of zelfs gestimuleerd wordt.

Hieruit kwam naar voren dat beide typen de ecologische functie negatief beïnvloeden. Dit wordt veroorzaakt door de ruimtelijke inname van de panelen, het weerhouden van zonlicht bij het bereiken van de bodem, het onevenredig verspreiden van regenwater dat op de modules valt en de interactie met dierlijke activiteiten. Voor de resultaten verder besproken worden moeten er nog wel drie kanttekeningen geplaatst worden. Ten eerste is er apart gekeken naar wat de invloeden zouden zijn als er ook besloten wordt om de loofbossen te rooien en de waterlichamen droog te leggen. Er wordt namelijk niet in het rapport van SMV beschreven of dit het geval is. Verder plant SMV 117 ha van de berm in voor elektriciteitsproductie, dit komt overeen met 37% van het totale areaal. Echter staat er niet beschreven welke 117 ha worden gebruikt. Ten derde beschrijft SMV in hun rapport dat 105 ha bedekt wordt met CMMMs met een dekkingsgraad van 100%, oftewel elk stukje berm wordt bedekt met zonnepanelen, en 12 ha worden bedekt met CMMMs met een dekkingsgraad van 65%.



Figuur 4: De kwalitatieve scores voor CMMM (inclusief het gebruik van bosgebied en waterlichamen, CMMM 100% (exclusief bosgebieden en waterlichamen), CMMM 65% en de VMBM.

Uit de evaluatie (zie fig. 4) blijkt dat de delen van de zonneweide die bedekt worden met CMMMs met een bedekkingsgraad van 100% de meeste negatieve gevolgen hebben, zeker als het areaal waar nu de loofbossen op groeien en de waterlichamen zich bevinden ook gebruikt worden. Mocht dit laatste inderdaad het geval zijn dan is de ecologische functie verwaarloosbaar en zal er nagenoeg geen ecologische activiteit meer zijn. Mochten deze gebieden niet gebruikt worden dan zal het zonnepark met een dekkingsgraad van 100% weinig ecologische functies aanwezig blijven. Met name het functioneren als habitat, foerageergebied en voortplantingsgebied zullen zeer negatief beïnvloed worden. Dezelfde functies zullen ook negatief beïnvloed bij de delen waar een dekkingsgraad van 65% wordt gehanteerd voor de CMMMs, al zij het in mindere mate. De minste invloed hebben de VMBMs. Dit komt vooral doordat meer licht het oppervlak kan bereiken en regen evenredig over het oppervlak verspreid kan worden.

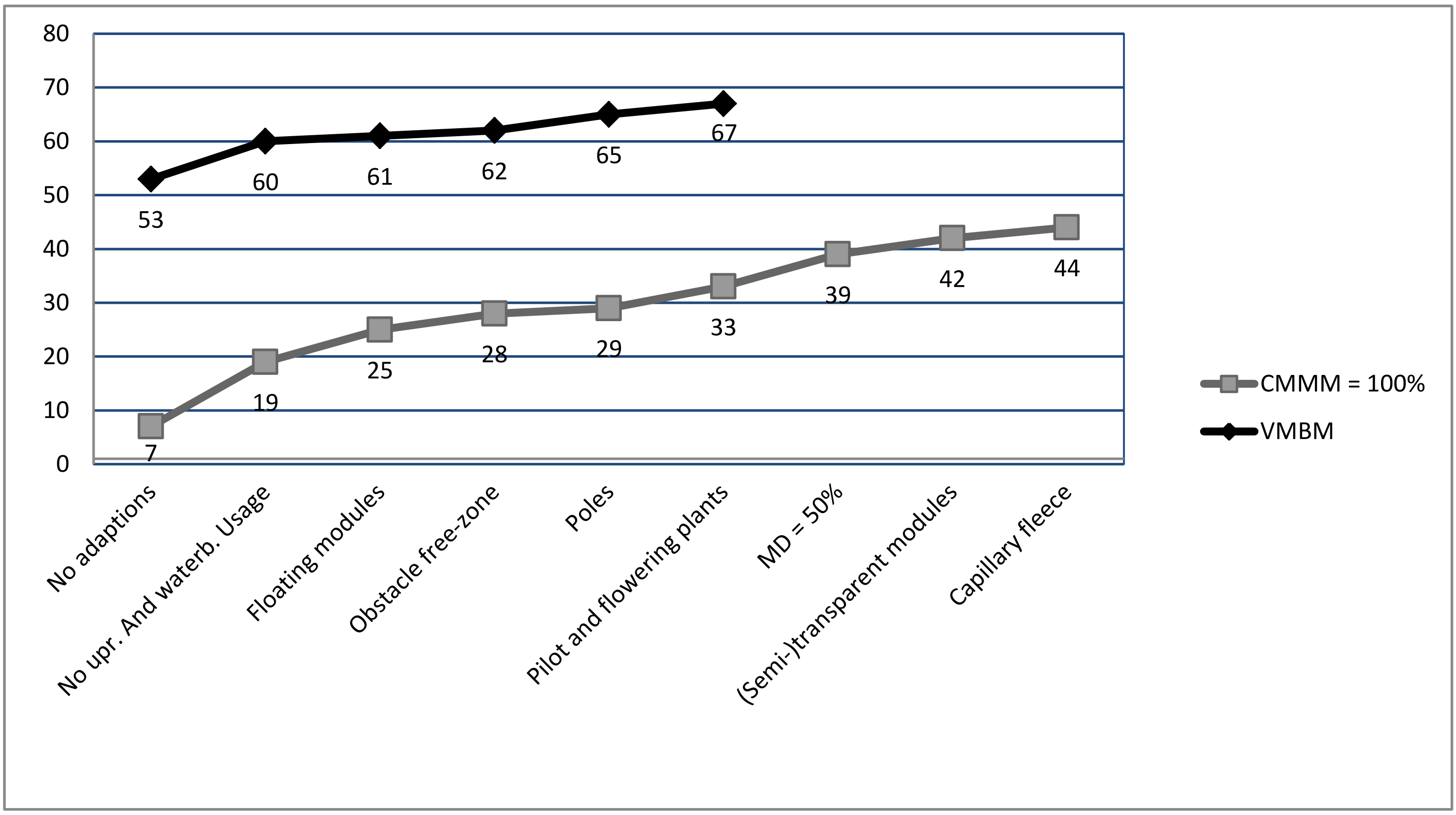
Aanpassingen

Op basis van de resultaten uit voorgaande hoofstukken zijn er verschillende aanpassingen opgesteld voor beide ontwerpen:

CMMM	VMBM
Geen gebruik van bosgebieden	Geen gebruik van bosgebieden
Drijvende panelen	Drijvende panelen
Obstakel vrije-zone	Obstakel vrije-zone
Panelen op palen	Panelen op palen
Bloeiende en waardplanten	Bloeiende en waardplanten
Lagere dekkingsgraad	Lagere dekkingsgraad
Hogere hoek van de paneel	
(Semi-)transparante panelen	
Deken met capillaire werking	
(Stedelijk gebied vs. Platteland)	*(Stedelijk gebied vs. Platteland)*

Vervolgens is er opnieuw een evaluatie gedaan van wanneer telkens één aanpassing is toegepast. De gebruikte methode voor deze evaluatie is hetzelfde als eerder beschreven. ‘Stedelijk gebied vs. Platteland’ staat tussen haakjes, omdat de aanpassing wel beschreven is, maar er teveel onbekende variabelen waren om een volwaardige evaluatie uit te voeren.

Uit de evaluaties is gebleken dat de (semi-)transparante zonnepanelen leiden tot de hoogste toename in ecologische functie punten voor de CMMM. Voor de VMBM blijkt dat ‘geen gebruik van bosgebieden’ en een lagere dekkingsgraad de meest belovende aanpassingen zijn vanuit een ecologisch oogpunt gezien. Verder bevat figuur 5 de toename in ecologische functies scores als meerdere aanpassingen worden toegepast. Hier moet echter bij vermeld worden dat sommige aanpassingen de zelfde functies stimuleren. Hierdoor zal het effect van bepaalde aanpassingen in figuur 5 minder zijn vergeleken met wanneer het de enige toegepaste aanpassing is.



Figuur 5: Ecologische functie score van de ontwerpen wanneer meerdere aanpassingen worden toegepast

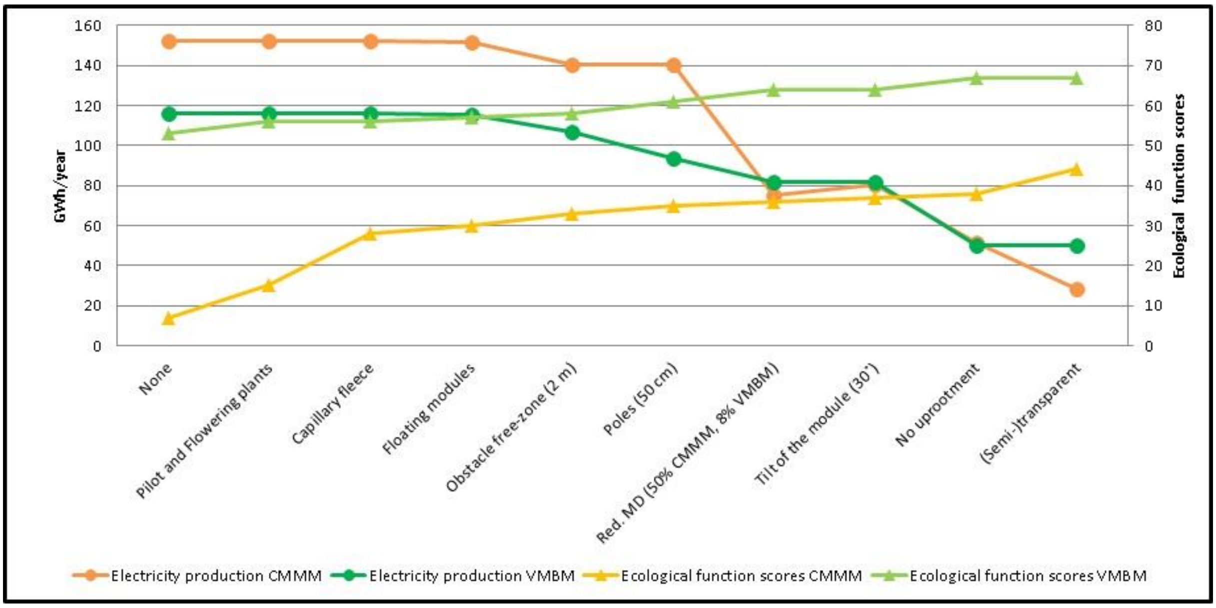
Elektriciteitsproductie

Allereerst is de theoretisch maximale elektriciteitsproductie van beide types bepaald. Hier komt uit voort dat het ontwerp met het CMMM-type de hoogste productie heeft; 152 GWh/jaar. Het ontwerp met het VMBM-type produceert 116 GWh/jaar. Vervolgens is er gekeken naar de productieafname als gevolg van de aanpassingen. De afname kan veroorzaakt zijn op twee manieren. Omdat er minder panelen gebruikt worden of doordat het rendement van de cellen veranderd door de aanpassingen. Niet alle aanpassingen beïnvloeden de elektriciteitsproductie, deze zijn logischerwijs dan ook niet meegenomen in de berekeningen. Voor het CMMM-ontwerp zijn de (semi-)transparante zonnepanelen (67,6 GWh/jaar), een lagere dekkingsgraad (70,3 GWh/jaar) en het niet rooien van bosgebieden (58,6 GWh/jaar) de aanpassingen die de productie het meeste doen afnemen. Voor het

VMBM-ontwerp zijn dat het niet rooien van bosgebieden (44,7 GWh/jaar) en een lagere dekkingsgraad (23,1 GWh/jaar). Aanpassingen die helemaal geen invloed hebben zijn bijvoorbeeld het deken met capillaire werking en het introduceren van bloeiende- en waardplanten. Figuur 6 laat zien wat de elektriciteitsproductie is wanneer meerdere aanpassingen zijn toegepast.

Financiële gevolgen

Alle aanpassingen zullen financiële consequenties met zich meedragen. Dit kunnen op twee manieren veroorzaakt worden. Enerzijds doordat de aanpassing een hogere investering vereist en anderzijds doordat de elektriciteitsopbrengst omlaag gaat, waardoor er minder elektriciteit wordt opgewekt en er dus meer moet worden ingekocht. Om te bepalen wat de omzet is van dit project is er van de marktprijs uitgegaan. Dit is gekozen omdat de hoeveelheid opgewekte elektriciteit niet RWS's eigen verbruik overschrijdt. De 'bloeiende waardplanten' is de goedkoopste aanpassing en zal ongeveer 200.000 euro kosten. Echter zijn er ook aanpassingen die een veel groter effect zullen hebben op de kosten. Bijvoorbeeld het niet rooien van bosgebieden en een lagere dekkingsgraad van het CMMM-ontwerp zal ruim 200 miljoen euro minder omzet opleveren t.o.v. van de base-case, dit wordt met name veroorzaakt doordat er minder elektriciteit geproduceerd wordt. Vanuit een financieel perspectief zijn alleen maar de (semi-)transparante silicium-type panelen niet rendabel.



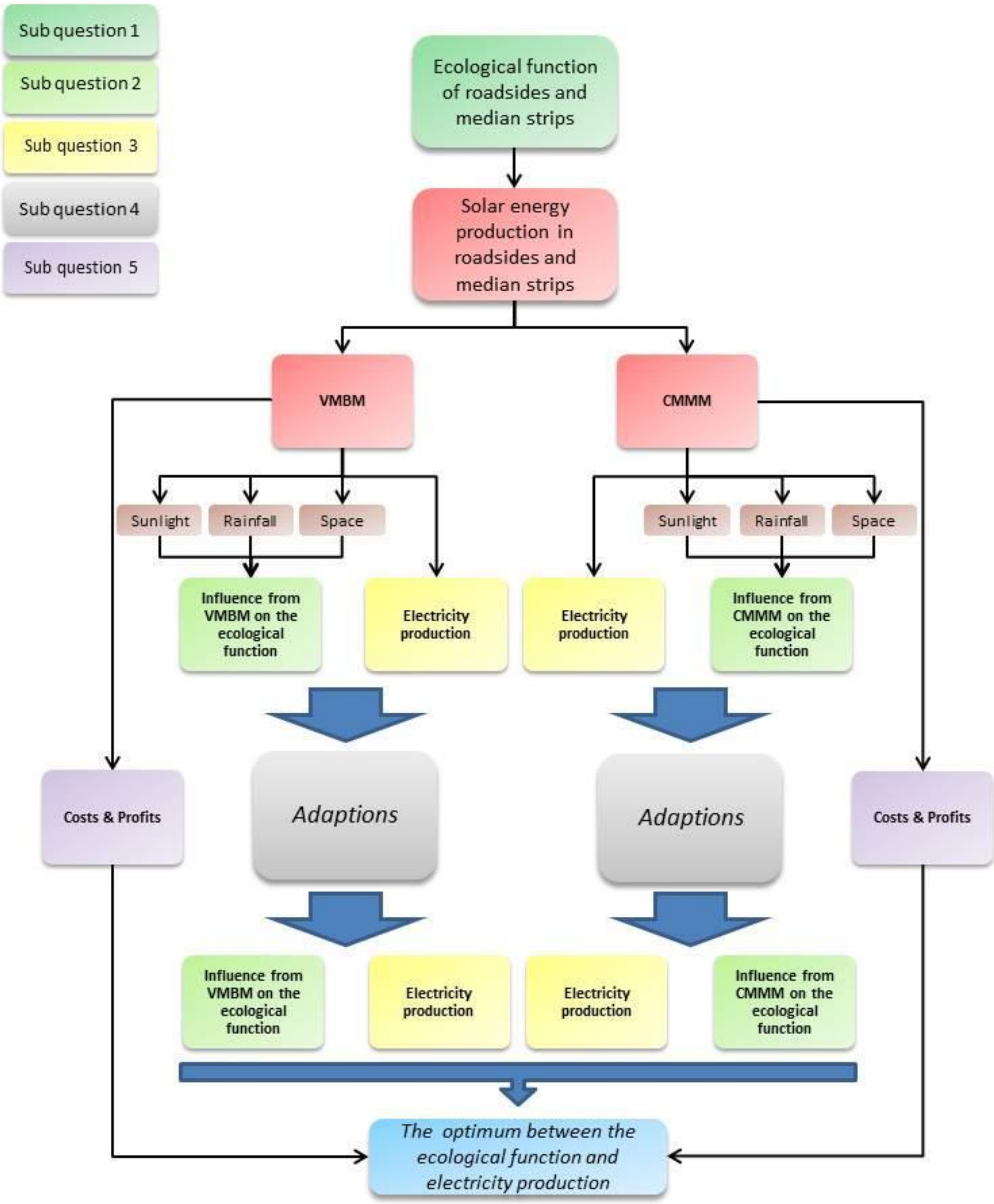
Figuur 6: Een overzicht van de afname in elektriciteitsproductie en de toename van de ecologische functie wanneer meerdere aanpassingen worden toegepast. De volgorde van de aanpassingen is gebaseerd om het effect op de elektriciteitsproductie.

Conclusie

Al met al zal het opwekken van zonne-energie een negatief effect hebben op de ecologische functie van de bermen van de A37, dit geldt voor zowel het CMMM-ontwerp als het VMBM-ontwerp. Vegetatie staat aan de basis van elk ecosysteem op land en vereist voldoende zonlicht, zonne-uren en regenwater, echter zal dit beïnvloed worden door de zonnepanelen. Doordat de vegetatie gehinderd zal worden in haar ontwikkeling zal ook de fauna de negatieve gevolgen merken. Verder zullen de panelen de fauna ook belemmeren in hun gedrag en overlevingspatronen.

Desalniettemin zijn er voldoende aanpassingen om ervoor te zorgen dat er genoeg ecologische functie aanwezig blijft in de berm. Dit zal wel ten kosten gaan van de elektriciteitsproductie en zal financiële consequenties hebben voor het project. Ondanks dat blijven er voldoende mogelijkheden die het overwegen waard zijn om de ecologische functie te stimuleren. Hierbij moet wel vermeld worden dat dit een kwalitatief onderzoek op basis van met name interviews en literatuur is. Experimenten en metingen zullen meer zekerheid bieden over het effect dat panelen zullen hebben op de ecologische functie.

Bijlage A (NL): Conceptueel raamwerk



Bijlage B (NL): Ecologische functie per fauna-groep:

	Breeding / Reproduction	Foraging	Habitat	Orientation	Passage	Protection
L. Mammals					Space for mitigation	
S. Mammals	High vegetation or holes	Presence of nutrition (species dependent)	Only mice: Holes, nutrients, protection			Vegetation (height varies per species)
Raptors		Open area + viewpoint				
Waterbirds	Vegetation is breeding-behavior dependent					
Songbirds	Vegetation is breeding-behavior dependent	Presence of insects				
Bats				Presence of trees		
Amphibians	Presence of water	Presence of invertebrates (indirectly dependent on grasses)				
Reptiles		Presence of invertebrates (indirectly dependent on grasses)	Closed and dense vegetation			High, woody vegetation (bushes)
Butterflies	Specific pilot plants (species dependent)	Flowering plants (species dependent)			Flowering plants (species dependent)	

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Abstract

This research studies the influence from solar energy production on the ecological function of the roadsides and median strips. An interesting potential highway, and therefore the case-study of this research, is the A37 from intersection Hoogeveen to the German border. Two base-cases are compared; a Conventional Mounted Monofacial Module (CMMM)-design and a Vertical Mounted Bifacial Module (VMBM)-design. These designs were chosen, since it's expected that they are each other's counterparts with respect to the influence on the ecological function. Subsequently it proposes potential adaptions in order to find the optimum between the ecological function and in the meantime maintaining an efficient and profitable solar energy production.

First, the ecological functions of the verges of the A37 were determined. An analysis of the present flora and fauna is the first step in determining the ecological functions. 14 different flora-types and nine different fauna-groups were distinguished. Six different functions were found for the observed fauna: foraging-area, habitat, orientation, passage-route, protection and reproduction-area. Vegetation stands at the basis of every terrestrial ecosystem and is therefore one of the main criteria for fulfilling an ecological function for fauna.Solar arrays influence the ecological function in three different ways; modules occupy spatial area, the interaction between the modules and abiotic factors (incoming light and rainwater distribution) and the interaction with faunal behavior. Both designs were qualitatively evaluated on its influence on the ecological function and received so called 'ecological function scores'.
Afterwards, nine different adaptions were proposed for the CMMM-design, while six were proposed to for the VMBM-design. These adaptions resulted in an higher increase of the ecological function scores for the CMMM-design, nonetheless the total scoring for the VMBM-design remained higher. Those adaptions varied from reducing the area used for solar energy production, since some areas have an higher ecological value, to changing the technology of the modules.

It can be concluded that solar energy will negatively influence the ecological function of the roadsides and median strips of the A37. Nonetheless, potential adaptions are available to maintain sufficient ecological functions and maintain a profitable electricity production, for both designs. The VMBM-design appears to be the most promising design from an ecological perspective, while the CMMM-design would be the best design from an electricity point-of-view. The CMMM-design scores also a little better financially, however both design are in the same cost-range.

Figures & Tables

Contents

List of abbreviations

B.P.	=	Before Present
Capex	=	Capital expenditures
cm	=	centimeter
CMMM	=	Conventional Mounted Monofacial Modules
GHG	=	Greenhouse Gas
GaAs	=	Gallium Arsenide
Ge	=	Germanium
GW	=	Giga Watt
GWh	=	Giga Watt hour
ha	=	hectare
hmp	=	hectometre post
km	=	kilometre
kWh	=	kilo Watt hour
k€	=	€ (x 1000)
LCOE	=	Levelized Cost Of Electricity
Lx	=	Lux (light-intensity)
m	=	meter
m^2	=	Square meter
MD	=	Module-density
MW	=	Mega Watt
MWh	=	Mega Watt hour
MW_p	=	Peak Watt
M€	=	€ (x1,000,000)
NDFF	=	Nationale Databank voor Flora & Fauna
Opex	=	Operational expenditures
O&M	=	Operation & Management
PV	=	Photovoltaic
RWS	=	Rijkswaterstaat
SMV	=	Studio Marco Vermeulen
USA	=	United States of America
VMBM	=	Vertical Mounted Bifacial Modules
W	=	Watt
W_p	=	Peak Watt
y	=	year
€	=	Euro

1 Introduction

1.1 Background

Global temperature variations is something of all time. Over the billions years-old Earth's history the planet has known multiple states, from the snowball-planet to temperatures several degrees higher than today (Bender, 2013). However, never before has the global temperature increased so rapidly as in the last century. At the end of the last ice-age temperature rose by 0.6 ˚C from 11,300 year B.P. till 5,500 B.P.. After this temperature increase the planet cooled down with 0.7 ˚C. In the last century, the temperature increased 1.2 degrees (Marcott et al., 2013). This temperature increase may cause (mass-)extinctions of flora and fauna and/or a permanent change of state of the planet (Barnosky et al., 2011; Pounds et al., 2005; Zickfeld et al., 2013).

Although this temperature increase depends on many factors, there is a direct relationship between the increase in carbon-concentration from Greenhouse Gas (GHG)-emissions and the temperature increase since the Industrial Revolution (Bender, 2013). Nowadays, there is huge consensus within the scientific world that this relationship is responsible for the temperature increase. Despite this consensus, annual global carbon emissions are still growing, mainly caused by growing economies (Boden et al., 2015).

Since the beginning of the 1990'ies multiple conferences have been organized in order to make agreements upon goals and limitations with respect to GHG-emissions (Rio de Janeiro 1992 & 2012, Kyoto 1992 , Johannesburg 2002, Copenhagen 2009, Paris 2015). Member states of the European Union agreed in 2010 to the 2020-agreements (European Commission, 2010). By signing these agreements, the member states agreed to achieve two main goals by 2020. First, to reduce their GHG-emissions by 20 % compared to 1990's emissions and secondly, generate 20 % of their energy from renewable resources. This percentages could be different per member state based upon the current national industry and society. For the Netherlands it implies that 14 % of the energy production must be generated renewably in 2020 (European Commission, 2015).

In 2015, 5.8 % of the Dutch energy consumption was produced renewably. This result seems promising, however it does not appear that the Netherlands is meeting their 2020-agreements in time (CBS, 2016a). Rijkswaterstaat (RWS), the executive agency of the ministry of Infrastructuur en Milieu (I&M)(English: Infrastructure and Environment), recognizes the urgency of an energy transition and wants to contribute to less GHG-emissions. Their goals are to reduce to amount of GHG-emissions in 2020 by 20 % compared to 2009 (Rijkswaterstaat, 2016) and to become completely carbon-neutral in 2030 (Rijkswaterstaat, 2017). One step towards achievement of this goal is to install solar farms on RWS' area.
RWS is responsible for all state-infrastructure including the highways (A-roads). In other words, they are responsible for 5340km asphalt (CBS, 2016b) and the accompanying roadsides and median strips. This results in large areas of potential solar farms, even after deduction of urbanized or occupied roadsides and median strips.

Solar energy is one of the options for carbon-neutral electricity generation and installation of it has been growing heavily over the last decades. Solar PV global capacity has been increasing exponentially over de last 10 years, currently generating 228 GW, with an increase of 50 GW in 2015 only (EIA, 2016). Solar energy is one of the primary alternative energy sources for fossil fuels, because it's pollution free, renewable and because of its abundance. Some of the other advantages are the independence functioning, low maintenance costs, long lifetime and high reliability (Singh, 2013).

Currently, roadsides and median strips have different functions already. Road safety is the main function. There is a positive correlation between the width of roadsides and median strips and the amount of accidents and severe injuries (FHA, 1993). Additionally, they can function as safety zone for car driver with mechanical issues, mainly where a guardrail is installed. Furthermore, the median strips can be used for non-road related purposes, like railway use. An example is the A4 and A 10 from Schiphol Airport to Amsterdam. There are many more functions to come up with, but one of them is the ecological function. Roadsides can be used by species as a migration-corridor, foraging-area or it is a habitat of specific organisms.

1.2 Problem definition and research question

The current rate of the energy transition in the Netherlands is going too slow. In 2015, 5.8% Dutch energy production was generated renewably, which only 1.9% higher compared to 2010 (CBS, 2016a). As it seems today, the Netherlands is not going to meet their 2020-agreements. Rijkswaterstaat recognizes the opportunity to accelerate this transition by introducing solar cells directly next to highways. However, they do realize that they are not completely free in their decision-making on where to install the arrays. Maintaining the ecological function of the roadsides and median strips is one element which may restrict their decision-making. Governmental legislations on ecosystem-preservation (Wet natuurbescherming; Natura 2000) limits the accessibility of solar cell arrays and it's expected by RWS that there will be critical questions about the effects on nature when the decision, whether to install PV panels or not, is to be made (Jonker, Pers. Comm. 2017). These expectations are, among other things, based on hindered plans to install solar panels in earlier cases (Van Ijsselmuide, 2016; Van Dijk, 2016).

This research attempts to find out how the ecological function of roadsides and median strips is influenced by photovoltaic electricity production. Subsequently it investigates potential adaptions to stimulate the ecological function, while in the meantime maintain a as high as possible and profitable electricity production. In other words, it investigates the optimum between maintaining the ecological function of roadsides and median strips and solar energy production.
No research has been done on the influence from photovoltaic electricity production on the ecological function of roadsides and median strips. Meanwhile, ecologists have a circumspect attitude towards to magnitude of the impacts on the ecological function. They are afraid that the arrays will have a damaging effect on the ecological quality and function of roadsides and median strips (Van den Hengel & Keizer, 2016, Pers. Comm.). However, this attitude is based on estimations or on "non-solar panel"-related research, rather than on topic-related scientific evidence. Furthermore, similar solar farm projects are already executed in Germany (Erberveld, 2017, Pers. Comm.) and in Massachusetts, USA (Fitzgerald, 2015), but the impacts from those solar farms on the ecological function hasn't been examined yet and is still unknown.
It's expected that the results will reduce the time of debate during the pre-installation phase and will create a positive attitude towards the implement of solar cell arrays on similar locations. Beside the solution for the A37, the research has another goal which will be used by RWS: a methodology applicable to similar future cases for different highways.

In order to find this optimum the following research question has been formulated:

How is the ecological function of roadsides and median strips influenced by the implementation of PV panels and what adaptions are available to optimize the relationship between electricity output and the ecological functions, directly next to highways?

The research question will be answered by finding answers to the following sub-questions:

1. What ecological functions are vital for the current ecosystems at roadsides and median strips?
2. How are these functions influenced by the implementation of PV panels?
3. What are possible adaptions to the solar panel field to positively influence nature or to minimize ecological impact
4. How does this influence the efficiency and electricity production of the panels
5. How do the costs and profits relate to the benefits from the proposed adaptions?

1.3 Case study

This research is a case-study of the Dutch highway A37; from intersection Hoogeveen to the German border near Zwartemeer. This location is chosen because RWS expects that this highway has large solar energy production potential, mainly caused by it's east-west orientation and the broad roadsides and median strips in an open large-scale agricultural landscape. The highway crosses urban areas near the municipalities of Hoogeveen, from hectometre pole (HMP) 0.0-2.0, and Klazienaveen, from HMP 34.8-38.2. The remaining hinterland is dominated by large-scale agricultural land.

1.4 Structure

Chapter 2 describes the scope and the general methodology of this research. Hereafter, chapter 3 is focused on the ecological function. It describes the current ecological function of the case-study, how it is expected to be influenced by solar energy production and what adaptions are proposed to improve the ecological function again. In other words, it gives answers to the first three sub questions. Chapter 4 deals with the latter two sub questions; How is the production efficiency of the park influenced by the proposed adaptions and what costs and/or profits are related to these adaptions. Afterwards, chapter 5 will provide a summary of both chapters and will connect the elements within those chapters to provide more insight in the relationship between the ecological function scores, electricity production and costs & profits. Chapter 6 contains the discussion of this research. Chapter 7 is contributed to the conclusions and answers the research question. Afterwards, chapter 8 provides an overview of the used literature. Lastly, chapter 9 contains the appendices.

2 Research scope & general methodology

First, the general definition of 'ecological function' will be described, based on literature. Secondly, the main principles, influencing aspects and the state-of-the-art developments of photovoltaic solar energy production are presented. Afterwards, the general framework and general methodology of this study will be elaborately described in order to create of clarifying picture of this research.

2.1 General definitions

2.1.1 Ecological function

The ecological function is, in fundamental sense, the roles played by flora and fauna that contribute to (a part of) the ecosystem. However, the definition can be described in multiple ways, depending on the topic of interest and therefore, an ecological function can either be roles, services, processes or the functioning of an entire system. Jax (2005) distinguishes four definitions of the term 'function' within ecology:

1. The interaction between two objects (can be both biotic as abiotic) resulting in state changes. The definition is simply descriptive and usually suggests a cause-effect relationship.
2. The second meaning identifies the function from a broader point-of-view and looks at it from a system-perspective. The two objects only part of a more complex structure and their interaction is described from a bigger picture; 'What process occurs in the system?' and 'How does the whole system function?'. The 'function' of this bigger system refers to the trajectory or state of the whole structure and to the total sum of processes that results in a sustainable system.
3. Objects are not merely users of the system, but they fulfil one or more specific roles within the system. The focus is on the relation between the system and the parts/objectives within it. The objective is not only a 'protagonist' of processes, but its processes bear functions of the whole system. For example, a honey bee does not only take nectar from flowers provided by the system, but by collecting the nectar it flies from flower to flower and thereby fertilizing the plants.
4. This definition extends the system by including the relationship the human activity. According to this description, functions of the system are dedicated to human. For example, the forest produces oxygen for human to breath or has a recreational function. This description has strongly intertwined with the term 'ecosystem services'.

These four definitions can be briefly described as: function as processes, functions of a system, functions as roles within a system and functions as services to human (ibid.). This research makes use of definition 1. In other words, the focus of this study is on the changing state of both abiotic and biotic conditions and their influence on the flora and fauna.

The characteristics of ecological functions of species strongly influence the ecosystem properties. These characteristics operate in multiple contexts, depending on the functions of dominating species, ecological engineers, fundamental species and the interaction among species (Hooper et al., 2005). Species possibly fulfil multiple functions within an ecosystem, which potentially leads to a more resilient ecosystem. However, the larger the ecosystem becomes, the more vulnerable it becomes to external and internal changes and subsequently more ecological functions needs to be consummated by, which in most cases means; a larger amount of species (ibid.). Modification in species-distribution within an ecosystem, caused by species invasions or anthropogenic activities, has altered the general functions and services of an entire ecosystem in plenty cases. Reversing these alterations is in many cases difficult, costly or even impossible, result in a permanent change in state and function (ibid.), therefore a preliminary analysis may provide better preparations and thus might reduce the difficulty and costs.

2.1.2 Photovoltaic solar energy production

Photovoltaic electricity is produced from the absorption of electromagnetic radiation, mainly from light, by semiconductor materials. It was discovered by Becquerel in 1839, however it had to be developed until 1954 using doped semiconductor silicon (Twidell & Weir, 2015).

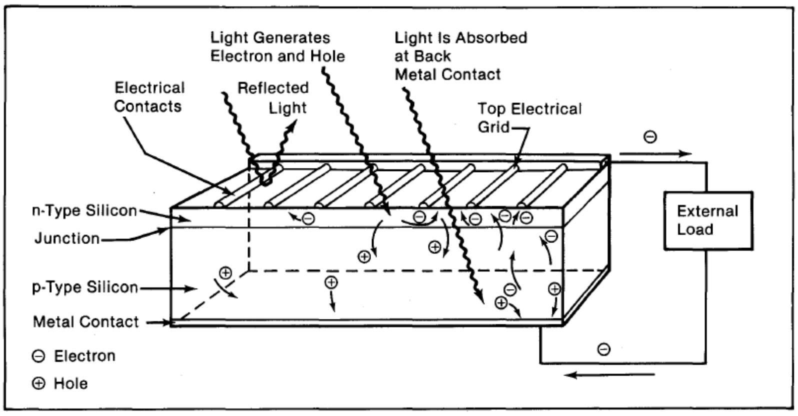


Figure 1: Outline of photovoltaic cells in a circuit (Varkie, 1981)

Power is generated when the positive and negative charge carriers within an absorbing material are separated by the photons of electromagnetic radiation. When there is an electric field present, the separated charges create a current in an external circuit. This field is present at junctions in PV cells, creating a voltage difference useful for power production (Ibid.)(fig. 1). In order to create power generation, the cells must match the radiation with regard to the wavelengths from infrared- (10 µm) to ultraviolet light (0.3 µm)(Ibid.)

Formerly, shading caused heavy damage, however nowadays there are solutions available to prevent damaging (Ramli et al., 2017). Nonetheless, (partial) shading still causes significant power losses, depending on the type of connection and the amount of cells and arrays included in the connection (Kazem et al., 2015). (Partial) shading makes the current (I) decrease proportional to the percentage of shaded area of the cell. Therefore the decrease in power output is also linear to the percentage of shaded area.

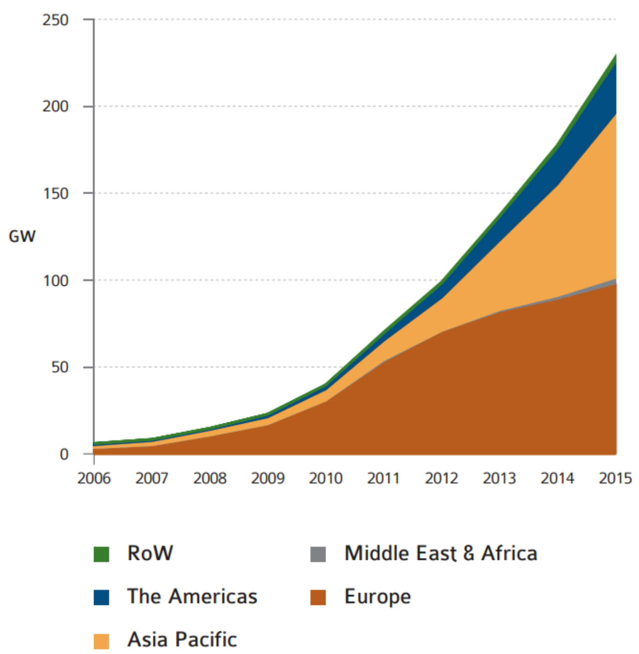


Figure 2: Evolution of regional PV installation over the period 2006-2015. (GW) (EIA, 2016)

94% of the currently producing cells are based on crystalline-silicon technologies. These cells have a commercial efficiency between the 16% and 25%. These cells have lower efficiencies compared to newly developed state-of-the-art cells, but the relatively low price is a major advantage for this technology (EIA, 2016). III-IV compound semiconductor cells, such as GaAs on a Ge substrate have reached efficiencies up to 40%, however this technology remains expensive and therefore less interesting for new investors. Organic thin-film PV cells, which make use of dye or organic semiconductors, are a rapidly evolving technology emerging into the PV cell-niche. For example, perovskite solar cells already reach a efficiency up to 20%, however this is not yet a stable market product (ibid.). The manufacturing and material costs of perovskite solar cells are low and their payback period is very short. This technology has the potential to evolve into the state-of-the-art of the future when the alternatives, currently being developed in laboratories, are able to be commercialized (Celik et al., 2016). Over the last decade electricity production from PV cells grew with 3000% (Fig. 2). This increase typifies the recognition of the potential of solar energy production and rapidly developing technologies such as the perovskite-technology might be able to boost this increase some more (EIA, 2016).

2.2 Scope & General Methodology

This section starts with a description of the geographical scope, the case-study A37, and the temporal scope. Afterwards, the general approach will be described together with an explanation of the characteristics where necessary.

2.2.1 Research scope

2.2.1.1 Geographical scope

The geographical scope of this case-study is the A37, which has a total length of 42 km (Rijkswaterstaat, 2015). The total area under RWS control near the A37 is 313 ha (Tab. 1).The upper-layer of the subsurface consists of sandy material (Keizer, 2008). The highway crosses two former peat-areas which are divided by the Hondsrug (Vermeulen, 2016). 15.5 km of this highway has a broad median strips, 14 km has a narrow median strips, while 5.4 km crosses urban area. The remainder consists of intersections or other infrastructural elements (Ibid.).

Type of roadside	Area in m^2	Area in ha
Junctions	464,842	46
Roadsides	1,603,676	160
Intersections	468,302	47
Median Strips	493,069	49
Service Areas	102,763	10
Total	3,132,651	313

Table 1: Total area of Rijkswaterstaat at the A37 (Folkerts et al., 2017)

2.2.1.2 Temporal scope

The temporal scope of this research depends on the lifetime of the PV panels and the pre-production-phase. Photovoltaic (PV) modules are known for their reliability. The average panel lifetime is 30 years (Weckend et al., 2016). The start of the production phase has been planned in 2019 and therefore the temporal scope is set at the coming 32 years, for the A37. Though, RWS plans to expand the solar energy production to other highways, resulting in large scale application within 15 years. This leads to a temporal scope for the methodology of 45 years.

2.2.2 General methodology

This research attempts to find the optimum between solar energy production and the ecological function of roadsides and median strips based on a base-case. In order to find this optimum, it compares two different designs with different types of modules; the Conventional Mounted Mono-facial Modules (CMMM) and the Vertical Mounted Bifacial Modules (VMBM). These designs are chosen because it's expected by RWS (Jonker, Pers. Comm., 2017) that the impact on nature will be as different as possible for these designs, mainly because of their difference in tilt and orientation.

This section will continue with the describing the main characteristics, and corresponding principles, of both types of modules and the main principles of the base-case . After which the main methods will be described more elaborately.

2.2.2.1 Conventional Mounted Mono-facial Modules

The Conventional Mounted Mono-facial Module (CMMM) (Fig. 3) is the most common known type of solar modules. Briefly, it is a 'flat-lying' module producing energy at the upper side of the module. Flat-lying in the sense that the modules can be tilted, however at an angle by which a horizontal set-up remains dominant over a vertical one.

Tilt is the angle which the modules makes compared to the earth's surface. It influences the daily electricity production of the CMMM significantly (Hussein et al., 2004). A CMMM with a tilt of 0˚ will result in higher peak production at noon, however electricity production will be low near sunrise and sunset. Increasing the tilt will lead to a more constant daily electricity production and thus higher production near sunrise and sunset, at the cost of lower peak production. Eventually, when the tilt overcomes the angle of the sun, the curve of the modules' production will have a dip at noon and two peaks in electricity production between sunrise and noon and between noon and sunset (ibid.). Optimum tilt depends on the angle of the sun and therefore on its yearly cycle. Adjustments on tilt would therefore increase electricity production, but require adapted technologies or labor hours. A tilt based on the yearly best average is therefore a good medium to obtain is satisfying electricity generation (Kacira et al., 2004).

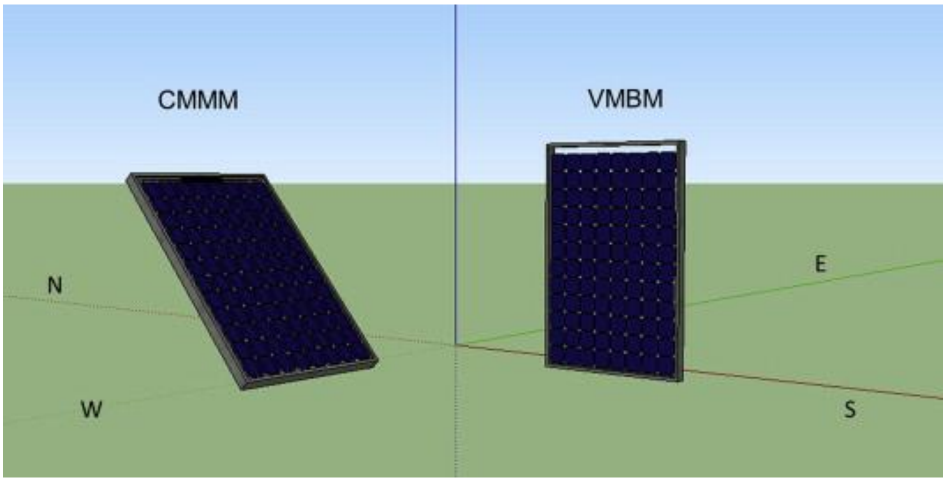


Figure 3: Setup of a CMMM and a VMBM in line with their orientation on the northern hemisphere (Guo et al., 2013)

The azimuth of the set-up describes the orientation of the modules. An azimuth of 0˚ means that the module is oriented to the north. Azimuths 90 ˚, 180 ˚, 270 ˚ refer to a west-orientation, south-orientation and east-orientation respectively. Preferably the azimuth of the modules is on the northern hemisphere directed to the south. However, local structures and disconformities may be obstacles to install the modules at this ideal azimuth. Experiments in the UK showed that an azimuth-deviation between 15 ˚ (165 ˚-195 ˚) would still supply an electricity production within 95% of its capabilities (Fordham et al., 1999).

2.2.2.2 Vertical Mounted Bifacial Modules

A Vertical Mounted Bifacial Module (VMBM)(fig. 3) is the counterpart, with respect to its influence on the ecological function, of the CMMM. As the name suggests the modules are vertically (tilt = 90˚)

installed and are capable of absorbing light on both sides (Guo et al., 2013). In contrast to the mono-facial modules, a VMBM contains a transparent (glassy) backsheet instead of an opaque one.

VMBMs are preferably installed in an east-west orientation and, due to their setup, require less space while produce an equivalent amount of energy compared to its mono-facial counterpart under the correct circumstances (Nordmann et al., 2012). Furthermore, the production- and maintenance costs of VMBM are comparable to the costs of CMMM with the same front surface (Robles-Oscampo et al., 2007).

Due to the orientation, and the capabilities to absorb light on both sides of the module the electricity production has two peaks during its daily production (fig. 4). Compared to a CMMM, the VMBM can start producing more electricity directly after sunrise and remain producing more closer to sunset. Meanwhile , a reduction in production capacities occurs during noon, due to the less optimal azimuth of the sun at that time of day (Obara et al., 2014). This results in a more equally distributed amount of electricity and therefore less stress on the grid, which could reduce the electricity price with ~30% (Alliander & Liandon, 2017).

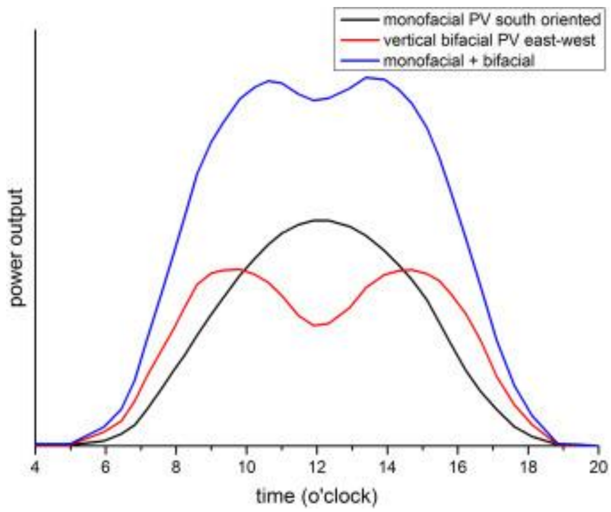


Figure 4: Power output curves for a CMMM placed in Japan facing south at 45°, a VMBM with east–west orientation and the sum of both power outputs. (Obara et al., 2014)

The backside of the VMBM (side not facing the sun) is still capable of producing electricity from diffuse light. To strengthen this, the transparent backsheet allows a reduced portion of light to transmit trough the module. This light becomes available as diffuse light either (Guo et al., 2013). An increased albedo would lead to higher electricity production as well. Finally, latitude will affect the electricity production too. Those factors combined determine whether or not a VMBM would be preferred over a CMMM. Generally, above a latitude of 45˚ VMBM would produce more electricity compared to the CMMM. Underneath this latitude it's the other way around (ibid.).

2.2.2.3 Base-case

RWS has asked three potential contractors to develop a first design on what they think is the ideal solar park for the roadsides of the A37, taking into account aspects as electricity production and safety, but also spatial integration and personal experience of the road-user. The three contractors that made a concept-design are POSAD, Studio MarcoVermeulen and IAA Architecten (Bijlsma, 2016). The design of Studio MarcoVermeulen (SMV) appears to be the most interesting, especially from a electricity yield perspective and a user-experience perspective (Folkerts et al., 2017; 't Hart, Pers. Comm., 2017) and is therefore chosen as the base-case for the CMMM-design.

The base-case will occupy 117 ha, corresponding to 37.4 % of the total available area along the A37 (StudioMarcoVermeulen, 2016). The size of the module is 2 m^2, however it remains unknown what the shape of the module is (ibid.). This research assumes that the modules are rectangular with a length of the module is 2m and a of 1m, because this is the most simple shape to continue the research. The setup of the entire PV-electricity production can be divided into two parts; 'Roadsides & median strips' and 'intersections'. 59.7% of the electricity production will come from the roadsides and median strips, while the remaining 40.3% will be produced at the intersections (StudioMarcoVermeulen, 2016):

According to SMV, CMMM will be installed at the roadsides and median strips of the A37. The MD is 100% at a tilt of 5˚ and the modules are planned to be installed directly on the surface, in order to maintain the open character of the surroundings. This means that the slope of the surface will be 5˚ as well. The MD is the share of the surface which is directly covered by the modules. SMV includes a two meter width obstacle-free zone directly behind the guardrails. 1.65m is legally required in order to provide bending space to the guardrail in case a vehicle crashes into it. Two meter would provide enough accessibility for maintenance. The roadsides will have the 1.65m obstacle free-zone that is required. The modules will be dyed with the same colours as the surroundings to make them least prevailing as possible. However this causes an efficiency reduction. The MD of the VMBM design needs the be much lower compared to the CMMM's to prevent (partial) shading. However, total area occupied by the modules and the width of the obstacle-free zone. The efficiency of the cells of VMBMs is equivalent to that of the CMMMs (Guo et al., 2013). Therefore, calculations of the electricity production of VMBMs will be based on a cell-efficiency of 16%.

All intersections have its own design according to SMV. This design depends on the presence of infrastructural elements, local landscape and other relief. Most intersection make use of the same type of CMMM with the same MD (100%) (fig. 5). However intersections 'Oosterhesselen and 'Holsloot' will have a MD of 65%(fig. 5). The differences of characteristics for the VMBM-design will be similar for intersections as they are for roadsides and median strips.

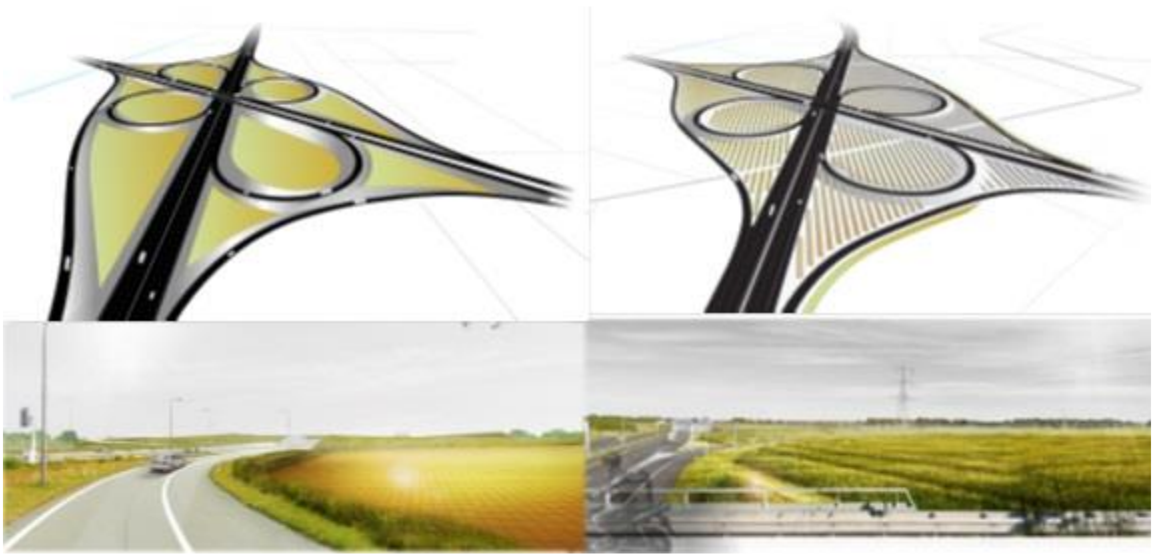


Figure 5: Bird-view (top) and artist impression (bottom) of SMV-design for intersction Hoogeveen, MD = 100% (left), and intersection Holsloot, MD = 65% (right) (StudioMarcoVermeulen, 2016)

2.2.2.4 General methodology

This study compares both designs in two separate parts. The first part focusses merely on how these designs influence the ecological functions of roadsides and median strips and answers sub question 1 to 3. The second part explains the electricity production and costs & profits of both designs and how the proposed adaptions influence these principles.

The first part, chapter 3, starts with describing the ecological functions of the roadsides and median strips of the A37. First, data-analysis will give more insight on the present flora and fauna. Based on the results of this analysis, an overview of the present ecological functions can be established. This overview will be the product of interviews with ecologists and case-experts both internal from RWS as externa. The overview will be supplemented by literature study where necessary. This overview will be the answer to sub question 1.

The comparison between both designs will start in the second section of chapter 3, by which sub question 2 will be answered. This section evaluates the influence on the ecological function for each distinguished fauna-group qualitatively. The fauna is dependent on a mature and dense vegetation-cover. In other words, a mature ecological function for fauna, means automatically a mature ecological function for flora. All functions will receive ecological functions scores based mainly on interviews and literature study. This will result in a final scores for both designs.

The final section of this chapter will answer sub question 3 and proposes specific adaptions which are expected to stimulate the affected ecological functions. These adaptions vary from array-level adaptions to a module-level. These adaptions are based on interviews, topic-related literature and common sense. A revised evaluates will provide new scores to the ecological functions.

The second part, chapter 4, will show the electricity production (sub question 4) and costs & profits (sub question 5) for both designs based on calculations. This will result in a theoretical maximum electricity production for both designs. This is the electricity production when no adaptions are applied. Subsequently the influence on the electricity production from each adaption will be calculated, based on similar methods.

The costs & profits-analysis will be based on literature study and calculations. The calculations will be based mainly on investment costs, Operation and Maintenance (O&M) costs, the market's electricity price and electricity production. This will result in aspects such as the LCOE of both designs, their simple pay-back-period, cumulative sales volume and total profits. Like the previous sections, this will be done for both designs with no adaptions first, after which each adaptions is analysed separately.

The results from these two chapters will make it able to make grounded conclusions and a satisfying answer to the research question. An overview of this general approach and methodology is visualized in a conceptual framework (Fig. 6).

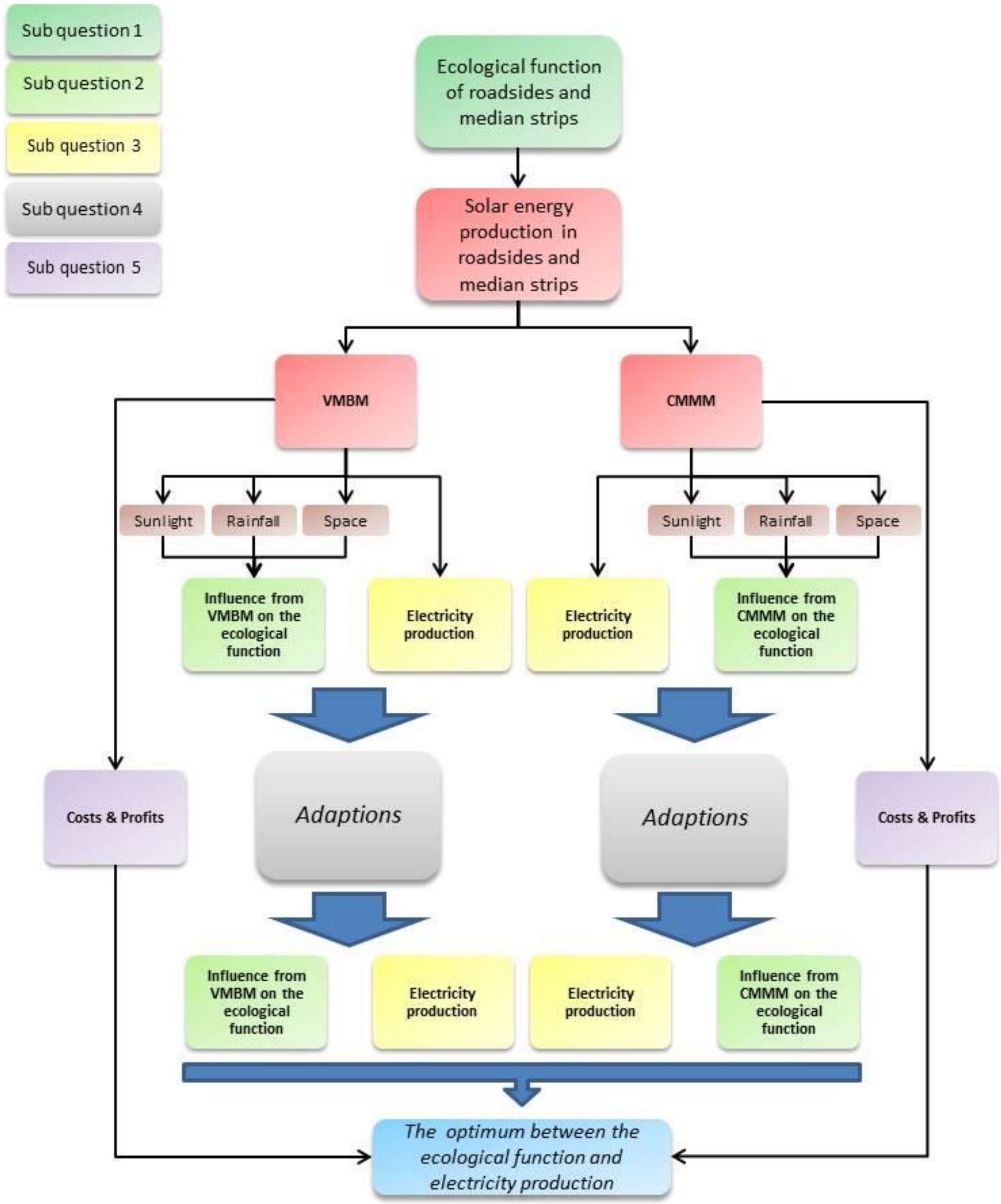


Figure 6: Conceptual Framework

3 Ecological Function

This chapter begins with describing the methodology used to find the answers to sub questions 1-3 (section 3.1). Secondly, an overview of the ecological function of the roadsides and median strips along the A37 is given (section 3.2). Table 2 provides an overview of the most fundamental results of section 3.2. Subsequently it provides clarity on how the ecological function is influenced by the base-case (section 3.3). Finally, potential adaptions are proposed and it's described how these adaptions will stimulate the ecological function based on the remaining ecological function from the base-case (section 3.4).

3.1 Methodology

3.1.1 What is the ecological function?

In order to determine the ecological function of the A37, a clear overview of the flora and fauna observed along the A37 was made. This was determined by an analysis based on two data-sources. Data of the flora was internally provided by RWS. RWS's ecologists has established a data-file on the type of vegetation per small terrain with similar vegetation-type (Appendix A). This results in 2483 monitored fields grouped in 14 types of vegetation. The following vegetation-types were distinguished: Arid grasslands, deciduous forests on sandy soil, ditches, cat's ear and birdsfoot, lawn, riparian vegetation, verge with Holcus mollis and hawkweed, heather, flowery wet brush, chimney ditch, ponds, violin caninae grasslands, false oat grass hay meadows, dry brush, reed banks, pools, retention ponds and talus.

Information on the occurrence of fauna was based upon data from the Nationale Databank voor Flora & Fauna (NDFF)(Appendix B). The NDFF listed the fauna observed along the A37 in a map of the highway. These observations are made by ecologists and needs to be confirmed by species-specific experts before they are included in the database. This strengthens the validity of the observations. The observations were made until November 2016, however there is no starting date. Therefore, observations might be relatively old, which leads to question-marks on the occurrence of those species nowadays. Fortunately, the verges remain a stable environment in a constantly changing landscape, therefore it's expected that the roadsides and median strips still provide the same ecological functions species which are observed years ago. And thus it's valid the assume that the specific species still appear in the roadsides and automatically still make use of the provided functions. Only observations within a range of 50 m from the highway were included in the analysis, in order to be certain that the species actually made use of the roadsides and median strips.

Semi-structured interviews with ecologists, both internally and externally of RWS (Appendix C), and literature study gave insight on the relationship between the verges and the observed species and the ecological function of the roadsides for the observed species. Based on this information, an overview has been made of the ecological functions of the roadsides and median strips for every observed species.

Most vegetation-types are introduced by human, otherwise it's maintained and controlled by human. Therefore all vegetation-type are semi-anthropogenic. Nonetheless, the functions provided by the vegetation-types remain similar compared to natural vegetation-types. Therefore the types are approached as natural, however the semi-anthropogenic characteristic needs to be taken into account.

3.1.2 Influence on the ecological function from the base-case.

A qualitative impact evaluation has been performed to determine the impact of the base-case on the ecological function of the roadsides and median strips. This impact evaluation is based on semi-structured interviews with both ecologists from RWS and external ecologists. Literature study filled in the knowledge gaps which remained after the interviews. Decisions on installation-properties of the CMMM are in this chapter based on the report provided by SMV (StudioMarcoVermeulen, 2016). In case of incomplete or unclear properties, assumptions will be made based on the characteristics of state of the art PV-installation according to scientific literature and/or up-to-date reports.

Each ecological function, based on the results of sub question 1, received a qualitative ecological function score depending on the magnitude of impact caused by the base-case (Appendix D & E). Each score has equal weighting, since this research focusses on the total ecological function rather than species specific. Score from 0-4 has been given to each function:

0 = Destroyed
1 = Heavily damaged
2 = Significantly affected
3 = Slightly affected
4 = Non-affected or stimulated

Each score was given to the specific fauna-groups, resulting in both average- and cumulative scores per function. Multiple interviewees mentioned that the fauna is directly dependent on the present flora (Van den Hengel & Keizer, Pers. Comm., 2017, Appendix C; Bolhuis, Pers. Comm., 2017, Appendix C; La Haye, Pers. Comm., 2017, Appendix C; Creemers, Pers. Comm., 2017, Appendix C). From there it's deduced that evaluating the fauna, and from there proposing the required adaptions, will automatically stimulate the flora as well. In other words, a mature ecological function for fauna, means a mature ecological function for flora as well. The maximum score per function is determined by the amount of groups currently making use of these functions multiplied by the highest possible score (4 points). The distinguished fauna-groups can be found in table 1. The six examined functions are listed below, with the theoretical maximum scores between brackets:

- Foraging (24)
- Habitat (8)
- Orientation (4)
- Passage (8)
- Protection (8)
- Reproduction (20)

3.1.3 Proposed adaptions

First, a list of potential adaptions has been established. This establishment is based upon literature study, solar energy-experts' opinions and state-of-the-art developments in the field of PV-technologies. Afterwards a renewed impact evaluation has been performed similar as the impact evaluation described in section 3.1.2. For each evaluation it is assumed that these adaptions are the only implemented adaptions to the base-case. This will give most clarity on the stimulation of the ecological function, influence on efficiency and involved costs and profits per adaption. However some adaptions stimulate similar ecological functions, therefore a cumulative score for all adaptions is not the sum of all increased scores. In order to derive the new quality of each function, after application of multiple adaptions, requires a new evaluation. Eventually, the new scores per ecological function show the increased quality of each function resulting from the proposed adaptions.

3.2 Ecological functions of the roadside

Every landscape and area has different ecological functions. This also counts for roadsides and median strips. Roadsides and median strips contain unique and specified ecosystems, because they serve as a constant save-zone in a sometimes changing environment and therefore their ecological function is distinctive. Every present organism is to a greater or lesser extent dependent on the type of roadside. This partly depends on the surrounding activity and therefore it would be short sighted to ignore the agricultural hinterland and environment and stop interpreting at the edge of RWS' area (Götz, Pers. Comm., 2017). The most western two kilometers of the A37 cross urban area, however the surroundings of most of the highway are dominated by largescale agricultural land with occasionally occurring woody area and wetlands (See section 1.3). 67 different animal species and 14 vegetation types are monitored within the roadsides of the A37. At the end of the chapter a schematic overview of the explanation is included (tab. 2).

Class	Amount
Large mammals	147
Small Mammals	165
Raptors	49
Waterbirds	1965
Songbirds	791
Bats	28
Amphibians	85
Reptiles	0
Butterflies	13

Table 2: Number of individuals per fauna-group

3.2.1 Flora

Fourteen types of vegetation cover have been monitored within the roadsides of the A37. They cover 97.4 % of the roadside. The remaining 2.6 % is covered by water-type or infrastructural elements. Even though these water-type areas are not described in this section, since they are neglected as suitable solar cell location in this study, however they do fill in an important role for the ecological function.

The roadsides are dominated by arid grasslands (74.4 %). Another important vegetation-type are the deciduous forests on sandy soils (14.0 %). A list of all vegetation-types can be found in Appendix A. The roadside-flora has different environmental functions. Most important functions are the prevention of erosion, improvement of infiltration of rainwater and increase of the carrying capacity (Bolhuis, Pers. Comm., 2017, Appendix C). However the flora has not only abiotic functions, but it's also found to fulfil different roles for the fauna, such as foraging-area, homing, passage-route and the providence of shelter (Bolhuis, Pers. Comm., 2017, appendix C; La Haye, Pers. Comm., 2017, appendix C).

This section is contains three sections. The first sections focuses on the arid grasslands, because of its high abundance and its promising characteristics for the installment of solar panels. The second section deals with deciduous forests. The deciduous forests have an anthropogenic origin, its high abundance and vital role for fauna make it important enough to approach it as a mature forest. The final section deals with the remaining vegetation-types and describes the ecological functions of these vegetation in general.

3.2.1.1 Arid Grasslands

Arid grasslands are characterized by its low, sometimes herby, grassy-vegetation. They have a pollen-like structure and are located on acidic to weak-acidic, oligothrophic to mesothrophic sandy or silty soils (Bal et al., 2001). Arid grasslands can develop from succession of "*sand atomizations*" or from *"Dry heather"* when erosion occurs (Bal et al., 2001). Intense mowing-regimes and/or grazing is vital to maintain the open vegetation, because these actions function as reset-mechanisms of the vegetation-type (Glenn-Lewin & van der Maarel, 1992). However mowing leads to a decrease in flowering species, therefore it is better to stick to a “once-a-year”-mowing regime, which has been found to cause the least damage to flowering- and seeding-vegetation (Jantunen et al., 2007). Arid grasslands are vulnerable to atmospheric depositions and effective prevention-measures are difficult. Arid grasslands in verges have an important contribution in the preservation of several plant-species (sýkora et al., 1993). The most common grass-species in Dutch verges are (Plantum, 2017):

- Festuca rubra 50%
- Festuca ovina / Festuca brevipila 45%
- Agrostis capillaris 5%

In order to preserve arid grasslands the environments needs to be moderately dry without the input of ground or surface water. Furthermore the soil has to be reasonably nutrient rich (Bolhuis, Pers. Comm., 2017, appendix C). The sandy soil present in this region provides opportunities for fast infiltration of rainwater, reducing the probability of high groundwater-levels. This is strengthened by the absence of large rivers or other large waterbodies. Normally, grasslands in verges are species-rich. In the Netherlands, the species-richness of grassy verges is, in general, twice to three times as high compared to regular grasslands. The grassy-species present in those verges are light-preferring species (Keizer, Pers. Comm., 2017, Appendix C). However it needs to be taken into account that the grassy roadsides of the A37 are classified as grasslands with a low species-richness compared to other roadsides. Grasslands with low biodiversity are overall less vulnerable to changes (Hoekemeijer, Pers. Comm., 2017), additionally those changes may provide opportunities for alien species to settle in the new environment (Bolhuis, Pers. Comm., 2017, appendix C). The roadsides are not only home to grassland plants, they form also a dispersal corridor for grassland species (Tikka et al., 2001).

3.2.1.2 Deciduous forests on sandy soil

Deciduous forests on sandy soils consist naturally out of (pedunculate) oak or the birch (Bal et al., 2001). It’s a low to moderately high type of forest with an open structure, appearing mainly on oligothrophic to mesothropic, dry and acid soils (Bal et al., 2001). These forests don’t need to be sustained (Bal et al., 2001). The deciduous forests can develop from succession of burial forests or directly from roots from the subsurface (Bal et al., 2001). Deciduous forests are known for its stabilizing effect on sandy soils (Savill, 2015).

The deciduous forests on sandy soil along the A37 cover 14% of the total roadsides. It’s acknowledged that these forests have an anthropogenic origin, however some parts have natural characteristics and therefore they have the same ecological functions as native deciduous forests. These trees might be used by bats as a place to rest (Bolhuis, Pers. Comm., 2017, appendix C) and for their orientation (La Haye, Pers. Comm., 2017, appendix C). The woodland areas along the A37 have an extra ecological function in relations with the hinterland. There is a sequence of vegetation types from the largescale agricultural land to the forest-like part of the roadside. Small mammals make use of the in height rising sequence from agricultural land, via bushes, to deciduous forests in their daily routine of survival. They look for food on the agricultural land, while find shelter in the bushes and forests. This sequence needs to be preserved in order the maintain this ecological function (Götz, Pers. Comm., 2017).

3.2.1.3 Others

The remaining (water-)vegetation types along the A37 are ditches (2.0%), cat's ear and birdsfoot (1.4%), lawn (1.3 %), riparian vegetation (0.7%), verge with Holcus mollis and hawkweed (0.7%), heather (0.7%), flowery wet brush (0.6%), chimney ditch (0.3%), ponds (0.2%), violion caninae grasslands (0.2%), false oat grass hay meadows (0.2%),dry brush (0.1%), reed banks (0.1%), pools, retention ponds and talus (<0.1%).

The water-related vegetation types, have an anthropogenic origin, however they still play an important role for the fauna and abiotic factors such as groundwater-levels. Ditches are relatively small linearly waterbodies fed by rain and/or groundwater. The water-bodies are home to many animals, for example buffered ditches are more biodiverse, they can be a habitat to 200 to 300 different species from invertebrates to fish, but it is also home to waterbirds (Bal et al., 2001). Ditches have been dug to improve the drainage-system and to create available surface-water for agricultural purposes. The water-plants positively influence the water-resistance of the ditch (Beltman, 1993). Pools and ponds are home to some amphibians or function as their reproduction-area (Creemers, Pers. Comm., 2017, Appendix C).

The terrestrial vegetation types all have their own characteristics. Some are dependent of high groundwater-levels (flowery wet brush), while others prefer more a specific grain-size with less dependence on water (heather on sandy soils). Finally some vegetation-type can have also an ancillary position like recreation (lawn) or biomass production (false oat grass hay meadows) (Schaminée et al., 1995-1999).

3.2.2 Fauna

3.2.2.1 Mammals

313 different observation of mammals have been passed on to the NDFF along the A37 untill November 2016. To be more specific: 147 deer (Capreolus capreolus), 98 moles (Talpa europaea), 16 hare (Lepus europaeus), 11 mustelids (Mustelidae), 4 hedgehogs (Erinaceus europaeus), 4 mice (Apodemus & Arvicolinae), 2 foxes (Vulpes vulpes) and 2 squirrels (Sciurus vulgaris). The deer is the only large mammal, while all other species are classified as small mammals. Most observed mammals are solitaire animals, except of the deer and hare. Bats are described separately in section 3.2.2.3. Every species has different preferences for its habitat, however it's observed that most mammals are monitored near arable land.

Large mammals (Deer)

The deer is the only large mammal monitored along the A37. The verges are no habitat for large mammals, however they are used as passages to other areas (Keizer, Pers. Comm., 2017, Appendix C). 147 deer are observed in the roadsides of the A37. The deer are mostly observed in the roadside where the hinterland consists of agricultural land.

The roadsides along the A37 need to be available for deer to migrate without being directed towards the highway itself (La Haye, Pers. Comm., 2017, Appendix C). Food supply is no necessary element, however it's preferred when this ecological function must be maintained.

Fauna-facilities are vital for mammals to migrate to other habitats. These fauna-facilities can vary from fences, to prevent highway-crossing and therefore fauna-fatalities, to ecoducts: ecological overpasses which provide safe crossing-points for migrating animals. These facilities improve the interconnection between formerly isolated areas, reduce the amount of traffic-fatalities among animals and increase the safety of highways. Fauna-facilities are part of an integrated landscape conservation strategy to preserve the values of natural ecosystems (Van Bohemen, 1998). Along the A37 are fauna-facilities present as fences, passages, pipes and guide assemblies. However these facilities do not provide deer the opportunity to cross the highway.

Small mammals

Eleven different non-flying small-mammal species are monitored in the roadsides of the A37. Each species can make use of the highway in different ways, however there is a inversed proportional relationship between the size of the mammal and the dependence on verges. The smaller the mammal, the larger the probability that the roadside fulfills ecological functions for the species (La Haye, Pers. Comm., 2017, Appendix C). The roadside is only part of the territory of relatively 'larger' small mammals (i.e. hare or badger), while smaller mammals (i.e. mice) will use it as a complete habitat.

The ecological function is dependent on different environmental elements. High vegetation provide cover for mammals against predation. Hedgehogs, for example, avoid open areas, except for the movement between fragmented vegetation (Rondinini & Doncaster, 2002). Mustelids show similar behavior, however mustelids prefer woody vegetation as hiding place and habitat (Rondinini & Boitani, (2002).

Where hare and mustelids combine the roadside with the agricultural hinterland as their habitat, mice will use the roadside as habitat on its own. The roadsides provide enough shelter, nutrition and housing opportunities for mice the survive in the verges. Holes and migration-trails, which are clear indicators for permanent housing, are witnessed in the roadside frequently (Keizer & van den Hengel, Pers. Comm., 2017, Appendix C).

3.2.2.2 Birds

Birds are the most common animals near the A37. Therefore it's decided to divide this order into three groups: Water(-related) birds, raptors and songbirds. 2805 birds have been monitored in or near the roadside of the A37. 49 of them are raptors, 791 are songbirds and 1965 birds are water(-related) birds (mainly geese and ducks). In total, 46 different species are monitored (Appendix B). Due to their high abundance there is no clear correlation between landscape and exact amount of present birds. However this distinction can be made on group-level.

The main function of roadsides for birds are foraging-area and nesting & breeding (Laursen, 1981). This has also been confirmed by the interviewed experts (Keizer & van den Hengel, Pers. Comm., 2017, Appendix C; Bolhuis, Pers. Comm., 2017, Appendix C). Raptors, hunting mice and other small animals, will forage in roadside in their search for prey (Keizer & van den Hengel, Pers. Comm., 2017, Appendix C), while song-birds (i.e. sparrow) eat the death insects, caused by collision with traffic (Laursen, 1981). Raptors (i.e. buzzard and hawk) may use larger obstacles (streetlights, traffic signs) as viewpoint over the roadsides searching for mice and other small mammals. They focus on the trails and holes made by the mice and so they scan the roadside specifically for prey (Keizer, Pers. Comm., 2017, Appendix C). There is a relation between the width of the roadside and the success-rate of raptors (Meunier et al., 2000).
High grasses create the ideal breeding-location for some species (Laursen, 1981) while infrastructural structures providing nesting sites for some raptors (Morelli et al., 2014). Water(-related) birds may use the roadsides as nesting site as well (Keizer & Van den Hengel, Pers. Comm., 2017, Appendix C). Experts expected that birds are less sensitive to disturbance of the roadsides' characteristics, since they migrate easier between other locations (Keizer, Pers Comm., 2017, Appendix C; Bolhuis, Pers.

Comm., 2017, Appendix C), however literature shows that there is a positive correlation between the tree-density (and shrubs) and the bird-presence in verges (Morelli et al., 2014).

3.2.2.3 Bats

Bats are the most least occurring group on the roadsides of the A37. Only 28 bats are monitored along the route, divided in 2 species; the common pipistrelle (25) and the serotine bat (3). All common pipistrelles (Pipistrellus pipistrellus) were found at hectometer post (hmp.) 15.2, while the all three serotine bats (Eptesicus serotinus) where found 100 meters further along the highway at hmp. 15.3. Bats are described separately because of their unique capabilities to fly compared to other mammals. The uncertainty margin of the observation is large (±500 m radius), therefore it's questionable whether the bats are actually observed along the highway. However, it cannot be excluded that the bats were monitored directly in the verges. Cause of the large radius is the difficulty of confirmation by experts. The NDFF demand confirmation of witnessed fauna by an expert, however this is very difficult when monitoring bats. Mainly because of their activity after sunset and the trouble of confirming that the observed individual by the expert is the same individual observed in the first instance (La Haye, Pers. Comm., 2017, Appendix C).

It is not expected that the verges have a direct function for bats. Nutrition from flying insects is unrealistic, because the wind from passing traffic will cause no insect-activity directly near the roadside and the absence of high vegetation leads to no shelter, which makes it not interesting for housing (Meijer, Pers. Com., 2017). However the highway (including its roadsides) itself may have a function in terms of coordination by bats. Bats use characteristic features in the landscape for their daily migration form shelter to hunting grounds (La Haye, Pers. Comm., 2017, Appendix C; Falk et al., 2014).

3.2.2.4 Amphibians and Reptiles

In total, 73 different amphibians have been monitored on RWS' property along the A37. Most of these amphibians are observed along the eastern part of the highway around hmp. 39.9 (13 common frogs (Rana temporaria)) and hmp. 40.3 (two common toads (Bufo bufo) and 41 Pelohylax)(appendix A). The observed amphibians live north of the highway at hmp. 39.9 two small pools are located and south of the highway is a ditch placed. However, a small population (5 organisms) of the common toad has been witnessed at hmp. 4.3 and a population of 7 common frogs has been observed around hmp. 29.9. Additionally, there are occasionally single individuals monitored at other locations, but no special interest will be paid to this location since it's only one individual. The common frog is the most appearing amphibian in the Netherlands (Van Buggenum, 2009). The Pelophylax is a collective name for the pool frog, marsh frog and its hybrid the edible frog.

Amphibians

Toads are hunters, they mainly eat invertebrates, but also other young amphibians (Martens & Snep, 2009). The same applies to both frog-species, however the pelophylax also hunts small frogs and small mice (Van Buggenum, 2009; Mulders & Creemers, 2009). The toad's preys are mainly found in grasslands (Creemers, Pers. Comm., 2017, Appendix B). The common toad is well protected to predation, because of the toxic in their skin. However, some predators are still able to kill a toad. The most important toad-predators are corvids, raptors (buzzard and owls), but also small mammals like the fox, hedgehog, polecat, batcher and the brown rat (Martens & Snep, 2009). Toads are nocturnal animals while many of its predators are diurnal, which makes them even less vulnerable to predation (Creemers, Pers. Comm., 2017, Appendix B). Bots frog-types don't have a toxic skin and therefore they are much more vulnerable to predation. However their high abundance solve the predation-problem on species-level (Van Buggenum, 2009. The common toad does prefer local varying landscape, but they are not restricted to any specific landscape (Martens & Snep, 2009), while the pelophylax is dependent on water all year round (Creemers, Pers. Comm., 2017, Appendix C). The common frog prefers it habitat somewhere in between, since it prefers moisty herbaceous vegetation, but it's not dependent on water, only for reproduction (Van Buggenum, 2009). During the rest of the year, the adult common toad and common frog is in hibernation or it prefers grassy areas and scrubs with the presence of potential food (Creemers, Pers. Comm, 2017, Appendix B).

The roadside along the A37, mainly consisting of arid grasslands, provide plenty hunting ground for the common toad. Furthermore, the presence of ditches and pools makes reproduction available and is a secure habitat for tadpoles (Martens & Snep, 2009). The arid grasslands of the roadside of the A37 are not the ideal habitat for the common frog. However, it's still an acceptable habitat, since this species is not compelled to a specific habitat. The more developed regions along the highway are more interesting for the common frog, especially in the presence of a ditch or pool. The roadside of the A37 is only a habitat for the Pelophylax when there is a ditch or a pool located nearby. Ditches are present at is significant part of the section and pools are located around hmp. 39.9. It would be expected that the Pelophylax would be present at hmp. 39.9, although they are not monitored at that specific location, but 400 meters to the east.

Reptiles

Creemers (2009, Pers. Comm., Appendix B) states that the region of the A37, with its sandy soils, would form a potential habitat for lizards, even though these animals are not monitored along the highway. Therefore he expects that species, like the 'slow worm' does live in the roadside, but has not been observed. Slow worms' diet is based on earth worms and slugs, while they are predated by various predators, especially buzzards (Spitzen-van der Sluijs & Creemers, 2009). Slow worms prefer to have a habitat that is moisty and overgrown with vegetation. Also rail- and roadsides, especially with hedgerows, are known habitats of this animal (Spitzen-van der Sluijs & Creemers, 2009).

The roadside of the A37 could form a home to the slow worm, mainly when it's a heather-like or forested roadside. These type of roadsides function as hunting ground and the relatively high vegetation provide enough shelter against predation.

3.2.2.5 Butterflies

The amount of individual butterflies observed along the A37 is 13 divided over three different species: 10 large skipper (Ochlodes Sylvanus), 2 Sooty coppers (Lycaena tityrus) and 1 purple emperor (Apatura iris).

Butterflies are strongly reliant the roadsides of the A37, because of the large scale agricultural landscape of the hinterland. This hinterland has a low biodiversity, especially compared to the verges. This make the roadsides the main ecological infrastructure from a butterfly-perspective. It functions as corridor to other regions, which is important for some present species (Vliegenthart, Pers. Comm., 2017, Appendix C). Butterflies need flowering plants for the nutrient-uptake and per species varying pilot plants to lay eggs on (Vliegenthart, Pers. Comm., 2017, Appendix C). An intense mowing-regime limits the amount of flowering species and also the amount of nectar per flower, which leads to significant losses in the butterfly-population (Saarinen et al., 2005). Projects like the "*honey highway"* might positively influence the nutrient-availability for butterflies when it's equipped correctly. The *honey highway* is a 6 km long project along the A4 from Schiedam to Delft, in which flowering plants are introduced in the roadsides of the highway (honeyhighway, 2017). Along the A37 are no nearby beehives, the closest one is 3,5km north of the highway near the municipality of Emmen. Usually bees don't forage further than 2.2 km from the hive (Ratnieks, 2000), however this phenomena might be interesting for butterflies if native species preferred by butterflies are introduced (Vliegenthart, Pers. Comm., 2017, Appendix C). The observed species all have their own preferences of habitat and pilot plants(Vliegenthart, Pers. Comm., 2017, Appendix C; Settele et al., 2008):

- **Large skipper**: This species prefers brush and high grasses. This species prefers nectar from the bramble blossom.
- **Purple emperor**: Willow-type vegetation is preferred for its nutrients. Furthermore they are dependent on wood-rich transition, including hedgerows and willows. High trees are necessary to reproduce.
- **Sooty copper**: Acid grasslands are ideal for this species. Sorrel-species are the most important pilot plants. Additionally, the sooty copper need some micro-relief.

To conclude, butterflies are very dependent of the roadsides of the A37, because of the high biodiversity especially comparted to the largescale agricultural hinterland. A mature, not too short, vegetation cover with nectar-rich flowers is important for the nutrient-uptake and the, per species varying, specific pilot plants are vital for reproduction.

	Breeding / Reproduction	Foraging	Habitat	Orientation	Passage	Protection
L. Mammals					Space for mitigation	
S. Mammals	High vegetation or holes	Presence of nutrition (species dependent)	Only mice: Holes, nutrients, protection			Vegetation (height varies per species)
Raptors		Open area + viewpoint				
Waterbirds	Vegetation is breeding-behavior dependent					
Songbirds	Vegetation is breeding-behavior dependent	Presence of insects				
Bats				Presence of trees		
Amphibians	Presence of water	Presence of invertebrates (indirectly dependent on				
Reptiles		Presence of invertebrates (indirectly dependent on grasses)	Closed and dense vegetation			High, woody vegetation (bushes)
Butterflies	Specific pilot plants (species dependent)	Flowering plants (species dependent)			Flowering plants (species dependent)	

Table 3: Schematic overview of the ecological functions of the roadside for each fauna-group and what are the requirements to fulfill this function. Details are on group-level. Details on species-level can be found in section 3.2.2.

3.3 Impact from base case

This section describes the influences of solar energy production on the ecological function in roadsides. This analysis is performed on both the CMMM- and the VMBM-design, which influences will be described separately. Furthermore, it can't be derived from SMV's report whether or not waterbodies and/or forestry areas will be consumed by solar energy production. After consultation with project-experts within RWS, has it been decided to describe the influence on the ecological function from uprootment and waterbody-usage separately. Both types of solar panels are expected to influence the ecological function. On first place, because they occupy spatial-area, secondly because of the interaction between the modules and abiotic factors (sunlight, rainfall distribution etc.) and thirdly it's expected that the modules will interact with faunal behavioral patterns.

Roadsides crossing urbanized areas fulfill less ecological functions, simply due to the lower ecological activity at this part of the highway. Meanwhile, roadsides nearby, or even crossing, a nature reserve or an area with high natural quality will contain higher ecological value and thus fulfill more ecological functions (Keizer & Van den Hengel, Pers. Comm. 2017, Appendix). The A37 crosses mainly largescale agricultural land. The first two kilometers in the west, around the municipality of Hoogeveen cross urbanized area. Furthermore, the highway crosses another urbanized area near Klazienaveen. On the other hand, the highway crosses rural area with an increased ecological value near service area Zwinderscheveld and intersection Zwarte Meer. An ecological connection has been established around intersection Zwarte Meer, connecting nature reserve with the ecological main structure north of the highway (StudioMarcoVermeulen, 2016). Ecologists within RWS advise to produce solar energy rather in the urbanized areas, simply to minimize the impact on the ecological functions (Keizer & Van den Hengel, Pers. Comm., 2017)

3.3.1 CMMM

Module-density = 100%

A module-density (MD) of 100% means that no direct sunlight nor rainwater will reach the ground below the modules. Literature shows that common impacts resulting from constructions in general are the 'destruction of vegetation', 'desertification', 'soil erosion' etc. (Ijigah et al., 2013). Soil erosion may lead to nutrient depletion, reduced infiltration capacities and out washing of sediments, while destruction of vegetation and desertification are the direct reason for erosion and they have direct impact on the ecology of the roadsides. Destruction of the vegetation will take away many ecological functions for the fauna, since, as has been derived in section 3.2, many functions for specific species are dependent on (grassy) vegetation.

Foraging areas will be damaged in different ways. A bare soil will result in the absence of invertebrates, which functions as food for toads and small mammals (Creemers, Pers. Comm., 2017, Appendix C). The absence of flowering plants is disastrous to butterflies. And raptors, which scan the roadsides from higher obstacles like streetlights for small mammals, will be negatively influenced by the decrease in preys due to the installation of CMMM. Another obstacle for the raptors is the fact that the array forms an obstacle in their hunting and flight patterns. The design of SMV leaves two meter space as obstacle-free zone, however it is estimated that these two meter cannot provide enough functions for every species.

The obstacle-free zone can be used by passaging large mammals as a corridor (La Haye, Pers. Comm., 2017, Appendix C). The passage-function for butterflies won't be present after installation, since no flowering plants will be present which are necessary to butterflies (tab. 3). The roadside will lose its function as reproduction-area for some small mammals, ground-breeding bird-species and butterflies, which are dependent on specific pilot plants. In order to function as a habitat (to mice and reptiles), the roadsides need to serve multiple other functions. However these function will be destroyed, by the absence of vegetation, and therefore the roadsides can't serve as habitat any longer (La Haye, Pers. Comm., 2017, Appendix C). On the other hand, the roadsides will stimulate the protection-function (for small mammals, amphibians and reptiles) to predation, since the obstacles hinder raptors in their hunting-behavior and the increase in shelter.

To conclude, the installation of CMMM with a MD of 100% will lead to desertification and thereby impacting all ecological function except protection (fig. 8; fig. 9).

Module-density = 65%

12 ha (~10 %) of the solar farm will have a MD of 65%. In practice, the MD of a solar energy array is 40-60% (Jonker, Pers. Comm., 2017). Experiments in the USA have shown that the luminance underneath a freestanding PV-module is less than 600 Lx, while light readings under open-sky circumstances at the same location reached over 1,240 Lx (Arsenault, 2010). Not every grass-species require the same amount of luminance and light-hours. Moderate sun species require 5-6 hours of sunlight while sun-preferring species require at least 8 hours of direct sunlight (Arsenault, 2010). The most common grass-species in Dutch roadsides are shadow-tolerant (Plantum, 2017), but even the most shadow-tolerant grasses require 2-3 hours of direct sunlight to maintain a mature and acceptable density (Bell, 2011). Grass is still able to grow in dominantly shaded areas, because they are still able to absorb near-infrared, red and blue scattered light (ibid.). Furthermore increased shadowiness influences the morphology of the grasses: clipping weight, root- and shoot-production and leaf area decreases and the percent moisture increases (Wilkinson and Beard, 1974; Bell, 2011)

A MD of 65% will cause a decrease in vegetation-density and therefore harm the foraging function of the roadside. The more vegetation, the more suitable is the roadside as foraging area, especially for small mammals, amphibians, butterflies and songbirds. Proportional to this, a decrease in vegetation-density would lead to a reduction in available nutrients and therefore increase competition. Despite an increase in competition, the function will remain present as long as the vegetation-density is high enough. Raptors will be influenced the same as with a MD of 100%.

The roadsides will maintain their passaging-function for large mammals. But the function will be damaged for butterfly, because the vegetation will transit to a shadow-loving type, which means a reduction in native flowering plants. The reproduction of butterflies will be influenced similar because of same reasons. It's expected that the shadow-loving grasses will provide enough shelter for small mammals (i.e. mice) to reproduce and to function as habitat (La Haye, Pers. Comm., 2017, Appendix C). The slow-worm prefers its habitat in closed and dense vegetation (Spitzen- van der Sluis & Creemers, 2009), which won't be present underneath the modules. Therefore the roadsides won't be a suitable habitat for reptiles. The roadsides will perform better on the ecological function 'protection' for similar reasons as a MD of 100%.

All in all, the installation of modules with a density of 65% will directly influence the ecological functions negatively. However the impact will be much lower compared to a MD of 100% (fig. 8; fig. 9).

3.3.2 VMBM

Insufficient research has been done on the influence of VMBM (fig. 7) on the ecological function in roadsides. Nonetheless, a qualitative analysis based on expert-interviews makes a grounded and realistic estimation possible.

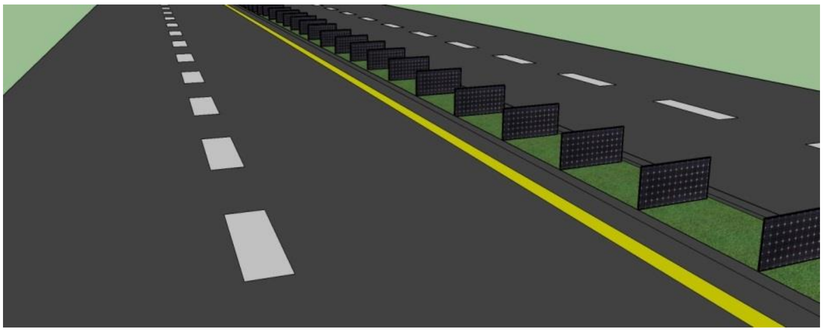


Figure 7: Simplified visualisation of the VMBM's setup in a narrow median strips

Because the VMBM is installed vertically less soil will be occupied. The estimated MD (share of the area directly covered by the module) will be 20%, based on the same shape and amount of modules as the SMV-design and assuming that the VMBM need a concrete basement with a width of 40 cm. However this will cause shading at high latitude regions and thus a reduction in electricity production, therefore the MD for the VMBM needs to be reduced, which will be described more elaborately in section 4.2.2. The MD will even be lower if the VMBM will be installed on poles. A concrete basement of 40 cm would result in 20 % vegetation losses. But the remaining 80 % vegetation receives significantly more direct sunlight and rainwater, enough for a healthy grassland. Additionally, the sunrays won't be blocked by the modules resulting in much higher light intensities reaching the soil and thus the grasses. The, in comparison with CMMM, improved environmental conditions will lead to an higher vegetation-density. Nonetheless the increased shadiness will promote shadow-loving grass-species. Where some experts predict an immature ecosystem without any satisfying ecological function (Keizer, Pers. Comm., 2017, Appendix C), other experts foresee enough opportunities as long as there is enough grass-vegetation in the roadsides (La Haye, Pers. Comm., 2017, Appendix C).

Interviewed experts expect different impacts on the ecological function. The VMBM's will provide more opportunities for fauna to still make use of the roadsides after installation of the modules. However, there are mixed opinions on the quality of the functions after installation. It's species dependent of the verges can still be used as foraging area; it's expected that the circumstances will be sufficient for small mammals and amphibians (La Haye, Pers. Comm., 2017, Appendix C; Bolhuis, Pers. Comm., 2017, Appendix C), however VMBM will be difficult obstacles for butterflies to overcome (Vliegenthart, Pers. Comm, 2017, Appendix C) and they will negatively influence the hunting behavior of various raptors (Keizer, Pers. Comm., 2017, Appendix C). Buzzards for example will be unable to make effective use of higher construction in their perching, because the modules will block their sight (Wuczynski, 2005). Another example is the impact on the hunting behavior of hawks. One possible hunting strategy of the hawk is to ambush the pray by flying at low altitude (~1 m) and thereby staying out of the line of sight for as long as possible (Roth & Lima, 2003).

Habitats for mice will be preserved by the conservation of the vegetation-cover (La Haye, Pers. Comm., Appendix C). Reproduction will be less influenced compared to CMMM, mainly because of the area available for ground-breeding bird-species and the presence of native pilot plants for butterflies. Passage-corridors are expected the be influenced similar for both CMMM and VMBM. It's likely that the function *protection* improves, by corresponding reasons as the CMMM has.

3.3.3 Consumption of forestry areas & waterbodies

It remains unclear from SMV's report whether or not the forestry areas and waterbodies will be used for solar energy production. For this reason, the possible consumption of these areas is described separately. This section might turn out irrelevant for the case-study, when it becomes clear that these areas remain unchanged. But the impact is expected to be significant when it's decided to consume these areas and therefore it's included in this research. The impact has been analyzed based on the CMMM design with a MD of 100%.

If uprootment is necessary, than the sequence from no/very-low vegetation from the agricultural hinterland to the high-vegetation of the forestry areas will be destroyed (Götz, Pers. Comm., 2017). Consequently small mammals can't find shelter anymore and will travel to more suitable locations. A decrease is grass-density and uprooting of trees will therefore destroy habitats. Three-nesting birds and small mammals will lose their reproduction area. And finally, bats will lose their orientation-point and will get lost in the area (La Haye, Pers. Comm., 2017, Appendix C).

Consumption of waterbodies for solar energy production will mainly influence the amphibians and waterbirds. Amphibians will lose first of all their reproduction-area and additionally, the pools won't be suitable habitats to pelophylax. For waterbirds, the waterbodies are a major part of their habitat in which they mainly forage. This function will be destroyed either when waterbodies are used for solar energy production (Keizer, Pers. Comm., 2017, Appendix C).

Figure 8 shows a schematic overview of how the different ecological functions are influenced by the installation of both designs, varying module densities and for the use of forestry areas and waterbodies for solar energy production. Figure 9 shows the average score per function for each analyzed setup.

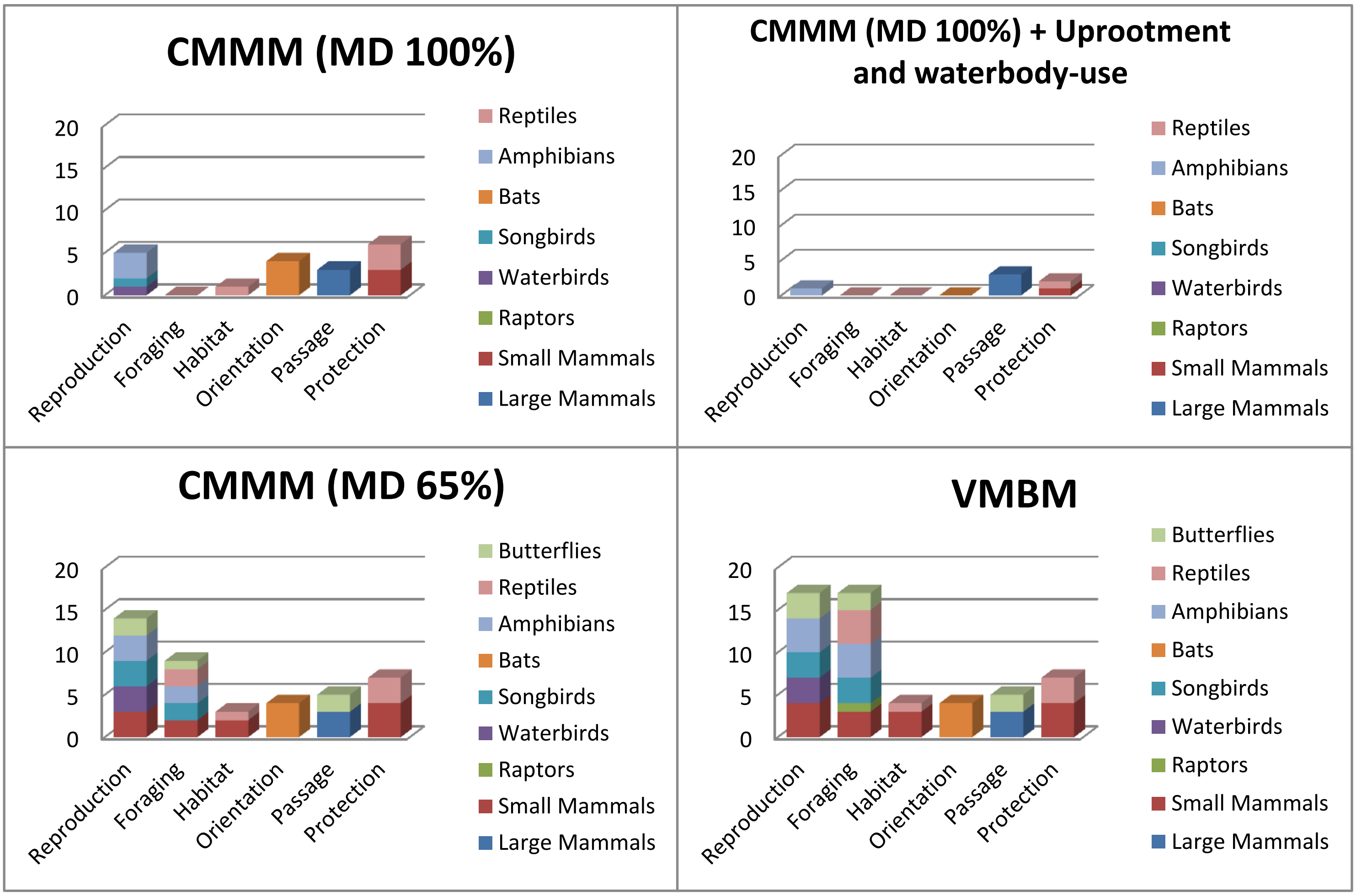


Figure 8: Qualitative scoring of the functions per design and varying module-densities. The scorings for use of forestry areas and waterbodies have been included in combination with CMMM with a module-density of 100%. Every fauna-group received a score per function ranging from 0-4. 0 = Destroyed, 1 = heavily damaged, 2 = Significantly affected, 3 = Slightly affected, 4 =non-affected/stimulated. The cumulative maximum score is of all function combined is 72.

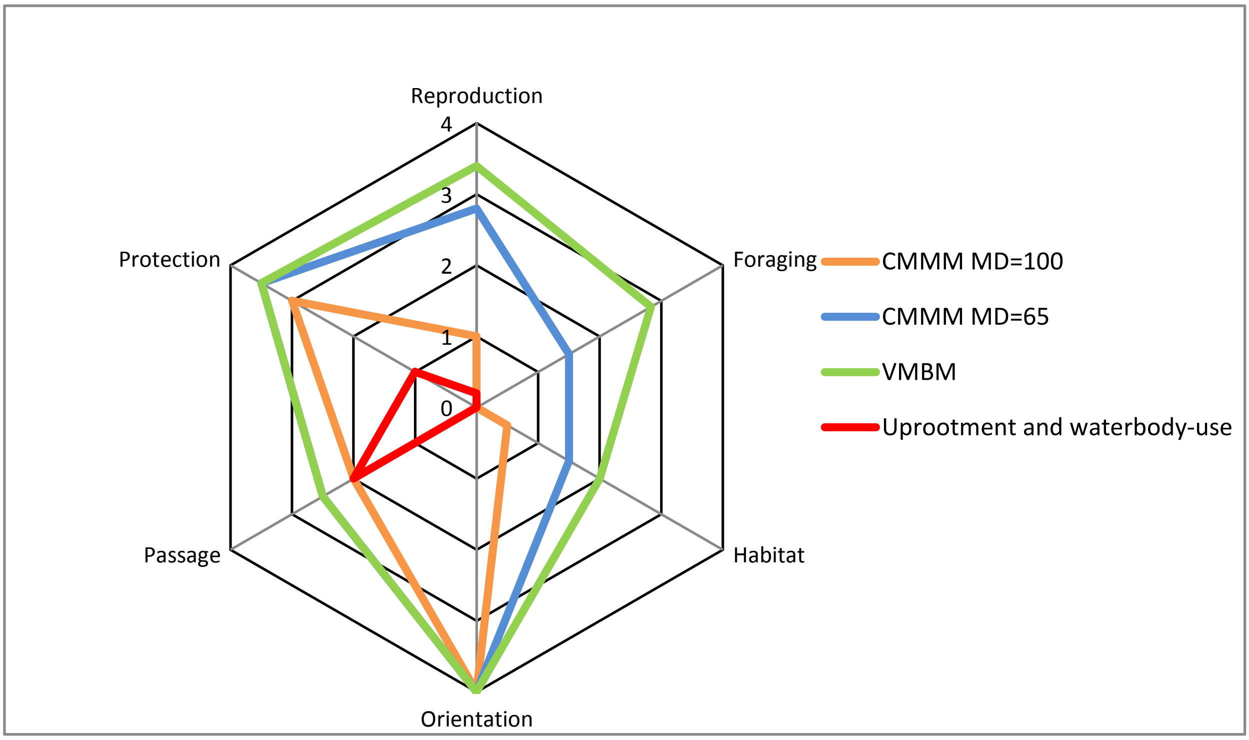


Figure 9: Qualitative scoring of the designs, including different module-densities and uprootment and the use of waterbodies. Based on the scorings from the evaluation. Every fauna-group received a score per function ranging from 0-4. 0 = Destroyed, 1 = heavily damaged, 2 = Significantly affected, 3 = Slightly affected, 4 =non-affected/stimulated. The theoretical maximum scores are shown in section 3.1.2. The cumulative maximum score is of all function combined is 72.

3.4 Adaptions

This chapter presents a conspectus of potential adaptions which are expected to reduce the impact or even trigger improvements of the ecological function and it describes how these adaptions preserve or trigger the ecological function and its specific design rule(s). The influences on the electricity production will be described in chapter 4. This chapter contains three paragraphs. The first paragraph describes adaptions required for both designs. Afterwards paragraph two and three will describe adaptions for CMMM and VMBM respectively. In section 3.2 it has come to light that the presence of vegetation, especially grass and trees, is a binding-requirement to maintain a healthy ecological function. Therefore primary solutions are focused on the preservation of vegetation. Section 3.3 showed that the vegetation was significantly influenced by both designs and for different MDs, mainly because sunlight and rainwater was limited in reaching the soil and by spatial occupation of the modules, characteristics which have been taken into account when selecting to adaptions. Every adaption has a table attached in which the improvements of the influenced ecological functions, derived in chapter 3.2, is shown. Graphic representation of the increased ecological functions is included in appendix D & E. The same scoring-methodology is used for figures 8 & 9 (3.3). The revised scores after application of the adaptions are compared to the original CMMM- and VMBM-design, without any other adaptions applied. Figure 9 shows the cumulative increase in ecological function scores when all adaptions are applied.

3.4.1 General adaptions

3.4.1.1 Prevention of uprootment of forestry areas

From the results of sub-questions 1 and 2 it has been found that the forests are vital for multiple ecological functions. First of all, they're an important part of the vegetation-sequence in relation with the hinterland. But they fulfill other functions for specific fauna-groups as well (tab. 2).

Based on these different functions, it can be concluded that the uprootment of forestry areas would destroy multiple ecological functions and therefore reduce the ecological value of the roadsides dramatically. Therefore uprootment of these forestry areas has to be avoided at all time, for both designs (tab. 4).

Function	Improved design rule	Old score	Score after applying adaption
Reproduction area for small mammals and birds	Increased amount of high vegetation	Destroyed	Heavily affected
Protection for small mammals and reptiles	Increase of high vegetation	Heavily damaged	Slightly affected
Habitat for reptiles	More closed and dense vegetation	Destroyed	Heavily damaged
Orientation for bats	Presence of trees	Destroyed	Non-affected

Table 4: Improved functions and design rule after the application of the prevention of uprootment.

3.4.1.2 Floating modules

Waterbodies have two main functions. Firstly, they are used by amphibians as a reproduction area. This mainly accounts for the still-standing waterbodies like pools and ponds. Moreover, the pelophylax is dependent on these waters all year round. Secondly, waterbirds will use the waterbodies as part of their habitat. For these reasons, the investigated designs are currently not suitable for solar energy production. Not using the waterbodies for electricity production is an option that stimulates the functions related to these waterbodies, however RWS is currently investigating adaptions to the setup of the arrays resulting in floating VMBMs (Jongsma et al, 2017), which is expected to have sufficient ecological function-improvements and thus is a considerable adaption. These floating modules will be installed at 2.5 m above water, making is possible for waterbirds to move underneath it. It’s important for amphibians that the very shallow edges of the waterbodies remain unused in order to keep is suitable for reproduction. Therefore, this research assumes that the edges remain unoccupied (tab. 5).

Function	Improved design rule	Old score	Score after applying adaption
Reproduction for amphibians	Presence of water	Heavily damaged	Non-affected
Habitat of pelophylax	Presence of water	Destroyed	Slightly affected
Habitat for waterbirds	Access to open waterbodies	Destroyed	Significantly affected

Table 5: Improved functions and design rule after applying the floating modules.

3.4.1.3 Obstacle free-zone

The verges only form a small part of the habitat of large mammals. Nonetheless, the verges are still used by deer to migrate from specific, otherwise isolated, foraging areas. So regardless of the small part of the deer’s habitat, the roadsides are essential to prevent isolation of different foraging area and therefore populations.

The design of SMV already includes an obstacle free-zone with a diameter of 1.65 meter (StudioMarcoVermeulen, 2016). According to SMV’s report, this obstacle free-zone is necessary to prevent shading on the panels and/or to enable maintenance of modules. Besides the prevention of shading and the accessibility for maintenance, the zone can also be used by deer to migrate between different foraging area. The obstacle free-zone is preferred away from the highway, in order to prevent highway-crossing. When it’s decided to install the obstacle free-zone directly next to the highway, a high fauna-fence needs to be installed to prevent highway-crossing (La Haye, Pers. Comm., 2017, Appendix C). All in all, an obstacle free-zone accessible to deer will provide deer with the opportunity to migrate between different parts of their habitat and therefore the roadside will maintain its function for passaging (tab. 6).

Function	Improved design rule	Old score	Score after applying adaption
Passaging for large mammals	Space for mitigation	Slightly affected	Non-affected

Table 6: Improved functions and design rules after the application of the obstacle free-zone.

3.4.1.4 Poles

CMMM with a MD of 100 % directly installed at the ground will make it unfeasible for grass-type vegetation and flowering- & pilot-plants to grow, simply due to the spatial occupation of the roadsides. Similar impacts will occur with lower MDs, although the available space between the modules will ease of the impact. Yet, directly underneath the modules is still no growth available. VMBM will need a stable basement to diminish impact from environmental circumstances. Concrete basements are the most common-used basements, however the MD of VMBMs can be decreased. The specific issue of the basement of VMBMs will be described more elaborately in section 3.4.2 . Section 3.3 describes the necessity of grass and plants in the roadsides for many functions.

Vegetation-growth is stimulated by the pole-based module installation. But still, the grass growth promoting circumstances are not only dependent on the space available directly underneath the module. At the same time the installation on poles vitalizes also other ecological functions in various ways. Amphibians and small mammals can migrate underneath the modules without being hunted by raptors. When the modules are installed directly on the surface, an intense mowing-regime is necessary to prevent the vegetation from overgrowing the modules. When the modules are installed on top of poles, a more extensive mowing-regime is optional. This allows flowering- and pilot-plants to develop, which is beneficial for the red list-species 'Sooty Copper', especially when the species habitat has become isolated (tab. 7).

Function	Improved design rule	Old score	Score after applying adaption
Reproduction area for ground-breeding birds and mice	Increased amount of grass-vegetation	Destroyed	Significantly affected
Foraging area for small mammals, amphibians and reptiles	Available spatial area + increased grass-vegetation	Destroyed	Heavily damaged
Protection for small mammals and reptiles	Protection against raptors	Slightly affected	Non-affected
Habitat for mice	More closed and dense vegetation	Destroyed	Heavily damaged

Table 7: Improved functions and design rules after the application of the installation on top of poles.

3.4.1.5 Pilot- and flowering plants

Different butterfly-species are dependent on specific types of plants. Section 1.7 of the results-section describes what pilot- and flowering plants are necessary for the observed butterfly-species. The same accounts for honey bees. When butterflies and honey bees are planned to be introduced in the landscape, the correct flowering- and pilotspecies need to be introduced either in order to let the roadsides be a foraging and reproduction area for butterflies (tab. 8).

Function	Improved design rule	Old score	Score after applying adaption
Reproduction area for butterflies	Presence of pilot plants	Destroyed	Stimulated
Foraging area for butterflies (and honey bees)	Presence of flowering plants	Destroyed	Stimulated

Table 8: Improved functions and design rules after the application of pilot- and flowering plants.

3.4.1.6 Urban- vs rural area

Ecologists within RWS advise to produce solar energy rather in the urbanized areas or at talus, in order to minimize the impact on the ecological functions (Keizer & Van den Hengel, Pers. Comm., 2017). This is because the rural areas have more ecological functions, since the ecological value is higher. This last statement can be validated by the observations:

Entire highway (42 km):	15.1	individuals/100 m
Municipality of Hoogeveen (hmp. 0.0-2.0):	6.1	individuals/100 m
Municipality of Klazienaveen (hmp. 36.8-38.6):	0.3	individuals/100 m

The ecological value near the municipality of Hoogeveen is relatively high compared to the value of Klazienaveen, but this is mainly caused by a swarm rooks of 80 individuals at hmp. 1.0. Service area Zwinderscheveld' contains a higher ecological value, especially to geese: 122.1 individuals/100 m (hmp. 12.4-13.2). Preferring locations along the route with lower ecological value will, first of all, minimize the impact on the ecological value of the roadsides and consequently, less adaptions will be required to make sure that the roadsides maintain their ecological function. This adaptions supports the House sparrow, since his nesting sites are already limited by urbanization. Solar energy production would increase the pressure on this species (tab. 2). No table is included for this section, because this adaption doesn't directly improve the state of specific functions. This adaption is not described in more detail, due to time limitations of the research.

3.4.2 CMMM adaptions

3.4.2.1 Reduced module-density

SMV's report describes a MD of 100 % for most of the roadsides. They propose a design with almost flat-lying modules (tilt = 5%) which leads to little shadow-formation. However it's optional to install the module at a certain tilt angle to increase solar energy production (see 3.4.2.2)(Asl-Soleimani et al., 2001). In practice, the MD depends on the chosen tilt angle, in order to prevent shading from the next array, especially for south-oriented solar parks. The larger the tilt, the more space is required between the arrays (Lieven, Pers. Comm., 2017, Appendix C). Usually, the MD of a solar park in the Netherlands is somewhere set between 40% and 60% (e.g. solarpark Azewijn) (ibid.; Jonker, Pers. Comm., 2017). A lower MD will result in more light reaching the surface directly, and thus an increase in light-intensity and direct sunlight-hours, but it will also increase the amount of scattered light. The 40% - 60% MD doesn't correlate with the proposed MD by SMV. Therefore a decrease in MD might be important to prevent (partial) shading on the underlying arrays and, likewise, it will stimulate multiple ecological functions (tab. 9).

Function	Improved design rule	Old score	Score after applying adaption
Reproduction area for ground-breeding birds	Increased amount of grass-vegetation	Destroyed	Significantly affected
Foraging area for small mammals, amphibians and reptiles	Available spatial area + increased grass-vegetation	Destroyed	Slightly affected
Reproduction area for butterflies	Presence of pilot plants	Destroyed	Significantly affected
Foraging area for butterflies (and honey bees)	Presence of flowering plants	Destroyed	Heavily damaged

Table 9: Improved functions and design rules after the reduction of the module-density to 50%.

3.4.2.2 Tilt of the module

Tilt is the angle the module makes compared to the ground. In SMV's design, the tilt of the modules is 5° when the MD = 100% and 30° when the MD = 65%. Originally tilt was introduced to PV solar energy production to increase the geometry factor by pointing the cells directly to the sun. An increase in tilt results in less surface-coverage from the module (fig. 10) but also increased shadiness, which makes a lower MD necessary (see 3.4.2.1). The surface-coverage of a module reduces, since the horizontal length of the module decreases based on equation (1). Improved ecological functions are similar as those of section 3.4.2.1 (tab. 9), however the magnitude of improvement depends on the amount of tilt. In the Netherlands, a common tilt is 30° (Lieven, Pers. Comm., 2017, Appendix C)

$$A = Cos(t) * L \tag{1}$$

Where: A = Horizontal length of the module (m)
L = Actual length of the module (m)
t = Tilt of the module (°)

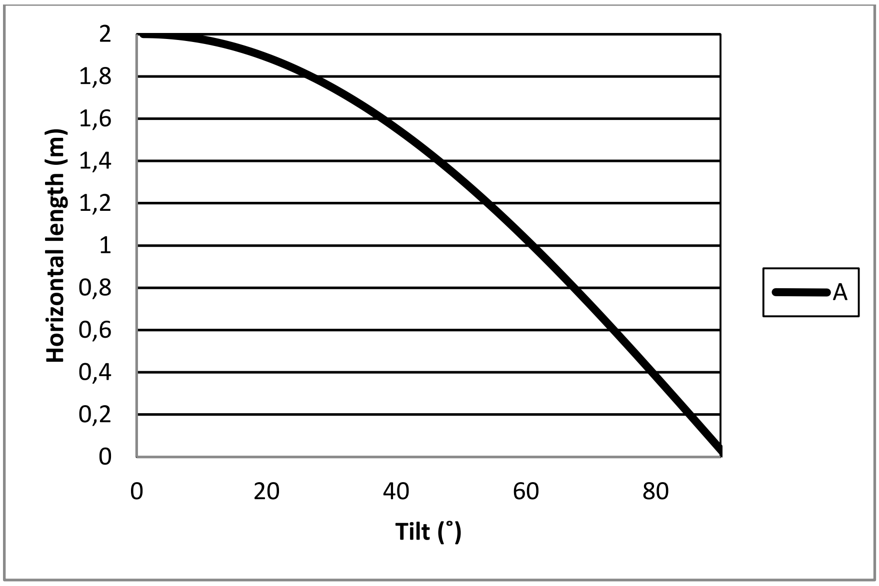


Figure 10: Horizontal length of the module to its corresponding tilt for L = 2 meter

3.4.2.3 (Semi-)transparent photovoltaics

(Semi-)transparent photovoltaics are different from conventional photovoltaics by the material used as backsheet. Instead of using opaque material, semi-transparent photovoltaics make use of a transparent backsheet. This concept has already been elaborately investigated for 'Building Integrated PhotoVoltaics', reaching a luminosity of 20-34% for transparent organic solar cells (Bag & Durstock, 2016; Yu, 2014; Zhang et al., 2016)).

The additional transmitted light will interfere with scattered light from the side, but the extra light reaching the vegetation will stimulate growth and vegetation-density nonetheless. Thereby improving ecological functions for fauna. The exact light-increase is dependent on multiple factors, such as current weather, albedo-level of the surface and size of the modules, therefore experiments on measuring the light-increase will be necessary to define the exact light-increase in-situ. The encouragement of vegetation-growth will stimulate similar functions as described in 3.4.2.1 (tab. 10).

Function	Improved design rule	Old score	Score after applying adaption
Reproduction area for ground-breeding birds and mice	Increased amount of grass-vegetation	Destroyed	Significantly affected
Foraging area for small mammals, amphibians and reptiles	Available spatial area + increased grass-vegetation	Destroyed	Slightly affected
Habitat for mice	More closed and dense vegetation	Destroyed	Heavily damaged
Reproduction area for butterflies	Presence of pilot plants	Destroyed	Significantly affected
Foraging area for butterflies (and honey bees)	Presence of flowering plants	Destroyed	Heavily damaged

Table 10: Improved functions and design rules after the application of (semi-)transparent modules.

3.4.2.4 Capillary fleece

Disproportionate rainfall distribution is another large obstacle to overcome in order to maintain a healthy and dense vegetation cover. Rainfall cannot directly fall onto the soil underneath a module, but it can be guided towards it by a capillary fleece. Cotton-material has high wicking capacities and would therefore be a useful material for the fleece (Patnaik, 2010). The fleece will be installed within the rootzone. Rainwater flowing down from the module will infiltrate into the fleece. Suction and capillary force will transport the water underneath the module, making it accessible for the vegetation underneath the module (Greenrooftechnology, 2017). On the contrary, it's expected that the fleeces will interact with subsurface-living fauna. Moles for example, will dig their holes at a depth varying from 5 cm – 100 cm, with a preference for 10 to 20 cm depth (Godfrey & Crowcroft, 1960). The increase in vegetation growth will stimulate similar functions as described in 3.4.2.1 (tab. 11).

Function	Improved design rule	Old score	Score after applying adaption
Reproduction area for ground-breeding birds and mice	Increased amount of grass-vegetation	Destroyed	Significantly affected
Foraging area for small mammals, amphibians and reptiles	increased grass-vegetation	Destroyed	Significantly affected
Habitat for mice	More closed and dense vegetation	Destroyed	Heavily damaged

Table 11: Improved functions and design rules after the application of a capillary fleece.

3.4.3 VMBM adaptions

Section 3.3.3 shows that a setup based on VMBM will have the least ecological impacts compared to the other investigated setups. Consequently, there are less mitigating adaptions required but unavailable as well. Most of the significant adaptions for VMBM are already described in section 3.4.1, however there are still two adaptions applicable to VMBM.

The MD decrease heavily when modules are installed vertically. Nonetheless, a concrete basement to provide stability results in a MD of 20% for a module of 2 m^2 (see 3.3.3). The MD can be decreased when it's decided to increase the height of the modules, while keeping the area constant. This results automatically in a decrease in width and therefore a decrease in MD. Previously was described that a decrease in MD results in more vegetation, with corresponding improvements on specific ecological functions. However, a higher module will increase impacts on the foraging behavior of raptors and will become more difficult to overcome for butterflies. Whether or not a higher VMBM will stimulate the ecological functions is dependent on the priorities of each ecological function.

Shadow is not only caused by an increase in tilt, but it depends also on the height of the module. Logically, a higher module will result in more shadow. Therefore a larger distance between modules is required to prevent (partial-)shading. A lower MD has as ecological benefit that more sunlight can directly reach the soil and rainwater can be more equally distributed over the surface, at the cost of less energy production. Similar results can be found for adaptions to the MD for CMMM (tab. 12).

Function	Improved design rule	Old score	Score after applying adaption
Reproduction area for ground-breeding birds	Increased amount of grass-vegetation	Significantly affected	Slightly affected
Foraging area for small mammals, amphibians and reptiles	Available spatial area + increased grass-vegetation	Slightly affected	Slightly affected
Reproduction area for butterflies	Presence of pilot plants	Slightly affected	Non-affected
Foraging area for butterflies (and honey bees)	Presence of flowering plants	Significantly affected	Slightly affected

Table 12: Improved functions and design rules after adapting the shape and module-density of the VMBM-design.

3.5 Synopsis

Many different species, both floral and faunal, are present in the roadsides of the A37. Each species depend in its own way on the environmental circumstances. However one clear correlation is visible within the fauna, which is automatically necessary as well for flora: Every species is reliant on the vegetation (flora), which stands at the base of every ecosystem, mainly grass and the lesser extent trees and bushes. And therefore they are indirectly dependent on rainfall distribution and light intensity reaching the surface, since these are vital elements for flora. Every vegetation-type fulfills a different ecological function, however the most function-providing vegetation types are the deciduous forest (providing protection, shelter and a connection with the hinterland) and the arid grasslands (foraging-area, passage-route, entire habitat, nesting site). The arid grassland are even more relying on light intensity.

Solar arrays influence the ecological function in three different ways; modules occupy spatial area, the interaction between the modules and abiotic factors and the interaction with faunal behavior. Spatial area can be reduced by increasing the tilt of and reducing the MD. Furthermore, uprooting of forestry area in order to create space for solar energy production would affect the ecological function heavily, since these areas have different ecological function locally and also in relationship with the agricultural hinterland. The interaction with abiotic factors has major impact in the vegetation directly underneath the module. From their it influences the fauna indirectly. Main impact is the decrease in luminance and direct sunlight-hours reaching the surface. Another major obstacle is the rainwater-distribution. Rainwater is less equal distributed by the modules, affecting the water-accessibility of the vegetation underneath the module. The interaction with faunal behavior is best visible by the behavior of raptors and breeding-patterns of birds. These behavior will be hindered and therefore the roadsides reproduction-function and foraging-function will be negatively influenced.

Section 3.4 contains 10 different adaptions, by which it's attempted to stimulate the ecological function while minimizing the decrease in solar energy production. Adaptions vary from prevention-measures to technical solutions. From section 3.2 it was concluded that vegetation is the main priority to maintain an ecological function, therefore most solution focus on triggering vegetation-growth. However, most adaptions will stimulate multiple ecological function, these functions can be described as 'multi-function'-solving adaptions. The CMMM-design has eight potential adaptions to increase the ecological function, where the VMBM-design has five. The cumulative scores for the ecological function increases for the CMMM (MD = 100%) from 7 to 44. VMBM show less increase, however its initial value was significantly higher compared to CMMM and therefore its final scores remain higher as well (Fig. 11).

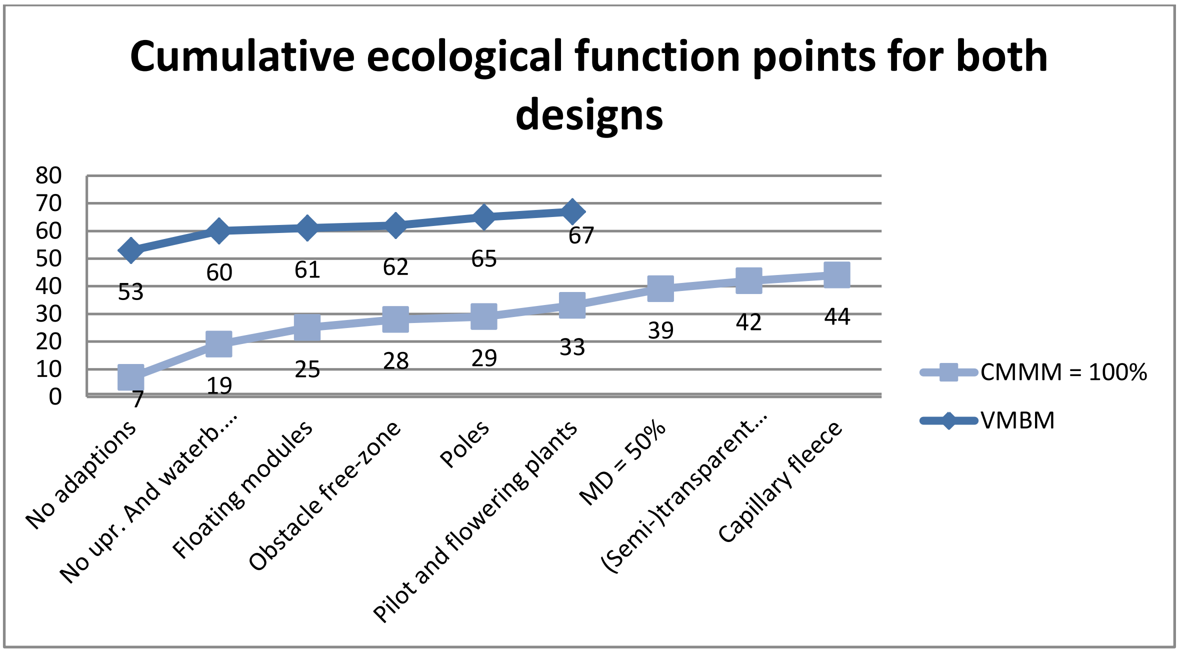


Figure 11: Cumulative ecological function scores for both designs. After implementation of all adaptions. The order of the adaptions is based on the order in which they are described.

4 Electricity production and costs

This chapter focusses on the electricity production and financial consequences from the proposed adaptions. The structure of this chapter is comparable to chapter 3. First the methodology used to answer sub questions 4 and 5 is described in section 4.1. Secondly, the impacts on electricity production is presented in section 4.2. Third, the involved costs and profits corresponding to the proposed adaptions are discussed in section 4.3.

4.1 Methodology

4.1.1 Influence on the electricity production

This chapter attempts to find the optimum between solar electricity production and the preservation of the ecological function of the roadsides and median strips of the A37. The influence from the proposed adaptions from section 3.4 is calculated by first determining the maximum electricity potential for the CMMM-design and the VMBM-design. Afterwards, the reduction from the proposed will be subtracted from this theoretical maximum electricity potential. This chapter divides the proposed adaptions in two groups; adaptions influencing the amount of electricity produced by reducing the area or amount of modules installed (array-level)and technical adaptions that influence the efficiency of the modules themselves (module-level)(tab. 13). The adaptions ‘Pilot and flowering plants’ and ‘Capillary fleece’ are not included in the calculations since these do not influence the electricity production. ‘Urban area vs. rural area’ is not included, since non-available additional data is necessary to make legitimate calculations.

Array-level adaptions	Module-level adaptions
No uprootment of forestry areas	Floating modules
Obstacle free-zone	Tilt of the module
Reduced Module-density	(Semi-)transparent modules
	Poles

Table 13: Adaptions influencing the electricity production divided in two groups; array-level and module-level.

The theoretical maximum electricity production depends on the Peak Power and the total area of the solar park. SEAC, a Dutch research institute focusing on solar energy systems and applications (SEAC, 2017), uses the following equations to calculate the total energy production (Folkerts et al., 2017):

$$W_p = I_{stc} * \eta * A \tag{1}$$

Where:

W_p = Peak Power (W)

I_{STC} = Incident Radiative Flux from the sun (W/m^2)

A = Area of the module (m^2)

η = Cell-efficiency

The I_{STC}, under STC with a spectrum of AM 1.5 and a temperature of 25˚C, is set at 1000 W/m^2. However I_{STC} varies per geographic location. For the case-study the global horizontal radiative flux (I_{GH}) 984 kWh/m^2/y. This value is based on a horizontal surface. The efficiency of the cells is 16% resulting in a peak power per module of 160 W_p. A correction (geometry-factor (G)) needs to be included dependent on the orientation and tilt of the module. This results in the following equation:

$$I = G * I_{GH} \tag{2}$$

Where:

I	=	Actual radiative flux (W/m^2)
G	=	Geometry-factor (G>1 when south-oriented and G<1 when north-oriented)
I_{GH}	=	Global horizontal radiative flux (kWh/m^2/y)

From here, the annual energy production per m^2 can be calculated:

$$E_{m^2} = PR * \left(\frac{I}{I_{STC}}\right) * W_p * h \tag{3}$$

Where:

$E_m{}^2$	=	Energy production per m^2 (Wh/m^2)
PR	=	Performance Ratio
h	=	Annual hours of direct sunlight (h)

The Performance Ratio is the ratio between the actual and theoretical maximum performance of the cells. Losses included in this performance ratio are temperature losses, inverter losses, shading losses, mismatches, reflection losses and cable losses. The total energy production of the solar park can be calculated by multiplying the energy production per m^2 with the total area of the modules.

$$E_{total} = E_{m^2} * A * MD \tag{4}$$

Where:

$E_m{}^2$	=	Energy production per m^2 (Wh/m^2)
E_{total}	=	Total energy production (Wh)
A	=	Cumulative surface-area of the modules
MD	=	Module-density

The physical properties to calculate the theoretical maximum electricity production for both designs are included in table 14. The G for the CMMM-design has multiple values, since SMV included various tilt within their design. Automatically, the I has multiple values either.

	CMMM	VMBM	
		East	**West**
A (ha)	117	117	117
G	1.05-1.14	0.64	0.66
H (hours/y)	985	985	985
I (W/m^2)	1033.20-1121.76	629.76	649.44
I_{GH} (W/m^2)	984	984	984
MD (%)	100% (105 ha), 65% (12 ha)	10.4%	10.4%
PR (%)	0.85	0.85	0.85

Table 14: Physical properties of both designs.

In practice, south-oriented modules have a tilt of 30˚and a MD of 50 %. Based on these parameters and equation (5) it has been calculated that the minimal angle of x to prevent shading is 30˚ for south-oriented modules. It's assumed that the minimal required sun's angle with no shading for south-oriented modules is similar for the east-west oriented VMBMs. Hereby it can be derived from

(5) that the minimal distance in order to prevent shading for VMBMs (L = 2m) is 3.46 m. Which leads to a MD of 10.4% for the VMBM-design. To determine the electricity production of a single VMBM it's better to approach both sides separately. This results in a geometry-factor for the east-oriented side of G = 0.66 and for the west-oriented side of G = 0.64 (Folkerts, Pers. Comm., 2017, Appendix C).

$$D = \frac{L_v}{Tan(x)} \tag{5}$$

Where:

D	=	Distance between two modules (m)
L_v	=	Height of the module (m)
x	=	Angle of the sun to the horizon

Equation (6) makes it able to calculate the electricity production yield for array-level adaptions. This equation state that the reduction in electricity production is linear to the share of area which remains unutilized for solar energy production.

$$E_{A_{sp}} = \frac{A_{sp}}{A_{total}} * E_{total} \tag{6}$$

Where:

$E_{A_{sp}}$	=	Energy yield for the specific area (Wh)
A_{sp}	=	Specific area (m^2)
A_{total}	=	Total area (m^2)

Equation (7) is useful to calculate the horizontal length covered by a tilted module:

$$L_h = \cos(t) * L \tag{7}$$

Where:

L_h	=	Horizontal length of the module (m)
L	=	Total length of the module (m)
t	=	Tilt (°)

Missing information for the array-level adaptions has been filled up by semi-structured interviews of solar energy experts and by scientific literature. This research uses information from scientific literature and state-of-the-art reports on PV-developments to determine the impact on efficiency for module-level adaptions. Costs & Profits

4.1.2 Costs & profits

This section shows the involved costs and profits related to the proposed adaptions. The data used for the calculations is based upon current market prices and technology related investment- and O&M costs. First, the costs and profits for the base-case of both designs are calculated. Afterwards, the costs and profits of the proposed adaptions will be described. Finally, an overview of the related indicators per adaption will be schematically presented in table 23.

The costs and profits will be presented by means of the Levelized Cost Of Electricity (LCOE), annual profits, total profits and simple payback period. The investment costs (Capex) and O&M costs (Opex) will directly influence these indicators. Note that this section describes the costs and profits of the proposed adaptions by presuming that it's the only implemented adaption.

Capex and Opex are the primary cost-source for solar energy production. Investment- and O&M-costs divided by the cumulative electricity production results in the LCOE and can be calculated by equation (8)(Fraunhofer ISE, 2015). The lifetime of the modules is 30 years and the discount rate will be 5%.

$$LCOE = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{M_{t,el}}{(1+i)^t}} \quad (8)$$

Where:

I_0	=	Investement expenditures in €
A_t	=	Annual total costs in € in year t
$M_{t,el}$	=	Produced electricity in the respective year in kWh
i	=	Real discount rate in %
n	=	Economic potential lifetime in years
t	=	Year of lifetime

The costs of the project are in the range of a 1 MW_p solar park, since the production capacities of the Zonneroute A37 are in this scale (Folkerts et al., 2017). RWS estimates that the start of the solar park installation will be in 2019. The expected Capex in 2019 are 0.912 €/W_p for a conventional 1 MW_p solar park. The Opex are set at 0.018 €/W_p*years, which is 2 % of the Capex. SMV's design makes use of dyed solar-cells, which increases the costs. Therefore the Capex and Opex used in this research are 1.248 €/W_p and 0.027 €/W_p*year respectively (Ibid.). The actual W_p of the Zonneroute A37 is 171 MW_p. The total profits is based upon the current electricity prices in the Netherlands. For large scale electricity consumers this is set at 0.2 €/kWh (CBS, 2017). It's chosen to use the market price instead of the APX-price, since the electricity production doesn't meet RWS' electricity consumption and thus is it financially more interesting for RWS to consume the electricity rather than selling it (Rijkswaterstaat, 2016). This leads automatically to prevented electricity-purchase.
The costs in €/W_p for VMBM are similar as for CMMM (Robles-Ocampo, 2007). Therefore the costs of the VMBM-design will be based upon the conventional 1 MW_p solar park.

In order to determine the costs related to the installation of poles has it been decided to use steel as material for the poles, since steel is relatively cheap has a long lifetime and is a strong construction-material . The market price for steel poles is 27.95 €/2m (installand, 2017).
The amount of steel required to set the modules at the correct tilt is determined by the amount of modules which need to be tilted and the maximum height of the modules. The height is determined by (9). It's assumed that the CMMM have a length of 2 m and a width of 1 m. The height on which the modules will be installed is 0.50 m. This results in 8 m of steel for each module (4 * 0.5 m and 6 m to support the construction).

$$H = L * \sin(t) \quad (9)$$

Where:

H	=	Height (m)
L	=	Length of the module (m)
t	=	Tilt (˚)

The amount of modules being tilted is the area of the flat-lying modules multiplied by the MD and divided by the area of the modules.

4.2 Influence on the electricity production

Section 4.2.1 describes the theoretical maximum electricity potential. Section 4.2.2 focusses on the influence on efficiency from the proposed adaptions. At the end of this section will a table be included that provides an overview of the impact on electricity production from the adaptions (tab. 16).

4.2.1 Theoretical maximum electricity production

The CMMMs have a W_p/m^2 of 152 W. By using the parameters of the base-case and the characteristics of the CMMM it can be calculated that the theoretical maximum electricity production for the CMMM-design is 152 GWh/y (1-4). , resulting in a theoretical maximum electricity production of 152 (1-4).[1]

The east-west oriented VMBMs have shown to cause less ecological impact compared to the CMMM. This is mainly due to a lower MD. The MD of the VMBM-design would be 20% when using the exact same amount of modules for the VMBM-design as used for the CMMM-design. However, in section 4.1.1 tells that the MD of the VMBM-design needs to be 10.4%, which is the minimal value to prevent significant shading. The lower MD has as consequence that the electricity production will decrease with respect to a MD of 20%. From equation 1-4 is calculated that the west-side of a single VMBM produces 168.73 kWh/year. The east-side produces 174.00 kWh/year. Both sides together results in the annual energy production by a single VMBM of 342.73 kWh/year.
The VMBM is 2 m high and has a width of 1 m. The distance between two modules is 3.46m, resulting automatically in one module per 3.46 m^2. 117 ha is enough space for 338,150 VMBMs with a distance of 3.46 between the arrays. Based on these parameters it has been calculated that the theoretical maximum electricity production of the roadsides and median strips of the A37, for a VMBM-design, is 115.89 GWh/year. This is 76.2% of the theoretical maximum electricity production of the CMMM-design with SMV's characteristics.

4.2.2 The influence on electricity production from proposed adaptions

4.2.2.1 Prevention of uprootment of forestry areas

The decision to prevent the use of forestry area for solar energy production will have large impact on the electricity production, since these areas cover a large share of the roadsides. This adaption is irrelevant when the consumption of areas now covered by forests for solar energy production is no part of the plans. However, it needs to be reminded that the SMV report does not give any insight on whether the forestry areas are included in the reserved 117 ha they have planned to consume. But since there is no clarity, it will be assumed that the areas are part of the reserved 117 ha. 14% of the

[1] SMV calculated an annual electricity production of 145.3 GWh. However, it seems they didn't use the correct methods, resulting in a different outcome.

total area of the roadsides and median strips of the A37 consists of forestry area, this is equivalent to 45.1 ha (Appendix A).

From (6) is calculated that the prevention of uprootment of forestry areas will result in an electricity yield reduction of 58.6 GWh/year for the CMMM-design (MD = 100%) and 44.7 GWh/year for the VMBM-design, assuming that all forestry areas were to be used for solar energy production in SMV's design.

4.2.2.2 Floating modules

The lower the temperature, the higher is the efficiency of PV-modules. Water has a cooling effect on the modules and therefore efficiency/module will increase (Twydell & Weir, 2015). On the other hand, to maintain the ecological function, the edges of the waterbodies need to be unoccupied. Cell-efficiency increases to 19% caused by the cooling effect (Jongsma et al., 2017). The total area of the pools and ponds along the A37 is 1288.7 m^2 (Appendix A). Subtracting the unoccupied edges results in 0.41 ha that is suitable for solar energy production. Calculations based on equations 1-4 result in 483.9 MWh/year solar energy production. Which is 49% of the electricity production according to SMV's CMMM-design, when it's decided to consume these waterbodies for solar energy production. Compared to the VMBM-design, this would be 63% of its electricity production.

4.2.2.3 Obstacle free-zone

SMV includes obstacle free-zones near intersections and talus. However, they are not planned in the roadsides. Obstacle free-zones need to be installed at both sides of the highway. This results in a total length of 44.18 km, when the zones are included in SMV's design. The zones have a width of 2 m, resulting in the total area for the obstacle free-zone of 8.8 ha. From equation (6) it's derived that this will lead to an annual electricity yield reduction of 11.4 GWh for the CMMM-design and 8.75 GWh for the VMBM-design (tab. 15).

	Original production (GWh/year)	Decrease in production (GWh/year)	Production when adaption is applied
CMMM	152	11.4	140.6
VMBM	115.89	8.75	107.14

Table 15: The influence of applying the adaption 'obstacle-free zone' on the annual electricity production.

4.2.2.4 Poles

Installing the modules on top of poles has no effect on the electricity for the CMMM-design, as long as all modules are at the same position relative to each other. However the installation of the VMBMs on top of poles will increase the length of the shade. A distance between the VMBMs of 3.46m results in no shading when the sun makes an angle of 30° with the horizon. However, this counts for modules with a height of 2m. When the modules are placed upon poles of 50cm this will result in an actual height of the bifacial modules of 2.5 m. In order to prevent shading when the sun is at the same height will require more distance between the modules or the modules need to be smaller (1.5m^2). A bifacial module of 1.5m^2 will result in an electricity production of 25%. The revised distance between the modules can be calculated from (4) and results in a distance of 4.33 m and a new MD of 9.2%. The new electricity production can be calculated by equation (4): 102.94 GWh/year. This is 11.2% lower compared to the VMBM-design installed directly on the surface.

4.2.2.5 Reduced module-density

SMV assumes for most part of the solar park MD of 100%. Reducing the MD will reduce the electricity yield based on equation (4). Table 16 shows the E_{total} for the CMMM- and VMBM-design with different MDs. The SMV's design contains 105 ha with a MD of 100% and 12 ha with a MD of 65% and these MDs produce 152 GWh/y combined.

Module-density	Electricity production
CMMM	**(GWh/y)**
SMV's design	152
60%	98.02
50%	81.68
40%	65.34
VMBM	
10.4%	115.89
10%	111.43
8%	89.15
6%	66.86

Table 16: Electricity production of the solar parks for both designs with different module-densities.

4.2.2.6 Tilt of the module

The current tilt of the SMV design is 5° for the modules at a MD of 100% and 30° for the modules at a MD of 65%. The tilt of the module has important influence on the electricity production of a single module. A better positioned module, facing directly to the sun, produces more energy. The optimal tilt in the Netherlands varies over the year, but over a whole year the ideal tilt for electricity production is between 30° and 40° (tab. 17). The tilt and orientation the module where corrected by SEAC using the geometry-factor. The more the module is tilted, the less surface it will cover. The amount of surface covered can be calculated based on equation (7).

As a consequence for the tilt, the MD of the park must decrease to prevent shading. Therefore, in practice, the MD is ~50%. This would result in an electricity production of 81.68 GWh/year. When 30° tilt is introduced, the electricity production of the park will increase to 92.26 GWh/year, an increase of 10.58 GWh/year.

	Orientation			
Tilt	**180 °**	**190 °**	**200 °**	**210 °**
5 °	1027	1026	1024	1020
10 °	1062	1060	1056	1050
20 °	1115	1112	1105	1093
30 °	1145	1141	1131	1116
40 °	1150	1146	1135	1117
50 °	1130	1127	1114	1097
60 °	1087	1083	1072	1053

Table 17: Electricity production (kWh/m^2/year) for different tilt at various orientations (Folkerts et al., 2017).

4.2.2.7 (Semi-)transparent photovoltaics

The state of the art power conversion efficiencies of semi-transparent pv-modules vary between 5.9%, for silicon-type cells, and 8.2% for p-i-n planar perovskite solar cells. A relatively low efficiency compared to the conventional photovoltaic cells, however the technology is very new and the amount of publications on the topic are increasing exponentially. This indicates rapid developments of the technology.

For the efficiency calculations it's assumed that the efficiency-improvements are frozen and that the 5.9% and 8.2% will remain constant. For both efficiencies the electricity production is calculated based on equations 1-4. This results in an annual energy production of 60.75 GWh/y and 84.43

GWh/y for power conversion efficiencies of 5.9% and 8.2% respectively. This is an electricity yield reduction of 60% for silicon-type cells and 44% for perovskite solar cells.

	Original electricity production (GWh)	Electricity reduction (GWh)	Electricity reduction (%)
CMMM	152	N/A	N/A
No uprootment		58.6	38.6
Floating modules		0.5	0.32
CMMM (MD=100%)	152	N/A	N/A
Obstacle free-zone		11.4	7.5
Poles		N/A	N/A
Pilot- and flowering plants		N/A	N/A
Urban vs. rural area		N/A	N/A
Reduced module-density (50%)		70.32	46.3
Tilt of the module (30°)		- 10.58	- 7.0
(Semi-) transparent modules (η=8.2%)		67.57	44.5
Capillary fleece		N/A	N/A
VMBM	115.89	N/A	N/A
No uprootment		44.7	38.6
Floating modules		0.28	0.24
Obstacle free-zone		8.75	7.6
Poles		12.95	11.2
Pilot- and flowering plants		N/A	N/A
Urban vs. rural area		N/A	N/A
Reduced module-density (8%)		26.74	23.1
Capillary fleece		N/A	N/A

Table 18: Annual reduction of electricity production, both CMMM- and VMBM-design, for each adaption separately. A negative electricity reduction mean a production increase (Tilt of the module).

4.3 Costs & profits

Every adaptions have different investment costs, but they also influence the electricity production in different ways and therefore influence the cash-proceeds of the Zonneroute A37. This chapter provides insight in the financial influences of the eligible adaptions, focussing on the investment costs and the influence on annual yield. Firstly, the initial costs of the SMV-design for CMMMs and the VMBM-design will be calculated. Afterwards the reduced electricity yield, and corresponding reduction in profit, will be determined.

4.3.1 Initial costs & profits

Investment costs (Capex) and O&M-costs (Opex) are the primary cost-source for solar energy production. Profits can be made by selling the electricity and/or abate electricity costs. Based on the Capex & Opex described in section 4.1.2 and the peak power of the solar park, it has been determined that the Capex will be 213.41 M€ and the cumulative Opex will be 4.662 M€/year for the

CMMM-design. This results, together with the produced electricity, in a LCOE of 0.21 €/kWh for SMV's design.

Current electricity prices in the Netherlands are 0.2 €/kWh (CBS, 2017). The total electricity production over 30 years is 4,560 GWh which together corresponds to a sales volume of 912 M€. The total yield divided by the Capex and Opex results in a payback period of 10 years. The total profit of the project is 560 M€.

The costs in €/W_p for VMBM are similar as for CMMM (Robles-Ocampo, 2007). The 338,150 VMBMs will have an electricity generation capacity of 54.1 MW_p for each side of the module, thus this capacity needs to be doubled to get the actual capacity of the whole module. This results in a total module's capacity of 108.2 $MW_{p.}$ The Capex and Opex of VMBM are therefore 98.68 M€ and 1.94 M€/year respectively. The LCOE of the VMBM-design is 0.07 €/kWh.
This results in a total solar volume from electricity production of 695.34 M€ , with a corresponding payback period of 2.4 years, significantly shorter than the CMMM-design. The total profits of the VMBM-design is estimated to be 616.9 M€. These results are summarized in table 19.

	CMMM	VMBM
Capex (M€)	213.41	98.68
Opex (M€/year)	4.62	1.94
LCOE (€/kWh)	0.23	0.14
Annual profits (M€)	30.4	23.2
Payback period (years)	11.58	6.8
Cum. sales volume (M€)	912	695.34
Total profits (M€)	560	538.5

Table 19: Cost- & profit indicators for the CMMM- and VMBM-design

4.3.2 Cost and profits of the adaptions

Costs, or yield, from the adaptions may have two causes. Firstly, applying the adaptions may cause extra investment costs and secondly, the electricity production, and thus the yield, may change due to the influence of the adaption. Both causes will be consistently described for each proposed adaption (sc 3). The adaption proposed in 3.4.1.6, urban area preferred over rural area, won't be described, since it's impracticable to give certain values to such a general adaption.

4.3.2.1 Prevention of uprootment of forestry areas

Uprootment will reduce in an electricity production with 58.6 GWh/year for the CMMM-design and 44.6 GWh/year for the VMBM design. Automatically this will also influence the yield in terms of money as well. The size of the park will remain big enough to base the cost-calculations on a 1 MW_p solar park. Therefore the Capex, Opex, LCOE and payback period can be calculated based upon the same values used in section 2. The W_p of the CMMM- and VMBM-design are 110.6 MW_p and 67.4 MW_p respectively.

For the CMMM, the Capex will decrease with 75.4 M€, while the Opex decreases with 1.63 M€ annually. The Capex and Opex for the VMBM-design will decrease with 31.3 M€ and 0.6M€/y respectively. In the meantime, the sales volume for CMMM will decrease with 351 M€, where the VMBM-design experiences a decrease of 266.3 M€. Total profits will decrease for the CMMM-design and VMBM design with 226.7 M€ and 217.1 M€ respectively(tab. 20).

Table 20: Cost- & profit indicators for the whole solar park when the 37 ha of forestry are not used for solar energy production.

	CMMM	VMBM
Capex (€ * 10^6)	138.03	67.4
Opex (€ * 10^6/year)	2.99	1.34
LCOE (€/kWh)	0.14	0.16
Annual profits (M€)	18.7	14.3
Payback period (years)	12.2	7.5
Cum. sales volume (M€)	561	429
Total profits (M€)	333.3	321.4

4.3.2.2 Floating modules

The floating module-technology is a rapidly developing technology which is still in its R&D-phase. Although the performance of the module itself is known and its technology isn't evolving very quickly anymore, the set-up, propellant material and construction-materials are still rapidly developing. Therefore, determining the Capex, Opex and LCOE becomes very difficult and more or less irrelevant since the technology is constantly evolving. However the reduction in profits can be calculated based on the electricity production. 483.9 MWh/year will result in a sales volume of 96.78 k€. This is 100 k€ less than the CMMM-design according to SMV and 56.8 k€ less than the VMBM-design. Elements influencing the Capex and Opex of the floating modules are:

- Set-up material
- Propellant material
- Access to grid
- High maintenance costs

On the other hand, aspects stimulating the profits compared to the original designs are:

- No shading
- Higher efficiency
- Long accessibility to direct sunlight
- No reclamation required

4.3.2.3 Obstacle free-zone

The obstacle free-zone will cause a reduction in annual electricity yield of 11.4 GWh for the CMMM-design and 8.75 GWh for the VMBM-design. This decrease is caused by the fact that less area is available for solar energy production. The less modules installed will lead to a decrease in investment costs. However the yield will decrease as well, resulting in the following financial results (tab. 21):

Table 21: Cost- & profit indicators for the whole solar park when a 2 meter width obstacle free-zone is installed next to the arrays.

	CMMM	VMBM
Capex (M€)	196.7	91.2
Opex (M€/year)	4.26	1.8
LCOE (€/kWh)	0.23	0.14
Annual profits (M€)	28.1	21.4
Payback period (years)	12.2	6.8
Cum. sales volume (M€)	843	642
Total profits (M€)	518.5	496.8

Capex of the CMMM-design will decrease with 16.7 M€ when it's decided to maintain a 2 meter obstacle free-zone for mitigation of deer. The Opex of the CMMM-design will decrease with 0.36 M€ a year. Capex and Opex of the VMBM-design will decrease with 7.4 M€ and 0.14 M€/y respectively. However production and therefore profits will decrease as well, resulting in a decrease in total sales volume of 69 M€ for the CMMM-design and 53.3 M€ for the VMBM-design. The corresponding decrease in total profits from this adaption is 41.5 M€ and 47.5 M€ for the CMMM-design and VMBM-design respectively.

4.3.2.4 Poles

The electricity production won't decrease for the CMMM-design when the modules are installed on top of poles. However the Capex will increase. The SMV-design has 105 ha with a MD of 100% and 12 ha with a MD of 65%, resulting in a total of 564,000 modules. Installing all modules on poles of 50 cm will therefore require 4,512,000 m steel. The total length of the poles multiplied by the price results in an increase of the Capex of 63.1 M€, neglecting installation and maintenance costs.

The VMBM-design contains 338,150 modules. However, the required reduction in MD when the modules are installed on top of poles will lead to 270,207 modules. Each module will be installed on top of poles with a height of 0.5 m and requires 1 m (width of the module) to strengthen to construction. This will increase the Capex of the VMBM-design with 7.6 M€. On the other hand, the decrease in amount of modules will decrease the initial Capex by 12.21 M€. Combined this result in an decrease of the Capex of 4.62 M€.

Furthermore, the electricity production decreases from 115.89 GWh/year to 102.94 GWh/year. This decrease in production and the increase in Capex result in the following parameters for this adaption (tab. 22):

Table 22: Cost- & profit indicators for the VMBM-design is installed at top of 50cm high poles

	VMBM
Capex (M€)	94.1
Opex (M€/year)	1.56
LCOE (€/kWh)	0.15
Annual profits (M€)	20.6
Payback period (years)	6.8
Cum. sales volume (M€)	617.4
Total profits (M€)	476.5

4.3.2.5 Pilot- and Flowering plants

Three types of vegetation where specifically mentioned in subchapter 1 in order to provide the butterflies with the correct pilot- and flowering plants. These are willow-type vegetation, sorrel-species and bramble blossom. Willow-type vegetation will be maintained when it's decided to prevent uprootment of the forestry areas. However, this type of vegetation cannot be introduced in the current SMV-design, since it's expected to overgrow the modules and spatial occupation. On the other hand, sorrel-species and bramble blossom can be introduced because these species won't influence the electricity production. Furthermore, the costs of this adaption is low compared to the other adaptions.

Sorrel is a rapidly spreading, pioneering, species and therefore it needs to be seeded at a low-density. By considering this is it assumed that 1 % actively seeded is enough. The price of sorrel is 0.83 eurocent per gram (Cruydthoeck, 2017). One gram consists of roughly 200 seeds. To seed 1 % of the 117 ha will cost 180 €.

Bramble blossom is more expensive (2€/10 seeds)(123zaden.nl, 2017). Bramble blossom can overgrow the modules (ibid.) and should only be installed at the edge of the arrays, while maintained by yearly pruning. One blossom every 20 meter would cost 850 €. The costs for installation and maintenance is dependent on the labour-costs and the time it takes to prune the blossoms. Labour-costs for seeding is estimated at is estimated at 1343 €, for a gross monthly salary of 2500 € and 10 km a day. Labour-costs for pruning is set at 5373 €/year for the same salary and 2.5 km a day.

4.3.2.6 Reduced module-density

A reduced MD results in a lower electricity yield and therefore a lower sales volume, despite the decrease in Capex and Opex. Subchapter 4 has calculated the electricity production at MDs of 40%, 50% and 60% for the CMMM-design and 6%, 8% and 10% for the VMBM-design. Table 23 shows the Capex, Opex, LCOE, annual profits, payback period, cumulative sales volume and total profits for the solar park at these MDs.

Table 23: Cost- & profit indicators of the various module-densities.

	Capex	Opex	LCOE	Annual	Payback	Cum. sales	Total
CMMM	(M€)	(M€/year)	(€/kWh)	(M€)	(Years)	(M€)	(M€)
60%	128.4	2.78	0.22	19.6	10.8	588	376.2
50%	107.0	2.31	0.22	16.3	10.8	489	312.7
40%	85.6	1.85	0.22	13.1	10.8	393	251.9
VMBM							
10%	94.9	1.87	0.14	22.3	6.8	669	518.0
8%	83.2	1.50	0.14	17.8	6.8	534	405.8
6%	62.4	1.12	0.14	13.4	6.8	402	306.0

4.3.2.7 Tilt of the module

Subchapter 4 showed that the electricity production increased when the tilt was optimized to the sun's altitude. However, a decreased MD is inevitable to prevent (partial)shading on the following module. Calculations and comparison (tab. 24) of the costs and profits of an optimized tilt are therefore based upon a MD of 50%. The optimized tilt is location-specific. The most common tilt for PV-modules in the Netherlands is 30°, which almost meets the ideal angle for solar energy

production (tab. 17). Therefore the costs and profits of this adaption is based upon an angle of 30° and shown in table 24.
SMV already planned to set modules spread over 12 ha of the solar park at a 30° angle. Therefore the expected increase of electricity production is a result of the remaining 105 ha only. The Capex increases mainly due to the additional use of steel, in order to set the modules at the correct tilt. The steel prize is similar as in section 4.3.2.4. And the total distance of steel-poles necessary for the adaption is 262,500 meter, equivalent to the amount of modules installed. This amount of steel will increase the Capex with 3.67 M€. The Opex is assumed to remain the same, because of the long lifetime of steel.

Table 24: Cost- & profit indicators at for an increased tilt (module-density = 50%)

	Original tilt	Tilt = 30°
Capex (M€)	107.0	110.67
Opex (M€/year)	2.31	2.31
LCOE (€/kWh)	0.22	0.20
Annual profits (M€)	16.3	18.5
Payback period (years)	10.8	9.8
Cum. sales volume (M€)	393	553.6
Total profits (M€)	251.9	373.63

4.3.2.8 (Semi-)transparent photovoltaics

Perovskite solar cells have a lifetime of 15 years (Celik et al., 2016), however lifetime of the project is set at 30 years. Therefore it’s assumed that the perovskite solar cells needs to be replaced once, resulting in double investment costs .
The investment costs of perovskite is set at 0.15 €/W_p (Cai et al., 2017). Installing 117 ha, with a similar MD as the SMV-design, would result in a peak production of 92.5 MW_p. Resulting in a Capex of 13.87 M€. This amount needs to be doubled to compromise the short lifetime, ending up with a Capex of 27.75 M€. The Opex of perovskite solar cells are low compared to conventional solar cells; 0.0011 €/kWh. The cumulative Opex costs for a period of 30 years are therefore 5.01 M€. The LCOE of perovskite solar cells can be calculated from (7) and is 0.03 €/kWh. The low LCOE of perovskite solar cells is mainly caused by the very low Capex and Opex. The total sales volume will be 506.58 M€. The payback period for perovskite-type solar cells is almost 2 years. This short period is mainly caused by a low Opex.

Very little research has been done on the costs and profits of transparent silicon-type solar cells. Manufactering- and installation costs of a single module with an area of 1.43 m^2 is 288 € (Ng & Mithraratne, 2014). A total of 788,811 modules is required to cover the same area, with the same MD, as the SMV-design. This results in a Capex of 227.18 M€. The maintenance costs are set at 0.140 €/kWh (Li et al., 2008), which results in a Opex of 8.5 M€/year. The LCOE of transparent silicon-type cells is 0.54 €/kWh. The annual and cumulative sales volume of transparent silicon-type solar cells are 12.15 M€ and 364.5 respectively. All this together results in a payback period of 39.7 year, longer than the lifetime of the project (tab. 25).

Table 25: Cost- & profit indicators of both types of (semi-)transparent photovoltaics

	Perovskite	Silicon-type
Capex (M€)	27.75	227.18
Opex (M€/year)	0.17	8.5
LCOE (€/kWh)	0.03	0.54
Annual profits (M€)	16.89	12.15
Payback period (years)	1.94	39.7
Cum. sales volume (M€)	506.58	364.5
Total profits (M€)	473.82	-117.7

4.3.2.9 Capillary fleece

A capillary fleece has no effect on the efficiency of the solar park. It increases the investment costs only. "Green roof technology" proposes the Optigreen RMS 500 – fleece. Market price of this fleece is 230 €/100 m² (donedeal, 2017). This would result in a total product-cost for the whole parc of 2.69 M€.

Labour costs for installation are 2.73 €/m^2. 2.73 multiplied with the area (117 ha) on which the fleece needs to be installed results in total labour costs of 3.19 M€. Therefore the cumulative costs of the capillary fleece are 5.89 M€. However, maintenance costs are excluded in this measure, because no clarity could be obtained on this topic. However, it's expected to be insignificantly low, since the fleece is insensitive to weathering (Optigreen, 2017).

4.4 Synopsis

At first the theoretical maximum electricity production was determined for both the CMMM-design as the VMBM-design. These calculations resulted in an annual electricity production of 152 GWh for the CMMM-design and 115.89 for the VMBM-design. Secondly, the reductions in electricity production caused by the proposed adaptions was calculated. This reduction could be caused either by a reduction in the amount of modules or by changing the characteristics of the modules or cells itself. Subsequently it was found that not every adaption will lead the production losses. Consequently, these non-electricity affecting adaptions are not described within the chapter, but they are included in table 17 nonetheless. This table provides a schematic overview of the production losses corresponding to the proposed adaptions.

Section 4.3 provides an overview of the costs & profits of the proposed adaptions. As it turned out, most adaptions will negatively influence the profits, either by increasing the investment costs or by reducing the electricity production and therefore reducing the profits. Only an increased tilt will stimulate the total profits, however this goes at the cost of a lower MD compared to the CMMM-design and an increased Capex due to the required steel. However, only silicon-type will cause negative cumulative profits and a payback period longer than the estimated lifetime of the projects. All other adaptions counts that, despite the fact that some will reduce the production significantly, the project will lead to financial profit at the end-of-life of the project.

5 Connecting the chapters

The goal of this research is to find the optimum between maintaining the ecological function of the verges of the A37 and solar energy production. Chapter 3 and 4 provided intelligence on the influences on the ecological function, electricity production and involved costs and profits.

5.1 Ecological function points

The VMBM-design initially scored higher compared to the CMMM-design, mainly due to the fact that more light could reach the soil, rainwater was more equally distributed over the surface and a VMBM requires less spatial area. Those aspects are fundamental for vegetation to grow and this is especially important, since vegetation stands on the basis of every terrestrial ecosystem. The increase in ecological value from the proposed adaptions was less for VMBM, mainly because of the higher initial environmental qualities, compared to CMMM.

The best adaption for the CMMM-design from an ecological point of view is '(semi-)transparent modules'. This adaptions resulted in an increase of ecological function score of 17, primary caused by much more access for light to reach the surface. Other high scoring adaptions are 'reduced MD'(14 points), because more light and rain has more access to the soil, 'no uprootment of forestry areas', since these areas provide a lot of functions to many species and a 'capillary fleece' (12 points), which will increase the water-accessibility for vegetation which result in more and qualitatively higher vegetation. An adaption that leads to less increase in ecological function points for the CMMM-design is the 'obstacle free-zone' (1 point), which only provides access to one species (deer) and creates only a minor increase since this zone is already planned, though with lower standards.

Best VMBM-related adaptions are 'no uprootment of forestry areas' (7 points) and 'reduced MD' (5 points), because of the same reasons described in previous paragraph. And the installation of top of poles (5 points), to reduce limitation on surface-accessibility for light and rainwater, a decrease in spatial occupation and more access for ground-living species. The least increasing adaption for the VMBM-design is the 'obstacle free zone' (1 point) as well.

5.2 Electricity production

Six adaptions had influence the electricity production for the CMMM-design, while five adaptions had an effect on VMBM's electricity production. An increase in tilt leads to higher electricity production compared to the SMV's design, however in needs to be taken into account that this adaption will stimulate shading and therefore a lower MD is necessary. The decrease in electricity production for lowering the MD will have more effect than the increase in production from an increased tilt. All other adaption listed above led to a decrease in electricity production, for both designs. A reduced MD caused most production losses for the CMMM-design (~70 GWh/year = 46.3%). 'No uprootment of forestry areas' and '(semi-)transparent photovoltaics' had also a large impact on the electricity production of this design, 58.60 GWh/year and 67,57 GWh/year respectively. 'No uprootment of forestry areas' caused the most losses for the VMBM design (44.70 GWh/year = 38.6%), while a reduced MD had also a significant impact (26.74 GWh/year)

5.3 Costs and profits

All adaptions will eventually lead to a loss in profits. Although the 'tilt of the module' will increase the production initially, the necessary MD-reduction will result in less profits compared to the original

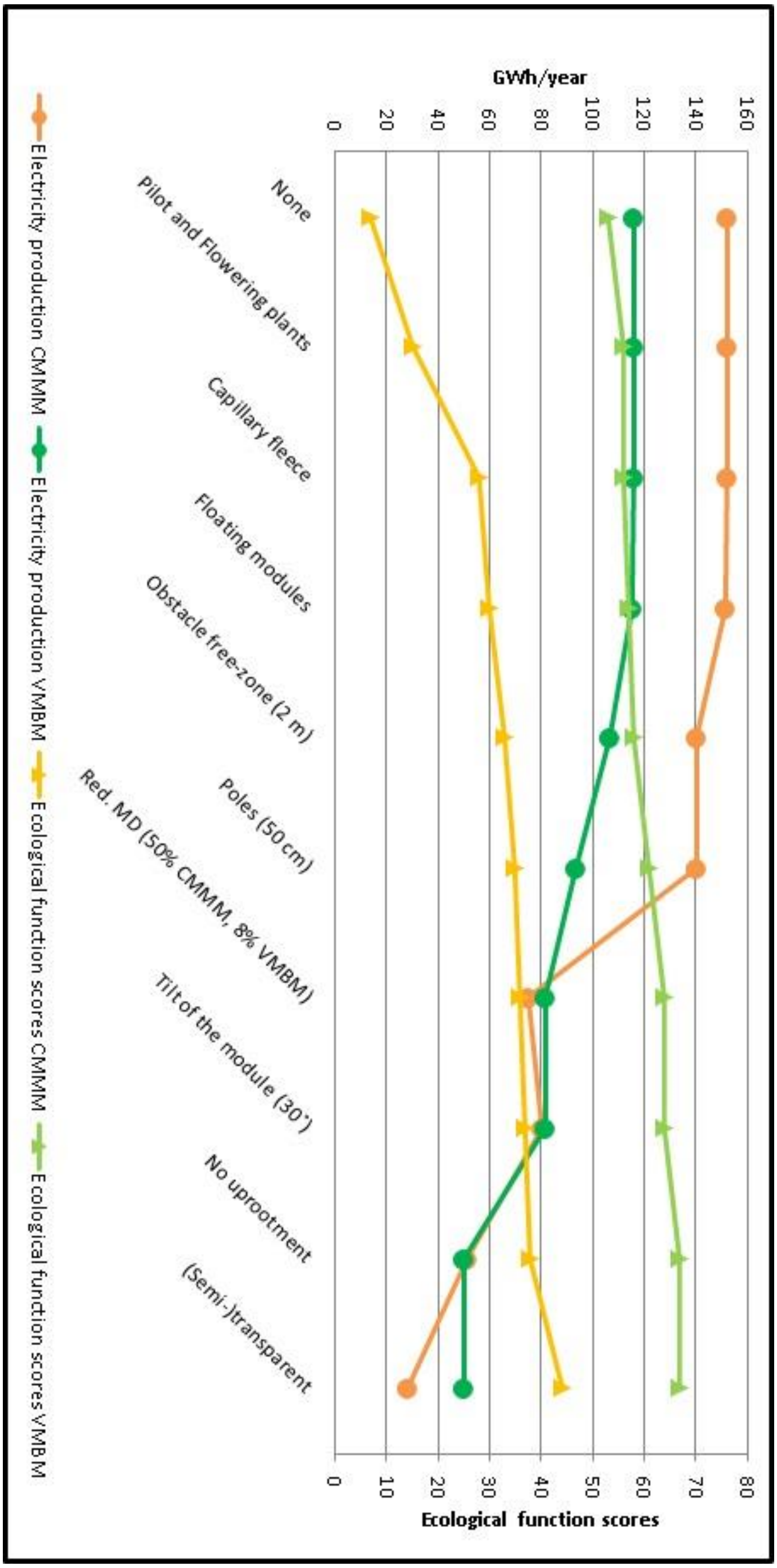
CMMM-design. However, costs vary heavily per adaption and can either be caused by an increase in Capex or a decrease in sales volume. Introducing ‘pilot- and flowering plants’ will have almost negligible costs compared to the total costs of both designs, ~200 k€ additional costs. The most inefficient adaptions from a financial perspective is using silicion-type transparent photovoltaics. This is the only adaption which have negative profits at the end-of-life. Other costly adaptions are low MD for the CMMM-design (40%) and ‘no uprootment of forestry areas’. Both adaptions reduced the profits with over 200 M€.

5.4 Optimum

Figure 12 shows the cumulative reduction in electricity production and the stimulated ecological function. All adaptions are weighted equally, because it’s expected that every specific function for every specific species is equally important in order to obtain a mature general ecological function. However, some adaptions affect larger area and therefore might be more interesting to implement. Another mark which should be made at figure 12 is that several functions stimulated the same ecological functions. Therefore the total ecological function score is not the sum of all specific scores, but it’s based upon an analysis which takes into account the maximum score of 4. For example, the capillary fleece made the ecological function scores increase relatively a lot and a reduced MD or an increased tilt stimulate the ecological function scores less according to figure 12, while those adaptions caused more improvements when they are evaluated individually.

‘An optimum’ is a relative term and depends on the preferences of the applier. Three preferences are highlighted in this section; High electricity production, high ecological function and the medium in between the pre-mentioned preferences (fig. 12). Figure 12 starts with the adaption with the least effect on the electricity production, which increases further along the graph. An high electricity production preference would be within the orange-marked area. The ecological function preference would be within the green-marked area, this is also the area in which the VMBM-design produces more electricity as the CMMM-design. When it’s decided to find the medium between both preferences, the yellow-marked area is the most interesting area. Both designs produce a comparable amount of electricity in this area.

Figure 12: Overview of the decrease in electricity production and increase of the ecological function from the applied adaptions. The order of applied adaptions is based on the impact on the electricity production, starting with the minimal impact. Only the increased 'tilt of the module' is placed after the 'reduced module-density' since this is a requirement when applying an increased tilt. Orange = Electricity production- preference, Yellow = medium between the ecological function and electricity production and Green = Ecological function preference.



6 Discussion

Determination of the present flora and fauna within the verges of the A37 was based on data provided internally by RWS and from the Databank Flora en Fauna. The observations within these data-files are double checked by ecologists and therefore is it valid to state that these observations are correct. However, some observations are rather old, wherefore it becomes questionable whether or not these observations are still relevant. An argument in favour of the relevancy is the fact that the roadsides and median strips of highways are a stable part of a constantly changing landscape and consequently and thus it can be said that the ecological functions for the old observed species are still present. Therefore all data is used for the analysis.

Up-to-date monitoring would take away this uncertainty, but fieldwork became highly impractical due to time-limitations. Another performed measure to overcome this, was to mention the observed species to the interviewed ecologist. Thereby gave them to opportunity to question the probability of its presence.

This study is partly qualitative, while a quantitative study would provide more concrete outcomes to build on in similar future case-studies. The qualitative characteristics of this study is caused by a combination of the broad geographical scope of the research and time limitation. Methods like the 'Natuurpunten Methodiek' (Van Gaalen et al., 2014) are proper methods for quantitative research. This is a method developed to determine natures quality depending on the quality for individuals, area and biodiversity, would be useful if the focus was at small, homogenous terrains instead of a 42 km highway or when the focus was only on a specific species, instead of the complete flora and fauna. In this case, there was too little time available to analyse the whole case-study based on these methods. For the same reason is decided to ignore invertebrates and to make no distinction in flora specific species. Quantitative result would perform more concrete results, however this research provide a plentiful indication, since the influences from solar energy production on the most important functions are extensively described and estimation on the magnitude of the influence is determined based on valuable expert-opinions/

There has been no similar research that focusses on the influence on the ecological function of verges from solar energy production. Therefore, the proposed adaptions are based on experts' opinions and other scientific research based on other objects causing similar impacts. This leads to a realistic analysis of the impact and corresponding proposed adaptions, but uncertainties will remain and therefore quantitative experiments are necessary to validate the results from this study in practice. Moreover, the magnitude of the impact and the reduction of this magnitude from the adaptions is based on similar sources. Therefore the magnitude is no absolute value, however it is a well-founded estimation. Additionally, unforeseen effects might occur which might influence local environment and thus the ecological function.

The natural characteristics of the verges along the A37 are approached as if they have a natural origin, although they do have an anthropogenic origin and are maintained by human. Topic related-literature, which is used for defining the ecological function, approaches the vegetation-types are natural, with no interference from humans. However, this does not mean that vegetation-types which are influenced by human don't provide similar functions. Anthropogenic influence does limit the development and succession of the terrains and thus are the functions affected but they will be present nonetheless.

A rule of thumb is that the smaller the animal is, the more functions will be provided in a smaller area and thus will these animals make use of more functions of the roadsides and median strips compared to larger animals. Consequently, it can be said that the larger the animal or the larger its habitat, the less dependent it will be on the verges, since they are only part of their habitat. The smaller part the verges fill within a habitat, the more likely it is that similar functions can be provided by other locations which are part of the habitat. The same accounts for easier mitigating species such as the observed birds and bats.

While determining the ecological function scores per adaption area-size was not taken into account, because the geographical location provided is in many cases linked with the surrounding hinterland and each function received the same weighting score. Nonetheless, adaptions which influence a large area might receive a undervalued rating and might have a larger influence on the total ecological function of the verges. This should be taken into account when deciding which adaptions will be implemented.

There is no design for the VMBM setup yet. However the goal was to compare the optimum for this design with the CMMM-design. It's decided to use the same characteristics for the VMBM-design as the CMMM-design if necessary, in order to make best comparisons. However, this doesn't mean that they are the best characteristics from other specific perspectives (i.e. financial perspective).

The cost analyses for several adaptions are incomplete, such as the 'floating modules'. The costs involved to apply this adaption are unknown, because the technology is still in its R&D-phase, resulting in a lot of uncertainties with respect to the setup and the used materials. Another incompleteness of the costs-analysis is that the costs for uprootment of forestry areas are ignored. This intel is beyond the reach of the researcher and is therefore ignored. However, these costs will be prevented when the adaptions are applied, resulting in a reduction of the Capex.

This study uses the market price of electricity instead of the APX-price, the price which received for electricity when selling it to the electricity producing companies. The electricity produced along the A37 doesn't meet RWS' electricity consumption and therefore using electricity produced by itself is more interesting than selling it to the grid. However, when RWS decides to sell it than this will be for the APX-price currently ≈ 4€ct/kWh (Nieuwestroom, 2017), which is 5 times lower compared to the market price. This will make the Zonneroute A37 financially significantly less interesting.

Finally, this base-case was based upon the design of SMV. The report was very useful for the analysis, but it did contain some minor errors, unrealistic approaches and incompleteness. For example, whether forestry areas and waterbodies will be used for solar energy production or the exact shape of the modules itself, instead of the area only. Building further upon such uncertainties create larger uncertainties. Therefore assumptions, though made within consultation of project-experts, became necessary to continue the research. These uncertainties need to be clarified first, before a decision can be made upon the application of the adaptions.

7 Conclusion

This study aimed to find the optimum between solar energy production and the ecological function directly next to highways. The search for this optimum was based upon a case-study; The Dutch highway A37, from intersection Hoogeveen to the German border near Zwartemeer. RWS has chosen this highway because of its open character, broad verges and its east-west orientation. This research compared two designs, each with a different type of module, which are the Conventional Mounted Monofacial Modules (CMMM) and the Vertical Mounted Bifacial Modules (VMBM). These types were chosen since they were expected to be each other's counterparts with respect to their influence on the ecological function.

In order to find this optimum, a reference to the current ecological functions was required. As first, observations on the most relevant flora and fauna was analyzed. Based on scientific literature and interviews with ecologists, a list of current ecological functions was defined. It was concluded that vegetation is vital for fauna, since it's on the basis of every terrestrial ecosystem. Vegetation requires sufficient direct sunlight-hours, enough luminance and an appropriate amount of rainwater. Especially the first two aspects, sufficient light-hours and luminance, are in violation with the concept of solar energy production. As result, multiple ecological function are determined. These functions are related to fauna only. However fauna is dependent on a mature vegetation-cover, which means that an ecological function for fauna means indirectly sufficient ecological value for flora as well. The distinguished ecological functions of roadsides are: foraging area, habitat, orientation, passaging, providence of protection and reproduction area.

A base-case was already developed by Studio Marco Vermeulen, which made use of a high-density CMMM-design. This case-study used similar area-consumption and module size for the VMBM-design in order to make best comparison. Comparison on the influence from both designs, without applying any adaption, showed that the CMMM-design had significantly more impact compared to the VMBM-design. This was caused by its occupation of spatial area and the interference with sunlight and rainwater that couldn't reach the soil. Installing SMV's CMMM design would result in a negligible ecological function. Furthermore, the uprootment of forestry areas had major influence for both designs as well. Forestry areas provide multiple functions to many fauna-species and has an important relationship with the large-scale agricultural hinterland.

Ten different adaptions to the solar park were evaluated for the CMMM-design, while six different adaptions were assessed for the VMBM-design. It was found for the CMMM-design that '(semi-)transparent modules', 'a reduced MD' and 'no uprootment of the forestry areas' would stimulate the ecological function the most. The first two adaptions mentioned will lead to an increase the amount of light available to reach the soil significantly. Additionally, a reduced MD would also increase of the amount of rainwater that can reach the surface. No uprootment stimulated all functions provided by the not-uprooted forestry areas.

Not all adaptions influence the electricity production of the solar park. Six adaptions are split in two groups when focusing on their influences on the electricity production. No uprootment of forestry areas, the obstacle free-zone and a reduced MD have influences on array-level. These adaptions do not influence the efficiency of the cells, however they do influence the area used for solar energy production. Floating modules, the tilt of the module and (semi-)transparent modules do influence the efficiency of the module/cell itself and are therefore grouped in the module-level adaptions. The CMMM- and VMBM-design, without applied adaptions, produce 152 GWh/year and 115.9 GWh/year respectively. Increasing the tilt of the modules is the only adaption that increases the electricity production, however this adaption requires a reduced MD, which will eventually lead to a reduced electricity production compared to the base-case. (Semi-)transparent modules, no uprootment of forestry areas, a reduced MD are the adaptions causing most production losses for the CMMM-design. The latter two are causing most losses for the VMBM-design as well.

'(Semi-)transparent silicon-type modules' is the least cost-efficient adaption, resulting in negative profits at the end-of-life. All other adaptions will negatively influence the profits, but the production will remain profitable for these adaptions. No uprootment of forestry areas is also a high-cost adaptions, mainly caused by the large decrease in electricity production. Similar reasons can be found for the high-costs of a 'reduced MD'. Introducing pilot- and flowering plants is a very low-cost adaption, costing only 200.000 €. The capillary fleece is also a low-cost adaption (5.89 M€). Both adaptions do not influence the electricity production and do not require an high investment.

To conclude, solar energy production in the roadsides and median strips of the A37 will have a significant influence on all ecological functions for either the CMMM-design as the VMBM-design. Vegetation stands at the basis of every terrestrial ecosystem and requires a sufficient amount of light and rainwater. Solar energy production will influence the ecological function by consuming spatial area, hindering sunlight to reach the surface and limit the rainwater distribution at the soil, therefore damaging the vegetation. Subsequently it will indirectly damage the ecological functions for fauna as well, since the fauna is dependent on a mature vegetation-cover. CMMMs will have a significantly larger impact compared to VMBM for the same reasons and adaptions are necessary the maintain a mature and dense ecosystem and thus functioning ecological functions.

From an ecological perspective '(Semi-)transparent modules' will be the best adaption for the CMMM-design, while 'Nu uprootment of forestry areas' will be the best for the VMBM-design. However, an increased tilt will be the most promising adaption for maintaining an efficient electricity production. 'Pilot- and flowering plants' and a 'capillary fleece' won't have negative impact either. Financially 'Pilot- and flowering plants' is the most interesting adaption for both designs. Figure 12 shows the optimum between the ecological function and the electricity production. The graph starts with the adaptions causing least impact on the electricity production. From this graph it can be derived that the optimum can be found in three zones, depending on the preference. The orange area includes all adaptions which can be applied while maintaining an high electricity production. The green area includes all adaptions and therefore is preferred from an ecological point-of-view. The yellow area meets both preferences halfway, this is also the area where both designs produces a comparable amount of electricity.

However, especially two aspects need to be taken into account. First, local circumstances and the area influenced by the adaption might influence the effect of these adaptions. This is a consequence of the large geographical scope of the research. Secondly, this is a qualitative research, which gives clear indications of the influences from solar energy production on the ecological function of the verges of the A37 and the stimulation of the proposed adaptions. But experiments and measurements on the ecological function after installation of the solar park can test this research and provide more clear answers.

The results found in this research provide knowledge on the influences from solar energy production on the ecological function of roadsides and median strips in the Netherlands and help the decision-making when the ecological value of roadsides and median strips wants to be preserved. This research can reduce the amount of debate on this topic and contributes to the rate of the energy-transition in the Netherlands.

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9 Appendices

Appendix A Flora

This appendix isn't included in this paper, because the data-file (Flora Observations A37) is too large to be included in this thesis. Information can be obtained by contacting the author: joostvleeuwen92@gmail.com

The data-file contains an overview of the observed vegetation-types within the roadsides and median strips of the A37. The appendix consists of 2429 observations of vegetation-types and their corresponding length, width, area, location, observer, etc.

Appendix B Fauna

This appendix isn't included in this paper, because the data-file (Fauna Observations A37) is too large to be included in this thesis. Information can be obtained by contacting the author: joostvleeuwen92@gmail.com

The data-file contains an overview of the observed fauna within the roadsides and median strips of the A37. The appendix consists of 67 species monitored at hectometer density (423 rows).

Appendix C Interviews

Interview: Beppie van den Hengel (B) & Peter Jan Keizer (PJ) (Ecologists RWS).

What is your function within RWS?

B: We advise RWS on everything of landscaping, along roads, canals and partly the rivers. This doesn't include Natura 2000 (however the work is influenced by Natura 2000), but it's about the remaining environment what RWS directly outsources to the contractor. In case of the river is a big part under control of the province, *staatsbosbeheer* or private organizations.

PJ: Mainly the management and maintenance, but also partly the installation. This is mainly due to the fact that maintenance and management is much more time consuming and there is not so much installation of landscaping-influences. The coast and large water-areas are excluded.

B: We also develop programs to improve the process of maintenance.

How will the solar energy production influence the ecological function in general?

PJ: You can easily say that there is no other environmental function left on the places where solar energy production takes place. There will be some vegetation present underneath and between, but there will be no ecological function left. There will grow some form of grass or what so ever, but this does not have a nature-function. This includes both designs. RWS strives for a chosen nature-quality where the ecosystem is filled with as much as possible indigenous species. The nature-quality can't be combined with solar energy production. Therefore we advise to combine the energy production with already present obstacles, like viaducts, sound barriers, safety-rails etc. Furthermore, we advise installment near urbanized areas, because you do keep nature intact as much as possible and you are close to your purchaser, this reduces the distance to the grid. This is strongly preferred and is more or less a recommendation from us. In this case, the unused areas can have another function.

To conclude, there is no other function available, when you choose for the function: solar energy production.

B: What PJ tries is to say is: Biodiversity is much lower under shadow-dominated circumstances compared to a sunlight-rich environment.

PJ: Literally underneath the solar panels is no ecological function available.

B: A completely covered area would also be disastrous for the soil. It doesn't receive any sunlight or water. No animal can survive underneath, is a lifeless soil.

In your opinion, which type of solar modules would be a better option from a nature-perspective? Conventional vs Bifacial?

PJ & B: The conventional solar cells would be disastrous for the vegetation cover and soil. Take into account that this could also results in erosion. With respect to the bifacial panels: there will grow some grass, but there won't be a mature ecosystem. Only shadow-accepting species could grow on this location. However, if it would be decided to implement solar arrays than we advise to install them in the median strips since there is the least ecological activity.

What is the roadside's ecological function for the flora?

PJ: In grassy roadsides live light-preferring species. When you uses this light for energy-production, than this will reduce light-intensity and quality underneath the panels. Similar happens underneath bridges, where almost no vegetation grows.

B: The module-density determines the magnitude of shadowiness.

PJ: The roadsides contain 2 to 3 times more species compared to the surrounding agricultural area. Roadsides are much more biodiverse and have more functionality simply due to the variety in wild-species. However, to make a more concrete advise I need to know the specific roadside.

How will the solar energy production influence the ecological function?
See question 2. PJ: you must realize that vegetation is the basis for every ecosystem. When you remove the vegetation, you will remove almost all ecosystems. You must preserve the vegetation's function in order to maintain any ecological function.
PJ: When you install solar cells, you need to install a guardrail as well. This guardrail leads to costs and the leakage of zinc, which is harmful for the local environment. This aspects of environmental damage are poorly taken into account.

Orchids appear relatively a lot on arid grasslands. How will they be influenced by the installation?
PJ: I do not expect that a lot of orchids occur in this region. However, the same influences will count for orchids as they to count for grasses. Until lately a lot of orchids were protected but this isn't the case anymore, thus you should deal with them similar as you would deal with regular grass-species.

Roadsides with low biodiversity appear to be better adaptable to changes (Hoekemeijer, 2017). Does this imply that the impacts will be lower on these types of vegetation-covers?
PJ: More information is necessary to answer this question to your liking.

Do you have any additional comments with respect to the flora?
PJ: There are multiple binding agreements with respect to biodiversity which should be taken into account at all time. Furthermore, every action has its consequences and different stakeholders wish different results.

What is the roadside's ecological function for birds?
PJ: Raptors hunt in roadsides, mainly on mice. They scan the roadside from higher points (poles etc.) for mice. Their preys occur much more in the roadside compared to agricultural land because the roadsides are less used by human. Furthermore raptors or scavengers eat the knocked-down animals from traffic-incidents. Songbirds do rarely live in roadsides. You can monitor them, but these are mainly passing birds. But songbirds do not have a specific solidarity with the roadside as ecosystem.
B: I expect that there are also geese and ducks which breed in the roadside.
PJ: Geese and ducks mainly breed at intersections and near bushes. Coots do graze the roadsides during wintertime.

How will the solar energy production influence the ecological function for birds?
B: It's known that barn owls settle on hectometer posts. Perhaps, when solar modules are installed, they will settle down on top of them as well, which could cause to more owl fatalities to do crashes with traffic.
PJ: implementation will remove the hunting ground of raptors and therefore take away this function.

Are birds less sensitive for the implementation since the can transfer more easily than other animals?
B: This is correct.

Solar modules installed on water have higher efficiency. In what way will this influence the water(-related) birds?

B & PJ: The pools within intersection are separated from other waters. Therefore some species are protected from hunting fishes. Think about dragonflies. But underneath floating solar cells happen similar aspects as on terrestrial modules. The water plants need a specific amount of light, as well, which will be significantly reduced by floating solar cells, leading the environmental damage to the aquatic ecosystem.

Are there any other comments you would like to make?
PJ: you should take a look at *meetnet bermflora.*
PJ: I would like to underscore that O&M of the arrays would be much more difficult than expected. Think about dust and soot which need to be cleaned.

B: Mowing patterns need to be adapted to the array and this is extremely expensive. Furthermore you should also take into account with what type of liquid you're going to clean the modules. And what chemical properties has this liquid. I have expect that you'll have to mow them manually, which is extremely expensive and very time-consuming.

<u>**INTERVIEW: Peter Bolhuis (Property expert RWS)**</u>

General:

What's your function within RWS?
Property expert on the disciplines roads (substructure and superstructure) roadsides, vegetation, landscaping road furniture and drainage-facilities. I am no ecologist.

How high do you rate the ecological value of a roadside consisting mainly of grasslands that crosses scale arable landscape?
Moderately high due to the deviating ecology i.r.t. the field landscape. Can function as a refuge area and connect with other cultures grasslands

Could you give your opinion on the issue conventional oriented south or east-west bifacial solar panels? What will be the effect from the solar panels on the ecological function in your opinion?
Bifacial panels will be less strain on the flora compared to the flat panels located. There will, however, due to the shadow effect be a change in the vegetation towards more shade-loving species. When flat panels are installed the shadow effect is even greater, and may even lead to complete disappearance of plant growth. Changes and even disappearance of the vegetation will change the living fauna. Migratory animals will probably no longer use the site because the natural cover is gone.

Are there in your view also benefits the ecological function?
This is unknown.

Are you familiar with the natuurpunt system? If so, do you think this is applicable to the shoulders?
No.

To what extent the current fauna facilities should be considered?
It will need to be researched what the effect is of the solar energy production on the habitat of animals and the connection with neighbouring areas.

Flora:

What role does the flora plays in the roadside of the A37?
From a technical perspective: preventing erosion, sod for the carrying capacity of the roadside, extensive maintenance, low biomass production, infiltration of rainwater.

The setting of a flower or plant must meet certain survival criteria. What are they for meager grasslands?
Moderately dry conditions without the influx of ground or surface water and reasonably nutrient

How will the two types of solar panels affect this?
Negative for the type of poor grassland. There will be opportunities for the development of shade-loving species

Roadsides with a low biodiversity are less vulnerable to changes (Hoekmeijer 2017). Additionally, the loss will be less. Does the prior mean that there will be no or negligible impact on certain natural features (eg. In species grasslands)?
Yes, this is indeed to some plots where a lawn is planned. The loss is limited.
In addition, it also offers opportunities for other species

Are there any other aspects that you want to name, you think I overlooked?
No

Mammals:

What are the functions of the roadside for mammals?
(Last) refuge for animals because of increasing urbanization; compounds in the landscape structure

How will these functions be affected by the solar panels?
Solar energy producten will lead to the displacement of passages in the landscape and it will become habitat to only small mammals (mice) perhaps.

How will the habitat be affected by the installation of solar panels?
By disturbances during construction-phase and the roadside becomes unsuitable as foraging-area by the change in vegetation.

The only large mammal in this region is the deer. Is he literally present in the roadside?
Yes, possible is forestry corners, otherwise only when the roadside functions as connection to other landscape-structures.

Which design would be preferred by the mammals? And why?
It needs to be research what the influence of a solar park will be on the habitat of mammals and the connection with other neighbouring areas. I expect that bifacial panels provide more opportunities because of more light-distribution, a better distribution of rainfall what is preferred by the flora.

Birds:

What are the functions of the roadside for birds?
Foraging-area and breeding-area.

Does the installation of solar lead to direct insurmountable damage to habitats? panels
Insurmountable? Limited. Birds we mitigate to surrounding appropriate areas.

To what extent will the installation have influence on birds?
Limited. There needs to be reasonably searched for a suitable location. Flora and fauna definitely need to be taken into consideration when a choice is made.

Solar panels water fetch higher yields. In what way does this affect the water birds?
Is not applicable here. I think the panels interfere with the birds in their flight from the water

Birds move easily from A to B. Will thereby deploying solar panels have less impact?
No, the type of habitat plays a role.

Butterflies:

How are butterflies related to the roadsides?
They are dependent of some flowering species.

How will these functions be affected by the solar panels?
Negatively. This also applies in the case of plant species that are developing newly. These then form islands with area foreign plants.

What are the survival criteria of butterflies?
Appropriate plant-species for reproduction egg-phase, caterpillar-phase and butterfly-phase and plenty plants for specific species with specific diets. Furthermore they need a suitable terrain.

If you estimate that these criteria will no longer be available after implementation, what are possible alternatives to ensure that the criteria will be still available?
Not at this specific location, but on the ground next to it. After all, we're talking about a limited amount of areas which are provided with panels.

If the butterflies can't find a resting place in the roadside, will they still cross the highway?
Yes, the solar parks are located in corners and enclosed roadsides. There will be almost no separation due to the solar parks.

Bats:

How are bats related to the roadsides?
By the presence of insects living in the verges.

Are trees of vital importance for bats in rural areas?
Yes, for orientation and many insects living in trees

Insects gather in warmer places. The solar panels will be very local care of a rise in temperature (albedo-effect). This may also be beneficial for the bats?
I think so.

Amphibians:

What are the functions of the roadsides for amphibians?
Foraging-area and habitat

How important are fauna facilities such as pipes and passages for amphibians?
This forms a connection between diverse habitats. These must meet certain requirements.

How will the installation of solar panels affect the species?
An inventory of present amphibians on the location of the energy production will give more insight. There habitat will change.

What changes do you think are necessary to amphibians?
See the F&F la wand mitigating measures.

<u>Interview : Maurice de la Haye (Zoogdiervereniging)</u>

Who are you and what is the zoogdiervereniging?
The zoogdierenvereniging is an association focusing on maintaining mammals as a population. We do not focus on individual cases (accidents), but our goal is to keep a species, as population intact. We are a hybrid team with members and volunteers and we try to protect the mammals in the Netherlands. However we are no animals protection, since they focus more on the individual. The association has both local as national teams, which can focus on specific species or ecosystems as a whole. We do not make profit, all profit is invested in the maintenance of the populations.

For myself, I coordinate research and I do research myself. Keep in mind that I'm no bat-expert. My research focusses mainly on land-mammals like mice and mustelids. I only coordinate bat-related research.

What's the ecological function of the roadsides for mammals?
Let's focus on the land-based mammals because flying-mammals can be present, but they will only use it as passage or foraging area. In case of the land-based mammal depends this on the species and its size. The smaller the mammals, the larger the probability that the roadside has specific functions for the mammals. Larger mammals will use it only as passage. Small mammals can both use it as passage and as habitat. Mice will use it as habitat, they will breed there and live in it. For other small-mammals like hare and hedgehogs will the roadside be part of its territory.

The only large mammal present in the roadside of the A37 is the deer. Is it reasonable to assume that this animals is literally present in the roadside?
It's likely that larger mammals will only use it as passage.

How large is the ecological value of the roadside for mammals?
This depends on the species and its size. But as already mentioned, the smaller the mammal, the more ecological value will be there for this species.

In what way will the production of solar energy influence the functions of the roadside for mammals?
This is not particularly dependent on the type of module, but when you'll install solar panels, you will consume some space. This will cost some habitat and how it influences the ecological function depends on how it influences the vegetation. More shadowiness can result in less plants and vegetation. When there is still vegetation present, than I think that there won't be much impact on the ecological function. Similar as sound barriers. The maintenance of the vegetation will have most influence on the mammals. And if you introduce obstacles to the roadside than this could cause more road-crossing and thus more road-fatalities. So to conclude, off course there will be some changes, but as long as there is vegetation than the impact will be minor.

Will there be a difference in the impact between conventional solar panels and bifacial solar panels?
Only when it leads to a change in vegetation cover. However it would be better to install them on top of posts, but I believe that posts would be better anyway, since you have to have an intensive mowing regime when you want to prevent shadowiness on the cells itself. It's a bit too extreme to say that bifacial improve the functions for mammals. Again, most importantly is the maintenance in

the sense of mowing-regime for example. I don't expect direct positive nor negative effects on mammals.

Are there advantages for mammals?
I don't expect direct positive nor negative effects on mammals.

What adaptions are necessary to maintain the ecological function?
Maintenance is the most important. I don't think that the installation have many influence, both positive as negative, on the mammals. I can imagine it has more impact on other kind of animals. Fauna-facilities are very important for mammals.

How will the cutting of bushes and forestry areas influence the function?
When higher vegetation will be cut down than you'll change the landscape. This will have impact on your ecosystem and therefore on your species too. Think for example about bats, who use those vegetation as orientation. But this depend on the cutting and not on the installation of solar arrays itself.

Why are there bats present at the specific location 15.3 while the surroundings consist of largescale agricultural land?
These can have two reasons. First of all, this can be a hiatus in the data of the NDFF. Since it's very difficult to collect data on bats. There is a lot of data collected but the data of the NDFF is checked by an expert and it is very difficult for an expert to validate the observation. To have clear information on this you'll need to go into the field and monitor yourself. So this is a warning, don't attach much value on these observation. Those observations are good, but it's limited. Secondly, bats have lots of old habits. Their flyways are in most cases very traditional. They use for example channels, but when this channels are drained than the bats have the intension to still coordinate based on this channel. Therefore it is an option that these bats used to have coordination points at this location which are now removed.

For more information you should contact Reinier Meijer of the VLED.

<u>Interview: Raymond Creemers (RAVON)</u>

Who are you and what is RAVON?
Raymond is team manager at RAVON. Originally, I'm an ecologist specialized in amphibians and reptiles. Assets of RAVON are always based on protection of the species. This is been done in multiple manners. Gathering data, coordination volunteers, research by employee's. Mostly commissioned by organization such as Rijkswaterstaat, Staatsbosbeheer, Natuurmonumenten etc. RAVON has very unique knowledge on these species. The kind of activity varies, sometimes it's monitoring, other times it is mitigation or compensation. This has in most cases a scientific background. There is cooperation with other nature-organizations, especially when the research scope is large.

What does your function imply?
This means that he supervises certain teams consisting of ecologists, project managers, employee's. Those teams check articles, reports, tenders and the manage the function- and assessment cycles and progress meetings.

What's the ecological function of the roadsides for amphibians?
The Pelophylax (Green frog) is dependent on water, therefore it's expected that this species is only closely found to pools. The other two species (common toad and common frog). They are 1 a 2 weeks in the water, at the start of the spring. After these two weeks these two species live on land, except for the tadpoles. Fields and pastures are not the favorite habitats for these species, due to an absence of food and shelter. They live mainly in rougher vegetation where insects, worms and woodlice occur. Most amphibians are only active at night, so shading has no influence. This would have been different for reptiles. Amphibians do not depend on bushes, the main vegetation type is grasses and herbs.

How will the amphibians been influenced by the installment of solar arrays
Amphibians move over the ground, therefore form their perspective it would be better to place the modules on posts. So they could walk underneath the modules. Vegetation losses would result is absence of the ecological function. Mainly, because no vegetation would result in no insects, woodlice and worms and therefore no food. Another aspect is less shelter, but this is of minor interest. Its pray lives mainly in grasses, heather and small bushes.

What's your opinion upon the dilemma conventional south-oriented solar modules and the EW-oriented bifacial solar modules? Which one is from an amphibians perspective preferred?
Bifacial would be preferred by amphibians, because vegetation is necessary to find food.

To what extent should the current fauna services been taken into account.
The present fauna services need the be preserved. No extension is necessary, unless the modules will be installed directly on the ground. In that case, the tubes need to be extended.

Are there advantages for the amphibians when solar arrays are installed?
No, there are no clear advantages for amphibians.

What adaptions are necessary for the amphibians?
Amphibians need a vegetation cover, so enough light and rainwater distribution. Secondly, it would be preferred if the modules are installed on top of posts.

On what scale do you expect that the modules will influence the ecological functions for amphibians?
In the case of the amphibians the geographical scale is only very local. Since there is mainly arable farming in the surrounding.

Others notes:
According to Raymond, reptiles would have been expected in the region of Drenthe, especially when the roadsides consist of heather. Think about lizards, if these animals are present in the roadsides, than the roadside would function as a connection to the other parts of the roadside.

INTERVIEW: ALBERT VLIEGENTHART (VLINDERSTICHTING)

Who are you, what is the 'vlinderstichting' and what is your function with this foundation?=
I am ecologist and projectmanager at the vlinderstichting. The vlinderstichting is a nature-preservation organization which focuses on butterflies, moths and dragonflies. It's an organization of over 30 people located in Wageningen. Activities are education, research, advice on activities etc. It's the knowledge-institute for butterflies and dragonflies. Butterflies are indicators for environmental changes, since they are very sensitive to those changes. So we can see the relation with biodiversity. We work together with municipalities, provinces, governments and therefore also RWS.

What are the function of the roadside for butterflies?
Roadsides have multiple function for butterflies and also other insects. For some species it's their home. It's where they rest, reproduce, find their food etc. For others it's only a corridor, a passage to other regions. The hinterland makes the verges very important. The hinterland is species-poor with respect to the vegetation. Butterflies use the edges of the agricultural land, but also the roadsides and ditches to survive. So the roadsides form together with the highway the main ecological infrastructure in this region.

This roadside has a very important function because the highway connects different peat areas from which the (br. Vuurvlinder) dependent is. This species is under pressure and installation will make this species even more vulnerable.

What are the specific survival criteria of butterflies?
Butterflies need some elements to survive. Nectar is one specific example, so flowers are important. Many species have very specific pilot plants. They use these plants the plant their eggs. Micro relief is also very important and diversity in height of the vegetation. Many species spent the winter as pop in the ground, which make the verges more important to these animals.

How will 100 % cover of installed solar panels influence the ecological function and survival criteria?
This would be disastrous for butterflies, but also for many other insects. But also for your vegetation. All in all, is killing for the whole biodiversity in the roadsides. Less to no light will find access to ground, making you to change the microclimate in the roadside. This will lead to other vegetation and insects need local heat, which you'll take away.

And how will the two designs influence this?
This is difficult to say, because you'll always have influence of shadowiness, so in that way there will always be an impact when you install solar panels. A solution is the spread the panels over a larger area, giving sunlight more opportunity to hit the ground. So you'll need a lower density.

If the habitat of butterflies meet their criteria, then they will simply stay there. If you disrupt their habitat, then you'll will make them move to more appropriate locations. In other words, the population will vanish. Objects are literally obstacles for butterflies. For example a forest on the edge of agricultural land; instead of flying across, they will decide to go around this forest. I think the same would count for solar panels.

Different species are present in the verges of the A37. In what way are those species dependent on the roadside?
Overall: a lot of flowers are necessary. Like the dandelion and the ragged robin.

Large skipper:	This species prefers brush. Higher grasses are preferred by this species. The brush-development is very important, with flowers included like the blackberry bush.
Grizzled skipper:	This is a species which is dependent of bog-areas. Flies low to the ground and can't fly very far. They use rosacea, tormentilla especially, as their pilot plant.
Purple emperor:	this species prefers willow-type vegetation. They are dependent of wood-rich transition. They also need high trees to reproduce. They need hedgerows and willows are their pilot plants.
Sooty copper:	this species need acid grasslands. So the soil is a bit acid and plants like the sorrel-species of which sheep's sorrel is the most important one. This species need some relief. The microclimate needs to be a bit capricious.

Are there any advantages?
No

What adaptations are necessary to maintain the ecological function?
Butterflies need their specific vegetation to survive. As I already said, some species are dependent of very specific vegetation. But in general, they need flowers for their nectar and need specific types of plants to put their eggs on etc.

Are project similar to the "honey highway" also effective for butterflies?
If it would be equipped well enough. The current honey highway along the A4 is wrongly equipped. They wrong kinds of flowers, non-native species, are planted over there. Those flowers don't belong there and the present butterflies will decide not the use those. Even worse, you will install an ecological trap, because the butterflies will come to the vegetation, which costs energy and when they arrive, they will find out that these flowers are not useful to them. If you would plant native-species, referring to our project 'idilis?', with pilot plants and grasses then you can create nature and thus an ecological function.

Are there other things you would love to mention?
I would like the advice at this kind of developments to involve an ecologist at all time. Take a critical look at the route and find the spots where the impact is the lowest. Think about urban areas or already present obstacles.
Secondly, if you choose solar energy: include the innovation for the asphalt itself or guardrails.

<u>Interview: Mark Lieven (Pfixx Solar)</u>

What is Pfixx Solar?
Founded in 2004 as installer of solar parks. Especially in the early years did we focus mainly on large scale solar parks in countries abroad, such as Spain and Germany. 6 to 7 years ago did the business and private sector become available to us. Lately, we're back to where we started, at large scale solar parks, due to changes in the solar energy sector. Consequently for this is that we neglected small scale business. We are active in this sector as a project developer.

What is your function within Pfixx Solar?
I'm sales-advisor, but also a bit of solar-engineering.

What is the most used module-density? (bedekkingsgraad/factor)
And for Solarpark Azewijn?
This is dependent of the setup of the solar park. Most of our parks are south-oriented and because you'll make use of a certain tilt, dependent on the location, you'll have to leave space between de modules-arrays to prevent shading. The space between modules will be larger when the tilt become larger. But also the height influences the distance. A common tilt in the Netherlands is 30°.
Currently we see a new development met flat-lying EW-oriented modules. This has as effect on the module-density, since the space will be occupied.
Module-density is roughly between 40 and 60%. We assume that a production of roughly 0.5 MW per hectare can be produced. So half of the area can be occupied by south-oriented modules, but the module-density will increase for EW-oriented modules.

Is the module-denisty in relation with the tilt?
What is the tilt usually and for Azewijn?
See question 3.

How does the vegetation directly underneath the module respond to the module?
We receive this question in more cases. Our experience is that it keeps growing. Since you don't cut light off completely, especially not for a south-oriented setup. There is also little space between modules in one array. So there is not always direct sunlight, but enough lights reaches the ground. In Germany we also experienced a greenhouse-effect. The modules generated heat underneath the module which sometimes triggers the vegetation underneath.

A lower vegetation-density makes somehow sense, however we do not experience this. Grass is mowed underneath the modules 2 – 3 times a year, in Germany. It's mainly grass what grows underneath the modules.

Appendix D Ecological function scores base-case

CMMM MD=100 Base-case	Reproduction	Foraging	Habitat	Orientation	Passage	Protection
Large Mammals					3	
Small Mammals	0	0	0			1
Raptors		0				
Waterbirds	0		0			
Songbirds	0	0				
Bats				0		
Amphibians	1	0	0			
Reptiles		0	0			1
Butterflies	0	0			1	
Total	1	0	0	0	4	2
Average	0,20	0,00	0,00	0,00	2,00	1,00

CMMM MD=100 No Uprootment	Reproduction	Foraging	Habitat	Orientation	Passage	Protection
Large Mammals					3	
Small Mammals	0	0	0			3
Raptors		0				
Waterbirds	1		1			
Songbirds	1	0				
Bats				4		
Amphibians	1	0	0			
Reptiles		0	1			3
Butterflies	0	0			1	
Total	3	0	2	4	4	6
Average	0,60	0,00	0,50	4,00	2,00	3,00

CMMM MD=100 Floating modules	Reproduction	Foraging	Habitat	Orientation	Passage	Protection
Large Mammals					3	
Small Mammals	0	0	0			3
Raptors		0				
Waterbirds	1		2			
Songbirds	1	0				
Bats				4		
Amphibians	4	0	3			
Reptiles		0	1			3
Butterflies	0	0			1	
Total	6	0	6	4	4	6
Average	1,20	0,00	1,50	4,00	2,00	3,00

CMMM MD=100 Obstacle free-zone	Reproduction	Foraging	Habitat	Orientation	Passage	Protection
Large Mammals					4	
Small Mammals	2	1	0			4
Raptors		0				
Waterbirds	2		2			
Songbirds	2	0				
Bats				4		
Amphibians	4	1	3			
Reptiles		1	1			4
Butterflies	0	0			1	
Total	10	3	6	4	5	8
Average	2,00	0,50	1,50	4,00	2,50	4,00

CMMM MD=100 Poles	Reproduction	Foraging	Habitat	Orientation	Passage	Protection
Large Mammals					3	
Small Mammals	2	0	1			4
Raptors		0				
Waterbirds	2		2			
Songbirds	2	0				
Bats				4		
Amphibians	4	0	3			
Reptiles		0	1			4
Butterflies	0	0			1	
Total	10	0	7	4	4	8
Average	2,00	0,00	1,75	4,00	2,00	4,00

CMMM MD=100 pilot + flow. plants	Reproduction	Foraging	Habitat	Orientation	Passage	Protection
Large Mammals					3	
Small Mammals	0	0	0			3
Raptors		0				
Waterbirds	1		2			
Songbirds	1	0				
Bats				4		
Amphibians	4	0	3			
Reptiles		0	1			3
Butterflies	4	4			1	
Total	10	4	6	4	4	6
Average	2,00	0,67	1,50	4,00	2,00	3,00

CMMM MD=50	Reproduction	Foraging	Habitat	Orientation	Passage	Protection
Large Mammals					3	
Small Mammals	2	3	0			3
Raptors		0				
Waterbirds	1		2			
Songbirds	1	0				
Bats				4		
Amphibians	4	3	3			
Reptiles		3	1			3
Butterflies	2	1			1	
Total	10	10	6	4	4	6
Average	2,00	1,67	1,50	4,00	2,00	3,00

CMMM MD=100 Transparent	Reproduction	Foraging	Habitat	Orientation	Passage	Protection
Large Mammals					3	
Small Mammals	2	3	1			3
Raptors		0				
Waterbirds	2		2			
Songbirds	2	0				
Bats				4		
Amphibians	4	3	3			
Reptiles		3	1			3
Butterflies	2	1			1	
Total	12	10	7	4	4	6
Average	2,40	1,67	1,75	4,00	2,00	3,00

CMMM MD=100 Capillary fleece	Reproduction	Foraging	Habitat	Orientation	Passage	Protection
Large Mammals					3	
Small Mammals	2	2	1			3
Raptors		0				
Waterbirds	2		2			
Songbirds	2	0				
Bats				4		
Amphibians	4	2	3			
Reptiles		2	1			3
Butterflies	0	0			1	
Total	10	6	7	4	4	6
Average	2,00	1,00	1,75	4,00	2,00	3,00

Appendix E Ecological function scores including adaptions

VMBM	Reproduction	Foraging	Habitat	Orientation	Passage	Protection
Large Mammals					3	
Small Mammals	4	3	3			4
Raptors		1				
Waterbirds	3		0			
Songbirds	3	3				
Bats				4		
Amphibians	3	4				
Reptiles		4	1			3
Butterflies	3	2			2	
Total	16	17	4	4	5	7
Average	3,2	2,83	1,3	4	2,5	3,5

VMBM Forest	Reproduction	Foraging	Habitat	Orientation	Passage	Protection
Large Mammals					3	
Small Mammals	4	4	3			4
Raptors		1				
Waterbirds	4		0			
Songbirds	4	4				
Bats				4		
Amphibians	3	4				
Reptiles		4	3			4
Butterflies	3	2			2	
Total	18	19	6	4	5	8
Average	3,6	3,17	2	4	2,5	4

VMBM Floating Modules	Reproduction	Foraging	Habitat	Orientation	Passage	Protection
Large Mammals					3	
Small Mammals	4	3	3			4
Raptors		1				
Waterbirds	3		2			
Songbirds	3	3				
Bats				4		
Amphibians	4	4				
Reptiles		4	1			3
Butterflies	3	2			2	
Total	17	17	6	4	5	7
Average	3,4	2,83	2	4	2,5	3,5

VMBM Obstacle free-zone	Reproduction	Foraging	Habitat	Orientation	Passage	Protection
Large Mammals					4	
Small Mammals	4	3	3			4
Raptors		1				
Waterbirds	3		0			
Songbirds	3	3				
Bats				4		
Amphibians	3	4				
Reptiles		4	1			3
Butterflies	3	2			2	
Total	16	17	4	4	6	7
Average	3,2	2,83	1,33	4	3	3,5

VMBM Poles	Reproduction	Foraging	Habitat	Orientation	Passage	Protection
Large Mammals					3	
Small Mammals	4	4	4			4
Raptors		1				
Waterbirds	3		0			
Songbirds	3	3				
Bats				4		
Amphibians	3	4				
Reptiles		4	3			3
Butterflies	3	2			3	
Total	16	18	7	4	6	7
Average	3,2	3	2,33	4	3	3,5

VMBM Module density (8%)	Reproduction	Foraging	Habitat	Orientation	Passage	Protection
Large Mammals					3	
Small Mammals	4	3	3			4
Raptors		2				
Waterbirds	3		0			
Songbirds	3	3				
Bats				4		
Amphibians	3	4				
Reptiles		4	3			3
Butterflies	3	3			3	
Total	16	19	6	4	6	7
Average	3,2	3,17	2	4	3	3,5

VMBM Pilot and flowering plants	Reproduction	Foraging	Habitat	Orientation	Passage	Protection
Large Mammals					3	
Small Mammals	4	3	3			4
Raptors		2				
Waterbirds	3		0			
Songbirds	3	3				
Bats				4		
Amphibians	3	4				
Reptiles		4	3			3
Butterflies	4	4			3	
Total	17	20	6	4	6	7
Average	3,4	3,33	2	4	3	3,5