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Bachelor Integration Project

Final Report

Light Pollution from Nobian at the Chemical Park in Delfzijl

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Abstract

Light pollution is becoming a problem at night due to the use of artificial lighting. The artificial light disturbs the day and night rhythms of humans and animals. Therefore, Nobian, who has three factories located on the chemical park Delfzijl and close to the Waddensea, wants to know if they cause light pollution and if there is pollution how it can be resolved. For industrial areas light pollution in the night is classified when the amount of lux is above 5. The amount of light will be measured in lux with the Peaktech 5086 and the data will be put into ArcGIS. ArcGIS can interpolate the data points and create a map which will show how the light is distributed across the area of Nobian. The maps produced by ArcGIS showed light pollution at all three factories, especially at the MEB factory. There are several measures which can be taken to reduce light pollution. The three ways used in this research are: shutting of or dimming lights, limit the area of lighting, and prevent over-illumination. This research provided an answer to the question of Nobian and provides ways to reduce the pollution. For further research instead of just focusing on Nobian, the whole chemical park should be taken into account.

Keywords— Light, artificial light, light pollution, industrial area, lux measurements, ArcGIS

Contents

1 Introduction **4**

2 Problem Analysis **6**
2.1 Problem Context . . . 6
2.2 System Description . . . 6
2.3 Stakeholder Analysis . . . 6
2.4 Problem Statement . . . 6
2.5 Goal Statement . . . 7

3 Research Design **8**
3.1 Research Strategies . . . 8
3.2 Research Questions . . . 8
3.3 Research Materials . . . 8
3.4 Deliverable and Validation . . . 9

4 Information about Nobian **10**
4.1 Location and surroundings of Nobian . . . 10
4.2 Previous research on light pollution . . . 11
4.3 Information about light and regulations . . . 12

5 How can light pollution be measured? **13**
5.1 Sky brightness . . . 13
5.2 Wavelengths of light . . . 15
5.3 Lux measurements . . . 15

6 Materials and Methods **16**
6.1 Materials . . . 16
6.2 Methods . . . 16
6.2.1 Methods used for light measurements . . . 16
6.2.2 Methods ArcGIS . . . 17

7 Results and analysis of light measurements **19**
7.1 Light measurements at Salt factories . . . 19
7.1.1 Measurements explained . . . 19
7.2 Light measurements at Delesto factory . . . 21
7.2.1 Measurements explained . . . 21
7.3 Light measurements at MEB factory . . . 23
7.3.1 Measurements explained . . . 23

8 Vision under different colors of illumination **25**

9 Possible solutions to reduce light pollution **27**
9.1 Shut off lights when they are not used . . . 27
9.2 Limiting the area of lighting . . . 27
9.3 Prevent over-illumination . . . 27

10 Conclusion **29**

11 Discussion **30**

12 Future research **31**

Bibliography **32**

Appendices **35**
A Detailed places of the measurements 35
B Background information Nobian 38
C Ranking of sky brightness at different locations 40
D Tables with measurement data 41
E Interview 44
F Transparent ArcGIS maps 45
G Light map Salt extended 47

Chapter 1: Introduction

Light pollution is becoming a significant problem in this modern world. Light pollution, or artificial light at night, is the excessive or poor use of artificial outdoor light, and it disrupts the natural patterns of wildlife, disrupts human sleep, and obscures the stars in the night sky [11]. Over the last 100 years, the natural patterns of light have been greatly disrupted through the introduction of artificial light into the night-time environment [19]. This artificial lighting can be useful to perform activities during the night, make objects visible and move safely in the dark. However, there are some negative aspects of artificial lighting. The artificial lighting disturbs nature and the visibility of the stars. Because artificial lighting is being used on an increasing scale, there is the urge if not the necessity to reduce the negative influences of artificial lighting [28].

Greenhouses make use of much artificial lighting. Therefore, not surprisingly greenhouses are the greatest contributors to light pollution in the Netherlands. The greenhouses create light nuisance for the residents living nearby the greenhouses. The NSVV, the Dutch foundation for light science, uses a methodology similar to the law for noise nuisance to determine the limit values for light. The limits are set for several types of areas such as a nature reserve, rural areas and urban areas which can be seen in figure 6.2 [26][28].

Light pollution is caused by light that is directed in the wrong direction or place. Therefore, the light is spilled which can cause economic and environmental losses together with disturbance and discomfort. One of the most notable forms of light pollution is 'sky glow'. Sky glow is being caused by light which is being projected upwards to the sky, and then is scattered back to earth. It is also caused by light which is reflected upward through other objects or surfaces. Cloud coverage has a large impact on the sky luminance. A study showed that in Berlin the clouds amplified the sky luminance by a factor 10.1 in the city center and by a factor of 2.8 32 kilometers away from the city center [26][22].

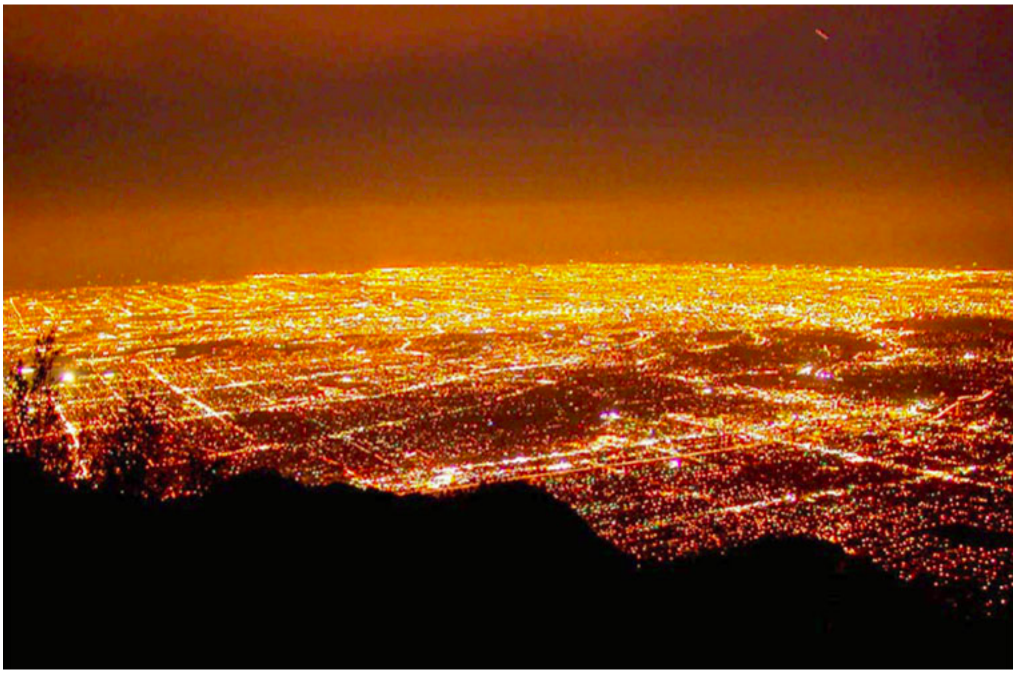

Figure 1.1: Figure which shows a representation of sky glow caused by all the city lights [33].

Sky luminance is therefore a big problem, this could also be the case for Delfzijl. It is especially a problem for the wildlife near the chemical park. Animals can experience increased orientation or disorientation due to additional illumination. Next to that, they are also attracted or repulsed by the glare which can affect foraging, communication and other crucial parts of their behavior. Reproduction is also affected by artificial lighting. Birds tend to choose a different nest site due to artificial lighting. Besides this, there is also a change in the egg-laying date of the birds especially in the urban and sub-urban areas [23][15].

Many studies have been conducted to investigate light pollution. Most of these studies focused on how light pollution affects flora and fauna. There are slim to none studies which have researched light pollution coming from industrial areas. One study researched the light pollution in residential areas in Beijing, which resembles the kind of research conducted in this study [21]. Another example, which is closer to home, is the research done by Esri Nederland. In 2018 they investigated light pollution coming from greenhouses in Almere. These greenhouses emitted a lot of light towards the Oostvaarderplassen [16].

The focus of this project will be on light pollution caused by the chemical park in Delfzijl. Nobian, a company located at the chemical park, wants to reduce their light pollution. Light pollution is becoming a problem for the Wadden Sea region which is on the UNESCO world heritage list. Together with Nobian and Science LinX, the science center of the University of Groningen, the artificial lighting problem is being investigated.

Chapter 2: Problem Analysis

2.1 Problem Context

Nobian wants to find out if they cause light pollution because studies have shown that it has a negative influence on the environment. It affects the day and night schedule of animals as well as humans. Therefore, the intensity of the light has to be reduced or the light should be directed in a different direction to prevent sky luminance. It is possible to implement these measures, but the requirements for the safety of the employers has to be kept in mind.

2.2 System Description

The focus of this project will be on the light pollution at Nobian. To visualize the system figure 2.1 is established.

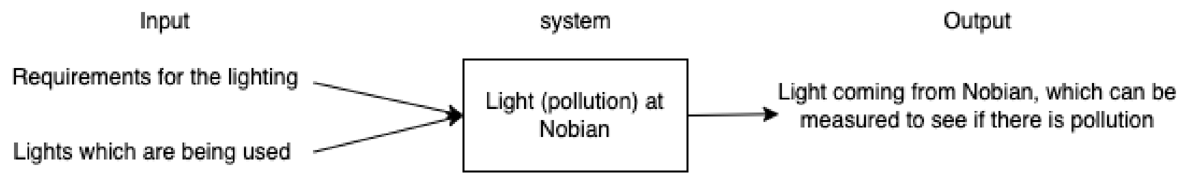

Figure 2.1: Visualization of the System.

Figure 2.1 shows the system of this project. The input of the system is the light which has to be measured. This will be done in the system itself, which makes use of the lux meter. The output will then be a certain amount of lux which indicates the intensity of the light. With this system, the problem of light pollution can be tackled.

2.3 Stakeholder Analysis

There are two stakeholders involved within this problem. The first stakeholder and problem owner is Nobian, especially Harry Jasken and Ian Pedonomou. Harry is the manager of in- and external affairs and Ian is the site technology lead. They want to see if it is possible to reduce the lighting they use on their site. The reason behind this is that they realize that the artificial light which is being used has a negative influence on the flora and fauna in the area as well as the day and night schedule of people. Nobian will have much influence on the project since it is their choice to tackle the problem of the light pollution.

The second stakeholder is Science LinX, since they are a research organization who started this cooperation with Nobian to tackle the light pollution coming from the chemical park. Science LinX is working on the project 'The Darkness of the Wadden Region' which is a project from the provinces Noord-Holland, Friesland and Groningen [6]. Reducing the light pollution coming from Nobian and the chemical park will help to keep the darkness at the Wadden region.

2.4 Problem Statement

The following problem statement has been made: *It is unknown whether the various sites of Nobian at the chemical park in Delfzijl contribute to light pollution, which is disturbing for the people and wildlife, which has therefore to be investigated.*

2.5 Goal Statement

The goal of the research is to investigate if there is too much light coming from Nobian. If there is too much light, than the amount of light being used has to be reduced. The norm value, set by the NSVV, for industrial areas is 5 lux (see figure 6.2), so if a site of Nobian has a value higher than 5 it should be reduced. This should be realizable by making use of light fixtures and custom lighting. Custom lighting means that you only use the light where necessary, when necessary and only the amount necessary.

The goal statement complies with the SMART restrictions. It is specific since the light pollution will be reduced by making use of custom lighting and light fixtures. How much of a reduction there will be is hard to quantify, but any reduction is already a positive outcome. The goal is measurable since the reduction in light can be measured. It is achievable because the amount of lux coming from the lights can be measured using light measurement tools and a plan can be made to reduce the light where necessary. The goal is relevant because reducing the light pollution will result in a better living environment for animals and humans. The time needed for this research will be 3 months and therefore the goal is time bound.

Chapter 3: Research Design

3.1 Research Strategies

The most significant decision which has to be made when constructing a research design is what kind of approach will be taken [32]. This research opts for an *in depth* research, by focusing only on the light pollution coming from Nobian. Part of the research is *quantitative* since light measurements have been done. The measurement results are compiled in tables and charts and are modelled. The other part of the research is *qualitative*, so it is verbal and contemplative. This is because different ways to reduce light pollution will be investigated. Most of the research is *empirical*, so research was done at Nobian and data has been gathered. *Desk research* is also used to obtain already existing knowledge about light pollution.

3.2 Research Questions

In order to achieve the goal of this research, research questions are formulated. The main research questions is: *What action should Nobian take to reduce the possible light pollution keeping in mind the requirements for the lighting?*

The main research question is answered by investigating the following sub-questions:

1. What is the current level of light intensity at the three different factories of Nobian?
2. What is the purpose of different colors of light and can this be used by Nobian?
3. What actions can be taken to reduce light pollution?

During the research, the sub-questions will be answered which will provide an answer to the main research question.

3.3 Research Materials

One of the first steps in making a research design is to choose what kind of material is needed. The first kind of material which is used is people. By interviewing employers at Nobian, knowledge has been obtained about when and where lighting is needed to perform their job. These requirements need to be taken into account to ensure that the employers have a safe working environment. The second type of material which is used is literature. By looking up literature about light pollution, knowledge has been obtained. This can be knowledge about requirements for lighting or about what causes light pollution. The last type of materials are experiments and measurements. With the use of light measuring tools (see chapter 5), the light at Nobian has been measured. With the use of these materials, the research questions can be answered. On the next page, figure 3.1 can be seen which displays what research methods have been used for each sub question.

	RQ 1	RQ 2	RQ 3
Obtained data	quantitative	qualitative	qualitative
Type op research question	knowledge	knowledge	knowledge
Research tools	measurements	literature	literature

Figure 3.1: Table with research methods per sub question.

3.4 Deliverable and Validation

The deliverable of this research is to find out if there is light pollution at Nobian and to locate where this pollution is coming from. When this has been determined, an approach on how to reduce light pollution can be made. The research can be validated by implementing this approach and then conduct the light measurements again. The new measurements can then be compared to the old measurements to see if and by how much the light pollution has been decreased.

Chapter 4: Information about Nobian

4.1 Location and surroundings of Nobian

Figure 4.1: This map displays where the factories of Nobian, the red rectangles, are located on the chemical park.

The three factories of Nobian are located in the North-West part of the chemical park, which can be seen in figure 4.1. Most of the other companies located on the chemical park are in the East side. The chemical park is part of a larger industrial area, which is the industrial area Oosterhorn (see figure 4.2). The Oosterhorn area is focused on port-bound activities, the port of Delfzijl is located in the top left part of the Oosterhorn area. Besides the port activities, it is one of the largest chemical cluster areas in the Netherlands. The construction of the industrial area started back in 1958, this was when salt was discovered in Heiligerlee and Veendam, and when the natural gas in Slochteren was found [5].

The other companies located in the Oosterhorn industrial area and the port area also use artificial lighting at night. This is something to keep in mind when the impact of artificial lighting on the nature areas is investigated. The Waddensea is close to the Oosterhorn area and therefore it is important to look at the Oosterhorn area as a whole.

Figure 4.2: This map displays the Oosterhorn industrial area, indicated by the orange area, and the chemical park Delfzijl, outlined by the red line.

4.2 Previous research on light pollution

In an environmental impact rapport from 2016, initiated by the municipality of Delfzijl, the light coming from the Oosterhorn industrial area was investigated. In the investigation the current levels of light intensity were mapped across the Oosterhorn area. They only took the artificial light into account coming from the companies located within the area. The map with the different levels of light intensity can be seen in figure 4.3 [14]. The dark blue line indicates where the amount of lux is 10, the light blue line where it is 5 lux. The light blue line can barely be seen, this is because it lies right next to the dark blue line. The green line indicates where the amount of lux is 1 and at last there is the yellow line which indicates values of 0.1 lux.

Figure 4.3: This map displays the intensity levels in the Oosterhorn industrial area in 2016.

4.3 Information about light and regulations

The amount of light which can be present is not stated in the environmental permit Nobian has. There is also nothing stated about light in the aspects and impacts assessment, it is only being looked at when there are complaints about light nuisance. However, in the permit there are maximum values set for noise or air pollution.

From a report in 2015, the scattering of light coming from Nobian is not relevant for the Zuidlaardermeer, Leekstermeergebied and banks of the Schildmeer. These three areas are part of the Natura 2000, which is a European network of protected nature areas. However, the scattering of light could be relevant for the Wadden region, especially for the seal, the grey seal and other animals which are sensitive to the light.

Chapter 5: How can light pollution be measured?

There are several ways to measure and express light pollution. The three most used methods are measuring the sky brightness, looking at different wavelengths of light, and performing lux measurements. In the sections below the benefits of each method will be explained.

5.1 Sky brightness

The brightness of the sky is made up of light from natural sources as well as artificial sources. Traditionally, astronomers measure sky brightness in the astronomical magnitude system mag/arcsec2 (magnitude per square arcsecond). The reason this system is chosen, is because if an area on the sky contained precisely one magnitude X star in each square arcsecond, the sky brightness would be X mag/arcsec2. This magnitude system was founded by the Greek astronomer Hipparchos, who assigned a magnitude of 1 for the brightest stars visible to the naked eye, and magnitude 6 for the faintest stars visible to the naked eye. Therefore, larger values in mag/arcsec2 indicate darker skies [20].

One way to measure sky brightness is simply with the human eye. It is a traditional method where the night sky quality is determined by the "limiting magnitude", which is the magnitude of the faintest star visible to the naked eye. This technique uses the contrast threshold of the human visual system: when there is a bright sky background, only bright stars can be noticed, while when there is a dark background fainter stars are distinguishable [20].

However determining the limiting magnitude with the naked eye is a poor criterion. It depends too much on someones visual acuity, time and effort expended to see the faintest star possible. One person can say that the sky has a magnitude of 5.5 when for another person this sky looks like it has a magnitude of 6.3. To help observers judge the true darkness of a site, there is the Bortle scale which has nine levels of brightness. Where 1 is an excellent dark-sky site and 9 is the inner-city sky which is brightly lit, this can be seen in figure 5.1 below [13].

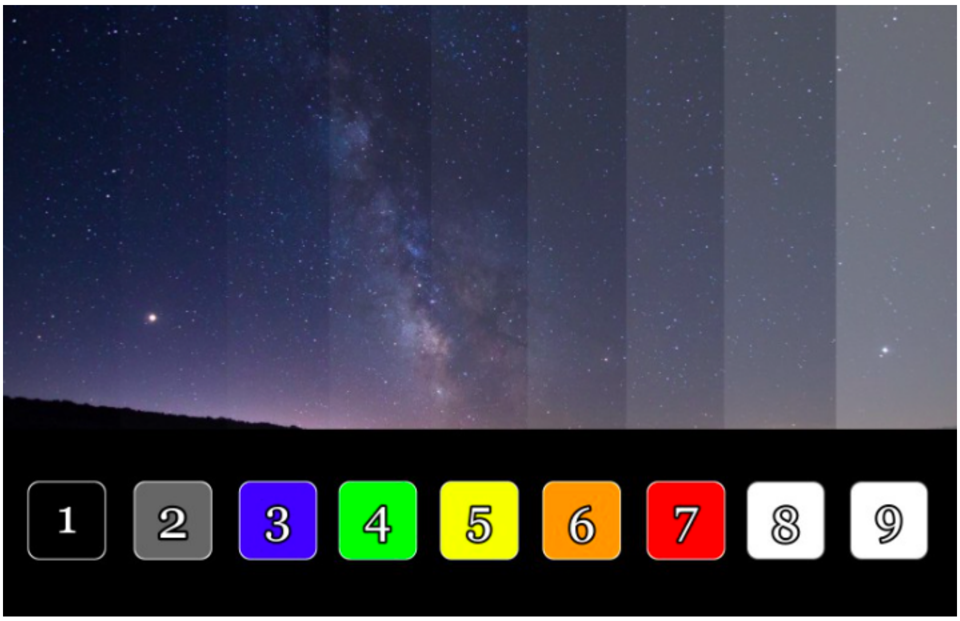

Figure 5.1: Figure which displays the different Bortle scales. Where scale 1 is an excellent dark-sky, up to scale 9 which is the brightly lit inner-city sky [25].

Another way to measure sky brightness is with the use of one dimensional instruments. These devices measure the sky brightness using a single channel and typically only observing at zenith, which is the point in the sky or celestial sphere directly above an observer. The one dimensional instruments determine the sky brightness as a sum of both the sky background brightness and the stars withing the viewing field. The most well known device is the Sky Quality Meter (SQM), which has been used in a large number of studies of sky brightness. The spectral response encompasses the photopic eye response, however it is more sensitive for shorter wavelengths such as blue or green. In certain areas with little artificial skyglow, nearby lamps can influence the measurement. This is caused by the residual sensitivity of the SQM at large angles, or scattered light from a lamp which dominates the natural sky brightness. To tackle this problem there is the SQM-L which has a lens. This L version has a reduced field of view, which makes it better to use around nearby light sources and will lead to consistent readings [20]. On the roof of the location office of Nobian a SQM-LU is installed. This device is installed by Science LinX for their research "Was het donker", the measurements can be seen on `https://washetdonker.nl/`. The measurements for different locations during the night can be seen in appendix C. The main difference between the SQM-L and the SQM-LU is that the latter is continuously measuring the sky brightness.

5.2 Wavelengths of light

A different way to investigate light pollution is to look at the wavelengths emitted by lights. For humans, exposure to light at night decreases the melatonin production and secretion. This can result in a phase shift in the daily rhythms of people. Besides the timing and exposure duration, there are two light variables responsible for the reduction of melatonin production which are: light intensity and wavelength [17]. However, this section will only discuss why light pollution is measured with wavelengths and how they can be measured.

In a study, in which the impact of different wavelengths on humans was assessed by measuring melatonin, alertness, heart rate and thermoregulation, it was proved that wavelength played a significant role. When exposed to two hours of mono-chromatic light in the evening at a wavelength of 460nm, there is a significant suppression in the melatonin secretion. However, exposure to light with a wavelength of 550nm under the same circumstances, did not result in the same effects [17].

To determine which wavelength a light puts out, a spectrophotometer can be used. The spectrophotometer measures the intensity of electromagnetic energy at every wavelength of light. The electromagnetic energy, coming from the light/sample, enters the device and is then separated into its component wavelengths by the holographic grating. The grating serves to distinguish each different color from the white light. The light is now separated and focused onto the CCD array detector where the intensity of the wavelengths can be determined. The CCD, charge-coupled device, transforms the electromagnetic energy into an electric load which makes it possible to determine the intensity of the wavelengths. After this the CCD is coupled to a computer which can then display the spectrum of the intensity of each wavelength of light [24].

5.3 Lux measurements

Measurements of light pollution often involve the determination of the illumination at a certain place. Illumination is identified as the amount of light incident per unit area. For ecological light pollution it is not the only measurement relevant but it is the most common one. Ecologists should measure the illumination as photons per square meter per second with associated measurements of the wavelength of light present. However, most of the times illumination is measured in lux, which expresses the brightness of light as perceived by the human eye. When illumination is measured in lux, the measurements place more emphasis on the wavelengths that the human eye detects best and less on those which the human eye receive poorly. The amount of lux decreases quadratic with the distance from the light source [8]. Lux is the standard for illumination used by almost all lighting designers, environmental regulators, and lighting engineers [23].

Chapter 6: Materials and Methods

6.1 Materials

The way to express light pollution in this research is done by using lux. The device used to measure the amount of lux for this research is the PeakTech 5086, see figure 6.1. This device was provided by Science LinX to conduct the research. The device has a memory which can hold up to 99 measurements, this made it possible to conduct all the measurements needed. After all the measurements had been taken the values could be read from the memory and be analyzed.

Figure 6.1: Figure which displays the PeakTech 5086, the device used to perform the lux measurements.

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To simulate how the light intensity spreads over the area of the factories, ArcGIS has been used. ArcGIS is the name for GIS-software produced by Esri, which was introduced in the introduction. ArcGIS is a very useful and extensive program which is used a lot for data processing. Fortunately, the university has a license for this software and therefore it could be used in this research. With the ArcGIS software a map could be made which simulates the spread of the light for the three different factories. With the use of spatial analysis technology, the ArcGIS software is able to simulate how the light is spread across the three different sites. There are several ways how the spatial analysis technology can determine the unknown data points. It can make use of the Inverse Distance Weighting(IDW), Kriging, natural neighbor, spline, spline with barriers, topo to raster, and trend interpolation [4]. When comparing the different interpolation methods, the IDW interpolation fits best with the data obtained in this research. Further explanation about IDW interpolation can be seen in the methods section below.

6.2 Methods

6.2.1 Methods used for light measurements

When conducting the light measurements there were certain methods and requirements to keep in mind. The measurements were all taken at a height of 1.5 meter, this height was set by the NSVV. The NSVV also determined the amount of lux which can be present in certain areas at specific times. This can be seen in figure 6.2 below, for industrial areas the amount of lux during the night, between 11pm and 7am, can be at most 5. The distance between the measurements was about 10 meters each time. This is the same distance that is being used in the paper of light pollution in residential areas in Beijing.

The NSVV has also set some other requirements when conducting light measurements. The wind speed should be below 5 on the scale of Beaufort, there can not be a change in cloud coverage, the weather has to be dry and there are many more requirements which have to be taken into account [27].

		Omgevingszone				
Te hanteren parameter	**Tijdsperiode (uur)**	**E0 Duisternis-gebied**	**E1 Natuur-gebied**	**E2 Landelijk gebied**	**E3 Stedelijk gebied**	**E4 Stadscentrum/ Industriegebied**
Verlichtings-sterkte E_v in lx op relevant geveldeel c.q. vensteropening	Dag en avond 07:00-23:00	n.v.t.	2	5	10	25
	Nacht 23:00-07:00	n.v.t.	0,1	1	2	5

Figure 6.2: Norm of lux values for different types of areas. Source:NSVV [28]

6.2.2 Methods ArcGIS

In the program there are a lot of so called basemaps, which are standard maps of the world which can be used as a background map. The basemap used in this research was just a standard satellite basemap of the world. At first, the measurements of the three factories had to be put into the program. This was fairly easy to do, since you could just add a data point at the place of the measurement and assign the measured value to it. This is why a basemap is very useful, you can just add the data point exactly on the place where the measurement was taken. After all the data points were added to the program, the outline of the area of each factory had to be drawn. This is necessary since an area needs to be assigned to the program in which the light distribution has to be modelled. Therefore, three different areas were outlined using the basemap. Now the program is ready to simulate how the light would be distributed across the area. As said in the material section, the IDW interpolation method is chosen to simulate the distribution.

IDW interpolation estimates unknown values by specifying search distance, barriers, closest points and power setting. Interpolated points are estimated based on the distance they have from the known cell values. The known cell values have a greater impact on nearby unknown points than points farther away, since the distance will be greater [10].

The formulas used by the IDW interpolation method are:

$$w_i = \frac{1}{d_{ix^*}} \tag{6.1}$$

$$x^* = \frac{w_1 x_1 + w_2 x_2 + w_3 x_3 + ... + w_n x_n}{w_1 + w_2 + w_3 + ... + w_n} \tag{6.2}$$

At first the weight of a known measurement is determined. This is done by determining the distance between a known data point and an unknown data point. The weight is then 1 over the distance between the points (see formula 6.1 above), this implies that points farther away have less influence than nearby points.

The second step is to determine the value of the unknown point, as can be seen in formula 6.2 above. This is done by first multiplying the weight of the known point by the value assigned to the point. This is done for all the data points which are put into the system and they are all added up together. Secondly, the sum of all these data points is divided by the sum of all the weights of the data points. This gives the value for the unknown data point and this is done continuously until the program has determined all the points in the outlined area.

Chapter 7: Results and analysis of light measurements

7.1 Light measurements at Salt factories

The first series of light measurements were performed on the night of Thursday 28 April to Friday 29 April. These measurements were conducted at the Salt factories of Nobian. The measurements were taken between 00:00 and 01:15, therefore it should be dark enough which is of course necessary to measure the light. The conditions for the measurements were good, the wind speed was between 1 and 2 Beaufort which is below the maximum wind speed of 5 Beaufort [27]. There was little cloud coverage which is also positive for the measurements, because cloud coverage increases the sky glow which in its turn increases the amount of lux measured.

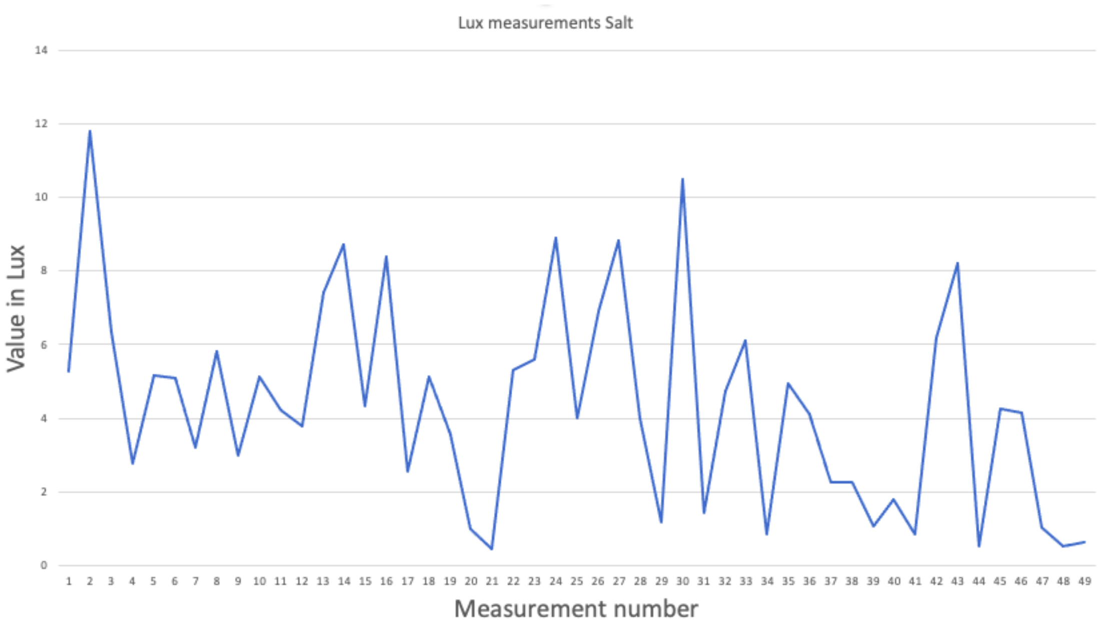

Figure 7.1: Graph of the measurements at the Salt factories.

7.1.1 Measurements explained

The different measurements conducted at the salt factory can be seen in the table in appendix D.1 and figure 7.1. In figure A.1, a clear overview has been made to see where exactly each measurement was taken and in figure F.1 the map has been made transparent. Therefore, it can be seen where exactly the light is coming from.

The average value of the measurements is 4.37 lux, this average is only used to compare the different measurements to each other. When looking at figure 7.1, it can be seen that there are some high values. Measurement 2 for instance has a value of 11.81 which is more than double the average value. This high value can be explained since there are two lampposts nearby the place of the measurement. The measurements 24, 27 and 30 are also way above the average value. This is because they were conducted near factory D where many fluorescent tubes are used. Factory D is not enclosed by any walls and therefore the light can shine in every direction.

Besides the high values, there are also values which are way below the average. When looking at measurement 21, which has a value of just 0.45 lux, it can be seen that it is about a tenth of the average value. This can be explained since the measurement was done at the backside of the site. There is almost no lighting at the backside, because there is only some storage which does not need to be accessed at night. The same goes for almost all the measurements conducted in the South-East corner which can be seen in figure A.1. There is only some storage of equipment which is left from the maintenance which had been conducted. Some measurements in the South-East corner are higher, but that is due to that they were measured near lampposts.

When looking at figure 7.2 it is clear to see where there is too much light. This makes it much easier to see where the amount of light has to be reduced. It can be seen that the illuminance at the salt factory ranges from 0.45 lux up to 11.75 lux. The light intensity is the highest around the center of the factory and south of it. This could be explained since the operators will be around the salt factory most of the times. Figure 7.3 shows where the amount of lux is above or below the threshold of 5 lux. In the black area the amount of lux is below 5 and the white area indicates values above 5 lux.

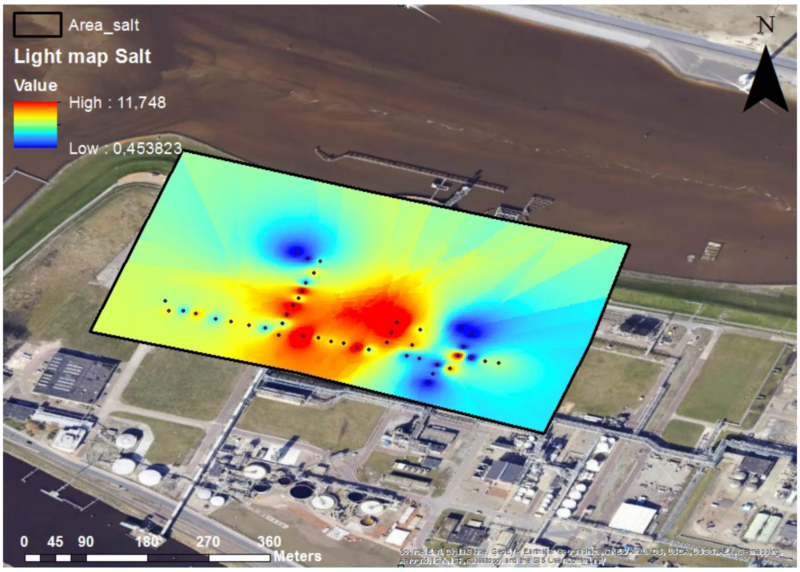

Figure 7.2: Figure which displays how the light is distributed at the Salt factories, made in ArcGIS.

Figure 7.3: Figure which displays where there is light pollution at the Salt factories, made in ArcGIS. In the black area the amount of lux is below 5 and the white area indicates values above 5 lux.

7.2 Light measurements at Delesto factory

The second series of measurements were performed on the night of Friday 29 April to Saturday 30 April. These measurements were conducted at the Delesto factory of Nobian. The measurements were taken between 23:45 and 01:00, therefore it should be dark enough to measure the light. The conditions for the measurements were good, the wind speed was between 1 and 2 Beaufort which is below the maximum wind speed of 5 Beaufort. There was little cloud coverage which is also good for the measurements.

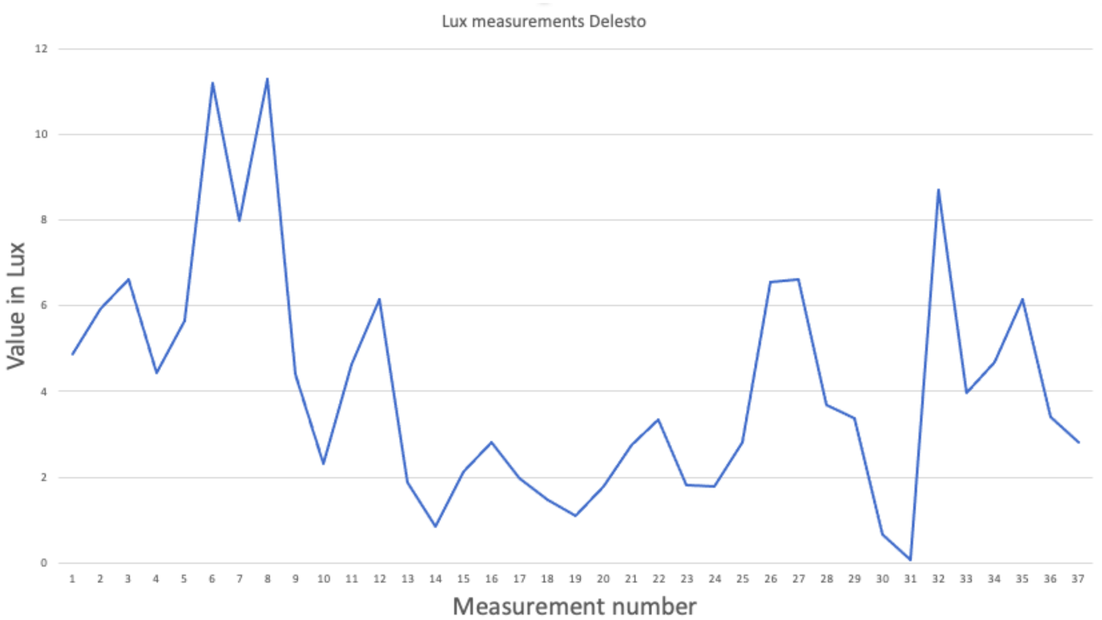

Figure 7.4: Graph of the measurements at the Delesto factory.

7.2.1 Measurements explained

The different measurements conducted at the Delesto factory can be seen in appendix D.2 and figure 7.4. In figure A.2, a clear overview has been made to see where exactly each measurement was taken and in figure F.2 the map has been made transparent. Therefore, it can be seen where exactly the light is coming from.

The average value of the measurements at Delesto is 4.13 lux. When looking at figure 7.4, there are some extreme values at measurements 6, 7 and 8. These measurements have high values since they were conducted near several lampposts. Measurements 26 and 27 are also above the average, the reason for this is that they were taken near the entrance of the control room. At the entrance of the control room there are three bright lamps. These lamps do not have a light fixture which points the light in a specific direction, therefore it is possible for the light to shine in every direction. The last high value is measurement 32, which was measured near a staircase on the outside of a building. There were many lights on the staircase, which are there to safely climb the stairs at night.

On the other hand, there are also values which are significant below the average value. Measurement 31 has a value of 0.06, which means that it is almost pitch black. The reason for this low value is that the measuring device was pointed towards the dike. Measurements 14, 17-20, 23, 24 and 30 perform way below the average value. This is because the lampposts near these measurements were broken at the time. Therefore, it was darker when compared to other measuring points.

When looking at figure 7.5 it is clear to see where there is too much light, which are the red and yellow areas. This makes it much easier to see where the set up of the lights needs to be changed. It can be seen that the illuminance at the Delesto factory ranges from 0.07 lux up to 11.3 lux. The highest light intensity is measured on the West side in the center of the site. Figure 7.6 shows where the amount of lux is above or below the threshold of 5 lux. In the black area the amount of lux is below 5 and the white area indicates values above 5 lux. It can be seen that the West part of the site has a value above 5 lux. There are some other places where the amount of lux is above 5, this is depending on the distance between the lights and the place of the measurement.

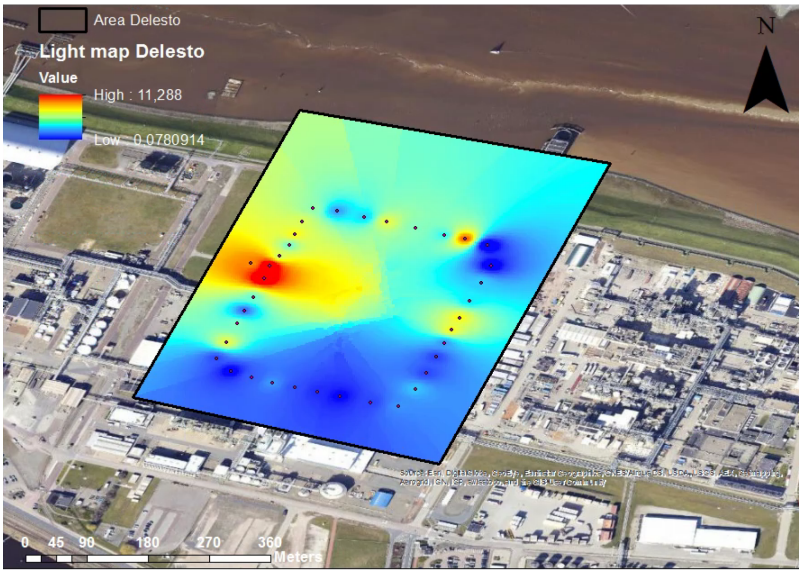

Figure 7.5: Figure which displays how the light is distributed at the Delesto factory, made in ArcGIS.

Figure 7.6: Figure which displays where there is light pollution at the Delesto factory, made in ArcGIS. In the black area the amount of lux is below 5 and the white area indicates values above 5 lux.

7.3 Light measurements at MEB factory

The third series of measurements were performed on the night of Wednesday 4 May to Thursday 5 May. These measurements were conducted at the MEB factory of Nobian. The measurements were taken between 23:45 and 00:30, therefore it would be dark enough which is of course necessary to measure the light. The conditions for the measurements were good, the wind speed was between 0 and 1 Beaufort. There was little cloud coverage which is also positive for the measurements.

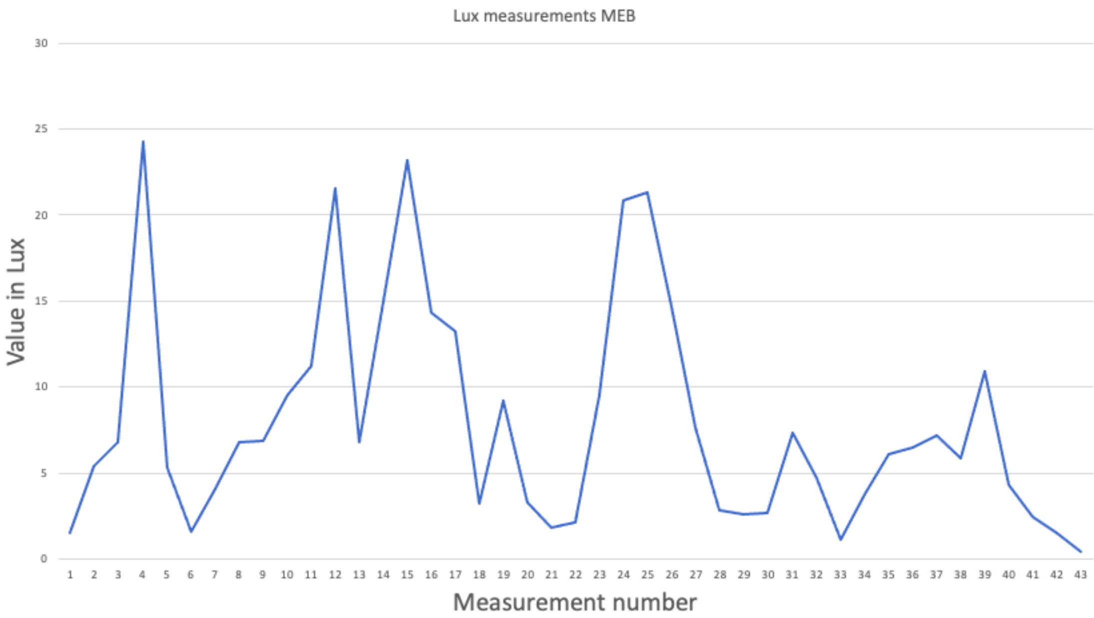

Figure 7.7: Graph of the measurements at the MEB factory.

7.3.1 Measurements explained

The different measurements conducted at the MEB factory can be seen in appendix D.3 and figure 7.7. In figure A.3, a clear overview has been made to see where exactly each measurement was taken and in figure F.3 the map has been made transparent. Therefore, it can be seen where exactly the light is coming from.

The measurements have an average value of 8.1 lux. When looking at figure 7.7, there are some outliers in the graph which are above 20 lux. One of these measurements is number 4, which has a value of 24.26 lux. This is a very high value which is caused by four lamps which are installed in a small shed on the site. The other measurements which are way above the average are 12, 24 and 25. The reason for this high value is that the lampposts nearby the places of the measurements had LED light. The LED lights were way brighter compared to the lights in the other lampposts.

Next to the high values, there are also values which are significantly below the average. This is the case for measurements 1, 41 and 42. These measurements were conducted in the South-East corner of the site. In this area there is not much light which explains why these measurements have a value below the average. Besides these measurement, number 6 also has a very low value. The reason behind this is that the lampposts near the place of the measurement was broken at the time. At last, there is measurement 21, which has a value of 1.83 lux. A low value was measured here since the North-West corner of the site is not really used, which can be seen in figure A.3. Therefore, there is also not a lot of light installed in this area.

When looking at figure 7.8 it is clear to see that there is too much light at the MEB factory, which are the red, yellow and light blue areas. This makes it much easier to see where the set up of the lights needs to be changed. It can be seen that the illuminance at the MEB factory ranges from 0.4 lux up to 24.3 lux. The highest light intensities are measured near certain lampposts which were just way too bright for the area. For instance near the lampposts with the LED lighting, see figure A.3. Figure 7.9 shows where the amount of lux is above or below the threshold of 5 lux. In the black area the amount of lux is below 5 and the white area indicates values above 5 lux. It can be seen that almost the whole site of the MEB factory is above the threshold of 5 lux. There are some exceptions to this, like the South-West corner, the South-East corner and a little bit in the North-West corner. This can be explained by looking at figure A.3 again. In these places there are not a lot of lights or they were broken at the time the measurements took place.

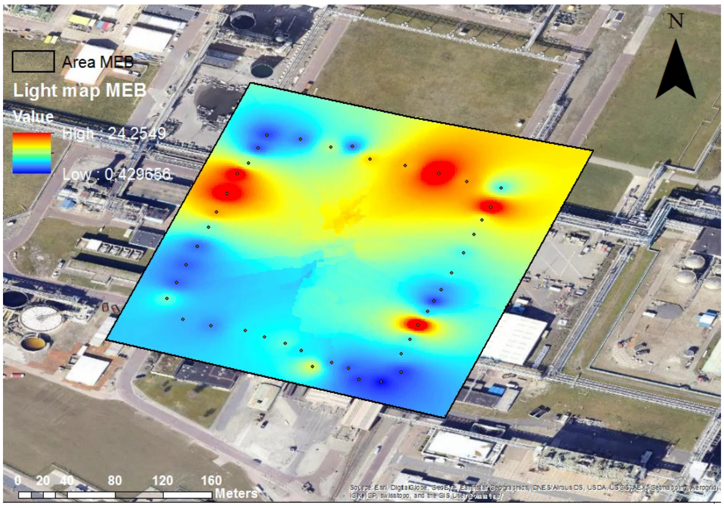

Figure 7.8: Figure which displays how the light is distributed at the MEB factory, made in ArcGIS.

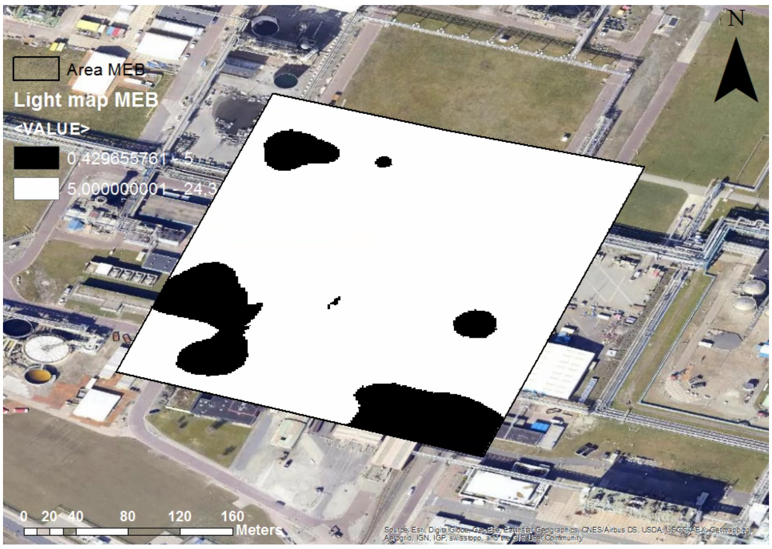

Figure 7.9: Figure which displays where there is light pollution at the MEB factory, made in ArcGIS. In the black area the amount of lux is below 5 and the white area indicates values above 5 lux.

Chapter 8: Vision under different colors of illumination

The visual system of humans is responsive to continual changes in illumination. This is accomplished by switching between two photoreceptor classes in the retina, sensitive rods and 3 types of less sensitive cones. The rods and cones have some overlapping light ranges. When there is high illumination cones are active and photopic vision is initiated which results in a good color perception. With intermediate illumination, mesopic vision, rods slowly become sensitive and the cones are still active. There are subtle changes and a reduction in both the perceptual quality and perceivable colors when compared to high illumination. Under low, scotopic illumination, only rods are active, color perception is still possible [34][30].

An important compromise vision has, is that there is a trade-off between increased sensitivity at lower light levels, and improved temporal and spatial acuity at higher light levels. When the light level increases, the high sensitivity is no longer necessary and is traded for improvement in spatial and temporal acuity. The rod system, due to its operation at lower light levels, has a lower acuity and higher sensitivity. There are around 100 million rods, but only 5 million cones in the human eye [12].

Spectral sensitivity refers to the relative sensitivity of a receptor type to all of the wavelengths. The cones are more sensitive to longer wavelengths, whereas rods are more sensitive to short wavelengths. Rods are most sensitive to wavelengths of around 507 nm and cones are most sensitive to wavelengths of 555 nm, which can be seen in figure 8.1.

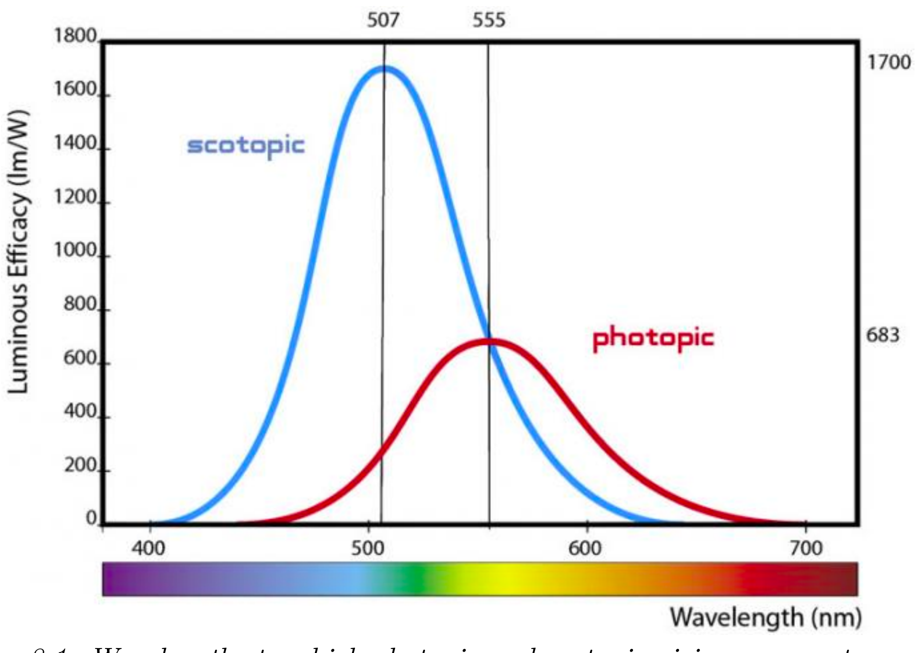

Figure 8.1: Wavelengths to which photopic and scotopic vision are most sensitive.

The difference in this spectral sensitivity is called the Purkinje shift. This shift happens when the eyes transition from day vision to night vision and the other way around. A practical implication of the Purkinje shift is that, when nighttime occurs, longer wavelengths (red) appear to be darker, whereas shorter wavelengths (blue and green) will appear brighter. This implies that red object are more difficult to see at night compared to blue or green objects with similar reflectance values [7].

Therefore, green or blue light would seem good to use during the night. However, this also means that every color which is not blue or green will look different during the night. White light contains all the colors so an orange object will reflect orange light which will make it appear to be orange. When green or blue light is being used, the orange object is not able to reflect orange light since it is not present. At the chemical park different colors, yellow for instance, are used on pipelines to indicate what is being transported through the pipelines. When the lights would be green or blue then it would not be possible to read what is written on the pipelines. This could lead to very dangerous situations when operators are not sure what is being transported through which pipeline.

Chapter 9: Possible solutions to reduce light pollution

There are several known solutions to possibly reduce the effect of light pollution on the night sky and environment. These solutions are: Shut off lights when they are not used, limiting the area of lighting, and prevent over-illumination.

9.1 Shut off lights when they are not used

First of all lighting should only be installed when it is actually necessary [29]. This can already prevent light pollution to a certain extent. The lights that are installed should only be on when they are actually needed. For instance when a person leaves a room it would be logic to turn the lights off. However, for outdoor lighting this is more complicated and the lights can not simply be shut off. Lighting can also be reduced by dimming the light at night. During the summertime there is more natural light which means that the light can be turned on later at night, and switched off earlier in the morning [18][17].

9.2 Limiting the area of lighting

Light that falls outside the area to be lit is called light spill. Light which is spilled above the horizontal plane directly contributes to the sky glow. This can be prevented by installing the light horizontally relative to the ground and not at an angle. Another way to prevent light spill above the horizontal plane is to shield new light fittings such that the light is only projected on the area or object to be lit. For existing light fittings shields can be installed to prevent light spill. Besides shielding of the light, placing lights closer to the ground also reduces sky glow, this is shown in figure 9.1 below [29].

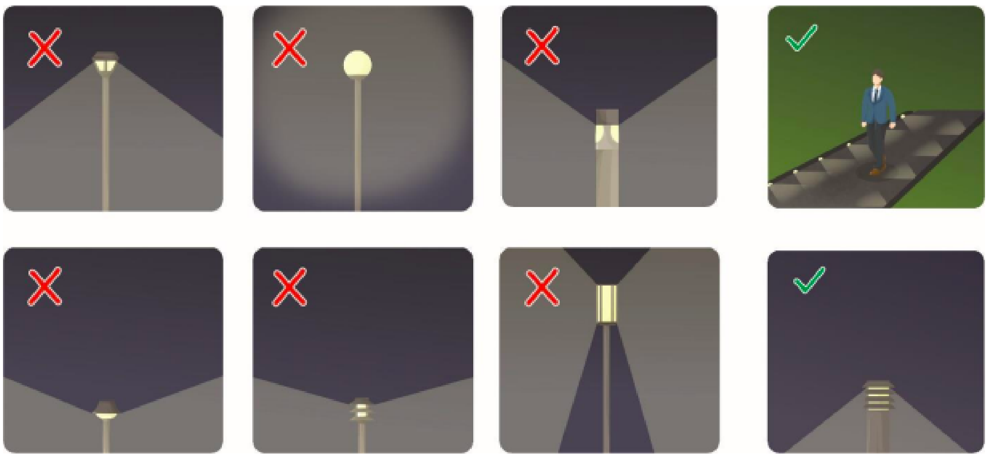

Figure 9.1: Lighting should be shielded, directed downwards and should be mounted as low as possible such as the walkway lighting.

9.3 Prevent over-illumination

To prevent over-illumination, the intensity of the lights used should be appropriate for the activity. Only the minimum intensity of light should be used to create safe and secure illumination for the area required for the lighting objectives. New bulb types, due to improved technology, produce a significant greater amount of light per unit energy. One LED light produces the same amount of light as 2 and up to 5 incandescent bulbs. It is not important to look at the amount of energy used in watt but to look at the amount of light produced in lumen, this is an important consideration to make sure that a certain area is not over lit [29].

By changing the wavelengths of light, the intensity of, and area impacted by skyglow will be effected. Since there is increased atmospheric Rayleigh scattering at short wavelengths, light sources which have dominant blue wavelengths produce more skyglow when compared to lights with more yellow wavelengths. Therefore, less blue dominant light can prevent over-illumination and skyglow [18].

Chapter 10: Conclusion

After the measurements and literature research the main research question and sub-questions can now be answered. To recall the main research question is: *What action should Nobian take to reduce the possible light pollution keeping in mind the requirements for the lighting?*

Before answering the main question, first the sub-questions need to be answered. The first sub-questions is: *What is the current level of light intensity at the three different factories of Nobian?* To answer this question, light measurements were taken at the three different factories. The data of these measurements were put into ArcGIS to simulate a map displaying the light distribution across the area of the factories. These maps give a clear overview on what the light intensity is in different places. The level of light intensity differs across the area of each factory. Where there is little light pollution at the Salt and Delesto factory, but there is a lot of light pollution at the MEB.

The second sub-question is: *What is the purpose of different colors of light and can this be used by Nobian?* When reading up on the subject, there were some articles which stated that blue or green light is better to use during the night time. The purpose of using blue or green light at night is that these colors appear brighter than red. This is due to the Purkinje Shift, red light has longer wavelengths and blue and green consist of shorter wavelengths. However, using green or blue light is not suited to be used at Nobian. When green or blue light would be used, colors such as yellow or orange can not reflect yellow and respectively orange light. This is because these colors are not present in the green and blue lighting. There are many different kinds of pipelines used at Nobian which are marked with multiple colors, such as yellow. When green or blue light would be used, it is not possible to read the yellow letters. This could lead to dangerous situations and therefore green or blue light is not a option for Nobian.

The third and last sub-question is: *What actions can be taken to reduce light pollution?* There are several actions which can be used to reduce light pollution. The three actions discussed in this research are: shut off lights, limit the area if lighting, and prevent over-illumination. Shutting of lights when they are not seems like an obvious solution, but it is something that people tend to forget. This can already reduce light pollution to a certain extent. By limiting the area of lighting, the light is only projected on the surface or object which needs to be visible. So, instead of having a light without a fixture which can shine in every direction, a light fixture needs to be used to project the light in the needed direction. The last action is to prevent over-illumination, this can be done by using a lamp with the right amount of lumen. Instead of looking at the amount of watt used by a lamp, lumen should be considered. The amount of lumen determines how bright the lamp is and thus the intensity of the lamp.

Now that the sub-questions have been answered, the main question can be answered. It is now known that there is light pollution coming from Nobian. There is light pollution at every factory, but especially at the MEB factory there is a lot of pollution. To reduce this light pollution the measures used in the last sub-question can be used. Lights which are not necessary can be shut off at Nobian, which reduces the amount of light. Besides this Nobian can limit the area of lighting by using light fixtures for lamps which do not have fixtures. For lights which do have fixtures, other fixtures can be installed which will decrease the area where the light is shining on. The last measure is to prevent over-illumination, this is the case for the LED lights used at the MEB. The LED lights are way too bright and other LED's can be installed with a lower amount of lumen. These actions can reduce the light pollution coming from Nobian.

Chapter 11: Discussion

The results which were obtained during this research exceeded the expectations set before the research started. It was of course not known if there was actually any light pollution caused by Nobian. The expectations were that there might be some light pollution. Since the operators are working there 24 hours a day and will have to use light at night to see their surroundings. However, the amount of light pollution, especially at the MEB, did exceed the expectations. Some places are extremely lit which is not necessary since no one would come there during the night.

The maps which were modelled to see how the light would distribute were different than expected. This is especially the case for a map which was modelled to see what the light pollution would be further away from the light sources, see figure G.1. It can be seen in the figure that the value of the light intensity increases as the distance from the light sources increases. This is rather controversial since lux decreases quadratic with the distance from the light source. It can be explained since ArcGIS uses a general formula where each known data point has an influence on the simulated points. Therefore, the exact formula for the decrease of lux is not used. This means that ArcGIS is not suited to simulate light distribution far away from the data points. The other results, which are simulated close to the data points, can now also be questioned. Further research would be necessary to verify that the simulated lux values are correct.

All the measurements were performed at a height of 1.5 meters. However, it is nice to know what the amount of lux would have been at 5 or 10 meters height. The light is not only present at the ground but also in the sky, since it is reflected by the ground towards the sky. Unfortunately, this could not be measured since there were no resources to get the lux meter that high up in the sky. However, there is of course the SQM-LU meter installed on the roof of the location office of Nobian. This device measure the sky brightness continuously during the night and could have been used in this research. But the problem is that by measuring sky brightness it is not possible to determine were the light pollution is coming from.

Chapter 12: Future research

For future research and measurements some things have to be kept in mind. All the measurement were conducted when there was a new moon, so future measurements are preferably done when there is a new moon. Other things to keep in mind is that the wind speed must be below 5 Beaufort otherwise it will influence the measurements. The weather must be dry, rain also has a negative influence on the measurements. At last, the cloud coverage should be considered, a different amount of cloud coverage will result in a deviation of the measurements. This must be kept in mind when new data will be compared with the data from this research.

To get a more complete picture of the light pollution coming from Nobian, more measurements can be taken in future research. When this data is then put into ArcGIS, it will result in a more detailed and precise map. Besides just focusing on Nobian, light pollution from the whole chemical park can investigated. Since Nobian is not the only company which is using artificial lighting at night to perform activities.

Instead of measuring inside the chemical park, measurements can be taken outside the park. Therefore, the light pollution leaving the chemical park can be measured. This is necessary to determine what the influence of light is on the Waddensea and other nature around the park.

The maps created in this research will be uploaded to the Esri community. Therefore, the results obtained in this research can be used by the community and be compared with other data. So, these results can be compared for instance with a research towards the population of a certain species of birds in the Waddensea.

Nobian can use the results from this research to come up with a policy plan to tackle the light pollution. With the results it can easily be seen where there is light pollution. Therefore, Nobian knows where measures have to be implemented to reduce the light pollution.

The municipality Delfzijl conducted a research in 2016 to look at the light coming from the chemical park. In the last six years, changes can have been made in the lighting used at night by the different companies. Therefore, for future research the municipality could conduct another research towards the lights used at the chemical park. Then a comparison can be made between the two researches to see if anything has changed.

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Appendix A: Detailed places of the measurements

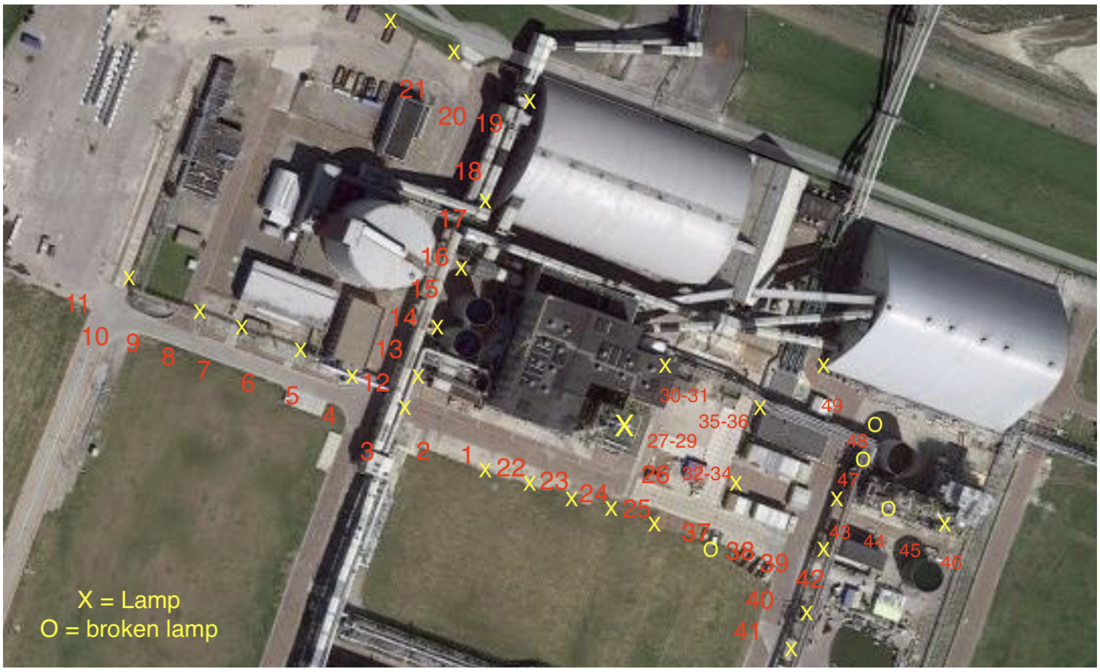

Figure A.1: Detailed overview of the measurements at the Salt factory.

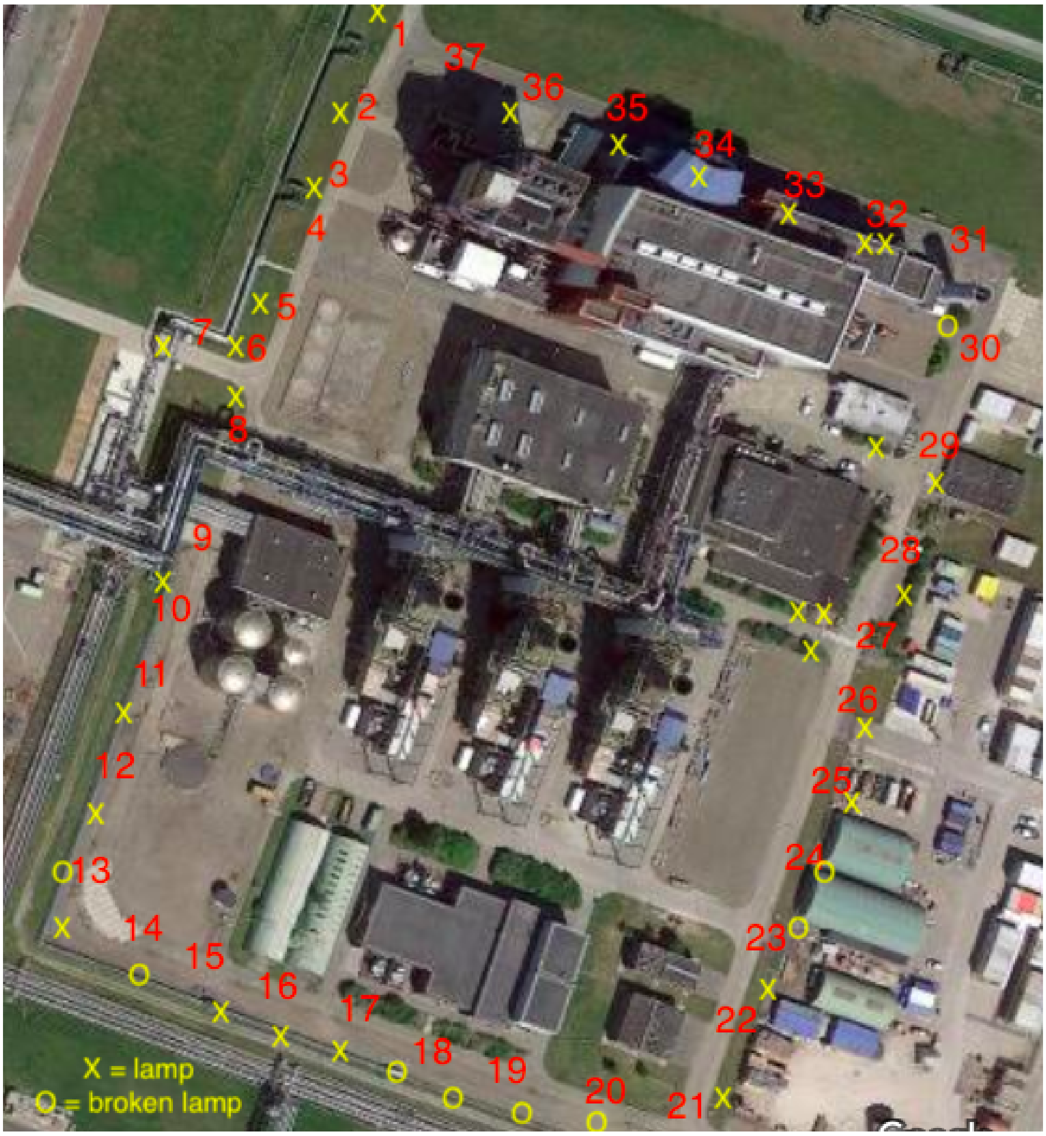

Figure A.2: Detailed overview of the measurements at the Delesto factory.

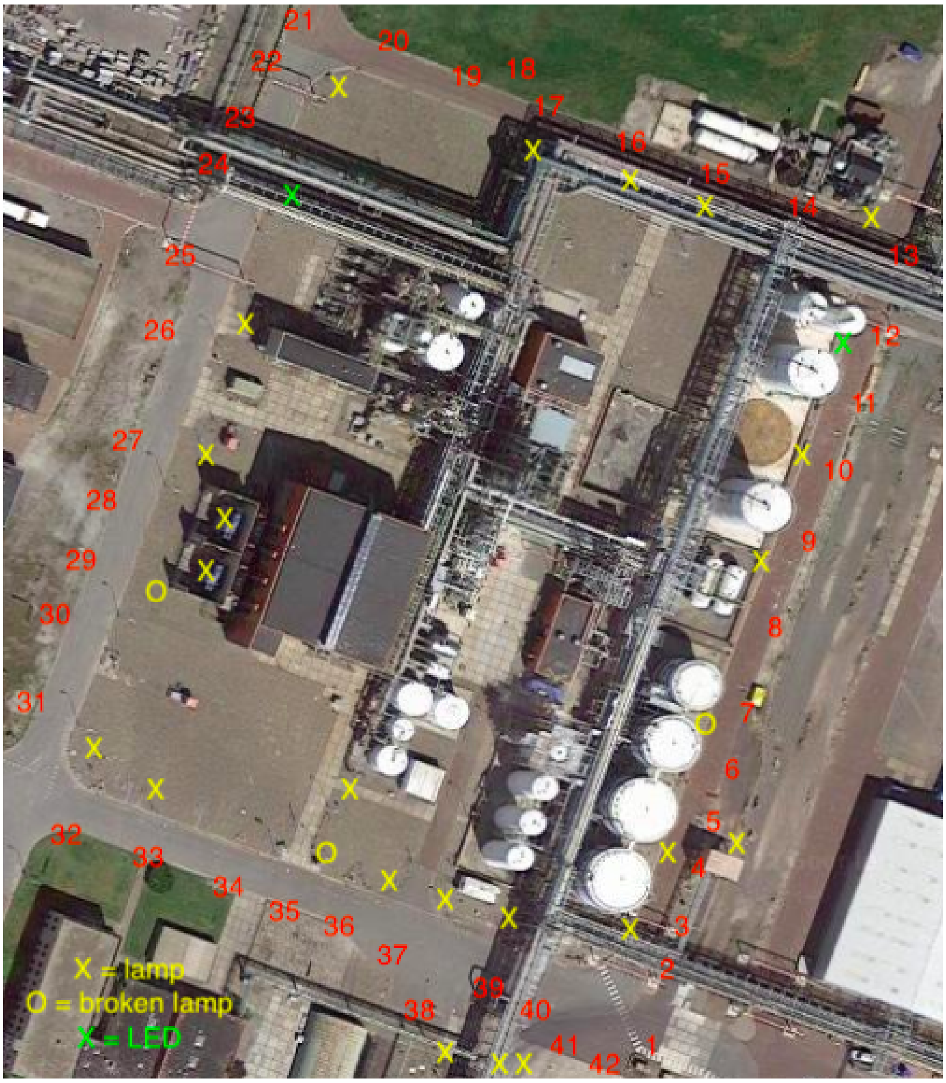

Figure A.3: Detailed overview of the measurements at the MEB factory.

Appendix B: Background information Nobian

Nobian uses much artificial lighting to be able to perform activities during the evening and night. Nobian has three different factories at the chemical park, Nobian Delesto, Nobian MEB and Nobian Salt. Nobian Delesto is the combined heat and power plant which provides the whole chemical park with steam and electricity. When Delesto produces too much electricity just for the chemical park, the electricity is going to the grid and then to households [1]. Nobian MEB makes chlorine, which is an important auxiliary raw material for multiple companies located at the chemical park [2]. Nobian Salt has four salt factories which are at the beginning of the integrated chain at the chemical park. The salt is being used locally, nationally and internationally for diverse purposes, especially for the production of chlorine [3].

B.1 Information Salt

There are 4 different factories A,B,C & D (see figure B.1). The salt is harvested in Heiligerlee with the use of underground pipes to reach the salt. These pipes have a double pipe wall, the outer pipe is used to pump water down into the ground which will let the salt dissolve. After this, the brine (salt dissolved in water) can be pumped to the surface through the inner pipe. The brine goes through underground pipelines to the storage location just outside the chemical park. From this location it is be pumped to the filtration systems which are located on the chemical park. The brine will go through 3 different filtration systems to get rid of all other materials which were also pumped up in Heiligerlee. Think about other minerals which are stored into the ground such as calcium or potassium. After the brine has been filtered it will be sent to the factory using pipelines. When the brine arrives at the factory, it will be turned into salt using vacuum salt technology, which employs raw brine combined with steam and electricity. After this process the salt is ready to be distributed and has the required purity. It will be put on a belt system which can direct it to the storage places or directly to the boat dock where it will be loaded on a ship. There are different kind of ships, for instance a frankfurter which is used for inland shipping which can carry up to 2000 tonnes of salt. This depends on how much salt is needed and what the current water level is.

B.2 Information Delesto

The main purpose of the Delesto factory is to produce steam and electricity which will be delivered to several companies located on the chemical park. The steam is made by using water from companies located on the chemical park and in return Delesto provides them with steam. The steam has 3 different 'qualities', there is steam which has a pressure of around 83 bar, 30 bar or 3 bar. Some companies require steam with 30 bar pressure and others with 3 bar pressure. The steam with 83 bar pressure is not actually used by other companies. This steam is used to power a generator which then turns it into electricity. By doing this you reduce the quality of the steam to a pressure of around 30 bar. This steam can then be delivered to companies, in that way the full potential of the steam is used.

Side activities of the Delesto factory are to take care of all the pipelines used for the transport of steam, water and gas. Besides this they have to make sure that in case of a fire there is always water pressure at the fire hydrant. This is done by compressors and in case the compressors fail there is a backup compressor. If this backup compressor also does not work due to a power outage for instance, then there are 4 diesel engines ready to provide the water pressure. This is one of the many side activities Delesto has to take care of.

Figure B.1: Map of where the four factories are located.

B.3 Information MEB

Several companies located on the chemical park require chlorine as a raw material and MEB delivers this chlorine. The chlorine is made from brine which is split into chlorine gas, hydrogen gas and caustic soda with the use of electrolysis. The electrolysis technology which is being used is one of the most energy efficient technologies in the world. After the chlorine gas has been made liquid it goes to MCA, Teijin Aramid and Lubrizol which use the chlorine as a raw material for their end products. The chlorine will most likely end up in swimming pools, cleaning products, but especially in synthetic materials [2]. The hydrogen gas goes to several companies such as Delesto, which will use the hydrogen gas to make electricity.

The caustic soda, which is produced during the electrolysis, has a purity of 32 percent. However, at the MEB they turn it into 50 percent purity(by damping). The reason for this is that 50 percent caustic soda is more expensive. Therefore, when the caustic soda is sold it will bring in more money. The pipes of the chlorine gas are made from synthetic materials because if metal was used the chlorine gas would attack the metal and oxidize. After the chlorine gas has been turned into liquid chlorine the pipes are from metal as well as the silos/storage tanks.

Appendix C: Ranking of sky brightness at different locations

	Locatie	Gemiddelde	10% percentiel	50% percentiel	Maximum
1	Ameland-Natuurcentrum-Nes	19.1337	19.018	17.978	19.308
2	Sellingen	18.9989	18.978	17.538	19.022
3	Roodeschool	18.7049	18.692	16.960	18.728
4	Termunten	18.6093	18.540	17.094	18.666
5	Hornhuizen	18.5972	18.542	16.964	18.688
6	Gorredijk	18.5247	18.406	17.110	18.642
7	Noordpolderzijl	18.5179	18.500	16.908	18.552
8	Vlieland-Oost	18.511	18.430	16.866	18.66
9	Borkum	18.5102	18.478	16.978	18.598
10	Weerribben	18.4975	18.442	17.302	18.58
11	Groningen-ZernikeCampus	18.4907	18.460	16.912	18.55
12	Akkrum	18.4834	18.430	17.114	18.55
13	Oostkapelle	18.4757	18.282	17.240	18.766
14	Oldenburg	18.4647	18.450	17.028	18.494
15	Tolbert	18.4644	18.418	16.950	18.49
16	Natuurschuur-Terschelling	18.4585	18.380	16.846	18.572
17	Stadskanaal	18.4576	18.440	17.084	18.47
18	Sappemeer	18.4473	18.426	17.028	18.486
19	Hippolytushoef	18.4378	18.258	17.044	18.57
20	Lochem	18.4342	18.332	17.450	18.538
21	Moddergat	18.4171	18.342	16.906	18.504
22	Texel	18.4078	18.248	16.936	18.632
23	Haaksbergen	18.3267	18.234	17.368	18.392
24	Heerenveen-Station	18.316	18.134	17.332	18.466
25	ZwarteHaan	18.2	18.086	16.882	18.294
26	Heerenveen01	18.2964	18.230	17.116	18.392
27	Boerakker	18.1924	18.128	16.634	18.264
28	DeZilk	18.1484	18.040	17.198	18.27
29	Groningen-DeHeld	17.9953	17.956	16.928	18.044
30	Leiden-Sterrewacht	17.9714	17.824	16.884	18.106
31	Rijswijk	17.7431	17.662	16.488	17.844
32	Farmsum	17.633	17.610	17.086	17.654

Figure C.1: Ranking of sky brightness at different locations. It can be seen that the chemical park (Farmsum) has the most brightness in the sky. If the average is larger then more stars can be seen.

Appendix D: Tables with measurement data

D.1 Salt measurements

Measurement number	Value in Lux	Measurement number	Value in Lux
1	5.26	26	6.9
2	11.81	27	8.83
3	6.36	28	3.99
4	2.78	29	1.18
5	5.16	30	10.49
6	5.1	31	1.43
7	3.21	32	4.73
8	5.8	33	6.09
9	2.97	34	0.83
10	5.12	35	4.93
11	4.23	36	4.11
12	3.78	37	2.27
13	7.4	38	2.26
14	8.7	39	1.06
15	4.34	40	1.8
16	8.4	41	0.83
17	2.55	42	6.18
18	5.11	43	8.19
19	3.55	44	0.53
20	1.01	45	4.25
21	0.45	46	4.13
22	5.31	47	1.02
23	5.58	48	0.51
24	8.89	49	0.63
25	4		

Table D.1: Table with measurements data from Salt factory.

D.2 Delesto measurements

Measurement number	Value in Lux	Measurement number	Value in Lux
1	4.86	20	1.8
2	5.92	21	2.75
3	6.6	22	3.34
4	4.44	23	1.82
5	5.65	24	1.78
6	11.18	25	2.81
7	7.99	26	6.55
8	11.3	27	6.62
9	4.39	28	3.7
10	2.32	29	3.38
11	4.61	30	0.66
12	6.15	31	0.06
13	1.88	32	8.7
14	0.84	33	3.98
15	2.14	34	4.69
16	2.82	35	6.16
17	1.97	36	3.41
18	1.49	37	2.83
19	1.1		

Table D.2: Table with measurements data from Delesto factory.

D.3 MEB measurements

Measurement number	Value in Lux	Measurement number	Value in Lux
1	1.49	22	2.16
2	5.36	23	9.49
3	6.8	24	20.82
4	24.26	25	21.34
5	5.29	26	14.68
6	1.61	27	7.67
7	4.05	28	2.83
8	6.76	29	2.56
9	6.89	30	2.66
10	9.54	31	7.35
11	11.25	32	4.68
12	21.58	33	3.78
13	6.81	34	6.09
14	14.94	35	6.45
15	23.18	36	7.18
16	14.29	37	5.85
17	13.22	38	10.88
18	3.24	39	4.28
19	9.21	40	2.4
20	3.33	41	1.52
21	1.83	42	0.41

Table D.3: Table with measurements data from MEB factory.

Appendix E: Interview

E.1 Interview Rene Lassche

The following information has been gathered by talking with Rene Lassche, who is the HSE (health, safety & environment) specialist.

The amount of light which can be present is not stated in the environmental permit Nobian has. There is also nothing stated about light in the aspects and impacts assessment, it is only being looked at when there are complaints about light nuisance.

ISO 14001 is an international accepted norm which indicates what a good environment management system should comply with. It sets out the criteria for an environmental management system and can be certified to. It tells a company or organization to follow a framework to set up a proper and effective environmental management system. The ISO 14001 is designed for any type of organization, independent of its activity or sector, it can provide assurance to company management and employees as well as external stakeholders that environmental impact is being measured and improved [9].

The benefits associated with the implementation and certification of the ISO 14001 standard have been extensively analyzed. The three main benefits are increased environmental performance, efficiency and profitability. Other benefits which have also merited great attention are improved image, improvement in customer satisfaction, improved staff results, improved competitive edge and improved relations with stakeholders [31].

The environmental impact assessment is the process when the likely hood of environmental impacts have to be evaluated for a proposed project or development. The assessment takes into account the inter-related socio-economic, cultural and human-health impacts, both beneficial and adverse.

The General Provisions Act (Wabo in Dutch) is the basis for many of the permits relating to the physical living environment. Within a project, Wabo makes it possible to perform different activities (construction, installation, assembly, use) with an all-in-one permit for physical aspects.

From a report in 2015, scattering of light is not relevant for the Zuidlaardermeer, Leekstermeergebied and banks of the Schildmeer which are listed in the Natura 2000. The scattering could be relevant for the Wadden region especially for the seal, the grey seal and other animals which are sensitive to the light.

Appendix F: Transparent ArcGIS maps

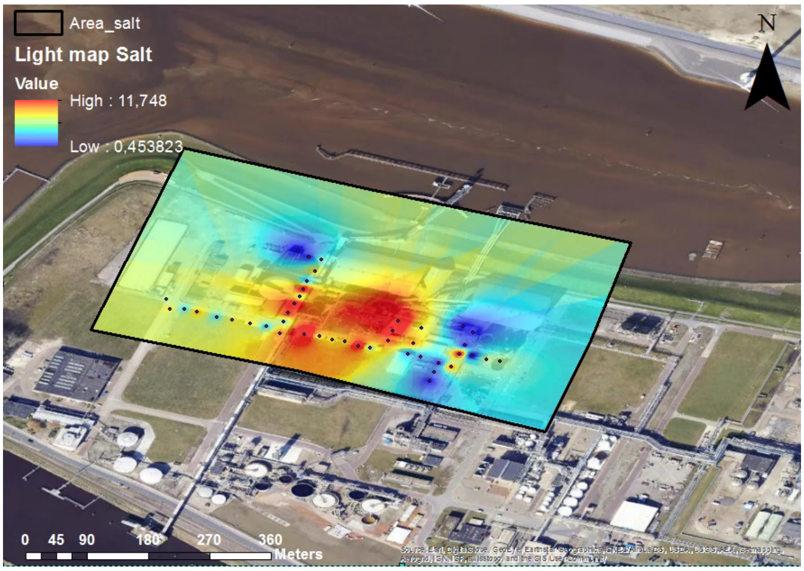

Figure F.1: Transparent figure which displays how the light is distributed at the Salt factories, made in ArcGIS.

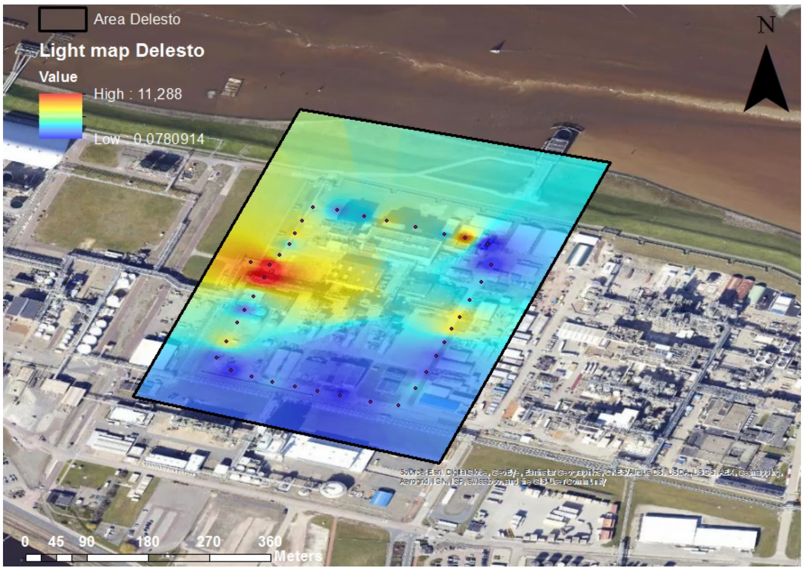

Figure F.2: Transparent figure which displays how the light is distributed at the Delesto factory, made in ArcGIS.

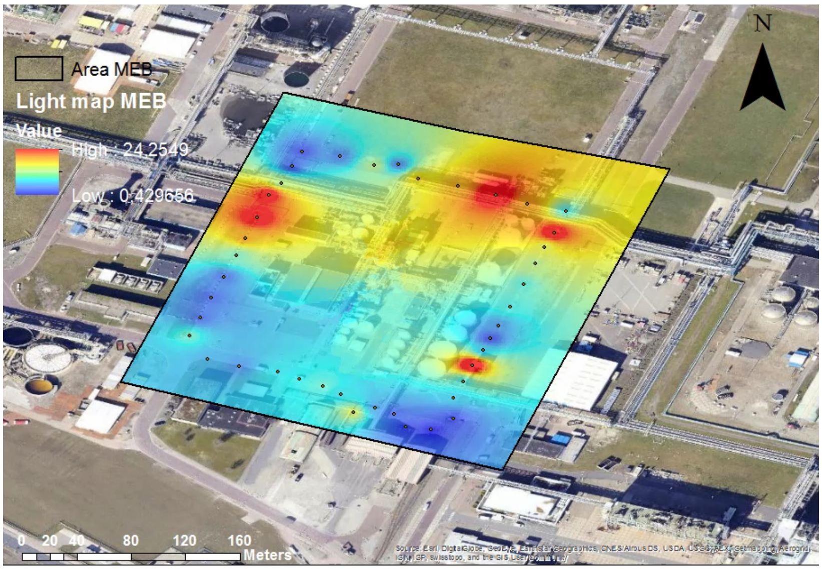

Figure F.3: Transparent figure which displays how the light is distributed at the MEB factory, made in ArcGIS.

Appendix G: Light map Salt extended

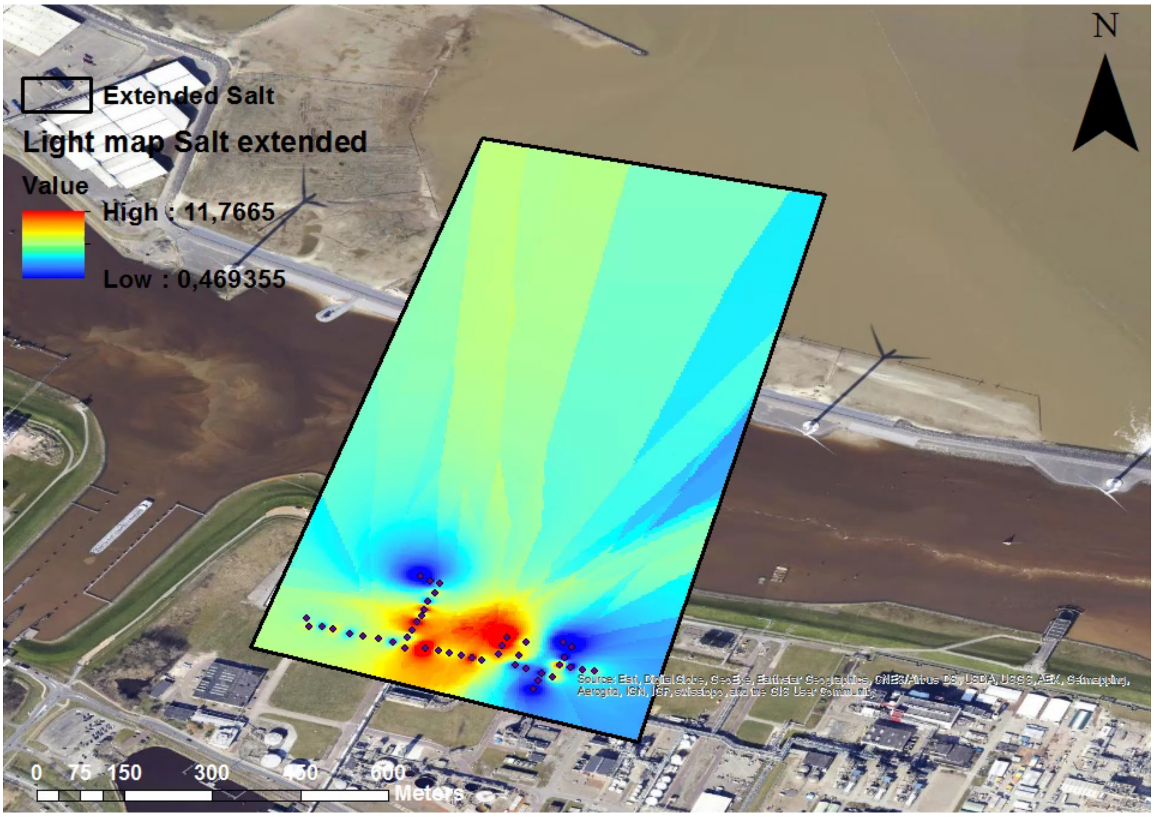

Figure G.1: Light map of extended Salt area, made in ArcGIS.