The future of shipping in the Netherlands: Investigating the effects of drought

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Abstract

Climate change is increasing the frequency and extremity of droughts causing problems in shipping, which was also the case in 2018 in the Netherlands. Multiple reports have been published reflecting on the previous droughts. In addition, research on climate change and how it affects infrastructure in the future has been conducted. However, there is a research gap in how the droughts will impact the shipping sector in the Netherlands in the future. The research aim therefore is to investigate the implications for the shipping sector due to climate change in the years 2050 and 2100, using 2018 as a case study. An analysis of the year 2018 will be conducted as a case, followed by setting the results of the analysis in the context of the future. The analysis shows that in the coming century, drought periods will be more frequent and more extreme. As a solution, the water level can be artificially kept higher to tackle the root of the problem. However, in situations where this is not possible, the type of ships should be adjusted to be more suitable for lower water levels. Smaller ships with lower capacity are causing new difficulties like river congestion and lack of personnel, which require adjustments to the river infrastructure and potential automation of ships. Future research should focus on the modal shift that will occur due to the change in climate, and the fact that some transportation methods will suffer more than others.

1 Introduction

Recent years have shown that in the Netherlands, significant economic damage was suffered because of drought events (van der Velde et al., 2018). The two sectors currently suffering the most from this are agriculture and shipping. During these drought events, the Netherlands uses a priority system for freshwater use (Rijkswaterstaat, 2024), which means that water demand in the lower priority sectors will have a high chance of not being fulfilled. One of the sectors that experience the most losses is the shipping sector. This sector is in the bottom category of the priority system for freshwater use in the Netherlands. Subsequently, this causes the boats that are currently in use for shipping to have accessibility problems during droughts (van der Velde et al., 2018). This is not only a problem for the shipping companies, but a problem for all companies that are reliant on products arriving on time. In addition, this issue will only increase throughout Europe, as stated by Forzieri et al. (2018): “The proportions of drought and heat waves will rise strongly, accounting for nearly 90% of climate hazard damage by the end of the century”. The Netherlands has traditionally focused on defending against water; however, this has created new challenges for the future, where a lack of water will be a common occurrence.

Currently, there is research indicating that the damage caused by drought events will be one of the biggest economic effects of climate change in Europe (Forzieri et al., 2018). This paper and similar research focus on the global or continental scale, often specifically in the current year (van der Velde et al., 2018). Subsequently, there has been no research done on the issues that the shipping sector will have to resolve together with the government to be able to stay as a viable transportation option in the future. It is important to do research into this now to give policymakers and the government the chance to start with preventative measures to reduce the possible losses. Scientists must work on a smaller scale regarding climate change, since it is difficult to work on measures to counteract problems on a continental or global scale. In this paper, a case study of the year 2018 in the Netherlands will be conducted to research the consequences in the shipping sector and economy during dry years in the future. The 2018 case is chosen and relevant since the severity of the drought is similar to regular occurrences in the future (KNMI, 2023) and because there is trustworthy information about the year (van der Velde et al., 2018; Deltaprogramma, 2019).

1.1 Research problem

This thesis aims to investigate the implications for the shipping sector due to climate change in the years 2050 and 2100, using 2018 as a case study. The current research targets either the effects of climate change or previous years in the shipping sector (KNMI, 2023; van der Velde et al., 2018) In addition, research on climate change and how it affects infrastructure in the future has been conducted (Forzieri et al., 2018). However, there is a research gap in how the droughts will influence the shipping sector in the Netherlands in the future. This paper will synthesise climate, infrastructure and transportation research to sketch a future scenario of the shipping sector to assist the Dutch government and shipping companies in adapting efficiently. This thesis will answer the following research question:

Using 2018 as a case study, what are the expected consequences for the shipping sector caused by climate change in the Netherlands around the years 2050 and 2100?

In order to answer the main research question, several sub-research questions have been formulated:

- *What was the severity of the drought in the year 2018 in the Netherlands?*
- *What were the consequences for the shipping sector and economy in 2018 because of the drought?*
- *What are the current-expected climate scenarios in the years 2050 and 2100 in the Netherlands in terms of drought?*

1.2 Structure of the thesis

The thesis will continue with the theoretical framework in chapter 2. In this chapter, it will be explained how lower water levels caused by climate change result in economic damage. Following is chapter 3 that will describe the methodology of the thesis. Then chapter 4 will delve into the case of 2018 when there was a drought in the Netherlands that caused damage in shipping. In addition, chapter 4 will feature the climate in the Netherlands in 2050 and 2100. Subsequently, chapter 5 will sketch a future scenario based on chapter 4 and the theoretical framework. And lastly, chapter 6 will conclude the thesis referring back to the literature and it will suggest future research.

2 Theoretical framework

2.0.1 Drought events

The Netherlands has had severe problems in recent years because of drought events. The year 2022 was the driest year of the last century (KNMI, 2022). The chance of severe droughts like this one will only increase in the next 100 years. As figure 1 highlights, the chance of a current extreme 1 in 100-year drought event will increase to around 35% in September in a standard resolution model and to around 80% in September in a higher resolution model. In addition, Forzieri et al. (2018) estimate that by 2100, droughts will be the cause of 90% of climate hazards. This would make it the most important hazard to do more research into so that policymakers can adapt the infrastructure to better deal with the problems that arise from it. The climate scenarios that will be used as a reference for future drought events will be from KNMI (2023). There are 6 different scenarios that they highlight. This research will focus on the high CO2 output wet scenario, high CO2 output dry scenario, low CO2 output wet scenario and low CO2 output dry scenario. They will not be a perfect representation of the future since it is a prediction, however it will be likely that the future climate will be within the range of these scenarios. This report will also take into account that other researchers on the topic still use older scenarios from 2014. The starting factor in figure 2 is the days that the water level is under the set target. This is caused by droughts and will increase in the future as droughts will be more frequent and more extreme.

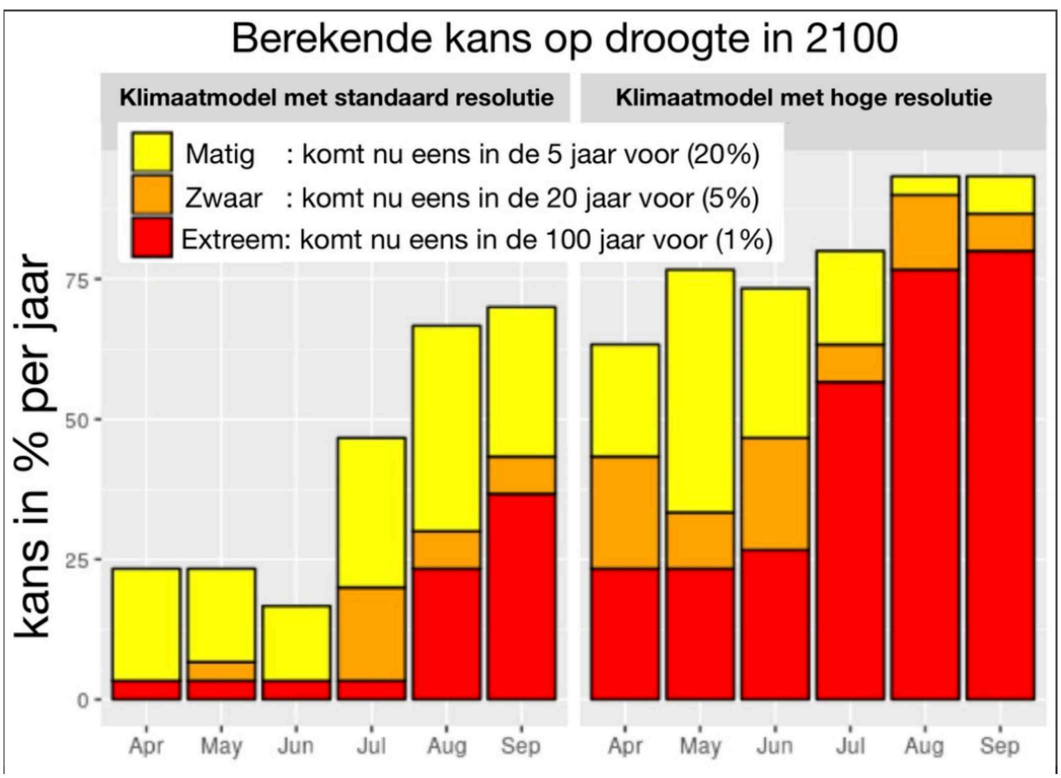

Figure 1: Calculated chance of droughts in 2100 (KNMI, 2018)

2.0.2 Problems in shipping sector

The leading cause for the problems in the shipping sector in this thesis is droughts, droughts cause the water levels in rivers to decrease Deltaprogramma (2019). This decrease varies between rivers, however in this paper, this will be generalised since the focus is on the sector in the entire country and not on specific waterways. The accessibility of a river is reliant on the lowest water level. This is because, if one part of the river is not traversable, the entire river is not accessible for the ship. These lower water levels have resulted in the shipping sector having to lower the load of the bigger ships and use smaller ships to transport goods for their customers (van der Velde et al., 2018). Subsequently, this increases the frequency of ships. This increase in frequency causes further difficulties, firstly there is a lack of personnel to operate the additional ships. Secondly, there is a lack of suitable ships that can traverse the rivers during lower water levels. Thirdly, there will be congestion on the rivers, especially at points such as sluices and bridges that have to open. This is the first part of the conceptual model, as seen in figure 2.

2.0.3 Economic damage

The problems that are present in the shipping sector during droughts are being offset to the customers as much as possible. Merkel et al. (2022) concluded that shipping tends to be an inelastic good, therefore the demand changes less than 1% for every 1% increase in price, this means that the sector itself does not suffer as much from the issues. The damage caused by droughts to the economy is measured through different direct and indirect variables (van der Velde et al. 2018). The direct effect is the increase in shipping costs. The CBS (Central Bureau of Statistics) keeps track of the price index of different shipping services in the Netherlands. The data that is collected is split into quarters of the year; this is useful to be able to compare prices between the dryer periods during the summer and the rest of the year. However, a price increase in shipping can be the result of many factors such as droughts, energy price increases and higher minimum wages. In addition, there are three main indirect damages to the sector caused by droughts. The first one is a modal shift, the second effect is added storage costs and the final effect is cancelling the shipment. However, cancellation is hard to include in the calculations as described by van der Velde et al. (2018).

2.1 Conceptual model

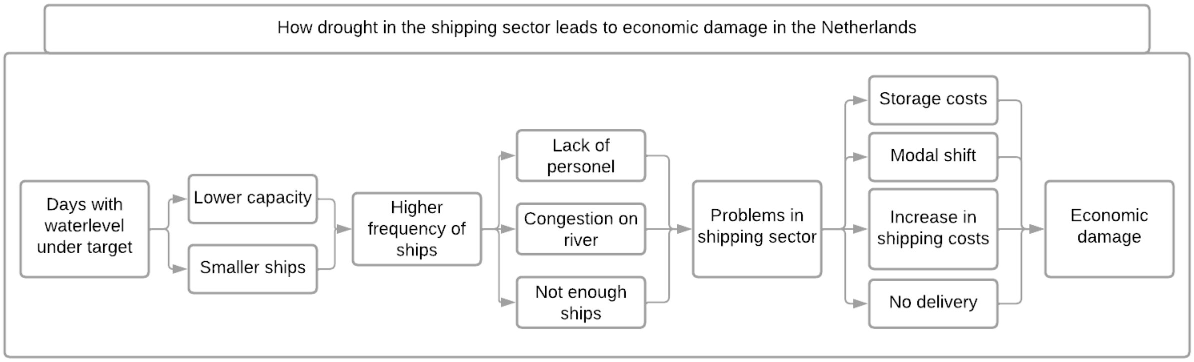

Figure 2: Conceptual model

The variables in figure 2 build on the research conducted by van der Velde et al. (2018). They have analysed the economic damage in 2018 that was caused by the drought in the Netherlands. It describes different factors that caused this, however there is no full model shown in their report. Van der Velde et al. (2018) have two different parts in their report. First they describe how the drought caused problems in the shipping sector, the model in this thesis takes their factors and creates a flowchart that results in "problems in shipping". The second part of their research is targeting the economic damage caused by the drought, the factors that are used in their calculation have been shown in figure 2 as a result of the problems in the shipping sector. Van der Velde et al. (2018) do not combine these two parts together into a full model. Therefore, figure 2 does not necessarily add more factors, however it synthesis a previous research into a full model that can be used to investigate how low water level results in economic damage. Previous research papers have stated that climate change will generate significant concerns for the economy. Forzieri et al. (2018) stated that drought will be the biggest contributor to this. Figure 2 is created to show how economic damage will be suffered because of climate change in the shipping sector. This could mean that by the end of the century, the consequences of climate change will result in a different approach to the shipping sector. This approach can be either to artificially increase the water levels in important rivers, a modal shift with smaller ships that require less water, or different transportation methods that are not affected by a dry summer.

3 Methodology

3.0.1 Research methods

This paper will conduct qualitative research based on a case study. Case studies are described by Gerring (2004) as "an intensive study of a single unit to generalise across a larger set of units". In the context of this paper, the year 2018 will be the case. This will then be used as an example of what the future could look like in terms of droughts in the shipping sector. The year 2018 was a particularly dry year in the Netherlands, van der Velde et al. (2018) and Deltaprogramma (2019) performed research at the request of the Dutch government. Van der Velde et al. (2018) estimate the consequences for the shipping sector because of the droughts, the damage to the shipping sector in euros and the economic damage that was suffered by the measures taken in the shipping sector. Deltaprogramma (2019) analysed the expected problems that will be present in rivers until the year 2050 with 2 climate scenarios. In addition, data from the KNMI will be used to compare the expected climate in the years 2050 and 2100 to the weather drought event in the year 2018 to see how common a similar year will be. The most recent data on expected climate scenarios published by KNMI is from 2023; this will be taken into account when researching the year 2018 since those reports use scenarios published in 2014. The thesis will first do a case study of the year 2018 to see what the problems and economic damage was during the drought. Then the paper will look into the future climate and compare it to the climate in 2018. Finally, these parts will be synthesised into one part that will investigate the future of shipping in the Netherlands.

3.0.2 Ethics and data quality

The data that is used in this thesis is all publicly available and does not contain sensitive data, as would be the case if for example an interview was conducted. Therefore, no special data management methods have been used. The main data source for this paper is van der Velde et al. (2018). This report was made as requested by the Dutch government and uses data mainly from other government institutions such as CBS and Rijkswaterstaat. This means that the data can be expected to be trustworthy and of high quality.

4 The year 2018 for shipping

4.0.1 The drought in 2018

In the year 2018, the Netherlands was facing extreme droughts. This was due to multiple causes: there was a lack of rain in May, June, July, and September; there were high temperatures in the summer; and there was a lot of sun in general, which increased evaporation (van der Wiel et al., 2020). The consequence of this is a combined damage of 450 to 2080 million euros for farming, shipping, and waterboards in the Netherlands. Figure 3 shows that the droughts are most extreme further from the coast, where the precipitation decrease was over 300 mm. The average precipitation was 240 mm less than other years in the country (KNMI, 2019). The highest precipitation levels were recorded in the southwest, where 720 mm was recorded, which is still 120 mm below the normal level, and the driest part was in Arcen in the southeast, where 445 mm of precipitation was measured.

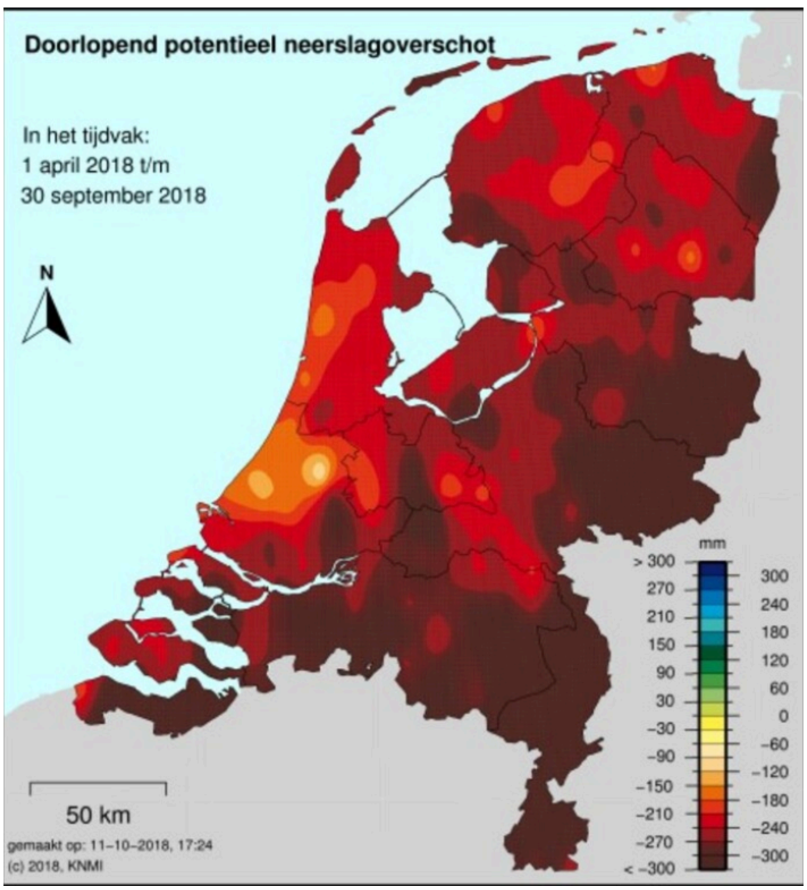

Figure 3: Excessive precipitation in the summer of 2018 in the Netherlands. (KNMI, 2018)

This part of the country is also the most vulnerable to this lack of water. This is because the higher sandy soils are harder to provide with river water compared to the west and around the IJsselmeer. Comparing this map to Figure 4, at least a part of all important rivers as described by Rijkswaterstaat (n.d.), in the Netherlands run through a region that is dealing with this extreme lack of water. The problem is that it will only take one part of the river that is not passable for a ship to not be able to reach its destination. According to van der Velde et al. (2018), the lowest water level in the Waal that was measured was 1,60m instead of the target value of 2,80 m, and the lowest water level measured in the IJssel was 1,45m instead of the target of 2,50m. In addition, the Waal had a total of 156 days when the water level was under the target value, 21 of which were at the mentioned 1,60m.

Figure 4: The big rivers of the Netherlands. (Rijkswaterstaat, n.d.)

4.0.2 The consequences of the drought in the shipping sector

Deltaprogramma (2019) explains in their report that for shorter periods, a lower water level is not a big problem for the shipping sector. This is because they can delay some shipping, which is usually not that significant. However, in 2018, the water level was under the target for multiple rivers for an extended period, which led to several issues, as described by van der Velde et al. (2018). The ships that transported goods over the above-mentioned rivers had to use less of their maximum capacity. Ships that used push boats were not able to use the rivers at all, which meant they needed other types of ships to substitute for them. This decrease in shipping capacity per ship led to various difficulties in the sector. Firstly, there were not enough suitable ships available to meet the transportation demand. Secondly, there was a lack of employees due to the increase in ships because of the lower capacity per ship. Thirdly, there was not enough storage to store goods temporarily in harbours, which caused ships to go to a different harbour. In addition, the time for loading and emptying of the ships was also increased because everything had to be loaded on more ships than usual. Lastly, the increase of ships on the river also caused congestion, especially at sluices where there was also an alternative operating plan to prevent the water level from dropping further.

4.0.3 The economic damage caused by the drought

During the 2018 droughts in the Netherlands, multiple sectors caused economic damage due to a lack of water. Mainly the agricultural sector, shipping sector and the water boards in the country (van der Velde et al. 2018). In the shipping sector, according to their research, the damage to the Dutch economy was 65 to 220 million euros and the total economic damage was 140 to 480 million euros. The main cause of this was that the shipping sector increased their prices by around 30% during the drought. And further during the end of 2018 and beginning of 2019 because the demand was still high after delivery for a lot of goods was delayed. The shipping sector itself did not suffer significantly from the drought, the total revenue increased by around 17.5% in 2018 (van der Velde et al., 2018).

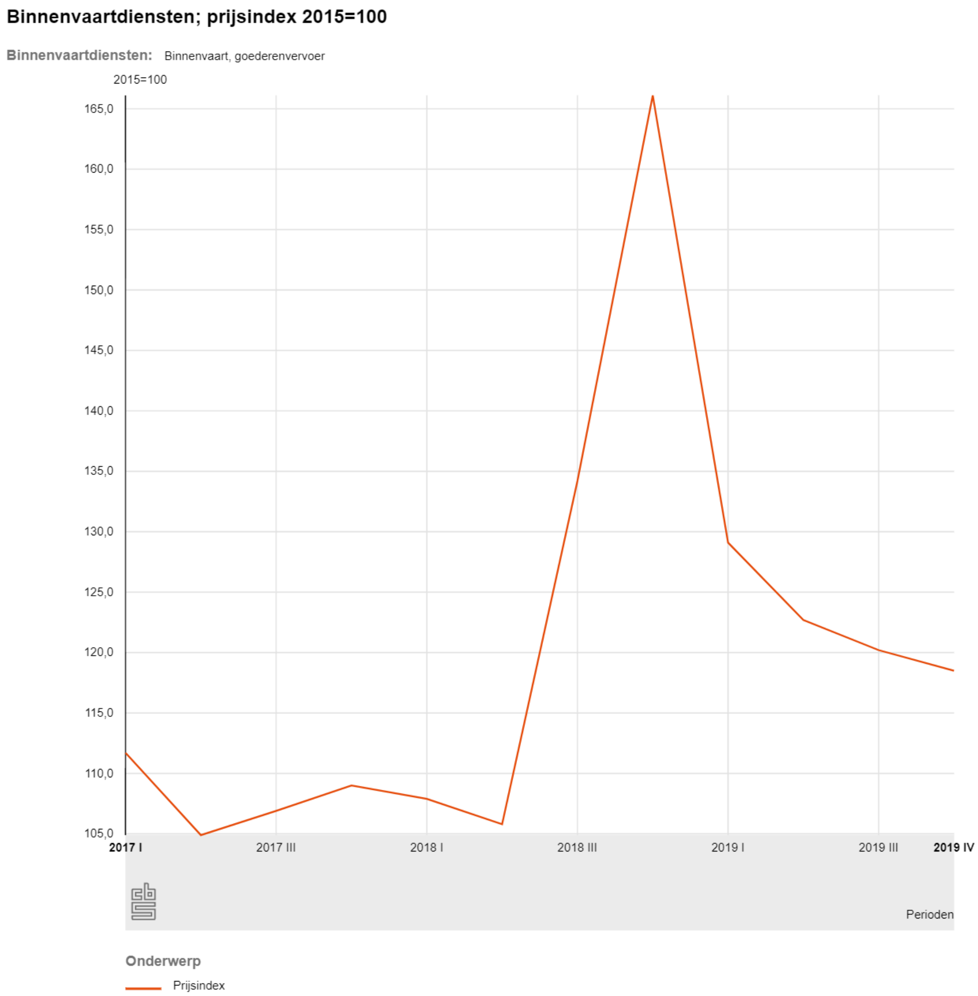

Figure 5: Price increase during 2018 drought. (CBS, 2024)

In addition, there were three indirect causes for the economic damage. The first cause was the modal shift that partially occurred. This was because for some goods the shipping sectors could not provide transportation and they were still necessary for some customers to operate. Therefore, alternative transportation methods have been used. However, these alternative transportation methods can be more expensive than shipping. For example, delivering high volumes of sand through trucking service is more expensive than shipping them. The best alternative in most cases would be rail, although this form of transport might not have the right connections, and trucking would still be necessary for part of the transportation. The second cause was the additional storage costs. The shipping sectors suffered from delays in delivering some goods because of the lack of personnel and ships. As a consequence, goods had to be stored in the harbours and warehouses for a longer amount of time, which resulted in higher total transportation costs. This also caused the storage facilities to overload and further increased the transportation costs by moving the goods to different locations. The last additional costs are the damages caused by the cancellation of deliveries. This cost is harder to estimate because if a delivery is cancelled, it is not always recorded in the data. Therefore, the models used to calculate the damage to the economy still need to fully include this data (van der Velde et al., 2018). The factors above are important to understand, to learn about what extra costs the drought periods cause in the shipping sector.

4.1 Future climate scenarios compared to 2018

Seizoen	Variabele	Indicator	Klimatologie 1991-2020	2050 Ld	2050 Ln	2050 Hd	2050 Hn	2100 Ld	2100 Ln	2100 Hd	2100 Hn
Wereldwijde temperatuurstijging ten opzichte van 1991-2020				0,8°C	0,8°C	1,5°C	1,5°C	0,8°C	0,8°C	4,0°C	4,0°C
Wereldwijde temperatuurstijging ten opzichte van 1850-1900				1,7°C	1,7°C	2,4°C	2,4°C	1,7°C	1,7°C	4,9°C	4,9°C
Lente	Droogte	maximaal neerslagtekort april en mei	76 mm	84 mm	81 mm	87 mm	80 mm	84 mm	81 mm	91 mm	82 mm
Zomer		maximaal neerslagtekort april t/m september	160 mm	194 mm	181 mm	214 mm	184 mm	194 mm	181 mm	280 mm	218 mm
		maximaal neerslagtekort april t/m september dat eens in de 10 jaar wordt overschreden	265 mm	302 mm	289 mm	342 mm	305 mm	302 mm	289 mm	427 mm	342 mm

Figure 6: Future drought scenarios in numbers (KNMI, 2023).

Seizoen	Variabele	Indicator	Klimatologie 1991-2020	2050 Ld	2050 Ln	2050 Hd	2050 Hn	2100 Ld	2100 Ln	2100 Hd	2100 Hn
Wereldwijde temperatuurstijging ten opzichte van 1991-2020				0,8°C	0,8°C	1,5°C	1,5°C	0,8°C	0,8°C	4,0°C	4,0°C
Wereldwijde temperatuurstijging ten opzichte van 1850-1900				1,7°C	1,7°C	2,4°C	2,4°C	1,7°C	1,7°C	4,9°C	4,9°C
Lente	Droogte	maximaal neerslagtekort april en mei	76 mm	+11%	+6%	+15%	+5%	+11%	+6%	+21%	+8%
Zomer		maximaal neerslagtekort april t/m september	160 mm	+22%	+13%	+35%	+15%	+22%	+13%	+79%	+37%
		maximaal neerslagtekort april t/m september dat eens in de 10 jaar wordt overschreden	265 mm	+16%	+9%	+30%	+16%	+16%	+9%	+63%	+30%

Figure 7: Future drought scenarios in percentage increase (KNMI, 2023).

Figures 6 and 7 show the drought scenarios in 2050 and 2100 for 4 different cases. Ld is the low CO2 output dry scenario, Ln is the low CO2 output wet scenario, Hd is the high CO2 output dry scenario and Hn is the high CO2 output wet scenario. The years 1991-2020 have been used as a reference period for this table. What can be seen from this table is that the droughts in the summer will increase no matter what scenario is going to occur. In 2018, the lack of precipitation was 240 mm on average in the country (KNMI, 2019). Figure 6 shows that in the years 1991-2020, this is close to a once-in-10-year drought but still 20 mm off. This means that 2018 was not the most extreme drought that can be expected in 10 years. Looking at the numbers in the future, it can be seen that the Hd scenario in 2100 will have a big step-up over the current experienced droughts. The drought in 2018 will be average in the summer months and the one in the 10-year event will be at 427 mm, which is close to double that of 2018. The Hn scenario, even though it increases the rainfall over the entire year by 8% (KNMI, 2023), will still lack precipitation during the summer period. This is because the precipitation will shift more towards the 3 other seasons. This will result in a climate where the droughts will be slightly less extreme during the summer period than in 2018 on average.

In conclusion, the future will always be dryer than the current situation. The Ln, which is the best-case scenario for shipping, will still have a 13% increase in maximal precipitation deficit in 2100. Therefore, it is important to keep researching climate adaptation in the infrastructure and transportation sector.

5 The shipping sector in 2100

This chapter will use the conceptual model and the results from chapter 4 to create a future scenario for shipping in the Netherlands. It will take the factors from the model and further expand on them based on what was mentioned in the previous chapter.

5.0.1 Smaller but more ships

A lower water level in rivers can be compensated by reducing the size of the ships in the fleet. In 2018 this was already partially the case and several problems occurred as can be seen in the conceptual model and explained in the "*Consequences of the drought in the shipping sector*" sub-section. Firstly, is that more ships require more personnel to operate. This will cost more money because of the reduction of the economy of scale. However, with the rise of AI and better computational systems, automation for ships will be possible and recommended by experts to improve safety and reduce environmental impact (Ehlers et al., 2022). This would solve the increase in price and the difficulties that come with recruiting and managing more people to compensate for the increase in the frequency of ships. In addition, the current cause of most accidents in the shipping sector is human error. Using tested automated systems will reduce the number of accidents in a sector that is already known as the lowest number of accidents per ton per mile transported. Secondly, if the ships are smaller, more ships are needed for the same demand. This will self-regulate in the sector, when the rivers will be less accessible more frequently.

The consequences that need to be dealt with in the scenario where more smaller ships are used, is the problem of congestion in the rivers. This mostly occurs at sluices and harbours. Firstly, the congestion at sluices. A sluice is a place that is used to regulate the amount of water between different water bodies. They are especially important during extreme drought or high water levels. During the drought in 2018, the sluices were used to regulate the water level in the rivers, therefore an alternative operating scheme was used that further caused issues. In the future, at rivers used for shipping the capacity and frequency should be increased if the frequency of ships increases. For example, the Tsjerk Hiddesluisbrug in Harlingen uses 2 ways for boats to pass. The bigger one is mainly used for bigger ships that transport goods, and there is also a smaller way for recreational ships to pass. In the future, systems similar to this will be more common to prevent congestion.

5.0.2 Recreational sailors

In the future it is likely that more smaller ships will be used during droughts as seen in the conceptual model. As a result, the rivers will be more congested with ships, especially at sluices. Droughts occur during the summer, this is also the time when recreational shipping is at a peak. These recreational ships are not always as experienced as the people doing it as a job. Therefore, these ships will not always know all the written and unwritten rules and regulations on the water (Binnenvaartkennis, 2021). This will lead to unnecessary time loss if they are using the same water as the shipping sector. In addition, at places like sluices, they tend to take more time than the more experienced water users. The sector should do research into whether allowing recreational sailors and business shipping companies on the same waters should be allowed. In addition, This could also improve safety, since a lot of recreational sailors do not understand that the bigger ships can not stop or turn quickly.

5.0.3 Waterverdringingsreeks

As the conceptual model shows, the cause for problems during droughts is the amount of days that the water level is under a certain value. The Netherlands uses the "Waterverdringingsreeks" as a way to divide the water during the events of a drought (Rijkswaterstaat, 2024). This priority system consists of four different levels. The first category is for safety and prevention of irreversible damage, the second category is for drinking water and energy provision and the third category is for small-scale but important uses like high-capital agriculture and the last category is the rest including the shipping sector and agriculture. This system is to ensure that during these drought events, it is clear what has the priority to ensure safety and prevent as much damage as possible. Shipping is in the rest category, which means that it is a lower priority than other water uses like dyke watering. This will have significant consequences when droughts are more extreme than they were in 2018 and even less water can be used for the lower categories than in the current situation.

5.0.4 Modal shift

Hänsel et al. (2023) conclude in their study that a multi-modal research approach is needed in transportation research, therefore understanding the modal shift that can happen during drought events is significant. A modal shift is a change in transportation method. This change will be induced by 2 direct factors; the price and the delivery time if the availability is equal. The droughts in 2018 caused the shipping sector to increase the price that they ask per unit. In addition, the deliveries were delayed which is problematic for some customers. This led to alternative delivery methods being used that are not affected by dry weather. If droughts become more frequent and extreme in the future, alternative transportation methods will be used more often and can adapt to the increase in demand for their services. This can lead to for example more railways that will not only be used during droughts but also normal weather conditions if their delivery time/cost ratio is better or similar to shipping via water.

5.0.5 Storage costs

One of the indirect effects of a lower shipping capacity is the additional storage costs. This is partly because of goods that have no temporary storage space in the harbour that they should be shipped from, which results in them having to be moved to a different harbour than intended. If delays will be more common in the future caused by drought, more storage capacity could be created in harbours that are located at a river that is sensitive to droughts. Some goods may not be as sensitive to later deliveries. In Combination with a priority system where some goods get priority over goods that can be delayed longer without big consequences, the overall damage during droughts can be reduced.

5.0.6 Water management

In the current situation, the water levels in rivers in the Netherlands are partially managed. However, as seen in the 2018 drought, this water level is under the target value for several days of the year, especially during droughts. Increasing the amount of management in rivers by the form of canalization would be a solution in situations where this has not been done yet. However, this can be challenging and expensive to do in every case. For example, in de Waal, which is a river that has not been canalised, the water level decreases by over 3 metres in summer (van Geest, 2019). This used to be the case in the Neder-Rijn and Lek, however these rivers have been canalised. This has resulted in the highest water levels remaining similar to before canalization, but the lowest water levels are higher than before canalization. The main rivers in the Netherlands have to be analysed on a case by case basis to compute the costs to damage reduction ratio. This way decisions can be made as to what rivers should be invested in.

5.1 Future scenario for shipping

Based on the results above and the conceptual model, three main scenarios for the shipping sector can be formed. The first scenario is that the government will mainly invest in keeping the water levels in the rivers as high as possible. This is most likely to happen in a low CO_2 output scenario or potentially in the Hn climate scenario. However, in the Hd scenario, this will most likely be too expensive to maintain a sufficient water level. The second and third scenario for the shipping sector is that the government will not invest in maintaining a higher water level. In the second scenario, smaller ships will still be able to travel on the rivers during dry periods. This would follow the conceptual model where new problems such as congestion on the rivers, not enough small ships and not enough personnel. These problems will be compensated by the sector in the future, for example increasing the amount of small ships, automating processes to reduce the demand for workers and the government can increase the capacity of water infrastructure such as sluices, which would be less expensive than maintain a higher water level. In addition; the price of shipping will go up, the temporary storage in harbours will be expanded, transportation could be cancelled for certain goods and a modal shift will occur. This would be the closest to the case of 2018. The third scenario is that during droughts periods, certain rivers will be completely inaccessible for all ships. The consequences for this are unpredictable, however it would create a modal shift where other transportation modes will compensate for the lack of shipping capacity. Overall, the future of shipping relies on a combination of the future climate, the infrastructure investment decisions of the government and the choices made by the sector.

6 Conclusion

Climate change is increasing the frequency and severity of droughts in the Netherlands significantly, even with lower CO2 output and a wet scenario. The Netherlands has been a country that historically has been known for its water management. However, during the drought in 2018, the country was facing challenges in the shipping sector that it was not ready to deal with yet. This caused a significant amount of damage, not just to the Dutch economy but also to the

Subsequently, this year is an example of the issues that the sector has to deal with in the future. This year was still less extreme than the current worst once-in-10-year droughts. The research paper by Forzieri (2018), predicts that in the future, droughts will cause the most economic damage from the extreme weather events. Although this thesis does not predict exact damage bandwidths, the future climate scenarios would predict that 2018 could become the standard of droughts in the Netherlands. That would mean that the damage suffered would repeat each other each year, if the sector does not adapt.

The shipping sector had to face several challenges in the year 2018. The cause of this is that the water level is too low in the river. The consequence of this is that bigger ships have to lower their capacity, which leads to other problems. These include; a lack of suitable ships, lack of personnel and congestion in the rivers. These difficulties are hard to solve in the form of governmental policies alone, the sector also has to work on this itself.

The direct solution to solving the difficulties in the shipping sector is to manage the water levels in the rivers to keep the water levels higher. This would tackle the problem at the root. However, executing this would be an expensive endeavour. Instead of the current water level targets, the targets could be lowered to suit mid-sized ships and then the water level could be artificially kept at that level, which should decrease the costs. Other solutions to the lowered water levels include; smaller and more frequent ships which require some changes in the rivers. For example, the current harbours and sluices cannot deal with more ships, therefore these need to be adjusted. More ships will also increase the need for personnel. A solution could be to create autonomous systems to decrease the amount of human labour that is necessary to operate more ships.

Future research can be done on multiple different aspects of the future of shipping. Firstly, the modal shift that will occur. The inter-modal approach when researching the future of transportation. The shipping sector in the future has scenarios where the capacity is lower than the demand. This will require a different distribution of the goods over the different transportation methods. Secondly, the effects of droughts on the different rivers in the Netherlands can be examined. The rivers get their water supply from different sources. Some rivers are more sensitive to precipitation differences than others. These differences require a different approach to retain the water levels in the rivers. In addition, a case by case analysis to compute the costs and damage reduction for investments in rivers in the Netherlands can be done to investigate what rivers should be invested in.

6.1 Discussion

The water level in different rivers changes due to different factors. This paper overgeneralizes the impact of a lack of precipitation over multiple rivers. This is because the research aim is about the increase in frequency and severity of droughts and how this impacts the shipping sector in the future, rather than analysing the future scenario for a specific set of rivers.

The paper is researching the future, this will always be mostly unpredictable. Therefore, this thesis is not taking definitive conclusions, but is analysing what is most likely to happen in the future based on a previous year. In addition, there are multiple future climate scenarios by KNMI (2023), this thesis is taking multiple scenarios into account to prevent the conclusions from only targeting a scenario that will not happen. Infrastructure development requires high capital investments and the infrastructure is made to last for the long term. Therefore, research papers like this one are necessary to guide what types of infrastructure investments are worth it for the future. If the Hd scenario happens in the future, it could turn out that half of the year some rivers will be inaccessible for most ships. This would mean that investing in other infrastructure, such as additional railways, will have a higher return on investment.

In case studies, over-generalisation is a limiting factor. This thesis is trying to prevent this by utilising multiple scenarios and to add the context of the future. As an example, in 2018 the lack of personnel was a problem in shipping. However, in the future, automation will reduce the amount of people that are needed to operate a ship. In addition, if more people are needed on a regular basis, the companies will have time to adjust and hire more people. This means that this factor will not necessarily be a problem in the future. This is also the case for the rivers where canalisation is an option, this would mean that the problems of droughts will not even be present in that part of the transportation chain. By taking conclusions with a future context perspective, over-generalisation can partially be prevented.

Hänsel et al. (2023) describe in their paper that an inter-modal approach is needed to assess the future of the transportation sector. The reason for this is that the impact of one transportation method will shift demand to a different transportation method in a modal shift. This modal shift is important to understand to create more accurate future scenarios. This paper is including a perspective where this modal shift is considered. Future research into the transportation sector should try to include this as well, to create more accurate results.

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