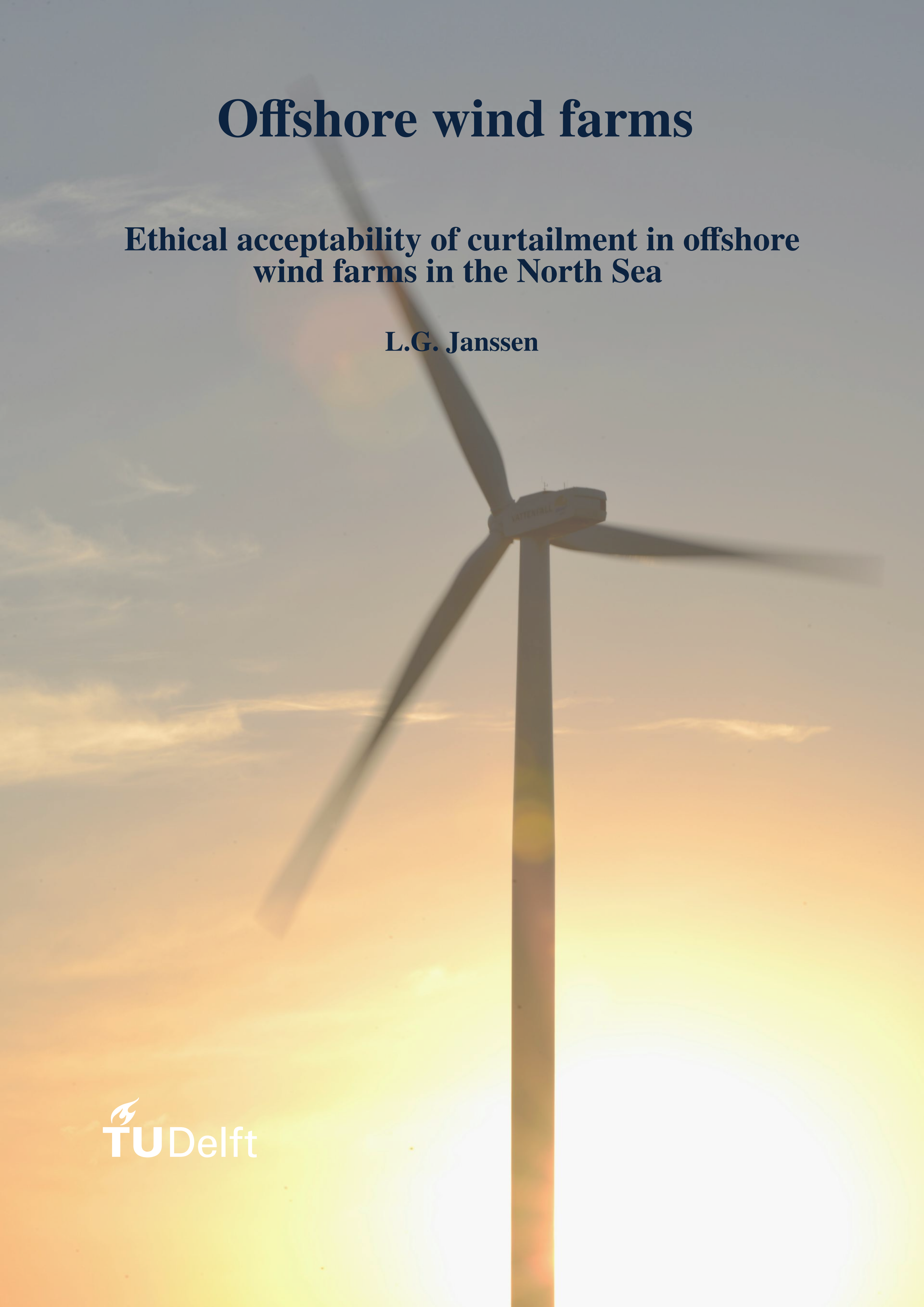
Offshore wind farms

Ethical acceptability of curtailment in offshore wind farms in the North Sea

L.G. Janssen



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L.G. Janssen
December 5, 2024

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by

L.G. Janssen

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Acknowledgements

This Master's thesis marks the end of my time as a student. I began my studies at The Hague University of Applied Sciences in Delft, pursuing a degree in Mechanical Engineering. I have always seen myself as someone who is technically minded and handy, therefore Mechanical Engineering seemed like a good choice, which it was. In four and a half years, I finished my Bachelor's and had a great time doing it.

After I got my Bachelor's, I felt like I still had more studying to do. Probably also because almost all of my friends were studying at the Delft University of Technology, either for a Bachelor's or a Master's. I had to get a Pre-Master's degree before I could switch from the University of The Hague to a Master's degree at the Delft University of Technology. It was clear to me that the best option was to do a Pre-Master's in Mechanical Engineering, a subject I was really interested in. Soon, I realised that the Pre-Master's at the Delft University of Technology was a bit too abstract, and maybe a bit too challenging as well. A year later, I switched to the Pre-Master's in Management of Technology, which I got within a year.

The Master's in Management of Technology was a challenge too. I did not pass all my exams the first time, in fact, I failed quite a few of them. I had a lot of discussions with my father about whether I should quit the Master's degree. However, each time we decided that I should just give it another go, and eventually, managed to pass almost all the exams. Unfortunately, things got worse when my father passed away after spending a long time in hospital.

I managed to pick up the last remaining subjects, passed them and then all that was left was the thesis itself. I chose something that was completely out of my comfort zone, which was an ethics thesis. As with my whole university career, the start was challenging, but I managed it in the end. As far as the duration of my thesis is concerned, I would like to take this opportunity to thank Dr. James Hutton in particular for the many meetings we had and the supervision as the advisor, but really as the acting first supervisor. I would also like to thank Dr. ir. Udo Pesch as chair of the committee and Dr. Servaas Storm as second supervisor for their supervision during my thesis. Furthermore, I would like to thank my father for the endless support and guidance, and my mother, brother, girlfriend, family and friends for their support during this time.

I hope that this thesis will be a useful addition to the Management of Technology field and that readers enjoy the insights and find them useful.

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Summary

As global temperatures rise, the need for sustainability becomes more urgent. Reducing reliance on fossil fuels and other CO_2 emitting energy sources is critical, making a shift to renewable alternatives such as offshore wind power essential. This study examines offshore wind farms in the North Sea, an area that presents both significant opportunities and challenges for a wide range of stakeholders. While the potential benefits are clear, the development of offshore wind farms is a complex undertaking and companies are continuously working on innovative solutions to improve their implementation. In particular, this thesis focuses on curtailment of offshore wind farms in the North Sea.

Curtailment means halting the operation of offshore wind turbines entirely or reducing the speed to a maximum of two rotations per minute. Curtailment is initiated when negative energy prices occur. Initially, it may appear that negative energy prices are not a significant issue. However, they are generally disadvantageous to consumers due to their disruptive effect on market balance. Furthermore, curtailment is initiated for the sake of grid stability. When there is a surplus of energy, grid instability occurs. This should be prevented to prevent power outages. Most importantly, when curtailment is initiated, bird mortalities are prevented. When offshore wind turbines halt their operation entirely or reduce the speed to a maximum of two rotations per minute, birds do not collide with offshore wind turbine blades, therefore preventing bird mortalities.

Curtailment in the Netherlands is initiated during nights of migration periods in Autumn and Spring, when a threshold of 500 birds per kilometre per hour are migrating. The way this works is that virtual kilometres are studied using bird radars, when 500 birds or more cross this virtual line in an hour, this implies mass migration. There is a downside of curtailing for the sake of offshore wind farms for the sake of preventing bird mortalities. If energy demand is not met due to the absence of the wind energy because of curtailment, gas-fired power plants are compensating this loss of energy. The gas-fired power plants use natural gas to produce energy. Gas fired power plants consequently emit CO_2. This implies that the Netherlands is willing to prevent bird mortalities while emitting CO_2. This raises the following ethical issue and main research question:

When, if ever, is curtailment ethically acceptable in offshore wind farms in the North Sea?

To answer this ethical research question, different ethical approached are studied, two in particular, consequentialism and non-consequentialism. Utilitarianism is derived from consequentialism, which is an ethical theory that focuses on the consequences of the actions taken. Non-consequentialism theories, in which the consequences of the actions taken are not all that matters, but places greater emphasis on the actions taken than on the consequences of those actions. In the field of ethics, it is not possible to satisfy both consequentialist and non-consequentialist perspectives simultaneously. Consequently, a choice must be made between the two. This thesis accepts a consequentialist approach and therefore rejects the non-consequentialist approach. The primary reason for this choice is that, according to consequentialist theories, there is a greater moral obligation to prevent suffering than according to non-consequentialist theories.

The consequences of curtailment for the sake of preventing bird mortalities is emitting CO_2. Emitting CO_2 affects both the environment and humans. This thesis focuses mainly on the consequences of these additional CO_2 emissions for humans. In this thesis the framework of Disability-adjusted Life Years (DALYs) is used. One DALY is the equivalent of one healthy year of a person's life lost. DALYs consist of Years of Life Lost (YLLs) and Years Lived with a Disability (YLD). Additional CO_2 emissions result in DALYs of human beings. In other words, by preventing bird mortalities the Netherlands are willing to emit CO_2, which eventually leads to the loss of a human life.

To derive exact amounts, a hypothetical curtailment scenario is assessed. The hypothetical curtailment scenario uses the offshore wind farm 'Borssele', real-life data and secondary data to derive exact amounts of the consequences of curtailment. Exact amounts include bird migration fluxes, number of bird mortalities prevented, amount of additional tons of CO_2 emissions, the monetary costs of additional tons of CO_2, the amount of DALYs per emitted ton of CO_2, the cost of one DALY, the amount of DALYs per hypothetical curtailment scenario and the amount of curtailment scenarios lead to the loss of one entire human life.

The offshore wind farm Borselle, with its 173 offshore wind turbines, are tested using three bird migration fluxes: the current threshold of 500 birds kilometre per hour, twice the threshold namely 1,000 birds kilometre per hour, and real-life data from the night of October 19/20 2022 of 1,386 birds kilometre per hour. The conclusion of these different bird migration fluxes is that for the bird migration flux of 500 birds per kilometre per hour, one human life is lost while 7,110 bird mortalities are prevented. For the bird migration flux of 1,000 birds per kilometre per hour, one human life is lost while 14,220 bird mortalities are prevented. And for the real-life data bird migration flux of 1,386 birds per kilometre per hour, one human life is lost while 19,710 bird mortalities are prevented. One human life is lost due to the fact that additional CO_2 emissions result in DALYs.

The question arises why or why not, people ought to be indifferent between a number of bird lives and one human life, thus a trolley problem arises. A trolley problem is an ethical thought experiment in which a decision must be made regarding the trajectory of a trolley on either Track A or Track B. The decision is made by pulling a lever, which determines the path of the trolley. In a trolley problem, individuals, animals, or other entities are situated on both tracks. The individuals, animals, or other entities on the track the trolley is headed to are killed, whereas those on the other track are spared. This means that in this trolley problem, people ought to choose between a human life, or a number of bird lives, depending on the threshold of the bird migration flux.

If the objective is to preserve human life, the curtailment of offshore wind farms is never justified when additional CO_2 is required to meet energy demand. Indeed, this would imply that saving any animal, even if it entails the emission of the slightest amount of CO_2 emissions, would be considered ethically unjustifiable. Consequently, animal-friendly facilities such as wildlife crossings, artificial birdhouses, bee hotels or fencing for wildlife protection are deemed unjustifiable as manufacturing facilities, given that such facilities emit CO_2 as a by-product of their production process.

Another framework used to determine whether or not to be indifferent between the life of a human being and a number of animals, is welfare ranges. The 'Moral Weight Project' obtained welfare ranges for 11 farmed animal species. A welfare range is a spectrum in which a human or an animal can feel pleasures and pains. Assuming that welfare is not exclusively important for humans but rather for all entities, it can be determined how much welfare an exact number of animals could achieve compared to one human being. The framework of the Moral Weight Project ought people to be indifferent between one human being and 19 birds. This would imply that the threshold of the bird migration flux ought to be decreased to 1.4 birds per kilometre per hour. If this is the right course of action, the Netherlands ought to curtail every single night during Autumn and Spring. This view is rejected in this thesis as this implies that offshore wind farms ought to curtail at a very low threshold.

Another way to determine welfare ranges for birds is by looking at the number of neurons in bird's brains compared to neurons of a human being. A reason to use neurons to derive a welfare range is as more neurons in a brain means greater cognitive capacity, meaning that a certain number of neurons is needed in order to be capable of complex thinking. Comparing the number of neurons of birds to the number of neurons humans have, lowers the welfare range for birds significantly compared to the Moral Weight Project. This changes the indifference ratio of one human being and 19 birds, to one human being and 3,019 birds.

It should be acknowledged that, given the ethical focus of this thesis, some readers may not agree with the theories and assumptions presented. In this study, certain assumptions will be made, although people may have alternative perspectives. This report does not aim to provide a comprehensive response to the assumptions. Although some theories and assumptions will be subjected to criticism, in certain instances, the assumptions made are the most probable estimates, given the inherent uncertainties.

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1 Introduction

As global temperatures continue to rise, the need for sustainability becomes increasingly urgent. Reducing dependence on fossil fuels and other CO_2 emitting energy sources is crucial, making the transition to renewable options such as solar energy, green hydrogen and wind power essential. This research focuses on offshore wind farms in the North Sea, an issue that presents both opportunities and challenges for various stakeholders. Despite the potential benefits, the development of offshore wind farms remains a complex issue and companies are continually seeking innovative solutions to improve their implementation. This chapter discusses the background of offshore wind farms, the problem statement, the scope of the research, the research question(s), the research objective, the research approach and the relevance for Management of Technology (MoT).

1.1 Background

Over the last 30 years, the demand for offshore wind energy has grown tremendously. The reason why offshore wind turbines are in demand over onshore wind turbines is the fact that offshore wind speeds are higher and more consistent in direction, meaning that they can produce the same amount of energy in less time (Archer, 2005). Furthermore, there is a problem regarding land scarcity, meaning offshore is preferred over onshore wind turbines. Moreover, the shadow flickering and the noise generated by the wind turbines affects the quality of life of nearby inhabitants (Verhoeven, Spruit, Van De Grift, & Cuppen, 2022). Another reason why offshore wind turbines are preferred over onshore ones is that nearby wind turbines can affect house prices. Shadow flickering, noise and the aesthetics of the onshore wind turbines contribute to this negative impact on house prices (Gibbons, 2015).

Regarding the installation, there are several different ways to secure an offshore wind turbine to the seabed, however there are two distinctions: bottom fixed and floating. In both cases there is some way of securing the turbine to the seabed (Jiang, 2021; Watson et al., 2019). In figure 1.1, the three turbines on the left are examples of bottom fixed wind turbines and the three on the right are examples of floating wind turbines.

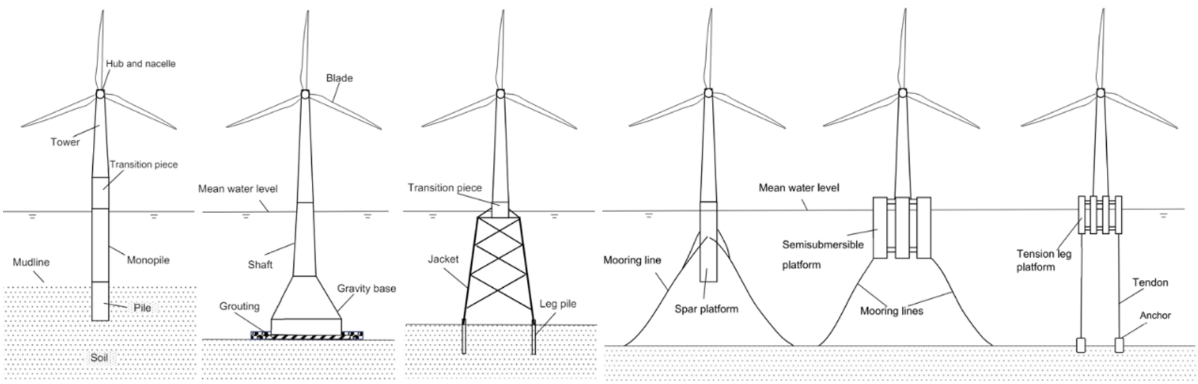

Figure 1.1: Different ways to mount an offshore wind turbine to the seabed (Jiang, 2021)

The installation of an offshore wind turbine is a complex operation. A simple explanation would be the following steps: site selection, planning, transportation and installation of the foundation, tower, nacelle and blades, and the grid connection by cables located on the seabed (Jiang, 2021).

There are also downsides for offshore wind turbines, for example the need for special equipment and the heavier weather conditions offshore. The storms at sea, waves and salty sea water cause corrosion to the structures (Perveen, Kishor, & Mohanty, 2014). Furthermore, there are ethical considerations arising from the realisation of offshore wind farms which are discussed in the next section.

1.2 Problem statement

In this section, the problem statement of the externalities of the transportation and manufacturing of offshore wind turbines and operational wind turbines will be discussed. An externality is an unintended side effect or consequence that affects a third party. Externalities can be either positive or negative (i.e. benefits or downsides).

There are multiple downsides of the manufacturing and installation of offshore wind farms, for example underwater noise. During the construction of offshore wind turbines, generated underwater noise could possibly affect stakeholders. Underwater noise is generated during the construction and installation when for example pile-driving and the foundation installation (Bergstrom et al., 2014; Tougaard, Henriksen, & Miller, 2009).

Another downside is that the installation of the towers of the wind turbines and the cables may harm the benthic zone of the seabed. The benthic zone is the bottom of the seabed. Alterations to the seabed can potentially occur due to physical changes made during the development of wind turbines (Bergstrom et al., 2014). Offshore wind turbines may potentially be located in areas where there is a risk of collision with animals. In some cases offshore wind farms are located out of the way of migrating bird routes. However, what happens when there are no more sites outside of migrating routes but there is still a need for offshore wind farms? Collisions with birds can occur with operating wind turbines or during the installation of the wind turbines. A potential way of preventing bird collisions with offshore wind turbines is curtailment. Curtailment means reducing the rotational speed of the wind turbines or alternatively, halting their operation entirely. (Bergstrom et al., 2014; Busch, Kannen, Garthe, & Jessopp, 2013; Lagerveld, Poerink, & Geelhoed, 2021).

Furthermore, there is a negative externality regarding shipping companies. A challenge lies in efficient transportation for wind turbine materials regarding the shipping routes. Potential disruption or over-utilisation could occur, which would be a significant problem (Gusatu, Yamu, Zuidema, & Faaij, 2020).

The question that remains is whether offshore wind turbine technologies are ethically justifiable. What methodology should be employed when weighing the benefits against the harms, given the numerous and diverse types of benefits and harms? It is evident that a number of ethical issues arise during the planning, transportation and realisation of offshore wind farms in the North Sea, as well as in relation to operational wind farms. This thesis will provide a detailed examination of the principle of curtailment. This thesis will, in particular, examine the ethical externalities that arise during curtailment.

1.3 Scope of the research

The relevance of this research is that ethics is an important and crucial part of engineering. Ethics is particularly important in this research as this is the key to preventing potential harm, providing long term sustainability and environmental protection. In engineering a downside is often related to ethical issues or a downside is an ethical issue. Ethical issues are defined as a problem where moral values are at stake (Van Gorp & Van de Poel, 2001; Van Gorp, 2005). Which is why ethical issues (i.e. ethical considerations) will be the focal point of this report. Furthermore, in order to ensure that the topic is not too broad, this report will focus on the North Sea region.

1.4 Research questions

In this section the main research question and sub-questions are provided. These questions are determined considering the previous described background, problem statement and scope of the research.

Main research question

When, if ever, is curtailment ethically acceptable in offshore wind farms in the North Sea?

Sub-questions

1. "Which ethical principles are relevant to offshore wind farms in the North Sea, and how can curtailment contribute to these principles?"
2. How can curtailment contribute to minimising the negative environmental impacts of offshore wind farms in the North Sea?
3. What are the ethical challenges of implementing curtailment in offshore wind farms in the North Sea and how can they be overcome?
4. Who are the stakeholders and how are these stakeholders affected regarding curtailment of offshore wind farms in the North Sea?
5. Which decision-making processes should be followed to effectively implement curtailment into offshore wind farms in the North Sea?

1.5 Research objective

The objective of the main research question is to identify when, if ever, curtailment is ethically acceptable in offshore wind farms in the North Sea. Consequently, one of the objectives of this research is how to ethically justify curtailment. The objective of the sub-questions is as follows. As this thesis dives into ethical issues, it should be known which ethical theories and principles are necessary to ethically assess curtailment of offshore wind farms in the North Sea. Also, one of the objectives is to obtain information on how curtailment contributes to environmental impacts, and which other challenges might occur with regard to actually initiating curtailment. Furthermore, the stakeholders need to be defined. And lastly, an objective is to determine which decision-making processes should be followed to implement curtailment.

In the field of ethics, when something is right or wrong, it is sometimes referred to as 'justifiable' or 'unjustifiable'. Ethically justifiable means whether something is morally acceptable. This thesis' focal point is the ethics behind the process of curtailment in offshore wind farms. The relevance is to foster sustainable development while minimising negative environmental impacts, to which the ethical considerations apply, and addressing stakeholder concerns.

1.6 Research design

A research can be both qualitative and quantitative. In this thesis a qualitative research will be conducted. This means that information in the form of text is analysed in order to draw conclusions. Furthermore, as this thesis contains ethical issues, both ethical theories and ethical reasoning will be used. The process of ethical reasoning entails the formulation of (calculated) assumptions on occasion. Therefore, a quantitative approach is not appropriate for this thesis.

Qualitative research

A qualitative research design is employed to explore and understand whether the condition of curtailment in offshore wind farms is ethically acceptable. A deep exploration of complexities around the ethical concerns in the context of offshore wind projects is needed. This research design facilitates the collection of rich and detailed data in the form of texts. This provides insights to diverse perspectives into why or why not curtailment is ethically acceptable. This means that the aim is theory development, as conditions X, Y and Z (yet unknown) make curtailment of an offshore wind farm ethically acceptable or not (yet unknown).

1.7 Relevance of the study

An ethical study on curtailment of offshore wind farms in the North Sea is of great interest to the master's degree in Management of Technology (MoT) for several reasons. In this section, it is pointed out what the relevance of this research is to the field of MoT.

One of the reasons for the relevance to MoT is that curtailment has direct ethical implications, it can lead to wastage of renewable energy, this may be in conflict with sustainability goals of the energy transition. MoT pays close attention to how new technologies develop and how they can be used strategically and ethically to address societal challenges. This includes offshore wind farms. Investigating the ethical issues of curtailment, helps to create awareness of the impact of the technology, and how to manage curtailment.

Furthermore, the relevance of this research is that ethics is an important and crucial part of engineering. Ethics is especially important in this research because it is key to justifying potential harm, providing long-term sustainability and protecting animals and their environment. In engineering, a downside is often related to ethical issues or a downside is an ethical issue. Ethical issues are defined as a problem involving moral values. The research helps to understand how ethical issues, such as curtailment, can be made more explicit.

Offshore wind farms are complex technological systems that require involvement of various stakeholders, such as governments, companies but also non-human stakeholders. Ethics play an important role in how non-human stakeholders are affected by decisions by curtailment. In conclusion, an ethical study of curtailment of offshore wind farms in the North Sea is important for MoT because it helps to understand how technologies can be managed in line with sustainable, ethical and social issues. It provides insight into the balance between technologies, responsibility and long-term goals for the energy transition.

2

Literature review

This chapter presents the theoretical background, the concept of uncertainty, the synthesis and integration of data, an analysis of the existing literature, the identification of gaps in research and the methodology for data collection and analysis.

2.1 Theoretical background

In this section, the research areas that will be used in the master thesis will be discussed. The research areas include ethical theories, the wide reflective equilibrium, environmental theories, disability-adjusted life years and welfare-ranges.

2.1.1 Ethical theories

In this section, the ethical theories which are used in this thesis will be discussed. The ethical theories include utilitarianism, deontology and virtue ethics. Ethical theories provide different perspectives on problems. To provide the different perspectives, the following thought experiment is introduced.

"Imagine you are standing on a bridge overlooking a railway track. A train is speeding toward five workers who are on the track and cannot move in time. You are with another person, and the only way to save the workers is to push this person onto the track. The person you push will be large enough to stop the train, sacrificing him to save the five workers. Do you push the person to save the five, or do you allow the train to kill the five people?"

- *Footbridge case* (Kleingeld, 2020)

Utilitarianism

Utilitarianism is a theory derived from consequentialism, which means that the theory focuses on the consequences of actions taken. The central principle of utilitarianism is to maximise the happiness for the greatest number of people, i.e. the ethical course of action is the action that maximises happiness. The utilitarian perspective on decision-making is therefore quite simple: if there is one option that makes one person happy, and another option that makes five people happy, the second option is chosen. This example is not very serious or violent and therefore seems plausible, but if we were to examine more serious or violent examples, the theory might be a little less plausible. For example, in a case where terrible murders are being committed and all the murders could be stopped by convicting one innocent person, this would be considered the right decision to make according to utilitarianism. Utilitarianism is often seen as a ‘duty of goodness’, but in some examples this might seem unjust (Driver, 2007).

To return to the case of the footbridge, a person would be morally obliged to push the person onto the track to save the five workers. It is in the person’s power to save a net of four lives, because five lives are saved by sacrificing one life. The benefit of saving five lives outweighs the harm of sacrificing one life, so according to utilitarianism, this is the morally right course of action.

Deontology

Deontology is an ethical theory that focuses on the respect of moral rules, where actions are considered right or wrong according to whether they are in line with these rules, with no exceptions. In this framework, the morality of actions is determined by their following of rules rather than their consequences. Immanuel Kant, a German philosopher, is the founder of Kantian ethics, a deontological theory. Decision making in Kantianism is more complex than in utilitarianism. For example, in the Footbridge case, the decision to push a person onto the track to save five workers would be considered morally impermissible according to Kant, even though it would save five lives. Utilitarianism, on the other hand, would regard this as the morally correct action because it results in greater net happiness. Kant's principle for determining the morally correct decision is based on the categorical imperative, which requires individuals to act according to universally accepted principles, regardless of personal desires. The action of pushing the man onto the track is not in line with the categorical imperative because it involves using him 'as a mere means to an end' rather than treating him as an 'end in himself'. To use someone 'as a mere means' is to treat him only as a tool to achieve an end, ignoring his autonomy. To treat someone 'as an end in himself', on the other hand, is to respect their dignity and autonomy. Kantian ethics highlights the importance of moral duties and the principle of respect for persons in guiding moral decisions (Driver, 2007).

Virtue ethics

Virtue ethics is a philosophical approach that emphasises moral character and virtues of people. Virtues are traits that people possess, e.g. honesty, courage and compassion. Virtue ethics is very different from utilitarianism and deontology because it looks at actions taken according to the traits of people (Driver, 2007).

Conflicting perspective

The ethical theories of utilitarianism, deontology and virtue ethics are all examples of normative ethics. The importance of these ethical theories lies in the diverse perspectives they offer. They can provide insight into what is morally right or wrong according to their perspectives. However, it is not possible to synthesise these three ethical theories in a way that will satisfy all parties. They simply cannot all get along as the perspectives of the theories are too diverse, so there is a need for other ethical perspectives. The only way to conclude if an action is justifiable, is to presume one of the theories as the truth and to accept the premise of the designated theory.

2.1.2 Wide reflective equilibrium

According to Taebi (2016), there is a difference between social acceptance and ethical acceptability. 'Social acceptance' is used to describe the public's readiness to adopt a new technology, the term 'ethical acceptability' requires a more in-depth consideration of the moral implications that arise with its introduction. Taebi (2016) further argues that prioritising social acceptance can sometimes overshadow significant ethical concerns. While returning to the topic of offshore wind farms, a similar situation can be observed: while the technology has been broadly accepted by the community, it is now facing ethical challenges as it is implemented more thoroughly.

One approach to integrating the concepts of social acceptance and ethical acceptability is through the framework of wide reflective equilibrium. This concept was first introduced by philosopher John Rawls. The Rawlsian wide reflective equilibrium involves a process of harmonizing and refining judgments and principles across three key levels:

- **Lower levels of considered judgments**: this involves looking at specific situations and the judgments people make about them;
- **Top level of theoretical moral considerations**: this is where ethical principles and theories come into play. It is an overarching framework of ethical thinking that guides decision-making processes;
- **Mid-level principles or rules**: this level represents our intuitions about what is right and wrong in different contexts.

In an ideal scenario the wide reflective equilibrium iterates between these three levels until a balance or coherence is achieved, i.e. equilibrium.

The lower levels of considered judgments, in the wide reflective equilibrium, suggests that judgments of people are taken into account. This could be interpreted as a form of common sense or just the opinions of individuals. Common sense would also suggest that destroying whole ecosystems for no reason is wrong. A reason why destroying whole ecosystems would be justifiable is when there are serious more (important) benefits countering the costs of destroying an ecosystem. In other words, damaging ecosystems in a serious amount should only be allowed when it brings serious benefits of another kind (Taebi, 2016).

2.1.3 Distributive and procedural justice

Distributive and procedural justice are useful considerations for justifying certain actions. This subsection will elaborate on these two concepts.

Distributive justice

Distributive justice is how we look at how goods are allocated (i.e. distributed) in a community. Distributive justice is fairness of the distribution of goods. Goods can be seen as material goods, but also for example risk levels, benefits and other resources resulting from the context in which the technology is implemented. Thus, the benefits and the burdens should be fairly distributed among the stakeholders, i.e. in this example human stakeholders, such as the wind farm developers, governments, local communities and other stakeholders. Distributive justice raises questions about *how* to compensate and *which stakeholders* to compensate. Theories of distributive justice can be seen as a response to utilitarianism, which holds that the morally right action or policy is the one that produces the greatest benefit to society, as mentioned in section 2.1.1 (Huijts, Molin, & Steg, 2012; Miller, 2023; Taebi, 2016).

Procedural justice

Procedural justice is also an important aspect to consider. While distributive justice focuses on the fairness and acceptability of the distribution, procedural justice concerns the fairness of the decision-making process that determines how the technology is implemented. It revolves around the stakeholders involved in the decision-making processes and how these decisions are made (Doorn, 2019; Huijts et al., 2012).

2.1.4 Environmental theories

In this section anthropocentrism and non-anthropocentrism theories are discussed.

Anthropocentrism

Anthropocentrism is an ethical belief in which humans are the most important and central beings of existence. In other words, anthropocentrism is human centered. Anthropocentrism believes that only humans have intrinsic value, i.e. they are valuable for their own sake, and moral standing (Doorn, 2019). This means that according to anthropocentrism the primary objective is to cover human benefits and interests (Kopnina, Washington, Taylor, & Piccolo, 2018; Taylor et al., 2020).

Biocentrism

Biocentrism is a non-anthropocentric ethical belief system which states that all living entities deserve moral consideration. This means that in biocentrism, all living beings have intrinsic value, and thus the impact on all living entities need to be taken into account. Living entities in biocentrism are animals, plants and other organisms (Doorn, 2019; Taylor et al., 2020).

Ecocentrism

Ecocentrism is, as well as biocentrism, a non-anthropocentric ethical theory. Ecocentrism believes that nature also has intrinsic value, e.g. ecosystems and non-living things. This means that not only living entities have intrinsic value. And thus, ecosystems have ethical rights as well (Doorn, 2019; Taylor et al., 2020). So, important considerations in ecocentrism are the preservation of ecosystems and biodiversity. Ecocentrism would fight for long term sustainability of an ecosystem. Although ecocentrism is an extreme position in environmental philosophy, it does not reject human activities, but argues for ethical decision-making to recognise the intrinsic value of ecosystems.

The importance of these environmental theories is that they provide, like the ethical theories described in section 2.1.1, different perspectives. They provide a different lens through which to view and approach environmental ethics and conservation. Furthermore, they also show that stakeholders do not stop at humans, but include animals, plants, other organisms and ecosystems as a whole.

2.1.5 Disability-adjusted life years (DALYs)

Disability-adjusted life years (DALYs) is a term which is used in the public health sector. A DALY is the equivalent of one healthy year of a person's life lost, or in other words, one year lost. The equivalent value is quantified in terms of the total overall burden of a disease. A DALY is therefore made up of two parts: Years of Life Lost (YLLs) due to a premature death, and Years Lived with Disability (YLDs) due to years of life lived with a disability or disease. If a person dies five years prematurely as a result of an accident, the YLLs are five years. The YLDs are defined with disability weights, which means that the more severe the condition, the higher the disability weight. For example, if a person becomes blind for the last 40 years of their life, and the disability weight of blindness is 0.50, then 20 years of healthy life are lost to this person. The total number of DALYs for both people is therefore 5 + 20 = 25 years. DALYs are explained in more detail in section 4.6.

2.1.6 Welfare ranges

Another framework that will be used in this thesis is the welfare ranges. A welfare range is a spectrum in which a human or animal can feel pleasure and pain. One assumption is that humans have the largest welfare range, in this thesis it is assumed that humans have a welfare range of 2.00. The spectrum consists of pleasures, positive +, and pains, negative -. It is also assumed that these pleasures and pains are symmetrical, thus humans experience pleasures to a maximum of +1.00, and maximum pains of -1.00. Assessing welfare for humans is straightforward, as humans can interact, and explore exact welfare magnitudes for different pleasures and pains (Fischer, 2023b).

Animal welfare ranges are less straightforward as these cannot be discussed with them. Fischer (2023b) explored over 90 proxies, for 11 farmed species. These proxies are then assessed. Some examples of proxies are: fear-like behaviour, loneliness-like behaviour, love-like behaviour, parental care, friendship-like behaviour, communication etcetera. All proxies are studied and assessed for credence, i.e. the certainty or confidence of the findings. Assessing over 90 variables with credence, and assuming utilitarianism, unitarianism, hedonism and valence symmetry, a welfare range for these 11 farmed species were constructed, which will be further elaborated on in section 4.7.1.

Comparing welfare ranges of humans to animals is a framework of determining when people ought to be indifferent between one human being and an exact number of animals. This is, if assumed that people are indifferent to welfare for an exact number of animals and one human.

2.2 Uncertainty

It should be noted that, as this thesis' focal point is ethics, some might not agree with certain theories and assumptions. In this thesis, assumptions will be made, while others may disagree. Such disagreements may not be discussed in this report. There will be arguments against certain theories and assumptions. On occasion, the assumptions are the most accurate estimates possible, despite the underlying uncertainties.

Ethics can be compared to politics. Both fields concern the determination of what is right and wrong, but there is no universally accepted standard. Just as in politics, where there are different ways of determining what is a 'right' policy, in ethics there are also different ways of determining what is morally right. In both cases, people may have different opinions depending on their values, beliefs and context. This makes ethics and politics dynamic fields where no single right answer is available.

2.3 Synthesis and integration

This section contains the synthesis and integrating of the findings, theories and concepts from the literature.

The ethical theories and environmental theories described in 2.1.1 and 2.1.4, give insights into what ethical considerations are, how decision-making processes are important and how stakeholders are obtained. For example, different ethical theories look at decision-making processes in different ways. A utilitarian and a kantian perspective look at problems from different angles. A utilitarian might argue that manufacturing an offshore wind farm is the right decision when it benefits more individuals than it harms. On the other hand a kantian would argue that manufacturing an offshore wind farm might not be the right decision to make if it harms even a few individuals.

When it comes to environmental theories stakeholders are obtained from different perspectives. For example, an anthropocentric individual would not think ecosystems have intrinsic value, though an ecocentric individual would. By taking ecocentrism into account, ethical problems arising from offshore wind farm development regarding ecosystems, are thus not ignored. Thus, by taking several environmental theories into account, it is determined that not only humans, but also animals, plants, other organisms and ecosystems as a whole are stakeholders.

Synthesis and integration is particularly important as it establishes the theoretical framework and identifies key concepts for this research. Unfortunately, as described in 2.1.1 synthesising utilitarianism, deontology and virtue ethics is not possible as the perspectives differ too much to please everyone. Thus, there is a need to synthesise other theories and principles to derive what ethical decision-making is and why ethical decision-making is important to obtain what is ethically justifiable.

Through the analysis conducted with the environmental theories, it has become evident that stakeholders extend beyond humans, involving animals, other organisms and entire ecosystems when talking about ethical considerations. Unfortunately, synthesising these theories is not possible for the same reason why synthesising utilitarianism, deontology and virtue ethics is not possible: the perspectives differ too much to please every theory.

Key concepts, besides ethical and environmental theories, which will be used is the Rawlsian wide reflective equilibrium, social acceptance and ethical acceptability. The Rawlsian wide reflective equilibrium is basically a method of determining which ethical assumption to work with. Even though it might not be very clear that this framework is used, it is. The Rawlsian wide reflective equilibrium suggests to start from common sense as mentioned in 2.1.2, and iterates between three levels until a balance or coherence is achieved, thus an equilibrium. The lower levels of considered judgments involve looking at specific situations and the judgments people make about them. Such will be seen in section 4.4. The top level of theoretical moral considerations is where ethical principles and theories come into play. This report will consider different ethical theories as mentioned in 2.1.1 in comparison with offshore wind farms in the North Sea, which will be elaborated on in chapters 3 and 4. The mid-level principles or rules represent intuitions about what is right and wrong in different contexts. This thesis uses certain assumptions whenever there is uncertainty, as mentioned in 2.2. This thesis therefore uses the Rawlsian reflective equilibrium without making it explicit when iterating through the different levels.

The DALY framework will be used to determine the effects of curtailment on different stakeholders. This will be explained in more detail in section 4.6. The importance of the DALY framework arose in the process of writing the thesis. As the study continued, and the further the technology of curtailment was studied into, the more problems arose. The framework of welfare ranges is particularly important as it allows to compare and obtain indifference ratios between the life of a human being and a number of birds. Welfare ranges are further elaborated on in section 4.7.1.

The synthesis of these key concepts highlights the varied nature of the ethical challenges associated with offshore wind farms. While different perspectives offer unique insights, together they may emphasise interconnections of environmental and social in decision-making processes.

Furthermore, a stakeholder analysis should be conducted. A quick research shows that for anthropocentrism different individuals would be the stakeholders. For biocentrism different animals, plants and other organisms would be stakeholders. And for ecocentrism different ecosystems as a whole would be stakeholders. It should be noted that although there is a favour for pleasing humans, i.e. an anthropocentric viewpoint, ecocentrism will be taken into account on the premise that, as stated in 2.1.1, destroying ecosystems is unjustifiable unless there are serious more important benefits countering the cost of destroying ecosystems. Further research would reveal the specific identities of the various stakeholders involved in the realisation of offshore wind turbines, with their corresponding issues, solutions or ethical justification for the ethical issues.

2.4 Literature gap

The literature gap, also known as the knowledge gap, is the part of the study that needs to be filled by new research because little or nothing is known about it. A thorough ethical analysis of the development of offshore wind farms should therefore be carried out, with particular attention to the justification of curtailment. Since it seems that little to nothing is known about this topic yet. Therefore, this can be stated as the thesis' knowledge gap. The principle of curtailment has not yet been applied on a large scale. The sub-questions such as what ethical principles are relevant, how curtailment contributes to minimising negative effects, ethical challenges curtailment possesses, who the stakeholders in offshore wind farm development are and what decision-making processes ought to be followed to implement curtailment in the North Sea are questions that will be tackled in this master thesis. The answers to the main research question and sub-research questions will close the knowledge gap.

2.5 Data collection

Data collection is divided into two categories, primary and secondary data.

Primary data

Primary data is data obtained by the researcher. A possible way to obtain primary data is by conducting interviews. Interviews constitute a valuable research method, as they offer researchers the chance to gather in-depth, qualitative data directly from participants. This approach allows researchers to gain a deeper understanding of participants' experiences, perspectives, and attitudes regarding a particular research topic. Semi-structured interviews are interviews in which open questions are asked, and depending on the respondent's answer, a specific follow-up question is asked (Smit, 2023). Although conducting interviews would be interesting and might provide new information, this thesis will focus on ethical issues regarding offshore wind farms. Information will be obtained using secondary data.

Secondary data

Secondary data is data that has been collected by someone else. Relevant documents, such as the sources mentioned above, are an effective way to collect secondary data. Relevant documents include environmental impact assessments, environmentalists' reports, company views, various frameworks, decision-making processes, etcetera. These relevant documents will be obtained using Google Scholar, Web of Science, Scopus and different types of journals such as JSTOR where various papers are stored. Journals of particular interest in the field of ethics are Environmental Ethics, Environmental Values, Environmental Politics, Environmental Philosophy, Stanford Encyclopedia of Philosophy, Technology in Society and Technology in Responsible Innovation. As the focus of this thesis is the ethical perspective of offshore wind farms, these sources can help to find relationships and connections with key concepts.

2.6 Data analysis

This section presents an analysis and interpretation of data from existing literature in order to provide answers to the research questions posed in this thesis. The data for this study were sourced from academic databases, including Google Scholar. These provided access to peer-reviewed articles, books and other publications about offshore wind farms and ethical implications. As mentioned before, the data was collected from other studies, i.e. secondary data.

To ensure validity of this study, triangulation of data sources and methods will be employed. Triangulation is combining data from different sources to strengthen insights (Smit, 2023). Meaning that by verifying the accuracy of contributions through other sources will be used to ensure credibility of the research. Reliability will be established through transparent documentation of the research procedures, therefore making the study replicable. Replicability is one of the scientific research characteristics and could be obtained by maintaining consistency in data collection and analysis (Sekaran & Bougie, 2016).

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L.G. Janssen
December 5, 2024

3

Stakeholder analysis

In section 1.2 and in the main research question, ‘ethically justifiability’ is introduced. The concept of ethical justifiability is very broad. As mentioned by Taebi (2016), ethical acceptability, or ethical justifiability, refers to the consideration of a new technology while taking into account the moral questions that arise when the new technology is introduced. This chapter examines the various stakeholders involved in offshore wind farms. In addition to a stakeholder analysis, this chapter explores the concept of animal ethics. Furthermore, illustrative examples and an analysis of different offshore wind farm innovations are provided.

3.1 Human stakeholders

To illustrate an example of moral issues, Al Jazeera (2023) mentions ‘dirty facts’ about the production of green hydrogen. Hydrogen is an energy source that can be used instead of fossil fuels. The use of hydrogen could be preferable to fossil fuels since hydrogen does not emit CO_2, unlike fossil fuels. A distinction is made between grey, blue and green fossil fuels. Grey hydrogen is produced from fossil fuels such as coal or natural gas without storing or capturing the CO_2 gas. Blue hydrogen is natural gas converted to hydrogen with CO_2 as a by-product. Green hydrogen is produced by splitting water into its two components, hydrogen and oxygen, using wind, solar or hydroelectric power, and does not produce CO_2 as a by-product (Howarth & Jacobson, 2021).

The ‘dirty facts’ of hydrogen production, as highlighted by Al Jazeera (2023), refer to Saudi Arabia. Ancient tribes were evicted from their homes to make way for an electrolyser that produces hydrogen. Those who refused to leave their homes were sentenced to death. The project in Saudi Arabia is still going ahead. This example of producing hydrogen for the sake of people and nature, to reduce CO_2 emissions, is ethically indefensible because it results in the eviction of people from their land and the loss of human life. Fortunately, offshore wind farms do not displace people from their homes. However, one of the assumptions of ethical justifiability is that any loss of human life is considered ethically unjustifiable, all else equal.

In the context of ethical justifiability for humans regarding offshore wind turbines, visibility is one of the downsides. Some offshore wind farms are still detectable to the naked eye from the shore. Reducing the actual visibility of the wind turbines is not possible, however wind turbines are made ‘matte’. By making the wind turbines’ blades matte, also known as low-gloss, this makes wind turbines less glaring and light reflective. Making the blades of the wind turbines less glaring, results in the rotation of the wind turbines as less visually harsh for humans, without making the wind turbines invisible. Applying low-gloss is thus not about making wind turbines less visible, but to the naked eye, applying low-gloss will result in less glaring and reflection (Freiberg, Schefter, Hegewald, & Seidler, 2019; Lanuv, 2002).

3.2 Animal stakeholders

This section discusses the animal stakeholders in offshore wind farms and the ethical issues raised by the construction of offshore wind farms. First, the section dives deeper into the basic principle of animal ethics, where after the downsides are stated for different animal stakeholders. A distinction is made between marine species, i.e. those that live under water, and aerial species, i.e. those that live above water.

3.2.1 Animal ethics

Firstly, the issue of offshore wind farms is considered more thoroughly. It is known that offshore wind farms have the downside that animals are hurt in the manufacturing process as well as when the offshore wind turbines are in operation. But how, and why, is it necessary to try and counter these downsides in order to save animal lives or to minimise animal fatalities?

In the next paragraphs more background information is given where after a 'thought experiment' is introduced. A thought experiment is an imaginary or hypothetical scenario designed to analyse, explore, hypothesise or to challenge moral principles and theories. A thought experiment in ethics is a hypothetical scenario designed to explore, analyse and challenge moral principles, intuitions and theories. Through the act of imagining and reflecting on these scenarios, it is possible to test the implications and practical applications of ethical concepts without the constraints of real-world complexities. Thus, thought experiments are used to highlight philosophical issues by isolating specific variables and encouraging deep reflection on moral judgments and reasoning (Brown & Fehige, 2023).

Ethical theories

As discussed in 2.1.1 consequentialism (consequentialist theory such as utilitarianism) is an ethical theory that aims for the overall most happiness, and deontology (non-consequentialist theory such as Kantianism) is the theory where violating moral rules is never justifiable, no matter the outcome. Furthermore, 2.1.1 indicates that the ethical theories are not compatible with one another, as they vary significantly and do not align with one another. Therefore the following paragraphs will illuminate why or why not to save animals from suffering or dying according to certain theories.

Consequentialism in animal ethics

Consequentialists argue that humans ought to improve animal welfare where possible. Given that trillions of animals endure unnecessary suffering, and that humans possess the capacity to reduce this suffering, it is imperative that humans should take action to reduce it. On the other hand, non-consequentialists argue that humans should respect the autonomy of animals and thus not interfere with animals. The question thus arises as to the position of both consequentialists and non-consequentialists with regard to offshore wind turbines. In other words, what is the stance on the use of a technology that may result in the suffering or death of animals? Should the autonomy of animals be set aside on the ground that suffering is a consequence of human action? It should be noted that for both consequentialists and non-consequentialists there is, in a way, a shared ethical framework in which animals should be helped in a reasonable way. Helping an animal could mean to intervene to make a life easier for an animal (e.g. by building artificial nests for birds), but also to not intervene (e.g. by respecting their autonomy). This illustrates that animal welfare is important for both consequentialists and non-consequentialists. To some extent, they align with a common moral framework in practice, namely the importance of animal welfare. Evidently, unnecessarily harming animals is ethically unjustifiable according to consequentialists and non-consequentialists (Sebo, 2022).

Utilitarianism in animal ethics

Consequentialists theories, such as utilitarianism, meaning that it views morality as being entirely dependent on the outcomes of actions. In particular, the ethical theory of utilitarianism holds that individuals have a moral obligation to pursue the greatest amount of positive well-being for the greatest number of people. This means that utilitarianism is indifferent between not causing suffering and preventing suffering, or reducing suffering and increasing happiness. Although it would seem plausible that reducing the suffering of one person is more important than increasing the happiness of another person, utilitarianism does not make this distinction (Sebo, 2022).

Rights theory

In contrast to consequentialist theories, which hold that individuals have a moral obligation to maximise positive outcomes and minimise negative consequences, rights theory, a non-consequentialist theory, suggests that people have a moral duty to reduce and repair harms caused by their actions without sacrificing anything of importance in the process. To take this to a practical example, this means that, according to the rights theory, it would be seen as ethically unjustifiable to kill one animal in order to save five animals. Even though in the end killing one animal would result in more happiness, i.e. the lives of five animals. The aim of the rights theory is that reducing and repairing suffering and death has a stronger duty than to prevent suffering and death (Sebo, 2022).

The rights theory does make exceptions in this previous case. While some people argue that killing one animal to save five would be morally right, the rights theory disagrees. However, when the ratios become substantially higher, the rights theory agrees. In order to illustrate this concept in a practical example, the rights theory might hold that humans are permitted to kill one animal in order to save thousands or more animals (Sebo, 2022).

Animal thought experiment

In order to illustrate the differences of non-consequentialism and consequentialism, an animal thought experiment is introduced. This thought experiment was initially an adapted thought experiment by Sebo (2022), who derived the thought experiment from Singer (1972), the original and a(n) (extreme) human thought experiment. An animal thought experiment is introduced:

"Imagine you have a pool in your backyard. One day a fawn falls into the pool due to a tear in the tarp (i.e. pool cover). Without your help the fawn will die due to drowning. The only way to save the fawn is to jump in the pool and pull the fawn out of the water, without sacrificing anything significant of yourself. Should you save the fawn or do you let it drown?"

- *Pool thought experiment* adapted from Sebo (2022) and Singer (1972)

According to utilitarianism, you should save the fawn from its imminent death because as a human being you have the power to make the world a better place by preventing the death of the fawn. According to the rights theory you should also save the fawn from drowning as you will reduce suffering which you caused. The fawn would not have fallen into the pool if you had repaired the broken tarp. As seen, the two theories have the same outcome, namely to save the fawn from dying, but for different reasons.

Considering a modification to the pool thought experiment, a pond thought experiment is introduced:

"Imagine you are walking through the park and you see a fawn drowning in a pond. Again, without your help, the fawn will die due to drowning. The only way to save the fawn is to jump in the pond and pull the fawn out of the water, without sacrificing anything significant of yourself. Should you save the fawn or do you let it drown?"

- *Pond thought experiment* adapted from Sebo (2022) and Singer (1972)

According to utilitarianism, the fawn should be saved in both cases, and thus the difference of the pool and pond is irrelevant. Again, you have the power to make the world a better place by preventing the death of the fawn. The view of saving the fawn according to the rights theory is different. There is no moral obligation to save the fawn in a pond in a park, as this would involve preventing harm that you did not cause.

In the first thought experiment, the fawn ought to be saved as the fawn fell into the pool due to a broken tarp which could have been repaired, so to reduce the suffering a person caused due to their own doing, they should save the fawn. However, in the pond thought experiment it is not the fault of the bystander, and is thus not morally obligated to save the fawn.

Assumption in this thesis

> This thesis will reject the outcome of the rights theory in the pond thought experiment. In the event that an individual has the possibility to save an animal without any significant personal sacrifices, it would be morally obligatory for them to do so, all else equal. In essence, the utilitarian perspective is thus accepted instead of the rights theory. This is, if no significant sacrifices have to be made. The situation and the outcome of the thought experiment to save an animal could thus change if, for example, sacrifices have to be made. Examples of sacrifices can be if the saving of an animal results in a loss of capital (e.g. a substantial amount of money), loss of other (more significant) animal life or lives, or other (unforeseen) externalities (e.g. high green gas emissions resulting from the saving of the animal). Real-life examples of these exceptions will be elaborated on in sections further along the thesis. However, given that a world with less suffering is a better place, it follows that animal suffering should be minimised even if it is not directly caused by someone.

Concluding, in the context of offshore wind farms, death and suffering is caused by the offshore wind company manufacturers. Both theories would agree that human beings have to help the animals from death and suffering.

3.2.2 Marine species

As mentioned in section 1.1, downsides happen during the manufacturing and installation of offshore wind turbines as well as when wind turbines are in operation. One of the downsides is the underwater noise while pile-driving the towers into the benthic zone i.e. the bottom of the sea bed. The pile-driving causes extremely high underwater noise which causes fleeing or escaping the site of marine mammals. Marine mammals include cetaceans, which are for example whales and dolphins (e.g. minke whales and porpoises respectively) and seals. Minke whales can detect a wind farm 18 kilometres away, porpoises can detect wind farms from only 63 meters away and seals could detect the wind farm between 2.5 and 10 kilometres away. It should also be noted that operational offshore wind farms rarely ever exceed noise levels in areas close to major shipping lanes (Stöber, Uwe and Thomsen, Frank, 2021). Underwater noise is also likely to cause injury and death to different fish species (Bergstrom et al., 2014).

There are companies researching a more animal-friendly way to install monopiles and jacket foundations offshore. GBM Works, one of these companies researching a more animal-friendly way, is a Dutch company that has integrated the ‘hammering’ method of pile-driving with water jets, reducing noise and vibration by up to 70%. By using the hammering method combined with water jets in the tower of the wind turbine, the sand in the ground becomes almost liquefied. This results in less friction which means less power needed for the actual pile-driving method of hammering (GBM Works, 2024). Adopting new technologies or investing in Research and Development (R&D) to make a technology more animal-friendly is considered more ethically justifiable. In the next paragraph, this last sentence will be explained in more detail using some background information in climate change and global warming, after which a real life scenario is given.

Climate change and global warming

As mentioned in section 1.5 and the introduction of chapter 3, ethical justifiability is the consideration of new technologies while taking moral questions into account which arise when new technologies are adopted (Taebi, 2016).

The biggest cause of climate change and global warming is the use of fossil fuels. When in the 18th and 19th century the coal powered steam engine was adopted, humans had little to no idea what the CO_2 emissions would cause to the climate. A steam engine uses fuels such as coal to heat water. This water becomes high-pressure steam, which is used to set a vehicle in motion. Due to low efficiency, the steam engine was replaced by the internal combustion engines (Ahmed Pervez, 2023). In 1872, the first liquid-fueled internal combustion engine was invented by the American George Brayton, and in 1892 a German named Rudulf Diesel invented the diesel engine (Sabhadiya, 2024). There are multiple scientists in the late 1800s who stated that CO_2 could eventually lead to the warming of the earth (Hofstrand & Takle, 2021; Vigna & Friedrich, 2024). Though, at that time no ways of preventing it had been adopted. In 2016, the Paris agreement entered into force. 196 countries signed the Paris agreement meaning that countries set the goal to minimise global average temperature to 2°C. Furthermore, continued efforts must be made to limit the rise in temperature to 1.5°C (UNFCCC, 2016).

The only way to minimise further climate change and global warming is the implementation of cleaner energy generation methods such as wind, solar, hydro etcetera power instead of fossil fuels. One of the ways humans are implementing large scale adoption of cleaner methods is by transportation using electrical vehicles. Large scale adoption of electric vehicles is happening right now, and some countries are even banning car manufacturers from building new combustion engines from the year 2030 onwards.

Real life example

In this paragraph another thought experiment is given. Single-use plastic represents a significant environmental challenge on a global scale, with a particularly damaging impact on marine life and the environment. Single-use plastics such as straws, bottles and food packaging often end up in the environment. The management of this plastic waste is a complex and expensive process, with low recycling rates. From an economic perspective, the use of single-use plastic leads to significant disposal costs and losses in sectors such as tourism and fisheries. Polluted beaches and waters have a negative impact on the appeal of tourist destinations, which affects revenue. Furthermore, the presence of plastic waste in marine environments can have a harmful impact on fish and other marine animals. Potential solutions include the implementation of regulations to limit use, the development of innovative biodegradable alternatives, the distribution of information to influence consumer behaviour or the establishment of a more effective recycling infrastructure (Dey et al., 2020). Moreover, in this year, 2024, the EU implemented a new innovation regarding plastic bottles, namely the attached bottle caps. By attaching the caps to the bottles the EU is aiming to reduce plastic waste, as the caps will not be separated from the bottle. Smith (2024) noted that the bottle caps are the most littered single-use plastic found at beaches. Despite the annoyance of people because of the attached cap, this innovation is considered ethically justifiable because of its environmentally friendly purpose. This shows that humans are able to reject old habits and implement new technologies.

From the background information in global warming and climate change, together with the real life example, it can be concluded that technologies can have potential downsides that have negative effects on human and animal health and on the environment. It is therefore evident that individuals should be aware of these externalities and that efforts should be made to minimise the harmful side effects of technologies. The same applies to sustainable energy sources: if a new innovation is implemented and disadvantages are observed, efforts should be made to avoid them.

3.2.3 Aerial species

In the context of offshore (and onshore) wind farms, two aerial species are of particular importance: birds and bats.

Bats

It has been demonstrated in numerous studies that bats are commonly found in offshore areas within the North Sea region. Given that bats display similar foraging behaviours around offshore wind turbines as they do around land-based turbines, it is likely that fatalities occur in a manner similar to those observed on land. Insect availability increases during migration season as some insects migrate during the same period as bats. This allows bats to fly and forage during their offshore migratory flights. It has been observed that bats frequently interrupt their migration to forage in the proximity of offshore wind turbines, where flying insects tend to gather (Lagerveld et al., 2021).

Several bat species have been observed in the North Sea. The species most frequently encountered in the North Sea region is the Nathusius' pipistrelle. The majority of bat sightings occur during the migratory periods, which span from late March to June and again from late August to October. According to Lagerveld et al. (2021), the only mitigation measure for bats would be curtailment of the wind turbines. This means reducing the rotational speed of the wind turbines or alternatively, halting their operation entirely. Curtailment of wind turbines is considered to be ethically justifiable, given that animal welfare is considered to take precedence over human interests. In general, when humans are willing to miss out on certain benefits, such as energy, money or other utilities, for the sake of animal welfare, then this is an ethically justifiable course of action.

Birds

The same applies to birds as to bats. During migration, the risk of collision is high, resulting in bird deaths due to collisions with wind turbine blades. The majority of birds migrate during the Autumn and Spring periods across the North Sea (Bradaric, Kranstauber, Bouten, Van Gasteren, & Baranes, 2024). According to Marques et al. (2014) one way to avoid collisions is to 'shut down on demand', meaning that the turbine, a group of turbines or an entire wind farm is stopped when the risk of collision is high. There are several reasons for bird collisions (the same applies to bats), such as species-specific factors (e.g. bird behaviour), site-specific factors (e.g. weather conditions) or wind farm specific factors (e.g. wind turbine characteristics). There are two mitigation strategies: one is to avoid mortality by siting new wind farms away from migratory routes. Another way to avoid mortality is to minimise mortality by: shutting down when not needed, limiting operating hours, habitat management, increasing the visibility of turbines, diverting birds away from migratory routes and using deterrent devices to scare birds away (Marques et al., 2014).

It is estimated that millions of birds undertake the annual migration across the North Sea. Some examples of migratory birds are soaring birds, ducks, divers, swans, geese, gulls and terns (Furness, Wade, & Masden, 2013). Although the principle of curtailment is not new, the adoption of the principle to avoid bird and bat mortality by countries surrounding the North Sea is. The Netherlands is a pioneer in the implementation of curtailment to avoid bird mortality. The adoption of curtailment on a large scale is not yet being applied (Degraer, Brabant, Rumes, & Vigin, 2024). It is seen as ethically justifiable for the countries around the North Sea to adopt the principle of curtailment on a large scale, all else equal. Chapter 4 provides a more detailed elaboration on the principle of curtailment.

3.3 Benthic zone

As mentioned before, the seafloor is also known as the benthic zone. In the context of the benthic zone, a number of stakeholders are involved. This includes both the animal species that inhabit the benthic zone, and the ecosystems that are present there. In this report, habitats are regarded as having instrumental value, and thus are not considered to possess intrinsic value. As mentioned in section 2.1.4, intrinsic value is when an animal or ecosystem has a value for its own sake thus having ethical rights (Taylor et al., 2020). Similarly, the North Sea is presumed to have no intrinsic value but is instrumentally valuable to animal species inhabiting or surrounding the North Sea, which do possess intrinsic value. The absence of intrinsic value in the North Sea and its ecosystems does not justify the damaging or destruction for no reason, as they are of importance to numerous animal species. Any damage done to elements of intrinsic value, such as ecosystems and the North Sea, ought to be compensated by advantages of a similar or greater magnitude.

3.3.1 Benthic zone of the North Sea

In the last 140 years, a lot has changed regarding the benthic zone of the North Sea. At first, the North Sea was covered with hard substrates. Hard substrates include oyster beds, glacial erratics or coarse peat banks. These substrates were functioning as habitats for animal species, but were unfortunately destroyed due to bottom-trawl fisheries (Ter Hofstede, Driessen, Elzinga, Van Koningsveld, & Schutter, 2022). As from then, the Southern part of the North Sea changed from hard substrates to sandy or silty substrates. Epibenthic species, i.e. animals living on the seabed, are now less diverse compared to 140 years ago (Ter Hofstede, Driessen, Elzinga, Van Koningsveld, & Schutter, 2022).

In addition to the ethical concerns associated with pile-driving, namely the destruction of the benthic zone, the injury and killing of animal species, there are several advantages associated with the manufacturing of offshore wind farms. Offshore wind farms, as well as oil and gas platforms and shipwrecks can serve as artificial reefs for a large considerable number of animal species. Furthermore, these human-made structures may serve as 'stepping stones', facilitating the connection of otherwise isolated ecosystems (Adams, Miller, Aleynik, & Burrows, 2014).

Moreover, the sandy and silty substrate of the North Sea can result in the washing away of the sand in the area surrounding the foundation of the wind turbine structure, as well as the cable crossings located on the benthic zone, due to the current of the water. One potential solution to this issue is the implementation of scour protection measures. Scour protection is the placement of rocks and pebbles of varying sizes around the foundation of the wind turbine and cable crossings. The rocks and pebbles stabilise the sand surrounding the wind turbine. It is expected that the laying of scour protection, which results in a diversity of shape of the seabed, affects the spread of epibenthic animal species resulting in a higher biodiversity. (Ter Hofstede et al., 2022). The scour protection method is implemented in most wind farms in the North Sea. The Netherlands has even made it mandatory to include elements in the offshore wind farms that will benefit the ecology of the North Sea (Dutch Ministry of Economic Affairs and Climate, 2022).

3.4 Coastal and marine developers

There are also organisations that facilitate the involvement of coastal and marine developers in order to ensure that environmental requirements are met in the context of specific projects. Companies such as 'Reefy', a Delft-based company, aim to restore and regenerate marine biodiversity by building artificial reefs. Reefy installs plastic-free structures near coastlines to act as breakwaters, protecting coastlines from flooding and erosion, while at the same time providing habitat for marine species. These artificial reefs also act as scour protection for offshore wind turbines, boosting biodiversity and rewilding the ocean (Reefy, 2024). Animal species such as fish, oysters and crustaceans (e.g. crabs, lobsters and shrimps), as well as plant and coral species are attracted to the artificial reefs because of their textured surfaces.

While scour protection is beneficial to both the wind turbines and the marine environment, not all wind turbines are equipped with scour protection. The use of scour protection and innovations, such as those from companies like Reefy, can help countries to make their wind farms more animal friendly. It should be noted that, although some work suggests that an ecosystem may be more thriving than before the installation of an offshore wind farm, site selection remains important to minimise the initial destruction of ecosystems.

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L.G. Janssen
December 5, 2024

4

Curtailment

This chapter provides information regarding the principle of curtailment. This information includes what curtailment is, the reason for curtailment and the policy of curtailment in countries surrounding the North Sea. Furthermore, the principle of curtailment is assessed using ethical reasoning using real-life data together with ethical assumptions.

4.1 The procedure of curtailment

As mentioned in section 1.2, the term curtailment refers to a reduction in the rotational speed of wind turbines, or alternatively, the complete halting of their operation (Degraer et al., 2024). The large-scale adoption of curtailment in order to minimise the fatalities of aerial species is seen as ethically justifiable, all else equal. The question thus arises as to what the outcome would be if not all else is equal. Curtailment in the North Sea is, not yet, adopted on a large scale. Although, the Netherlands is exploring the large-scale adoption of curtailment. The Netherlands is the first country ever to curtail offshore wind farms for the sake of bird lives and currently the only country to curtail offshore wind farms in the North Sea. Surrounding countries of the North Sea like France and Germany are testing curtailment in the Mediterranean Sea and Baltic Sea respectively. Belgium, Denmark, Norway and the United Kingdom are not curtailing offshore wind farms in the North Sea or anywhere else to avoid bird collisions whatsoever. Reasons for not implementing curtailments are for example as offshore wind farms are out of the way of important bird migration routes, there is incentive, yet still in the planning phase, or just because there are no plans in the near future as it is not yet seen as a necessity (Eneco, 2023; Degraer et al., 2024; Noordzeeloket, 2023).

4.2 Lack of curtailments

It is not the policy of Belgium, Denmark, Norway or the United Kingdom to curtail offshore wind farms in the North Sea or elsewhere in order to avoid bird collisions. The rationale behind the lack of curtailments has two reasons. Firstly, offshore wind farms are not situated in close proximity to significant bird migration routes, which presents minimal disruption. Secondly, there is currently no immediate need for such measures, as there are no concrete plans in place (Degraer et al., 2024).

4.3 Procedure of curtailment by the Netherlands in the North Sea

In the second semester of 2023, the Netherlands has implemented a curtailment measurement procedure for the first time on offshore wind farms in the North Sea. The procedure is initiated when a predetermined bird activity threshold is surpassed. The curtailment measurement procedure is currently in place between 15 February and 31 May, and also between 15 August and 30 November. In this section, the following stakeholders are introduced: TenneT, Ministry of Economic Affairs and Climate and Rijkswaterstaat. TenneT is the Dutch transmission system operator for electricity and gas. TenneT is responsible for ensuring the optimal functioning of the high-voltage transmission network and the transportation of gas in accordance with the established operational plan.

The Ministry of Economic Affairs and Climate Policy is the governmental department with the responsibility of formulating and implementing policies related to the Dutch economy, energy, and climate. Rijkswaterstaat is the Dutch government agency with the responsibility of managing the national infrastructure related to water, roads, and public works. The curtailment measurement procedure is outlined as follows:

1. **Prediction**. A forecast of a mass migration of birds is indicated daily two days in advance, during Autumn and Spring.
2. **Alarm or no alarm**. There are two possible outcomes:
   a. *Alarm*. The model indicates that the bird density *exceeds* the threshold.
   b. *No alarm*. The model indicates that the bird density *is below* the threshold.
3. **Message stakeholders**. On a daily basis, the model automatically transmits a message containing the bird migration forecast to the relevant parties
4. **Supply security analysis**. There are two possible outcomes:
   a. *Go*. TenneT advises the Ministry of Economic Affairs and Climate that offshore wind farms can be safely stopped.
   b. *No Go*. TenneT advises the Ministry of Economic Affairs and Climate *not* to allow offshore wind farms to be shut down.
5. **Decision Ministry of Economic Affairs and Climate**. There are two possible outcomes:
   a. *Shutdown decision*. The Ministry of Economic Affairs and Climate decides to shut down the wind farm.
   b. *No shutdown decision*. The Ministry of Economic Affairs and Climate decides *not* to shut down the wind farm.
6. **Rijkswaterstaat (RWS) imposes the shutdown of an offshore wind farm**. The Ministry of Economic Affairs and Climate mentions date, start and end times of the curtailment.
7. **Announcement**. An announcement of non-availability wind farms is published within one hour of shutdown.
8. **Curtailment initiated**. The owners of the offshore wind farms curtail the wind turbines at the designated time. Rotational speed is reduced to a minimum of two rotations per minute.
9. **Enforcement of RWS**. The RWS checks if the wind farms are curtailed according to protocol.
10. **Evaluation**. The RWS ensures data from bird radars are analysed to confirm the bird migration and prevention of possible fatalities.

(Noordzeeloket, 2023)

Mass migration of birds

Note that in step 1, the prediction bullet point, the term 'mass migration of birds' is outlined. According to Noordzeeloket (2023), a mass migration of birds is when a minimum of 500 birds migrate per kilometre per hour (Van Bemmelen, de Groeve, & Potiek, 2022). The variable of birds per kilometre per hour is measured in accordance to the following procedure. It is assumed that a virtual line of one kilometre is situated somewhere on the North Sea. When a bird crosses this line, it is detected by bird radars. If, in one hour, more than 500 birds cross this virtual line, the threshold is exceeded and curtailment is initiated (Van Bemmelen et al., 2022; Noordzeeloket, 2023). This measurement of migration is conducted using vertical radars. Another possibility to measure bird migration flux is done by horizontal radars, which is elaborated on below.

Horizontal versus vertical radars

Horizontal radars work differently compared to vertical radars as there is a need for different variables, e.g. ground speed of the migrating birds and track directions. Using these different variables calculations can be made when and where birds are located at different times, thus it can be calculated when the threshold is exceeded (Bradaric, 2022). Whether using vertical or horizontal radars is better has been determined by Kraal et al. (2023). Both vertical and horizontal radars contain pros and cons. However, in Autumn 2022, when data from experts (e.g. wind direction, wind speed, weather forecast, etcetera) and the vertical radar data forecasted high migration peaks, the horizontal radar data did not, resulting in a flawed data model and rejecting the horizontal radar data (Kraal et al., 2023).

The Minister of Climate Policy and Green Growth, can make the decision to initiate curtailment from 500 birds per kilometre per hour onwards. The Minister of Climate Policy and Green Growth can also advise offshore wind farm operators to curtail from 153 birds per kilometre per hour. If the Minister of Climate Policy and Green Growth advises this threshold of 153 birds per kilometre per hour, the offshore wind farm operators are not obliged to curtail (Van Bemmelen et al., 2022). In order to provide a more detailed and structured overview of the aforementioned process, a flowchart has been constructed, as illustrated in figure 4.1.

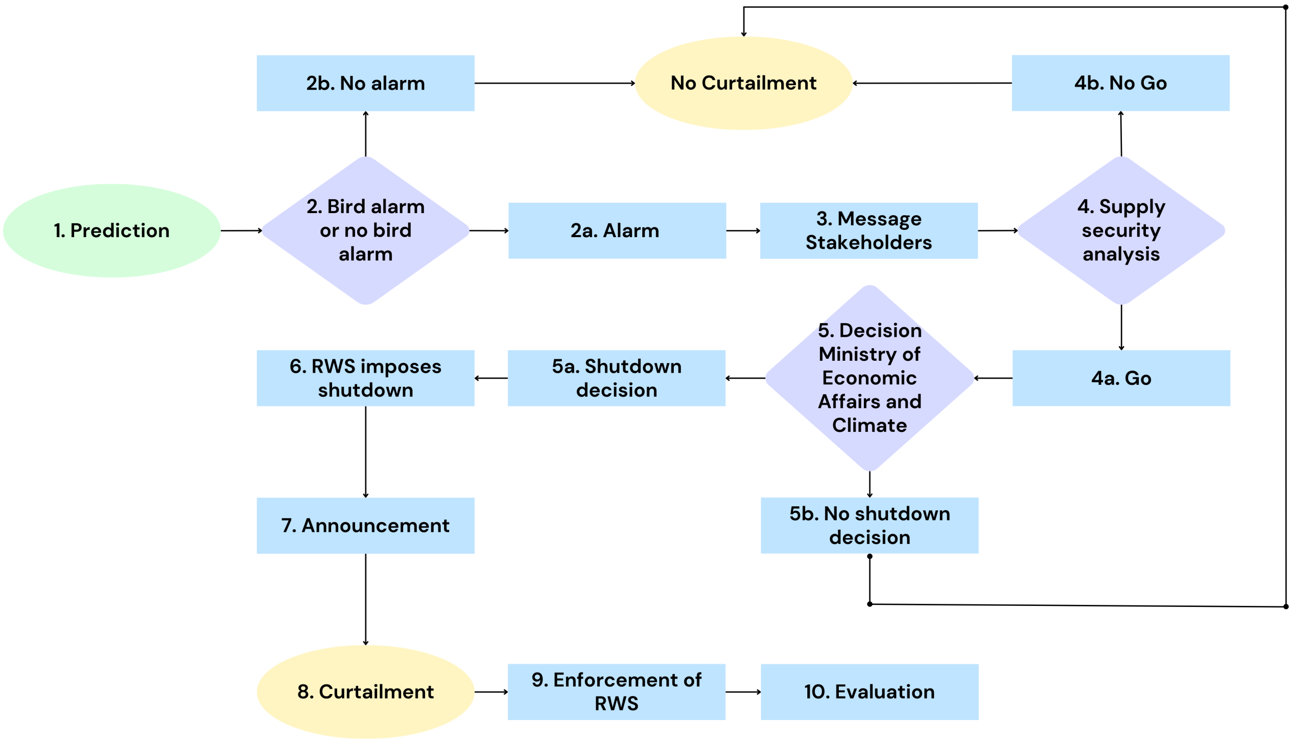

Figure 4.1: Flowchart decision-making process of curtailment in the Netherlands

Decision-making process in advance

As the initial decision-making process bullet point indicates, a prediction of the migration is required two days in advance. This is due to the fact that the entire decision-making process can be a significant undertaking, and therefore requires sufficient time for its completion. Another reason why curtailment cannot be initiated immediately is because the energy grid operator, in this case TenneT in the Netherlands, requires a sufficient period of time to act. The model allows for the early prediction of significant migration events, thereby affording grid operator TenneT a considerable time to guarantee the stability of the high-voltage grid. In the event that curtailment is only possible by the use of other energy sources, in this case natural gas, than the grid operator will have sufficient time to guarantee energy supply by purchasing enough natural gas for that period of time (Degraer et al., 2024; Noordzeeloket, 2023).

Grid stability issues

In the event of grid stability issues caused by an excess of energy, curtailment procedures are initiated. In the event that there is no migration of birds and the wind speed exceeds the initial forecast, the offshore wind farms will produce more energy than the agreed amount. As a result, the stability of the energy grid would be compromised, leading to curtailment. In the event that curtailment is not initiated resulting in instability of the energy grid, costs are charged. These costs are referred to as imbalance costs. However, there is an opportunity to avoid these charges by utilising curtailment, which can result in cost savings (Damste, 2023; Degraer et al., 2024).

Rising problems of curtailment

There are however a few problems with the decision-making process of curtailment regarding the prevention of bird mortalities. As mentioned by Noordzeeloket (2023), curtailment of wind turbines can result in CO_2 pollution due to energy production using natural gas instead of green energy using wind turbines. Another problem with the decision-making process is that curtailment to avoid bird mortalities is only initiated during the nights, and not during the day. The rationale behind the curtailment process being initiated exclusively during nighttime hours is twofold. Firstly, birds are known to migrate more frequently during nocturnal hours (Degraer et al., 2024). Secondly, the energy demand is significantly higher during daytime hours compared to nighttime, necessitating less additional energy production during nighttime curtailment than daytime curtailment (Bahmanyar, Estebsari, & Ernst, 2020; Torriti, 2016). The curtailment procedure is also only initiated during Autumn and Spring, as migration of birds are during these periods. And lastly, as mentioned in section 3.2.3 not only birds migrate during Autumn and Spring but also bats migrate during these periods. In the decision-making process bat migration is not taken into account. The latter can be implemented into the decision-making process as follows:

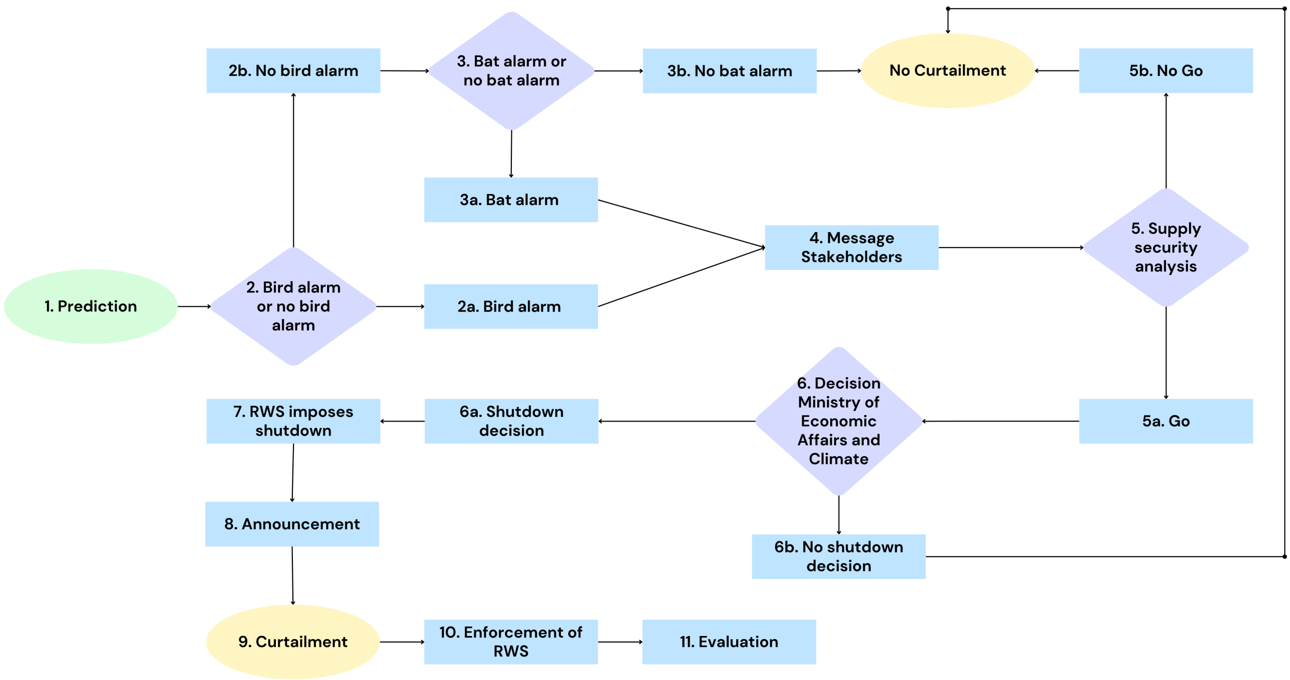

Figure 4.2: Flowchart decision-making process of curtailment in the Netherlands including bats

Note that as for the prediction of bird migration, another model needs to be made in order to predict bat migration. The bird migration model is currently modelled by a PhD student of the University of Amsterdam (UvA) using weather data and bird detection radars (Hoekstra, 2024; Vogelbescherming Nederland, 2023). In addition to birds, the bird detection radar is also capable of identifying bats and insects (Hoekstra, 2024). It is worth noting that bat detection extraction has only recently become reliable. The bird migration model was, as the name suggests, not designed for bat migration prediction. Consequently, bat migration was excluded from the project. There may be scope to include bat migration models for the curtailment measurement procedure, but there are few radars that can detect bats sufficiently to draw conclusions about bat migration. It would be prudent to gather more data over a longer period of time before drawing any conclusions about bat migration (Hoekstra, Personal communication, September 24 2024). As bats migrate during the same period as birds do, the curtailment procedure in the Netherlands may already result in reduced bat mortalities while simultaneously applying the curtailment measurement procedure for reducing bird mortalities.

In addition to the lack of bat mortality prevention, the question of why it is or is not justifiable to use natural gas to generate electricity during curtailment. As mentioned, the use of natural gas results in CO_2 emissions, rather than reducing emissions using offshore wind farms but consequently the death of birds, is the question that should be addressed. In section 4.4 a hypothetical curtailment scenario is considered.

4.4 Hypothetical curtailment scenario

This section provides background information on how energy supply works, followed by background information on an offshore wind farm in the Netherlands, named ‘Borssele’. A hypothetical scenario is then created for this offshore wind farm in order to calculate certain values.

4.4.1 Understanding how an energy grid operates

The following section provides an overview of the operational principles of an energy grid. The term ‘peak demand’ is used to describe the point at which the aggregate power consumption from the electrical grid reaches its maximum level. A peak demand occurs for example during the summer when the majority of the households are using air conditioning to cool the indoor temperature of their houses. The consequence of this is that the demand for energy rises to a level that cannot be met by the available supply. However, in order to prevent power outages, peaker plants are employed. Peaker plants are gas-fired power stations that can be rapidly activated and deactivated. This results in the generation of rapid power, but at high costs. In contrast, coal-fired power stations (i.e. base load power stations) are unable to provide such a rapid response due to their inability to change power generation quickly. This results in conventional normal base load/coal-fired power stations having high fixed costs and low variable costs, while peaker plants have low fixed costs and high variable costs (Fields, 2023; Johnson & Keith, 2004; Meltek, 2020). It is evident that if there is no peak demand at all, thus an off-peak, curtailment of not only necessary as energy is not needed, but also ethically justifiable as no sacrifices need to be made in order to save more bird lives compared to when an offshore wind turbine is in operation.

4.4.2 Offshore wind farm ‘Borssele’

Borssele is an offshore wind farm located 23 kilometres from the shore. The offshore wind farm consists of five sites, namely Borssele I, II, III, IV and V. Borssele I and II combined is called ‘Ørsted’, Borssele III and IV combined is called ‘Blauwwind’ and Borssele V is called ‘Two Towers’. Ørsted consists of 94 turbines, Blauwwind consist of 77 turbines and Two Towers consists of, as the name suggests, two turbines. Thus the total amount of the Borssele wind farm consists of 173 wind turbines. Ørsted’s, Blauwwind’s and Two Towers’ energy capacity is 752 MW, 731.5 MW and 19 MW respectively, resulting in 1,502.5 MW or 1.5 GW. The total area of the Borssele offshore wind farms is 344 km^2 (Borsboom, 2021; Ministry of General Affairs, 2024; Noordzeeloket, 2021).

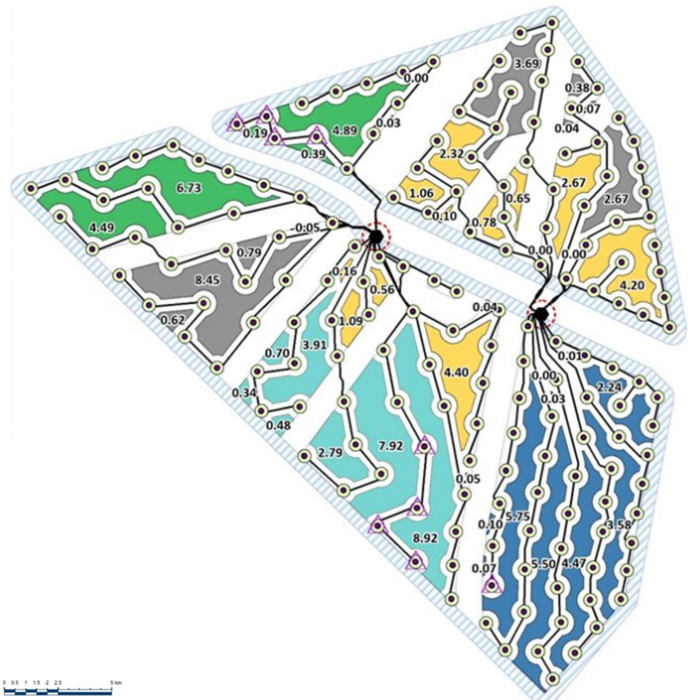

Figure 4.3: Wind farm Borssele (Windopzee, 2020)

The illustration of figure 4.3 depicts the offshore wind farm Borssele. The green shaded areas represent areas designated for nature development, the light blue shaded areas are for mariculture, the dark blue areas are for passive fisheries, the yellow shaded areas are for renewable energy generation (solar panels), and the grey shaded areas are for innovations that have yet to be determined (Windopzee, 2020).

4.4.3 Hypothetical curtailment scenario

Next, a hypothetical curtailment scenario is constructed to derive real-life measurements. In this hypothetical curtailment scenario assumptions are made, and real-life variables are used. The real-life variables are from the night of October 19th to October 20th, 2022. During this night an average bird migration flux (or Mean Traffic Rate (MTR)) was measured of 1,386 birds per kilometre per hour. The average migration bird flux had a duration of eight consecutive hours, with a bird migration peak of 2,858 birds per kilometre per hour (Kraal et al., 2023). It should be noted that these bird fluxes were measured before the Netherlands started the process of initiating curtailment. As these high bird migration fluxes are likely to occur again in the future, (i.e. if similar conditions were to happen again) these amounts are used for the following hypothetical curtailment scenario.

"Imagine there are 1,386 birds per kilometre per hour migrating over the North Sea in the Netherlands. The decision-making process of curtailment in the Netherlands is initiated. The offshore wind farm Borssele is curtailed for eight hours during the night, from 22:00 until 06:00. There is no peak demand. However, the loss of energy from the wind turbines needs to be compensated using natural gas in order to meet demand. This is necessary as grid operator TenneT needs to guarantee the stability of the high-voltage grid. There is a trade-off, namely more CO_2 emissions, but the prevention of bird deaths. How can we justify the curtailment?"

- *Hypothetical curtailment scenario* adapted with information from Kraal et al. (2023)

Note that for the hypothetical curtailment scenario, the vertical radar detection method is used, as described in 4.1. According to Krijgsveld, Akershoek, Schenk, Dijk, and Dirksen (2009) 0.14% of all bird lives are saved when wind turbines are inactive, this means that one in 714 birds will collide with a wind turbine, as 714 * 0.14% = 1 bird. It should be noted that this is the aggregate percentage of both day- and nighttime, and measured during winter and autumn, nevertheless in this hypothetical curtailment scenario this value will be assumed.

In order to determine the number of birds that fly through the Borssele wind farm, it is first necessary to establish the size of Borssele. As mentioned before, wind farm Borssele consists of 173 wind turbines and has an area of 344 km^2. As seen in figure 4.3, Borssele is almost triangle shaped, to make calculations easier, it is assumed that Borssele's area is an equilateral triangle, meaning all sides are equal.

Assumptions for the hypothetical curtailment scenario of offshore wind farm Borssele

- Borssele is almost triangle shaped, to make calculations easier, it is assumed that Borssele's area is an equilateral triangle, meaning all sides are equal;
- Taking the area of Borssele of 344 km^2, then each side is equal to approximately 28.2 kilometres;
- It is also assumed that the bird migration is perpendicular to one of the sides of the equilateral triangle area of Borssele. See figure 4.4 as an illustration.

It should be noted that there is uncertainty. Real-life data is used and calculated assumptions are made. However, there is reason to believe the data is correct due to the fact different approaches are compared, and data is triangulated in order to check that at the very least, the orders of magnitude are in the same order.

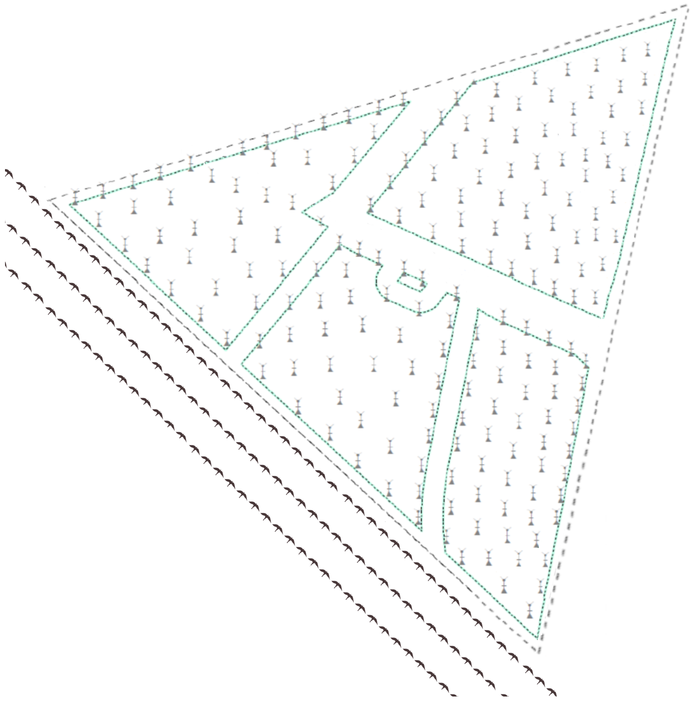

Figure 4.4: Wind farm Borssele as an equilateral triangle

It is important to note that birds that fly through the central area of the region are more likely to encounter wind turbines and, as a result, are more likely to be struck by the wind turbines. Vice versa, birds that fly through either side of the area are less likely to be struck by a wind turbine, as they fly through fewer wind turbines. In other words, the number of bird mortalities is higher in the central area of the wind farm than in the outer areas of the Borssele wind farm.

In this hypothetical curtailment scenario an average will be taken, meaning that no distinction will be made in the calculation that a higher mortality rate will occur in the middle of the offshore wind farm compared to the outer sides. One might argue that the following calculations do not contain the number of wind turbines in the bird mortalities, and more wind turbines mean more bird mortalities. However, since wind turbines are located a designated and mandatory distance from each other, the number of wind turbines is already included into the area of the offshore wind farm. Since the area is given an hypothetical equilateral triangle shape, thus all sides begin equal lengths, the number of wind turbines is accounted for in the calculations.

Assumptions for the hypothetical curtailment scenario of offshore wind farm Borssele

- 1,386 birds migrate per kilometre per hour (derived from real-life data);
- Borssele has equal lengths of 28.2 kilometres.

With the previous mentioned assumptions, it can be calculated how many birds fly over Borssele per hour, which is:

$$1,386 \left[\frac{\text{birds}}{\frac{km}{h}}\right] * 28.2\ [km] = \textbf{39,085} \left[\frac{\textbf{birds}}{\textbf{h}}\right] \tag{4.1}$$

As the curtailment period lasts eight hours, the following number of birds are estimated to fly over the Borssele offshore wind farm:

$$39,085 \left[\frac{\text{birds}}{h}\right] * 8\ [h] = \textbf{312,682 [birds]} \tag{4.2}$$

This indicates that during the eight-hour curtailment period, approximately 312,682 birds would fly over the Borssele offshore wind farm. In light of the aggregate percentage of prevented bird mortalities, which is estimated to be 0.14%, according to Krijgsveld et al. (2009), the total number of bird mortalities prevented is:

$$312,682 \text{ [birds]} * 0.14 \text{ [\%]} = \textbf{438 [birds]} \tag{4.3}$$

Curtailment decision

It is important to note that a curtailment duration of eight hours is a relatively long period, and a number of 1,386 birds per kilometre per hour is a relatively high bird migration flux. Although this example may appear extreme, the variables are derived from real-life data from 2022, making it a plausible scenario that may occur again in the future. To put the hypothetical scenario in perspective: (1) according to Ferris (2022), 17 birds per wind turbine per year are killed, (2) according to Zimmer (2024), an average of five birds per wind turbine per year are killed and (3) according to Sanou (2024), 19 birds per wind turbine per year are killed. This is an average of 14 bird deaths per wind turbine per year. In this hypothetical curtailment scenario, the offshore wind farm Borssele would be responsible for 2,422 bird deaths in one year. Consequently, in this hypothetical curtailment scenario, the prevented bird deaths are approximately 18% (namely 438/2422) of all bird mortalities of Borssele over a year in only eight hours. Nevertheless, in this scenario, the Netherlands would initiate curtailment for the offshore wind farm Borssele. The curtailment procedure would, hypothetically, save 438 birds. During these eight hours of curtailment, the Netherlands is willing to curtail.

Consequences of curtailment

The question that follows is the magnitude of the CO_2 emissions generated by natural gas, the extra costs by using natural gas and lastly the costs per avoided bird deaths during the eight hours of curtailment. The Blauwwind site of the Borssele offshore wind farm generates approximately 3 TWh of energy every year (Borsboom, 2021; Wind & Waterworks, 2023). As Blauwwind's power generation is 731.5 MW, and Borssele's total power generation is 1.5 GW, approximately twice the amount of Blauwwind's energy generation, it is assumed that Borssele's total energy generation per year is 6 TWh. To keep the calculation simple it is assumed that Borssele generates a continuous amount of energy every hour. In the next equation the energy generation in one year is converted to power generation per day.

$$\frac{6.0 \; [TWh]}{365 \text{ [days]}} = 0.0164 \; [TWh] = \textbf{16.4 [GWh]} \tag{4.4}$$

It is assumed that Borssele generates a continuous amount of power on an hourly basis. Consequently, during periods of curtailment, the following amount of power is not produced:

$$\frac{16.4 \; [GWh]}{24 \; [h]} * 8 \; [h] = \textbf{5.5 [GWh]} \tag{4.5}$$

This means that by curtailing Borssele for eight hours, 5.5 GWh worth of energy needs to be generated by natural gas. According to the Central Statistical Office (2024c), one m^3 of natural gas accounts for 35.17 MJ worth of energy. In order to determine the amount of natural gas required to produce 5.5 GWh of power, it is necessary to convert the units to ensure consistency. This is achieved by first converting the gigawatt-hours (GWh) to megajoules (MJ), as follows:

$$1 \; [GWh] = \; 1 \; [GW] * 1 \; [h] = 1,000,000,000 \; [W] \; * \; 3,600 \text{ [sec]} = \textbf{3,600,000 [MJ]} \tag{4.6}$$

As one GWh of energy is equal to 3,600,000 MJ of power, then 5.5 GWh of energy is equal to:

$$3,600,000 \; [MJ] * 5.5 \; [GWh] = \textbf{19,800,000 [MJ]} \tag{4.7}$$

As mentioned, one m^3 of natural gas accounts for 35.17 MJ worth of energy, then 19,800,000 MJ equals:

$$\frac{19,800,000\ [MJ]}{35.17\ [\frac{MJ}{m^3}]} = \mathbf{565{,}714\ [m^3]} \tag{4.8}$$

According to the Environmental Protection Agency (2024) and Zijlema (2019) one m^3 emits approximately 1.9 kilograms of CO_2. Knowing the amount of m^3 of natural gas required, it is possible to determine the amount of kg of CO_2 that will be emitted:

$$565,714\ [m^3] * 1.9\ \left[\frac{kg}{m^3}\right] = 1,074,857\ [kg] \approx \mathbf{1{,}075\ [tons]} \tag{4.9}$$

Thus, by curtailing for eight hours, assuming the energy production for a whole year is constant per hour, the Netherlands needs to use 565,714 m^3, which results in approximately 1.1 million kilograms of CO_2, in order to meet the demand of energy which is not produced by the wind turbines. Over half a million m^3 of natural gas, and thus also 1.1 million kg of CO_2 seems like an absurd amount. Next, this will be put in perspective. According to the Central Statistical Office (2024b) and Times (2024) the Netherlands has consumed 30 billion m^3 of natural gas in 2023. This includes energy generation, industry, agriculture and the built environment. Of this 30 billion m^3, 7.14 billion m^3 was used for energy generation. This means that 565,714 m^3 compared to 7.14 billion m^3 of gas is:

$$\frac{565,714\ [m^3]}{7,140,000,000\ [m^3]} * 100\% = \mathbf{0.0079\ \%} \tag{4.10}$$

So, by curtailing for eight hours, assuming the energy production for a whole year is constant per hour, the Netherlands would use 0.0079% of their total electricity energy consumption of one year.

Knowing the amount of CO_2 emissions, and the number of birds saved, it is possible to determine how many tons of CO_2 the Netherlands is, hypothetically, willing to emit per saved bird:

$$\frac{1,074,857\ [kg]}{438\ [birds]} = 2,454\ \left[\frac{kg}{bird}\right] \approx \mathbf{2.5}\ \left[\frac{\mathbf{tons}}{\mathbf{bird}}\right] \tag{4.11}$$

This means that in this hypothetical scenario, the Netherlands is willing to emit 2.5 tons of CO_2 in order to save one bird. Note that this calculation is for 1,386 birds per kilometre per hour, this number is almost three times the threshold the Netherlands is currently curtailing for. If the threshold is exceeded by zero, thus 500 birds per kilometre per hour, the Netherlands is still curtailing. However, the tons of CO_2 emitted per bird are almost tripling. Vice versa, if 2,000 birds are migrating per kilometre per hour, the tons of CO_2 per bird are lower. Calculations regarding different bird migration fluxes can be found in appendices A and B. The calculation found in appendix A regards a hypothetical curtailment scenario of exactly the threshold, thus a bird migration flux of 500 birds per kilometre per hour. The calculation found in appendix B regards a hypothetical curtailment scenario of a bird migration flux of 1,000 birds per kilometre per hour, which is twice the threshold.

Costs of curtailment

The next step is to determine how much the amount of 565,714 m^3 of natural gas costs. According to the Title Transfer Facility (2024), in the last 12 months the average gas price of natural gas was 34.545 €/MWh. As curtailment would mean a loss of 5.5 GWh, which is equal to 5,500 MWh of energy, than this amount of energy is worth:

$$5,500\ [MWh] * 35.545\ \left[\frac{€}{MWh}\right] = €189,997.5 \approx \mathbf{€190{,}000} \tag{4.12}$$

Consequently, the Netherlands would face a cost of €190,000 for a curtailment of eight hours. It should be noted that the procedure for measuring curtailment is likely to be more costly due to the additional costs associated with time and capital, given the involvement of multiple stakeholders. Nevertheless, taking this hypothetical scenario and the initiation of curtailment in the Netherlands into account, the following monetary value is placed on a bird's life:

$$\frac{190,000\ [\text{€}]}{438\ [\text{birds}]} = 433.8\ \left[\frac{\text{€}}{\text{bird life}}\right] \approx \mathbf{434}\ \left[\frac{\textbf{€}}{\textbf{bird life}}\right] \tag{4.13}$$

Concluding, the Netherlands has a curtailment measurement procedure on offshore wind farms in the North Sea. This means that when a threshold of 500 birds per kilometre per hour is exceeded during migration periods and during the nights, curtailment of an offshore wind farm may be initiated. In this hypothetical scenario the offshore wind farm Borssele is curtailed for eight consecutive hours due to a high migration flux of birds, namely 1,386 birds per kilometre per hour. The Netherlands is willing to make the following trade-offs in this hypothetical scenario. (1) The Netherlands is willing to 'pay' €434 for a single bird life. (2) Consequently, this curtailment scenario will cost the Netherlands a total of €190,000. (3) The Netherlands is willing to emit 2.5 tons of CO_2 in order to save one bird's life.

4.5 SWOT analysis of curtailment

The hypothetical scenario mentioned in section 4.4, is a scenario which may occur in the Netherlands. The fact that this might occur does not immediately make it justifiable. Thus, the question remains why, or why not, it is justified to emit 2.5 tons of CO_2 and pay €434 to save one bird's life. The justification for curtailment is examined in more detail below, by looking at the pros and cons of curtailment.

In order to determine whether curtailment of offshore wind farms in the North Sea is justifiable, a SWOT analysis is conducted. SWOT is an abbreviation for strengths, weaknesses, opportunities and threats. A SWOT analysis is a way to evaluate a project or a company. The strengths and weaknesses are factors of a project or a company and are referred to as 'internal factors'. Whereas the opportunities and threats are factors outside a project or a company, which are referred to as 'external factors'. The strengths and opportunities are identified as factors that are helpful, whereas the weaknesses and threats are classified as factors that are harmful. The importance of a SWOT analysis lies in the fact that it enhances situational awareness which supports both strategic planning and decision making processes (Parsons, 2024; Renault, 2024; Shewan, 2024).

A figure of a template of a SWOT analysis is shown (figure 4.5), whereafter the strengths, weaknesses, opportunities and threats are mentioned. Different strengths, weaknesses, opportunities and threats are abbreviated by S1, S2, S3 & W1, W2, W3 & O1, O2, O3 & T1, T2, T3 respectively.

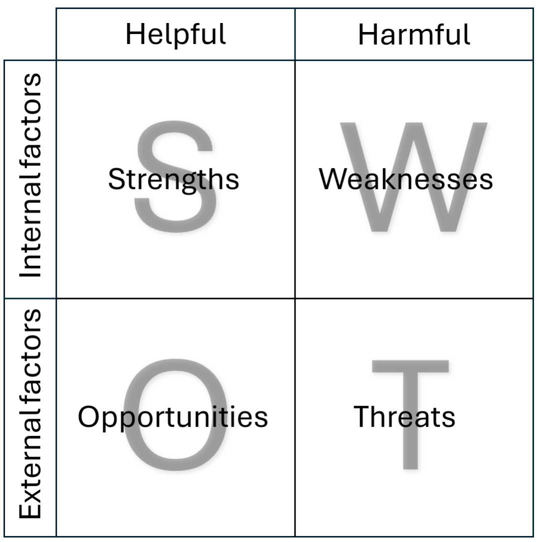

Figure 4.5: SWOT analysis template

4.5.1 Strengths of curtailment

This section identifies the strengths of curtailment.

- **S1: grid stability:** as mentioned in section 4.1, when the energy supply exceeds energy demand, the grid stability is compromised. Instability to the energy grid can lead to blackouts (i.e. power outages). Blackouts can lead to houses having no electricity or hospitals not being able to treat sick people (Marsh, 2023). By curtailing offshore wind farms, overloading the grid can be prevented and stability can be ensured.
- **S2: prevention of negative energy prices:** by curtailing offshore wind turbines negative energy prices are prevented. When energy generation is too high for the demand negative energy prices occur. At first glance, negative energy prices may not appear to be a significant issue, but the prevention of negative energy prices through the curtailment of offshore wind turbines results in a more balanced energy market, which in turn encourages greater competition and benefits the consumer.
- **S3: reducing bird and bat mortalities:** as mentioned before, by temporarily curtailing offshore wind turbines, i.e. halting their operation entirely or reducing the speed to two rotations per minute prevents birds and bats from colliding with wind turbines. This reduces bird and bat mortality and contributes to biodiversity.

4.5.2 Weaknesses of curtailment

This section identifies the weaknesses of curtailment.

- **W1: higher CO_2 emissions:** when curtailment is initiated due to a low energy demand, gas peaker plants and coal stations continue to emit CO_2 while green energy is not being produced. Ideally, the opposite scenario should occur, whereby a gas peaker plant or coal power station, for instance, would be shut off instead of an offshore wind farm to meet the energy demand. However, due to the higher costs involved, this is not a common practice. Nevertheless, curtailment in this scenario is an inefficient use of renewable energy and still emitting CO_2.
- **W2: economic losses:** when curtailment is initiated due to an oversupply of energy on the grid, green energy is essentially 'wasted'. Potential income of wind farm operators is lost due to not-generated energy. Some offshore wind projects' financial viability (i.e. ability to generate cash flow) is based on energy production. By curtailment this is affected due to not generating energy resulting in a lower cash flow. Lower energy production can also result in lower investor's confidence in offshore wind farm projects as offshore wind farms' cash flow is.
- **W3: impact on energy transition goals:** consequently due to higher CO_2 emissions, energy transition goals are slowed down. Given the crucial role offshore wind farms play in the decarbonisation of the planet, it is imperative to generate as much green energy as possible in order to mitigate the warming of the earth. The initiation of curtailment procedures has the effect of slowing down the pace of energy transition and underutilisation of offshore wind capacity.

4.5.3 Opportunities of curtailment

This section identifies the opportunities of curtailment.

- **O1: development of sustainable energy sources:** the restriction of offshore wind energy could offer opportunities for advancement of other sustainable sources such as nuclear and solar power. Obviously solar power is only possible to use as a replacement of wind energy if an offshore wind farm is curtailed during the day.
- **O2: development of energy storage technologies:** a focus on grid stability can facilitate innovation in energy storage technologies, such as batteries and hydrogen, which could be essential for maintaining a stable energy supply in the future.

- **O3: improved planning and grid integration:** the curtailment of offshore wind farms can facilitate more effective long-term planning of energy infrastructure. This could mean enabling optimal utilisation of the power grid.

4.5.4 Threats of curtailment

This section identifies the threats of curtailment.

- **T1: falling behind competitors:** companies that curtail their offshore wind farms could lose their competitive advantage in the transition to clean energy over companies that do not curtail their offshore wind farms. This regards only the factor of energy generation, companies that do curtail may have an advantage due to being more animal-friendly.
- **T2: increased dependence on fossil fuels:** the restriction of wind farms may result in an increased dependence on fossil fuels, which could have significant environmental implications, which leads to CO_2 emissions.
- **T3: loss of credibility:** another consequence of curtailing wind farms is the potential loss of (inter)national credibility. The cancellation of wind energy projects can have the effect of undermining international climate agreements. This could result in damaging a company's reputation as a leader in renewable energy.

It is helpful to know which strengths, weaknesses, opportunities and threats curtailments have, although rating whether reducing bird and bat mortalities is more important than preventing higher CO_2 emissions remains an ethical question. There is a need for another approach to answer this ethical question.

4.6 Disability adjusted life years

As mentioned in 4.5, there is a need for another framework to determine how CO_2 emissions versus bird and bat mortalities can be assessed. One framework which is used in the public health sector is the use of disability adjusted life years (DALYs). A DALY is defined as an equivalent value representing one year lost to a healthy life of a human being. The equivalent value is quantified in the overall burden of a disease. DALYs are used to establish a reasoned approach to balancing different types of health effects, whether they result in death or illness. Therefore, DALYs combine two elements: years lost due to premature death or years of life lost (YLLs) and years lived with an illness or disability (YLDs) (Moini, Badolato, & Ahangari, 2020; Sreenivas, 2023). One DALY represents one year of healthy life lost. One DALY can be calculated as follows.

$$DALYs = YLLs + YLDs \tag{4.14}$$

In order to provide a more concrete example, a thought experiment is introduced.

"Imagine 'Person A' passes away due to an injury or a disease. For example: Person A dies due to a car accident at the age of 50, whereas the life expectancy is 80 years. Imagine 'Person B' having a disability. For example: Person B lost his or her hearing for the last 20 years of his or her life. Losing his or her hearing for the last 20 years of his or her life limits Person B's ability to work and enjoy a happy life to the fullest. What is the amount of the disability adjusted life years (DALYs) in this thought experiment?"

- DALY thought experiment

In order to determine the DALYs of this thought experiment, it is first necessary to determine the YLLs and YLDs. The calculation of the YLLs is relatively straightforward. In this case, Person A dies at the age of 50 due to a car accident, whereas the life expectancy is 80 years. Therefore, Person A has lost the following years of his or her life:

$$YLLs = 80 \text{ [years]} - 50 \text{ [years]} = 30 \text{ [years]} \tag{4.15}$$

Thus, the number of YLLs is 30 years. In order to determine the YLDs, it is necessary to introduce another variable. In the context of DALYs, the severity of different disabilities varies. The disability weights are obtained by means of data obtained from surveys (Charalampous, Polinder, Wothge, Von Der Lippe, & Haagsma, 2022; Liu et al., 2023; World Health Organization, 2004). Different conditions are assigned to different disability classes with corresponding disability weights by the World Health Organization (2004). The data are presented in table 4.1.

Disability class	Disability weights	Conditions
I	0.00 - 0.02	Stunting from malnutrition, schistosomiasis infection and lasting scars from burns (covering less than 20% of the body).
II	0.02 - 0.12	Examples of such conditions include a finger amputation, asthma, tooth loss, the removal of a breast (mastectomy), significant anaemia and urinary stress incontinence.
III	0.12 - 0.24	Health issues include chest pain (angina), HIV that has not yet progressed to AIDS, infertility, problematic alcohol use or dependence, partial vision loss (worse than 6/18 but better than 3/60) and rheumatoid arthritis.
IV	0.24 - 0.36	Conditions include arm amputation, heart failure, hearing loss (deafness), substance addiction, Parkinson's disease and tuberculosis.
V	0.36 - 0.50	Examples of conditions include bipolar disorder, mild cognitive impairment, neurological complications from malaria and recto-vaginal fistula.
VI	0.50 - 0.70	Health conditions include untreated AIDS, Alzheimer's disease and other forms of dementia, total blindness and down syndrome.
VII	0.70 - 1.00	Severe conditions such as psychotic episodes, major depression, intense migraines, paralysis of all four limbs (quadriplegia) and end-stage cancer.

Table 4.1: Disability classes for the Global Burden of Disease (World Health Organization, 2004)

Hearing loss, or deafness, is assigned in disability class IV, with a disability weight ranging from 0.24 - 0.36. To simplify this thought experiment, the average will be taken of this disability weight:

$$\text{Disability weight} = \frac{0.24 + 0.36}{2} = \mathbf{0.30\ [\text{-}]} \quad (4.16)$$

This indicates that the severity of Person B's hearing loss is 0.30, on a scale from 0.00 to 1.00. Person B is unable to fully enjoy their life to the extent that they would otherwise be able to by 30%. Consequently, the YLDs to obtained in the following equation:

$$YLDs = 0.30 * 20\ [\text{years}] = \mathbf{6}\ [\textbf{years}] \quad (4.17)$$

In the thought experiment where Person A dies 30 years prematurely, the YLLs is 30 years. The YLDs due to the hearing loss of Person B is six years. This means that the DALYs from this thought experiment is:

$$DALYs = YLLs + YLDs = 30\ [\text{years}] + 6\ [\text{years}] = \mathbf{36}\ [\textbf{years}] \quad (4.18)$$

Concluding, in the thought experiment the amount of DALYs is 36 years. This means that 36 years of healthy life is lost over Person A and Person B.

The reason DALYs can help to answer the question whether CO_2 emissions versus bird and bat mortalities matter more is due to the fact that there are estimates of DALYs lost compared to tons of CO_2. According to Eckelman and Sherman (2017), the United States' healthcare sector emitted 614 million tons of greenhouse gases in 2013. The associated health impacts in DALYs in the United States ranged from 123,000 to 381,000. In the study conducted by L. Tang, Furushima, Honda, Hasegawa, and Itsubo (2018), three scenarios were investigated in relation to global warming and their corresponding CO_2 emissions. The three scenarios are referred to as Shared Social-economic Pathways (SSPs), which are climate change scenarios. The three distinct scenarios, designated as SSP1, SSP2, and SSP3, are associated with average DALYs per ton of CO_2 emitted of 0.0013, 0.0015, and 0.0020, respectively. The SSP1, SSP2 and SSP3 scenarios assess the impact of different temperature rises on Earth. Yakar and Kwee (2020) estimated the DALYs associated with CO_2 emissions from airplane travel by the Radiological Society of North America (RSNA). The findings suggest that the total annual DALYs range from 51.4 to 79.0, which is estimated to be equivalent to 39,506 tons of emitted CO_2 by the RSNA. According to McAlister, Morton, and Barratt (2022) the global healthcare system is responsible for an estimated 3.06 million DALYs annually, which corresponds to 2.0 gigatons of CO_2 emissions. According to Romanello et al. (2023), the healthcare system is responsible for a total annual amount of DALYs of 4 million globally, taking 1.4 gigatons of CO_2 emissions into account. The information of this paragraph is summarised in table 4.2.

DALYs	**Tons of CO_2**	**DALYs/ton of CO_2**	**Average DALYs/ton of CO_2**	**Source & year**
123,000 - 381,000	614,000,000	0.00020 - 0.00062	0.00041	Eckelman and Sherman (2017) (Data from 2013)
-	-	0.0013, 0.0015 and 0.0020	0.0016	L. Tang et al. (2018) (Data from 2014)
51.4 - 79.0	39,506	0.0013 - 0.0020	0.00165	Yakar and Kwee (2020) (Data from 2017)
3,060,000	2,000,000,000	0.0018	0.0018	McAlister et al. (2022) (Data from 2021)
4,000,000	1,400,000,000	0.0029	0.0029	Romanello et al. (2023) (Data from 2020)

Table 4.2: DALYs per ton of CO_2 emitted

The data of table 4.2 is displayed from average $\frac{DALYs}{\text{Ton of CO}_2}$ from low to high. It would have been optimal for the values of the DALYs to be identical. Since the values are all within the same order of magnitude, the mean of the $\frac{DALYs}{\text{Ton of CO}_2}$ is sufficient for the purposes of this study. However, the following calculations are also assessed using the minimum and maximum amount of $\frac{DALYs}{\text{Ton of CO}_2}$, as can be seen in Appendix E. Taking the information of table 4.2 into account, the average $\frac{DALYs}{\text{Ton of CO}_2}$ is:

$$\frac{DALYs}{\text{Ton of CO}_2} = \frac{0.00041 + 0.0016 + 0.00165 + 0.0018 + 0.0029}{5} = \mathbf{0.00167} \left[\frac{\textbf{DALYs}}{\textbf{Ton of CO}_2}\right] \tag{4.19}$$

Next, this information is compared with the hypothetical scenario earlier mentioned in section 4.4. In equation 4.9, it is derived that the amount of tons emitted from the curtailment scenario is 1,075 tons of CO_2. As derived in equation 4.19 known that the amount of $\frac{DALYs}{\text{Ton of CO}_2}$ is 0.00167 and the amount of tons of CO_2 is 1,075, it can be determined how many DALYs the hypothetical curtailment scenario is responsible for:

$$0.00167 \left[\frac{DALYs}{\text{Ton of CO}_2}\right] * 1,075 \, [\text{tons of CO}_2] = \mathbf{1.80} \, [\textbf{DALYs}] \tag{4.20}$$

The hypothetical curtailment scenario is responsible for the loss of 1.80 DALYs. In order to determine what the monetary value of 1.80 DALYs is, it first needs to be determined what the monetary value of a single DALY is. According to the SSIM (2024), one DALY has a monetary value of €80,000 in the Netherlands. According to the study of Itsubo, Sakagami, Kuriyama, and Inaba (2012), one DALY has a monetary value of €113,000. According to another study, by Dong, Hauschild, Sorup, Rousselet, and Fantke (2018) and Weidema (2008), one DALY has a monetary value of €109,000. As these values differ, the average is taken:

$$\frac{80,000[\frac{€}{DALY}] + 113,000[\frac{€}{DALY}] + 109,000[\frac{€}{DALY}]}{3} = \mathbf{100{,}667} \left[\frac{\mathbf{€}}{\mathbf{DALY}}\right] \tag{4.21}$$

As one DALY is determined to have a monetary value of 100,667. Consequently, the 1.80 DALYs derived in equation 4.20 of the hypothetical curtailment scenario has the monetary value of the following amount:

$$1.80\ [DALYs] * 100,667\ \left[\frac{€}{DALY}\right] = \mathbf{€181{,}200} \tag{4.22}$$

Concluding, as derived in equation 4.12 this hypothetical curtailment scenario has a cost of €190,000 because of the need for natural gas to meet energy demand. Besides the cost of €190,000, the amount derived in equation 4.22, a hypothetical amount of €181,200 is lost due to the externality of CO_2 emissions.

Given the information that one curtailment scenario loses 1.80 DALYs, it can be determined how many hypothetical curtailment scenarios will be responsible for an entire human life. In order to derive the amount of hypothetical curtailment scenarios that are responsible for an entire human life, the life expectancy is needed. In this example, the life expectancy of the Netherlands is used. According to the Central Statistical Office (2024a), the life expectancy for women was 83.3 years in 2023, while men had a life expectancy of 80.3 years in 2023, which gives an average life expectancy in the Netherlands in 2023 of 81.8 years. As one hypothetical curtailment scenario has a cost of 1.80 DALYs, then the following amount of hypothetical curtailment scenarios lose an entire human life:

$$\frac{81.8\ [\text{years}]}{1.80\ [DALYs]} = 45.4 \approx \mathbf{45\ [curtailment\ scenarios]} \tag{4.23}$$

This implies that if the Netherlands were to curtail 45 times as per the hypothetical curtailment scenario an entire human life is lost. This is due to the quantity of supplementary tons of CO_2 that would be emitted as gas peaker plants are required to generate the equivalent amount of energy that would not be generated by offshore wind turbines to meet the energy demand. One hypothetical curtailment scenario also implies that a total of 438 birds are saved, derived in equation 4.3. The amount of 45 curtailment scenarios would therefore imply that the following number of bird lives are saved:

$$45 * 438\ [\text{birds}] = \mathbf{19{,}710\ [birds]} \tag{4.24}$$

In summary, in the hypothetical curtailment scenario, the data shows that an average of 1,386 birds are migrating per kilometre per hour for eight consecutive hours over the offshore wind farm Borssele. The offshore wind farm Borssele will be curtailed for these eight consecutive hours to save 438 birds from being struck by the offshore wind turbines. Gas peaker plants are used to meet the energy demand in the Netherlands, generating electricity that would otherwise be produced by the offshore wind farm Borssele. The use of gas peaker plants results in 1,075 tons of CO_2 emissions being released into the atmosphere. Consequently, 1,075 tons of CO_2 emissions result in losing 1,80 DALYs. Concluding, 45 hypothetical curtailment scenarios result in the loss of an entire, healthy, human life for the sake of the prevention of 19,710 bird mortalities.

4.7 Curtail or not curtail

An alternative scenario is that the Netherlands does not initiate curtailment, which would result in 19,710 bird mortalities. Gas peaker plants are not required to generate any additional electricity, as there is no loss of energy. The offshore wind farm Borssele will continue to generate electricity. No additional CO_2 is emitted as no wind turbines are curtailed, but as a result, 19,710 bird lives are lost. This raises the following ethical question:

"Ought we to be indifferent between saving 19,710 birds and one full healthy life of a human being?"

A trolley problem emerges from the statement above. A trolley problem is a thought experiment in which a decision has to be made for track A or track B. A lever needs to be pulled to decide which track a coming trolley is going to drive to. In a trolley problem there are individuals, animals or other entities on both tracks. The individuals, animals or other entities on the track the trolley is headed to, are killed, whereas the individuals, animals or other entities on the other track are spared. The trolley problem which emerges from the statement above is if one ought to be indifferent between saving 19,710 birds and one human. Figure 4.6 depicts the trolley problem. The top track serves as the depiction of 19,710 birds, whereas the bottom (deflecting) track serves as the depiction of a human being.

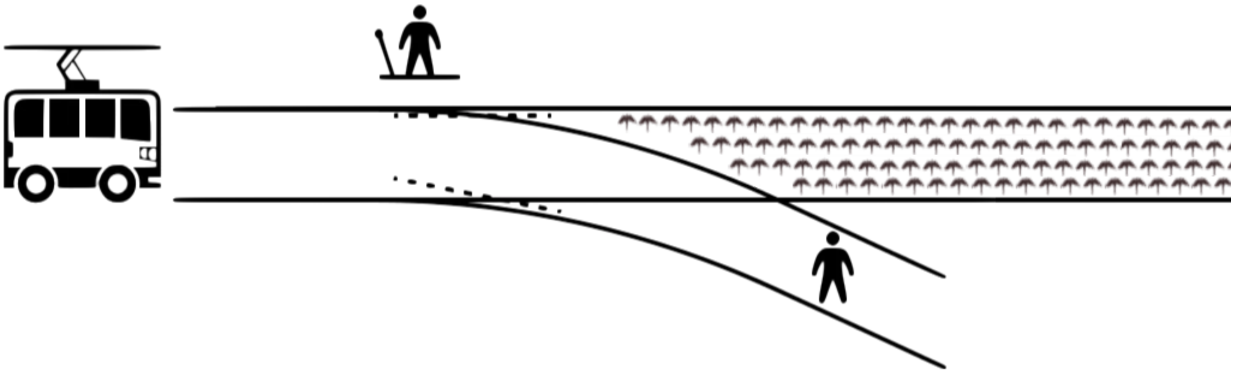

Figure 4.6: Trolley problem

A few conclusions can be drawn from this statement. If choosing to save 19,710, or more, bird lives over one healthy human life, curtailment is justifiable. Because when curtailment is initiated the Netherlands prevent bird mortalities but consequently emit CO_2 emissions to meet energy demand. If choosing one human life over 19.710 or more bird lives, curtailment can never be justified. The latter would also imply that any amount of emitted CO_2 **ever** to save an animal life, is unjustifiable as the emitted CO_2 eventually leads to the death of a human being, but the prevention of animal mortalities. In other words, saving an animal while emitting CO_2 is unjustifiable, while saving an animal while not emitting CO_2 is justifiable.

To change this trade-off somewhat, an alternative thought experiment is presented to make the problem more explicit. This thought experiment is derived from the drowning fawn thought experiments introduced earlier in section 3.2.1.

"Imagine you are camping in the woods during the winter and you see a fawn drowning in a lake. The lake is frozen, but the fawn has fallen through the ice. Again the fawn will drown without your help. You can save the fawn from drowning by jumping into the lake and pulling the fawn out of the water without sacrificing anything significant of yourself. You have saved the fawn from drowning, but it turns out that the fawn is suffering from hypothermia. The only way to save the fawn is to put up your tent, use your gas stove you brought with you to warm up the inside of the tent in order to keep the fawn warm and prevent it from dying of hypothermia. Using the gas stove means emitting CO_2. Assume that the only reason for warming up the tent is for the sake of the fawn, you are not suffering from hypothermia. Should you save the fawn or do you let it die?"

- *Lake thought experiment* adapted from Sebo (2022) and Singer (1972)

The lake thought experiment suggests a trade-off between saving a fawn, without any sacrifice to one's self, while emitting CO_2 or letting the fawn die without emitting any CO_2. As mentioned before in section 3.2.1: *"In the event that an individual has the possibility to save an animal without any significant personal sacrifices, it would be morally obligatory for them to do so, all else equal."* Utilitarianism is accepted while the rights theory is rejected. To reiterate, utilitarianism is derived from consequentialism which focuses on the consequences of the actions. The rights theory is derived from non-consequentialism, which places greater emphasis on the actions themselves than on the consequences of those actions. According to the rights theory a person has the moral duty to reduce and repair harms caused by their actions without sacrificing anything of importance in the process. According to utilitarianism a person has the moral obligation to save the fawn from drowning, while according to the rights theory a person does not have the moral obligation to save the fawn from drowning due to the fact that the drowning fawn is not a harm that is caused by the bystander.

The lake thought experiment is slightly different from the pond thought experiment. In the lake thought experiment the fawn is, besides drowning, also suffering from hypothermia. In order to save the fawn, the fawn needs to be saved from drowning, whereafter the fawn needs to be saved from hypothermia. The question remains thus if according to utilitarianism it is morally obligatory to save the fawn from hypothermia by creating a heated environment to keep the fawn warm. The downside of saving the fawn from hypothermia, is emitting CO_2. In order to answer this question it should be known if saving the fawn results in more benefits such as contributing to biodiversity or the prevention of suffering, than the actual burden of the CO_2 emissions. Although according to the rights theory, one would not even pull the fawn out of the lake as one is not morally obliged to do so, and a utilitarian would make a trade off between saving the fawn from hypothermia by emitting CO_2 and letting the fawn die, common sense would suggest that the most appropriate course of action would be to save the fawn from drowning and saving it from dying from hypothermia by creating a heated environment in the tent.

Consider now the consequences if the idea is accepted that it is always impermissible to emit CO_2 in order to save animal lives. This would imply that any aid for animals for which even the slightest amount of CO_2 is emitted, is considered unjustifiable. Thus in both the pool thought experiment and the pond thought experiment saving the fawn is justifiable as no CO_2 is emitted. In the lake thought experiment saving the fawn from drowning is also justifiable. But after saving the fawn from drowning it becomes clear the fawn is suffering from hypothermia and the only way to save the fawn is to create heat inside the tent and consequently emitting CO_2, this would be unjustifiable. Concluding, in the lake thought experiment a person ought to save the fawn from drowning, but consequently not being morally obliged to save the fawn from hypothermia as heating up the tent would would be unjustifiable due to the emitting of CO_2.

This would therefore also imply that any animal-friendly facilities such as wildlife crossings, artificial bird-houses, bee hotels or fencing for wildlife protection are considered unjustifiable as manufacturing facilities as such emit CO_2. Meaning that animal-friendly is considered not ethically friendly. Assuming animal-friendly is not ethically friendly, environmental theories such as sentientism, biocentrism and ecocentrism should be rejected and anthropocentrism is the only right environmental theory to follow. To reiterate and as mentioned in section 2.1.4, anthropocentrism is an ethical theory in which humans are the most important and central beings of existence and believes that only humans intrinsic value. Sentientism is a non-anthropocentric environmental ethical theory which believes that animals have intrinsic value as well. Biocentrism is a non-anthropocentric environmental ethical theory in which all living entities have intrinsic value, such as plants and trees. Ecocentrism is the most extreme non-anthropocentric environmental ethical theory which believes that ecosystems as a whole have intrinsic value.

The assumption that all animal-friendly facilities on Earth are ethically unjustifiable is, at the very least, implausible. This would therefore imply that humans should be, at some point, indifferent between a human life and a number of animal lives. This statement, just like the trolley problem stated earlier in figure 4.6, might feel slightly uncomfortable, choosing for a number of animal lives over one human life. It is important to note that the experienced discomfort of such trade-offs is not unusual. Further elaboration on this topic can be found in 4.7.1. The key takeaway of this point is that we ought to be indifferent between a human life and another number of animal lives, there ought to be a trade-off ratio (Fischer, 2024). Consider the following two trolley problems:

Trolley problem 1: "Imagine a train on a track which is approaching a Y-junction. On the track to the left there is a human being, and on the track to the right is a bird. You have to decide which way the train will go by pulling a lever. Pulling the lever to the left will kill the person, and pulling the lever to the right will kill the bird. Which way do you pull the lever?"

Trolley problem 2: "Imagine a train on a track which is approaching a Y-junction. On the track to the left there is a human being, and on the track to the right are one million birds. You have to decide which way the train will go by pulling a lever. Pulling the lever to the left will kill the person, and pulling the lever to the right will kill one million birds. Which way do you pull the lever?"

Both the trolley problems are extreme. In the first trolley problem there is a trade-off between one human and one bird, and in the second trolley problem there is a trade-off between one human and one million birds. In the first trolley problem it is evident that the majority of the people would choose to save the human being, it does not seem plausible that one human being is as important or less important than one bird. In the second trolley problem the trade-off is more extreme, but it would seem more plausible that people would choose to save one million birds. The first trolley problem seems more uncomfortable than the second trolley problem. By assessing the way people tend to feel less uncomfortable in such trolley problems, Fischer implies that there should be a number one would choose for the animals instead of the human, the only problem is finding the exact trade-off rate, i.e. the rate in which humans ought to be indifferent between an exact number of animals and one human being (Fischer, 2024). One way of finding this indifference ratio is by looking at the welfare ranges of animals, which will be elaborated on in section 4.7.1.

4.7.1 Welfare ranges

As mentioned before in section 3.1, one of the assumptions of ethical justifiability is that any loss of human life is considered ethically unjustifiable. This would imply that the hypothetical curtailment scenario, or curtailment in general for the sake of other non-human stakeholders such as birds is always considered unjustifiable.

Another way to tackle the problem of the trade-off between whether one ought to be indifferent between a human life or bird lives, is by looking at the welfare ranges. A welfare range is the spectrum in which an entity can experience pleasure and pain. In a study of Fischer (2023b) welfare ranges of 11 farmed animal species are described. Fischer's study is called 'The Moral Weight Project'. In the Moral Weight Project the welfare ranges that are obtained are relative to that of humans. This implies that the welfare range of a human is 2.00, and the welfare ranges for animals are below 2.00. No animals exceed the welfare range of that of humans, assuming humans can experience the most pleasures and pains. It should be noted that this framework assumes utilitarianism, unitarianism, hedonism and valence symmetry (Fischer, 2023a). These concepts will be explained in further detail below.

As mentioned in section 2.1.1 and 4.7, utilitarianism focuses on the consequences of taken actions and therefore aims to maximise happiness.

According to unitarianism, equal amounts of welfare are valued equally, regardless of whose welfare they belong to. In other words, taking utilitarianism and unitarianism into account, one ought not to make a difference between equal happiness of a human compared to a bird. In fact, if one ought to choose between a bird finding a worm, and a person drinking a cup of coffee, and the bird is more happy with the worm than the person is with a cup of coffee, the person ought to choose for the bird eating the worm (Fischer, 2023b).

Hedonism is an ethical theory that places emphasis on pleasure. Hedonism holds that pleasure is intrinsically valuable whereas pain is not intrinsically valuable. Hedonism focuses thus on good and bad experiences (Fischer, 2023b; Weijers, 2012). Assuming hedonism, welfare ranges are fully determined by positive and negative experiences.

Valence symmetry implies that the maximum pleasures and maximum pains are on the same level. To put this in perspective, assuming a human being has a welfare range of 2.00, the maximum amount of pleasure is therefore +1.00 whereas the maximum amount of pain is -1.00. The welfare range is symmetrical around the neutral point (Fischer, 2023b).

As mentioned in Fischer's study, 11 farmed species are studied. The reason farmed species are studied and not wild species, is for the simple reason that a lot of the same species are present at the same time to study. Over 90 different variables of the 11 farmed species were studied. To illustrate the variables, a couple are named: Fear-like behaviour, loneliness-like behaviour, love-like behaviour, parental care, friendship-like behaviour, communication etcetera. All proxies are studied and assessed for credence, i.e. the certainty or confidence of the findings. Assessing over 90 variables with credence, and assuming utilitarianism, unitarianism, hedonism and valence symmetry, a welfare range for these 11 farmed species were constructed (Fischer, 2022, 2023b, 2023a).

One of the studied 11 farmed species, were chickens. The obtained welfare range for chickens is 0.664. This means that, according to the Moral Weight Project, the pleasures and pains chickens can experience are about 33.2% compared to what humans can experience. No other birds were studied among the 11 farmed species. Therefore, from now on, it will be assumed that birds in general have a welfare range of 0.664 with symmetry around the neutral point. Birds can therefore experience pleasures of +0.332, and pains of -0.332. It should be acknowledged that migratory birds might not have the same welfare range as chickens. However, for the purpose of this study and assuming Fischer 's study, chickens' welfare range is highly likely in the same order of magnitude of migratory birds. Therefore, as no other birds were studied in the Moral Weight Project, the assumption is that birds in general have the same welfare range as chickens, namely 0.664.

As welfare ranges for humans and birds are known, welfare of humans versus welfare of birds can therefore be assessed. The reason welfare ranges are used in comparison is because welfare improvements for non-human entities can be averted to DALYs for humans, meaning the prevention of DALYs. In other words, using welfare ranges, one can assess whether it is more important to improve bird lives versus the loss of a DALY. To illustrate this the following thought experiment is introduced using the information mentioned in this section:

> *"Assume humans to have a welfare range of 2.00, which is symmetrical around the neutral point of 0.00, meaning humans have the ability of a maximum 'pleasure' of 1.00, and a maximum 'pain' of -1.00. Now assume seagulls to have a welfare range of 0.664. Seagull's welfare range is also symmetrical around the neutral point of 0.00, meaning seagulls have the ability of a maximum 'pleasure' of 0.332, and a maximum 'pain' of -0.332."*
>
> \- *Welfare thought experiment* derived from (Fischer, 2023b, 2023a)

Two assumptions are made, the symmetry around the neutral point, and the assumption that a seagull's welfare range is the same as a chickens'. As mentioned before in section 4.6, the average life expectancy in the Netherlands in 2023 is 81.8 years. The average life expectancy of a seagull is 13 years (Birdfact, 2024; Reynolds, 2023; Tracy, 2024). The welfare ranges of both humans as well as seagulls are depicted in figure 4.7. The depicted orange shaded rectangle corresponds with a human, while the smaller, blue shaded rectangle corresponds with a seagull.

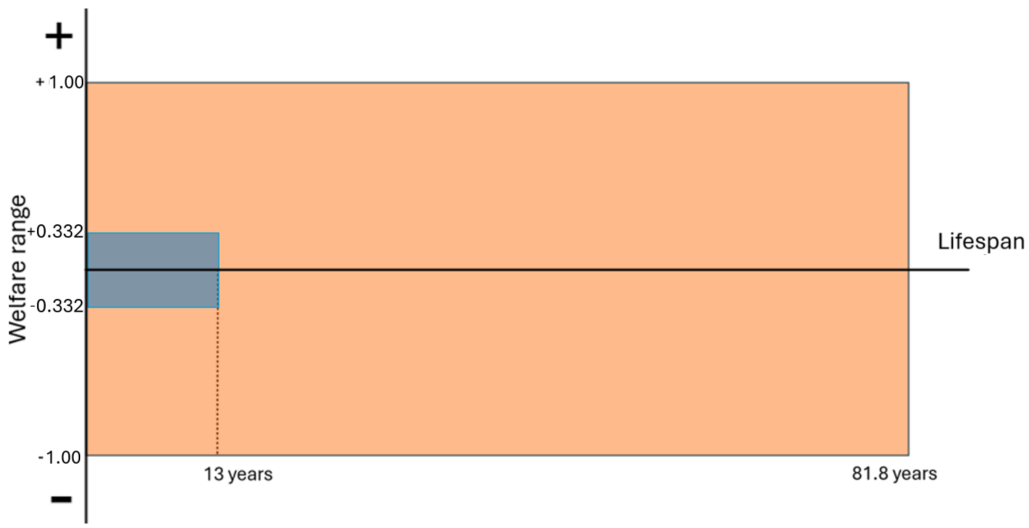

Figure 4.7: Welfare range humans versus seagulls

Assume now that both a human and seagulls are living the best life, thus both having the most positive welfare possible. The human has a positive welfare of 1.00, whereas the seagulls are experiencing positive welfare of 0.332. Now assume that both the human and the seagulls are living until the full life expectancy, thus the human lives up to 81.8 years whereas the seagulls live up to 13 years. This would imply humans have the following welfare capacity:

$$1.00\ [positive\ welfare] * 81.8\ [years] = \textbf{81.8 [-]} \tag{4.25}$$

Thus a human has a welfare capacity of 81.8. Note that the units of output are not of importance, the importance lies in the comparisons of the magnitudes of both humans and seagulls. Given that a seagull has a positive welfare capacity of 0.332 and a lifespan of 13 years, one seagull is capable of the following welfare capacity:

$$0.332\ [positive\ welfare] * 13\ [years] = \textbf{4.32 [-]} \tag{4.26}$$

This means that if a human being lives up to the full life expectancy and experiences the most positive welfare in their life, the capacity for welfare is 81.8. Also, if a seagull lives up to the full life expectancy and experiences the most positive welfare in their life, the capacity for welfare is 4.32. Next, it can be determined how many seagulls experience the same amount of welfare as a single human being:

$$\frac{81.8\ [-]}{4.32\ [-]} = 18.95 \approx \textbf{19 [seagulls]} \tag{4.27}$$

Concluding, assuming that seagulls have a positive welfare capacity of 0.332, then the capacity of welfare that one human can experience in a lifetime, is equal to the welfare 19 seagulls can experience in their lifetime. If the welfare ranges mentioned above are correct and welfare ranges are the correct way to determine the indifference between humans and animals, the new threshold for bird migration flux should be 1.4 birds per kilometre per hour. This is, if one would be indifferent between one human and 19 seagulls. The calculation can be found in Appendix C.

To reiterate earlier mentioned thresholds of bird migration fluxes: if assumed that the hypothetical curtailment scenario mentioned in section 4.4 is ethically permissible, the Netherlands ought to be indifferent between one human and 19,710 birds. If assumed that the hypothetical curtailment scenario mentioned in Appendix A is ethically permissible, the Netherlands ought to be indifferent between one human and 7,110 birds. If assumed that the hypothetical curtailment scenario mentioned in Appendix B is ethically permissible, the Netherlands ought to be indifferent between one human and 14,220 birds. Therefore, if assumed that welfare ranges are the correct way to assess the trade-off between one human and a number of birds, we ought to assume the following positive welfare for birds:

Threshold birds/km/h	**Humans vs birds**	**Positive welfare capacity birds**	**Percentage welfare capacity birds compared to humans**
1.4 (Appendix C)	1 vs 19	0.332	33.2%
500 (Appendix A)	1 vs 7,110	0.00088	0.088%
1,000 (Appendix B)	1 vs 14,220	0.00044	0.044%
1,386 (Section 4.4)	1 vs 19,710	0.00032	0.032%

Table 4.3: Welfare ranges for birds assuming various bird migration fluxes

In conclusion, assuming that the positive welfare capacity for birds is 0.332, the average bird migration flux ought to be 1,4 birds per kilometre per hour to be the appropriate ethical threshold, as this threshold prevents 19 bird mortalities.

Also, it can be determined what the welfare range for birds would have to be if assumed that previous thresholds mentioned are correct. This is thus, if assumed that the welfare range of 0.332 for birds is not correct. Assuming that the average bird migration flux of 500 birds per kilometre per hour is the appropriate ethical threshold, and thereby preventing 7,110 bird mortalities, the positive welfare capacity for birds would have to be 0.00088. Assuming that the average bird migration flux of 1,000 birds per kilometre per hour is the appropriate ethical threshold, and thereby preventing 14,220 bird mortalities, the positive welfare capacity for birds would have to be 0.00044. Assuming that the average bird migration flux of 1,386 birds per kilometre per hour is the appropriate ethical threshold, and thereby preventing 19,710 bird mortalities, the positive welfare capacity for birds would have to be 0.00032.

Table 4.4 shows what welfare ranges of birds should be in order to be indifferent between one human and a number of birds. The number of birds compared to a human being a person is indifferent to is depicted in the first column. In the second column the welfare range is stated, so for example, if a person is indifferent between one human and 100 birds, a person would believe one bird's positive welfare range is 0.0630, compared to a positive welfare range of a human being. The third column is the needed bird flux for a hypothetical scenario in which the same number of hours is curtailed during one night. Once more, 45 hypothetical curtailment scenarios are 'equivalent' to one human life. Note that still assumptions are made, such as the average life expectancy of a human and the life expectancy of a seagull is taken as the lifespan of birds in general. The most important assumption is assuming that welfare ranges are the correct proxy to conclude that people ought to be indifferent between one human life and an exact number of birds.

Indifferent between	Positive welfare capacity of a bird	Corresponding bird flux
1 human and 1 bird	6.30	0.1 birds/km/h
1 human and 5 birds	1.258	0.4 birds/km/h
1 human and 10 birds	0.630	0.7 birds/km/h
1 human and **19 birds**	**0.332** (as section 4.7.1)	**1.4 birds/km/h**
1 human and 25 birds	0.252	1.8 birds/km/h
1 human and 50 birds	0.126	3.5 birds/km/h
1 human and 100 birds	0.0630	7.0 birds/km/h
1 human and 200 birds	0.0315	14 birds/km/h
1 human and 300 birds	0.0210	21 birds/km/h
1 human and 400 birds	0.0157	28 birds/km/h
1 human and 500 birds	0.0126	35 birds/km/h
1 human and 1,000 birds	0.00630	70 birds/km/h
1 human and 3,019 birds	0.00208	107 birds/km/h
1 human and 5,000 birds	0.00126	352 birds/km/h
1 human and **7,110 birds**	**0.00088** (as Appendix A)	**500 birds/km/h**
1 human and 10,000 birds	0.000630	703 birds/km/h
1 human and **14,220 birds**	**0.00044** (as Appendix B)	**1,000 birds/km/h**
1 human and **19,710 birds**	**0.00032** (as section 4.4)	**1,386 birds/km/h**
1 human and 50,000 birds	0.000126	3,516 birds/km/h
1 human and 100,000 birds	0.0000630	7,032 birds/km/h
1 human and 500,000 birds	0.0000126	35,162 birds/km/h

1 human and 1,000,000 birds	0.00000630	70,323 birds/km/h
1 human and ∞ birds	0.00	∞ birds/km/h

Table 4.4: Welfare ranges indifferences with corresponding bird flux

Conclusion of the welfare ranges

In this section welfare ranges are discussed. In the Moral Weight Project, welfare ranges are constructed. The comparison of welfare ranges of different species of animals to humans can be used to answer the question of when humans should be indifferent to a human life and a number of animal lives. In this section, it is assumed that the use of welfare ranges represents an appropriate framework for determining the indifference ratio between one human being and a specified number of birds. In this section, it is assumed that birds in general have a welfare range of 0.664, with symmetry around the neutral point. It is assumed that humans have a welfare range of 2.00. In consideration of the life expectancies of both humans and birds, the precise number of birds that humans ought to be indifferent to, in comparison to one human being, is calculated. The answer to this question is that, according to the welfare range of 0.664 for birds with a life expectancy of 13 years, and a welfare range of 2.00 for humans with a life expectancy of 81.8 years, humans ought to be indifferent with one human being and 19 birds. This would therefore also imply that the current threshold of the Netherlands to initiate curtailment, which is 500 birds per kilometre per hour, should be changed to 1.4 birds per kilometre per hour. The threshold of 500 birds per kilometre per hour is more than 350 times higher than the threshold according to the Moral Weight Project.

The findings would imply, assuming the Moral Weight Project's welfare ranges are correct, the threshold of 500 birds per kilometre per hour should be changed to 1.4 birds per kilometre per hour, would also mean that wind turbines would almost always be in curtailment phase. 1.4 birds per kilometre per hour is a very low threshold to follow. During Autumn and Spring, this threshold is reached every single night (Kraal et al., 2023). This would therefore imply that, assuming welfare ranges, offshore wind farms in the North Sea ought to be curtailed every single night during Autumn and Spring. For this reason, the welfare ranges approach is rejected. The threshold of 1.4 birds per kilometre per hour is not the correct ethical threshold to assume.

4.7.2 Neurons

Another way to derive a welfare range is by comparing neurons of animals to neurons of humans. Neurons (nerve cells) are cells in the brain which are the fundamental units for receiving sensory input (Woodruff, 2023). Neurons define people and animals as who they are. By determining the number of neurons in the brain of an animal and comparing it to the number of neurons of a human being, a welfare range can be constructed. Why neurons could be used to determine a welfare range will be elaborated on in this section.

Thus the question is, why ought people to think that the number of neurons in an animal's brain should be used as a proxy for determining welfare ranges? The number of neurons and neuron density have a causal relationship with intelligence and consciousness for mammals (Dicke & Roth, 2015). Also, more neurons in a brain mean a greater cognitive capacity, meaning that a certain number of neurons is needed in order to be capable of complex thinking. Examples of complex thinking are understanding pain, emotions or other feelings (Herculano, 2012). It should be noted that there are objections about using neurons as a proxy for determining welfare ranges. However, in this section, it is assumed that neurons are a correct proxy for determining welfare ranges.

According to Azevedo et al. (2009) and Herculano (2012) humans have an average number of 86 billion neurons. Again, it is assumed that humans have a welfare range of 2.00, with a positive welfare of +1.00 and a negative welfare of -1.00. To compare this to birds, the average number of neurons from two different duck species, geese, and pigeons is taken. As pigeons have the same sized brain as a seagull, and the causal relationship between the number of neurons and brain size, it is assumed that seagulls have the same number of neurons as pigeons (Kverkova et al., 2022). The reason this data is displayed is as these species migrate over the North Sea during Autumn and Spring (Furness et al., 2013). The data regarding the number of neurons is displayed in table 4.5.

Bird species	Number of neurons
Wood duck	305,816,000
Marbled duck	386,920,000
Common wood pigeon	258,681,000
Red-breasted goose	482,705,000

Table 4.5: Number of neurons per bird species (Kverkova et al., 2022)

Given the information in table 4.5, the following average number of neurons is derived:

$$\frac{305,816,000 + 386,920,000 + 258,681,000 + 482,705,000}{4} = \textbf{358,530,500 [neurons]} \tag{4.28}$$

The average number of neurons of the four mentioned bird species in table 4.5, is 358,530,500 neurons. As mentioned in section 4.7.1 the welfare range of humans is 2.00, and that of animals is lower than 2.00. Therefore, a welfare range for the mentioned species in table 4.5 can be calculated. The welfare range of birds is calculated as follows:

$$\frac{358,530,500\ [neurons]}{86,000,000,000\ [neurons]} = \textbf{0.00417 [-]} \tag{4.29}$$

If assumed welfare ranges ought to be determined by the number of neurons, then birds ought to have a welfare range of 0.00416. Again, assuming symmetry, the positive welfare capacity of birds is 0.00208. Assuming a positive welfare capacity of 0.00208, and a life expectancy of 13 years, a birds' welfare capacity is as follows:

$$0.00208\ [positive\ welfare] * 13\ [years] = \textbf{0.0271 [-]} \tag{4.30}$$

Thus the new welfare capacity of a bird is 0.0271. Next, it can be determined how many birds experience the same amount of welfare as a single human being. As a human being has a welfare capacity of 81.8, as derived in equation 4.25, people ought to be indifferent between one human being and the following number of birds:

$$\frac{81.8\ [-]}{0.0271\ [-]} = 3,018.6 \approx \textbf{3,019 [birds]} \tag{4.31}$$

This means that, taking neurons into account to act as a welfare range proxy, people ought to be indifferent between 1 human being and 3,019 birds. To reiterate, and as mentioned in section 4.6, when 45 hypothetical curtailment scenarios occur, one human life is lost due to additional CO_2 emissions. Next the new bird migration flux is calculated. In order to determine the new bird migration flux it should be determined first how many birds are flying over the offshore wind farm Borssele. First, it needs to be determined how many birds mortalities per curtailment scenario are prevented:

$$\frac{3,019\ [birds]}{45\ [curtailment\ scenario]} = \textbf{67.1} \left[\frac{\textbf{birds saved}}{\textbf{curtailment scenario}}\right] \tag{4.32}$$

The number of total bird flux can be calculated as follows:

$$\frac{67.1\ [birds]}{0.14\ [\%]} = \textbf{47,915 [birds]} \tag{4.33}$$

In order to determine the number of birds per hour, the number needs to be divided by eight hours due to the curtailment period of this number of hours:

$$\frac{47,915\ [birds]}{8\ [hours]} = \mathbf{5{,}989}\ \left[\frac{\textbf{birds}}{\textbf{h}}\right] \tag{4.34}$$

The final step to determine the bird flux per kilometre per hour is to rephrase the birds per hour to birds per kilometre per hour. As the offshore wind farm Borssele has equal sides of 28.2 kilometres, the following bird migration flux is obtained:

$$\frac{5,989\ \left[\frac{birds}{h}\right]}{28.2\ [km]} = 212.4 \approx \mathbf{212}\ \left[\frac{\textbf{birds}}{\frac{\textbf{km}}{\textbf{h}}}\right] \tag{4.35}$$

Conclusion of neurons as welfare ranges

This section discusses the welfare ranges based on the number of neurons in birds and humans. A welfare range is constructed by dividing the number of neurons of birds, by the number of neurons of humans. The derived welfare range of birds in comparison to humans can be employed to answer the question when humans ought to be indifferent to a human life and a number of bird lives. In this section, it is assumed that the number of neurons of birds is the appropriate framework for determining the indifference ratio between one human being and a specific number of birds. It is calculated that the welfare range of birds is 0.00417, with symmetry around the neutral point. It is assumed that humans have a welfare range of 2.00. In consideration of the life expectancies of both humans and birds, the precise number of birds that humans ought to be indifferent to, in comparison to one human being, is calculated. The answer to this question is that, according to the welfare range of 0.00417 for birds with a life expectancy of 13 years, and a welfare range of 2.00 for humans with a life expectancy of 81.8 years, humans ought to be indifferent with 1 human being and 3,019 birds. This would therefore also imply that the current threshold of the Netherlands to initiate curtailment, which is 500 birds per kilometre per hour, should be changed to 212 birds per kilometre per hour. The current threshold of 500 birds per kilometre per hour is approximately five times higher than the new derived threshold of 212 birds per kilometre per hour, derived using neurons.

The findings would imply, assuming neurons are the correct framework to determine welfare ranges, that the threshold of 500 birds per kilometre per hour should be changed to 212 birds per kilometre per hour. As mentioned in section 4.1, the Minister of Climate Policy and Green Growth can advise offshore wind farm operators to curtail at 153 birds per kilometre per hour besides the mass migration threshold of 500 birds per kilometre per hour. According to the obtained welfare range of birds derived by using neurons, the threshold ought to be 212 birds per kilometre per hour. Concluding, the mass migration bird flux of 500 birds per kilometre per hour ought to be scaled down to 212 birds per kilometre per hour. Another possibility is that the advice for curtailing at a bird migration flux of 153 birds per kilometre per hour, is scaled down to an advice for curtailing at a bird migration flux 212 birds per kilometre per hour.

5 Discussion

Although this thesis offers significant insights into the ethical issues surrounding curtailment, there are still crucial areas that require further investigation and several potential limitations that should be taken into account. Take for example the fact that this thesis uses DALYs exclusively for human beings. It is evident that CO_2 emissions also have negative impacts on animals. Take for example coral reefs, due to the rise of CO_2 emissions coral reefs are threatened due to ocean acidification and therefore threatening the habitat of animals. In addition, rising global temperatures contribute to habitat loss for various species. For instance, the warming of the Arctic is causing habitat loss for polar bears, as the ice they depend on for hunting and shelter melts. This thesis exclusively addresses the ethical justification of the prevention of bird (and bat) mortalities by emitting CO_2, but how sure are we that the additional CO_2 emissions by preventing bird mortalities outweigh the disadvantages of other animals' lives lost? Maybe we ought to sacrifice birds in order to save other animals. This is something for future research: does the prevention of bird mortalities really outweigh other consequences of the CO_2 emissions besides the loss of human lives?

The statement above that it is evident that CO_2 emissions also have negative impacts on animals, suggests, indirectly, that the thresholds derived in the thesis should actually be higher. This is, as this thesis only addresses birds vs humans, but the actual comparison should be birds vs humans and other animals. The reason that this comparison is not addressed, is as the variable of $\frac{DALYs}{Ton\ of\ CO_2}$ for animals is not known. Assuming that CO_2 emissions also affect animals, the harm of emitting CO_2 during curtailment, and thereby preventing bird mortalities, is actually higher than this thesis derives.

Another implication which emerged while writing this thesis, was the fact that there are all these kinds of animal-friendly technologies in offshore wind farms to prevent animal mortalities. The number of animal mortalities prevented compared to for example chicken battery-farms or other bio-industries in the Netherlands is actually modest. This thesis uses the Moral Weight Project as a source that we ought to be indifferent between a number of animals and a human life, for the justification of offshore wind curtailment. One might argue that the 'real' problem is not offshore wind farms, but such bio-industry farms for example. Firstly, it is not the purpose of this study to justify such industries, which would require a separate investigation. However, it is important to minimise suffering and death. Secondly, it is imperative to strive for every potential positive difference, however minor it may be. The reduction in bird mortality resulting from offshore wind curtailment is nevertheless a significant outcome, despite the relatively modest impact. It should be reiterated that while there are larger issues related to animal suffering or CO_2 emitting industries, this should not be used as a reason to dismiss curtailment as a way to prevent animal mortalities.

Unfortunately, this previous paragraph raises another problem. The problem it raises is that when the Netherlands initiate curtailment, they prevent animal mortalities, but consequently emit CO_2 into the atmosphere. This means that the benefits for the Netherlands (and Europe or wherever the migrating birds are flying to) are preventing bird mortalities, but emit CO_2 into 'the Earth', thus the harms are for everyone. Thus a remaining question to tackle is: 'How can benefits in one place be justified while the harms are localized to many other countries?' This is a problem to tackle for a follow-up study.

Another problem which emerged during this thesis was the amount of $\frac{DALYs}{Ton\ of\ CO_2}$ from the different sources in table 4.2. The problem lies in the fact that the amounts still differ. The first number of 0.00041 and the fifth number of 0.0029 differ around seven times in magnitude. If these highest and lowest magnitudes were to be used, this outcome will differ significantly. These minimum and maximum magnitudes are used in another calculation in Appendix E. Appendix E shows that the minimum amount of 0.00041 $\frac{DALYs}{Ton\ of\ CO_2}$ obtains 186 hypothetical curtailment scenarios equivalent to an entire healthy human life, while the maximum amount of 0.0029 $\frac{DALYs}{Ton\ of\ CO_2}$ obtains 26 hypothetical curtailment scenarios equivalent to an entire healthy human life. This is another limitation of the thesis. Due to uncertainty the average of the $\frac{DALYs}{Ton\ of\ CO_2}$ were used, as the amounts were in the same order of magnitudes, however, the minimum and maximum amounts still differ seven times in magnitudes.

Another part this thesis did not discuss is the DALYs averted, thus how many tons of CO_2 the Netherlands, or other countries, avoided by building offshore wind turbines. In other words, how many lives have we 'saved' by building offshore wind farms and the avoidance of CO_2 emissions. One could argue that there are no ethical issues arising from the development of offshore wind farms due to all the good it produces, i.e. the avoidance of CO_2 emissions and the path to being CO_2 neutral. However, this statement is indirectly rejected in the thesis, as it is argued that countries should curtail at a certain point, even if this means emitting CO_2 and preventing bird mortalities. Some would argue that curtailment is ethically impermissible, if assuming CO_2 emissions for preventing bird lives is unjustifiable.

Furthermore, why is the Netherlands the only country to implement curtailment in the North Sea? Currently, the Netherlands is the only country curtailing at a predefined threshold in the North Sea. Germany is currently testing curtailment in the Baltic Sea if a predefined threshold is exceeded. France is testing curtailment in the Mediterranean Sea on an offshore wind farm test site at predefined periods in Spring and Autumn. Meaning that France is not even measuring bird migration densities. The United Kingdom, Denmark, Norway and Belgium are not initiating curtailment or testing curtailment anywhere whatsoever.

The United Kingdom simply has no plans implementing curtailment in the near future. Until now, Denmark is confident that their offshore wind farms are located outside important bird migration routes. In the near future, in 2026, curtailment will likely be implemented on a new offshore wind farm site in Denmark. As for Norway, only the first offshore wind farm is developed, using 11 floating wind turbines. Plans of curtailment are in order as weather and bird detection radars have been financed. Belgium is currently not curtailing as curtailment is not implemented in the permits of the offshore wind farm. But as these permits can be changed, there is a possibility for initiating curtailment in the existing and future wind farms of Belgium. Concluding, the Netherlands is at the forefront of the implementation of wind farm curtailment measures in the North Sea, with Germany and France also initiating trials of these strategies. The Netherlands employs a predictive bird migration model to assist in the planning of turbine shutdowns when collision risks are elevated. This model is currently being refined for broader application. Recent studies have confirmed that curtailment measures, such as the temporary shutdown of turbines during periods of high bird migration, are an effective means of reducing bird fatalities without causing significant energy losses. However, the necessity for site-specific monitoring remains crucial to further refine these strategies and validate their effectiveness. This will be elaborated on in Chapter 6 and the personal reflection section.

Another limitation emerged from the calculated CO_2 emissions in section 4.4. The average energy consumption of the Netherlands is considered per hour, in real-life, this is not entirely correct. During the night, people use less electricity and gas compared to during the day. Therefore, it would be interesting how the calculations would change if using real-life gas consumption data during nights in Spring and Autumn. Assuming that gas consumption is actually lower during the nights, there is less natural gas needed to meet the energy demand, resulting in less hypothetical curtailment scenarios resulting in the death of a human being.

6

Conclusion

This chapter presents the conclusions and recommendations for further research, as well as a personal reflection.

To reiterate, this thesis aims to answer the following research question:

When, if ever, is curtailment ethically acceptable in offshore wind farms in the North Sea?

In order to answer the main research question, the following sub-research questions were developed:

Sub-questions

1. "Which ethical principles are relevant to offshore wind farms in the North Sea, and how can curtailment contribute to these principles?"
2. How can curtailment contribute to minimising the negative environmental impacts of offshore wind farms in the North Sea?
3. What are the ethical challenges of implementing curtailment in offshore wind farms in the North Sea and how can they be overcome?
4. Who are the stakeholders and how are these stakeholders affected regarding curtailment of offshore wind farms in the North Sea?
5. Which decision-making processes should be followed to effectively implement curtailment into offshore wind farms in the North Sea?

The sub-research questions will be answered separately below.

Sub-research question 1: *"Which ethical principles are relevant to offshore wind farms in the North Sea, and how can curtailment contribute to these principles?"*

As mentioned in sections 3.2.1 and 4.7 the rights theory is rejected and the utilitarian perspective is accepted. This means that the consequentialist view has been accepted while the non-consequentialist view has been rejected in order to derive the justification of curtailment of offshore wind farms in the North Sea. To reiterate section 4.4, by taking a bird migration flux of 1,386 birds per kilometre per hour into account, the consequence of 45 hypothetical curtailment scenarios is that due to the CO_2 emissions as a result of curtailment, one human life is lost while preventing 19,710 bird mortalities. A human life is lost due to the fact that it is known how many DALYs a ton of CO_2 emits. Also, as mentioned in section 4.7, people ought to be indifferent between one human life and a number of animal lives. Otherwise all animal-friendly technologies that emit CO_2 should be considered ethically unjustifiable. This statement is rejected in section 4.7, thus people ought to be indifferent between a human being and a number of birds. Other variables to consider in the conclusion that people ought to be indifferent between a human being and a number of birds are derived from the Moral Weight Project, using welfare ranges. The ethical principles that are relevant for this conclusion for the justification of curtailment are therefore utilitarianism, welfare ranges and DALYs. These concepts were the most important to reaching this conclusion.

Sub-research question 2: *How can curtailment contribute to minimising the negative environmental impacts of offshore wind farms in the North Sea?*

Curtailment of offshore wind farms in the North Sea contributes to the prevention of bird mortalities in the North Sea. By halting the operation of offshore wind turbines entirely or reducing the speed to two rotations per minute bird mortalities are prevented. However, there is a potential negative externality. If energy demand is not met due to the absence of the generated offshore wind energy, the energy demand needs to be compensated by gas-fired power plants. Consequently, additional CO_2 is emitted by burning natural gas to generate electricity. Thus there is a trade-off between preventing bird mortalities and emitting CO_2. Curtailment therefore contributes to environmental impacts by preventing bird mortalities, but unfortunately sometimes emitting CO_2.

Sub-research question 3: *What are the ethical challenges of implementing curtailment in offshore wind farms in the North Sea and how can they be overcome?*

The ethical challenges lie in the fact that there is no factual or straightforward answer to the question whether additional CO_2 emissions or bird mortalities is more important. There was a need for an ethical framework to answer this question, and as mentioned in section 2.2, people still would have objections to this. Nevertheless, this thesis used a consequentialist approach, meaning that it is focused on the consequences of the actions taken to tackle this question. Ethical reasoning is applied to answer the question how these ethical challenges can be overcome. The conclusion is that people ought to make up their mind that sometimes we ought to choose for animal lives over a human life, otherwise it would always be impermissible to save an animal life if this means emitting even the slightest amount of CO_2.

Sub-research question 4: *Who are the stakeholders and how are these stakeholders affected regarding curtailment of offshore wind farms in the North Sea?*

The stakeholders affected by curtailment are humans, birds and bats. First, human stakeholders are assessed. Humans are affected by curtailment as natural gas is used to generate electricity and consequently emitting CO_2. Human stakeholders are affected in both financial and health-related ways. Human stakeholders are financially affected as the additional natural gas needed to meet energy demand needs to be paid. Curtailment is also initiated when negative energy prices occur, or when there is grid instability. Furthermore, human stakeholders are affected health-related as the additional CO_2 emissions result in DALYs. To reiterate and as mentioned in section 4.6, a DALY is a disability-adjusted life year, meaning that one DALY equals the loss of one healthy year of human life. The amount of DALYs per emitted ton of CO_2 is known. Therefore, it can be calculated how many tons of CO_2 emissions will hypothetically result in the loss of a human life. Having calculated how many CO_2 emissions will hypothetically result in the loss of a human life, it can be determined how many curtailment scenarios result in the loss of a human life, and on the other side the prevention of an exact number of bird lives.

This thesis focuses mostly on birds when talking about curtailment. Bird mortalities are prevented during curtailment. Bird mortalities occur when offshore wind turbines are in operation, and birds collide with the blades of the wind turbines. During curtailment, birds do not collide with the blades, thus preventing mortalities. Besides birds, bats also migrate during Autumn and Spring. It is assumed that therefore, during curtailment periods, bat mortalities are prevented at the same time. However, this is assumed and thus uncertain. This will be elaborated on in the conclusion of sub-research question 5.

Sub-research question 5: *Which decision-making processes should be followed to effectively implement curtailment into offshore wind farms in the North Sea?*

The Netherlands already has a procedure for the initiation of curtailment, as outlined in figure 4.1. The procedure for initiating curtailment includes a 'bird alarm' but does not include a 'bat alarm'. The term bird alarm indicates that the bird migration flux threshold is exceeded. The term bat alarm would therefore indicate that the bat migration flux threshold is exceeded. To this day, there is no bat migration flux threshold, in fact, curtailment is not initiated for the sake of bat lives. This is due to the fact that none to very little is known regarding bat migration, thus no bat migration model exists. Figure 4.2 depicts the decision-making process that ought to be implemented if there was a bat migration model.

Main research question: *When, if ever, is curtailment ethically acceptable in offshore wind farms in the North Sea?*

The role of curtailment is ensuring grid stability, preventing negative energy prices, and most importantly, preventing bird mortalities. When large bird migration fluxes occur during autumn and spring, curtailment is initiated to prevent bird mortalities. The threshold of curtailment initiation is 500 birds per kilometre per hour. It does not matter how many additional birds fly through an offshore wind farm, the procedure remains the same. The only difference is that the higher the bird migration flux, the higher the prevented bird mortalities. A hypothetical curtailment scenario is created using real-life data. The offshore wind farm Borselle, with its 173 offshore wind turbines, each 9.5 MW, are tested using three bird migration fluxes: the threshold of 500 birds kilometre per hour (appendix A), twice the threshold namely 1,000 birds kilometre per hour (appendix B), and real-life data from the night of October 19/20 2022 of 1,386 birds kilometre per hour (section 4.4). The reason to investigate this hypothetical scenario is to obtain insights of the exact consequences of curtailment. Using DALYs, the number of hypothetical curtailment scenarios are obtained in which the amount of emitted CO_2, results in one lost human life, and on the other side prevented bird mortalities. This is where the second half of the main research question comes into play, how can curtailment be justified. The question is why or why not ought people to be indifferent between a human life and a number of bird lives? The answer to this question is that people ought to be indifferent between a human and a number of bird lives.

The Moral Weights Project contains a thought experiment, in which the number of animals increases, while on the other hand it remains one human being. The more the number of animals increases, the more uncomfortable one would become in making the decision. The uncomfortable feeling suggests that there should be a number of animals people ought to be indifferent to. As mentioned, this research uses DALYs per ton of CO_2 to derive the trade-off of a human being and a number of birds. If one believes that emitting a large amount of CO_2 to save an animal life is never justifiable, then the majority of animal friendly technologies are unjustifiable. Meaning that wildlife crossings, artificial birdhouses, bee hotels or fencing for wildlife protection are considered unjustifiable as manufacturing facilities as such emit CO_2. This is rejected in section 4.7.

Another way to look at being indifferent between one human being and a number of birds is welfare ranges according to the Moral Weight Project. Welfare ranges are developed to determine how much animals can experience pleasures and pains, relative to a human. According to the welfare range of chickens, which are assumed to be the same as migratory birds, the new threshold of curtailment ought to be 1.4 birds per kilometre per hour. According to released data of bird migration in 2022, this would mean that curtailment ought to be initiated every single night. This is rejected.

Yet another way to look at being indifferent between one human being and a number of birds is the welfare range based on the number of neurons in birds' and humans' brains. According to the new obtained welfare range, the new threshold of curtailment ought to be 212 birds per kilometre per hour. As mentioned in 4.1, the Minister of Climate Policy and Green Growth can advise offshore wind farm operators to curtail at 153 birds per kilometre per hour besides the mass migration threshold of 500 birds per kilometre per hour. Assuming the neurons based obtained threshold is correct, there are two options: the threshold of 500 birds per kilometre per hour is decreased to 212 birds per kilometre per hour, meaning a lot more curtailment hours if accepted by the stakeholders of the curtailment initiation procedure. The second option is that the Minister of Climate Policy and Green Growth advises offshore wind farm operators to curtail at 212 birds per kilometre per hour instead of 153 birds per kilometre per hour. Thus the new neuron based threshold obtained becomes an advice.

Furthermore, as only the Netherlands is currently applying curtailment in the North Sea, it is recommended that other countries also implement the principle of curtailment as well. More explicitly, this thesis argues that humans have a moral obligation to help animals, as discussed in section 4.7. Therefore, the countries around the North Sea are morally obliged to curtail at a certain threshold. It is known that certain countries do not have plans of implementing curtailment. The United Kingdom simply has no plans to implement curtailment. Denmark is confident that its offshore wind farms are located out of the way of migration routes. Norway has just built its first offshore wind farm but has plans of curtailment in the future. Belgium is currently not curtailing as the permits of the offshore wind farms do not include the permission of curtailment. France is testing curtailment in the Mediterranean Sea while Germany is testing curtailment in the Baltic Sea, thus both not in the North Sea. These countries ought to initiate curtailment when a certain threshold is exceeded.

Recommendations

Another way of preventing or minimising collisions with birds is increasing visibility of wind turbines. As mentioned in section 3.1, low-gloss wind turbine blades are being implemented to prevent the visual glaring of the blades for human interests. For aerial stakeholders, the visibility of the wind turbines should be as high as possible to avoid collisions. In other words, as visibility increases, less collisions and thus less mortalities will occur (Colin, 2013; Martin & Banks, 2023).

Normally turbine blades are white, this is done due to multiple reasons. One reason is because the colour white is a reflective colour for warmth, meaning that heat is reflected, increasing the turbine's life cycle as the tower, nacelle and blades remain cooler compared to other colours. Consequently, when maintenance is being done, the wind turbine is not too hot inside, making maintenance work done by employees more pleasant. Furthermore, the colour white blends in with the sky and clouds, which results in less horizon pollution when wind turbines are seen from the shore. So from a horizontal point of view the turbines are less visible from far away. On the contrary, from a vertical point of view, the wind turbines are white due to good visibility from above so pilots of planes and helicopters can see them (Colin, 2013; Doster, 2020; Van Gessel, 2022).

There have been multiple studies to increase the turbine blade visibility to prevent the mortality of aerial species such as birds and bats. Visibility can be improved by the literal painting of one or multiple wind turbine blades. If all the blades are white, they tend to blend together into a blur, making it difficult for birds to recognise them as objects to avoid. This is called motion smear (Van Gessel, 2022; May et al., 2020). In Norway, on a small island named 'Smøla', four wind turbine blades of four different wind turbines were painted black (May et al., 2020). The mortality rates of birds was significantly reduced by 70% for the four painted wind turbines compared to the unpainted turbines. May et al. (2020) stated that there were no negative reactions from nearby inhabitants from any annoyance, glaring or other optical externality. According to Van Gessel (2022) this can be explained. Norway is not known for its nice weather. The contrary is the case, Norway's coast often has grey and rainy weather, or days with a mixture of fast moving clouds. As a result, the black blades were barely visible.

In another study, one of the three blades of seven different RWE wind turbines in Eemshaven, near one of the four coal-fired power stations in the Netherlands, was painted black. Eemshaven is located in the province of Groningen. In this study, a collaboration between RWE, Vattenfall, Province of Groningen and other public and private organizations, the effectiveness of the painted wind turbine blades is being monitored. The fatalities of birds are monitored using sensors and cameras. The sensors measure vibrations in the blades, microphones are added on the turbines which measure acoustics to detect birds, and a 3D radar is installed to measure the flight behaviour of the birds.

Figure 6.1: Wind turbine one black blade (Van Gessel, 2022)

Furthermore, manual searches were conducted around the sites for bird fatalities. After eight months, the first impression is that there is still no clear difference in bird deaths between turbines with and without black-painted blades. The study is still ongoing, so it is too early to draw any conclusions. The research regarding the painting of a single wind turbine blade is expected to run until winter 2024/2025 (Province of Groningen, 2023; TNO, 2023).

Another study, by Martin and Banks (2023), even suggests that all three wind turbine blades should be painted. Not all black, but rather black or white every one third of the wind turbine blades. It is also suggested that the tower should be painted black and white using equal lengths, which should be half the length of the blade sections. Painting the wind turbines' towers would even result in less mortalities than just painting one, or more blades (Martin & Banks, 2023).

Figure 6.2: Wind turbine all blades painted (Martin & Banks, 2023)

It should be noted that the studies by Van Gessel (2022); Martin and Banks (2023); May et al. (2020); Province of Groningen (2023) and

TNO (2023) are all studies for onshore wind turbines. The reason why these studies are carried out onshore is for the following reasons. One reason is that the painting of the wind turbine blades was done when the wind turbines were already installed and operating. This meant that the wind turbines were temporarily shut down to allow workers to paint the blades. Access to onshore wind turbines is easier and less expensive than offshore, as there is no need for ships to reach the turbines. Another reason for the onshore study is that bird deaths can be measured manually. Offshore bird deaths are more difficult to measure because it is easier to locate deceased birds on land than offshore due to their tendency to drift away. While there is no final conclusion yet about this technology adoption in the Netherlands, it is seen as ethically justifiable to experiment with this technology. If it turns out that painting one turbine blade black, collisions are reduced by 70% like in 'Smøla', this technology can be experimented offshore or even implemented immediately.

Personal reflection

Now there is room to be more opinionated and to reflect on the thesis. To begin this personal reflection, the Moral Weight Project is discussed. A subjective limitation is that the framework of the Moral Weight Project's moral weights are quite high. The welfare range for chickens is 33.2% compared to the welfare range of humans. In this thesis it is assumed that birds in general have a welfare range of 33.2% compared to the welfare range of humans. I believe that this welfare range is high, but as mentioned above, this is subjective. Sometimes we have to deal with uncertainties, and sometimes well considered assumptions are the best we have. Therefore I do not completely disagree with the Moral Weight Project, I think it is a good framework for people to understand the complexities in the decision-making processes of trade-offs between humans and animals. In the Moral Weight Project, less 'murderous' examples are assessed using welfare ranges, which results in easier choices. In this thesis, I tried to make the trade-offs as explicit as possible: a whole human life versus a number of birds.

When there are uncertainties, it is difficult to make the problem explicit. I come from a Mechanical Engineering and Management of Technology background. While ethics is a part of the curriculum of MoT, in Mechanical Engineering it was not. During the thesis I tried to make the problem as explicit as possible. This meant to sometimes make calculated assumptions or just assumptions. This was definitely not in line with what I learned during my studies. There is not one framework that states that it is ethically permissible to emit CO_2 in order to save animal lives. The simplicity of this problem lies in the fact that there is not one framework to obtain an answer for this problem. This resulted in a lot of problems during this thesis. Ethics is not as black and white as Mechanical Engineering. In Mechanical Engineering for example, we look for a strong material to work with. Either the strongest material or the most rigid material is chosen for a mechanical purpose. Ethics is unfortunately not as explicit, even though, I tried my best to make the problem as explicit as possible. How more explicit can curtailment be justified by obtaining a trolley problem and making a trade-off between one human being and a number of animals?

I argue that there should be a trade-off between a human being and a number of animals, and thus curtailment is justifiable. Some people would argue that it is evident that curtailment is justifiable, as animals are sometimes just as important as one human being. Therefore I do believe that there will be people who believe that this thesis tackles a problem in which the answer is already known. On the other hand, I also do believe that there are people who would believe that humans are always more important than a number of animals. The primary objective of offshore wind farms is the reduction of CO_2 emissions, unfortunately the negative externality is bird (and bat) mortalities. This is in my view the beauty of ethics: If someone else with totally different views conducts this same problem, another conclusion could be drawn. This is at the same time the pitfall of ethics as, what I discussed above, this makes decision-making during the thesis very hard. Sometimes you have to make up your mind and decide to accept an ethical theory and reject another, not because one is factual and the other is not, but simply because you agree with one more than the other.

Going back to the thesis topic. I believe that the countries around the North Sea should, at the very least, start studying the principle of curtailment and implement the procedure of curtailment. This cannot be implemented overnight of course, but as I believe countries are morally obliged to curtail offshore wind farms for the sake of animal lives, countries should start as soon as possible. This is my view of curtailment in the North Sea. I think that the Netherlands will be a good example for the countries around the North Sea and perhaps when the Netherlands are a good example for other countries around the North Sea, these countries will follow.

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A

Hypothetical curtailment scenario 500 birds/km/h

"Imagine there are 500 birds per kilometre per hour migrating over the North Sea in the Netherlands. The decision-making process of curtailment in the Netherlands is initiated. The offshore wind farm 'Borssele' is curtailed for eight hours during the night, from 22:00 until 06:00. There is no peak demand. However, the loss of energy from the wind turbines needs to be compensated using natural gas in order to meet demand. This is necessary as grid operator TenneT needs to guarantee the stability of the high-voltage grid. There is a trade-off, namely more CO_2 emissions, but the prevention of bird deaths. How can we justify the curtailment?"

Note that for the hypothetical curtailment scenario, the vertical radar detection method is used, as described in chapter 4. According to Krijgsveld et al. (2009) 0.14% of all bird lives are saved when wind turbines are inactive, this means that one in 714 birds will collide with a wind turbine, as 714 * 0.014% = 1 bird. It should be noted that this is the aggregate percentage of both day- and night time, and measured during winter/autumn, nevertheless in this hypothetical curtailment scenario this value will be assumed.

In order to determine the number of birds that fly through the Borssele wind farm, it is first necessary to establish the size of Borssele. As mentioned before in section 4.4, wind farm Borssele consists of 173 wind turbines and has an area of 344 km^2. As seen in figure 4.3, Borssele is almost triangle shaped, to make calculations easier, it is assumed that Borssele's area is an equilateral triangle, meaning all sides are equal. Taking the area of Borssele of 344 km^2, then each side is equal to approximately 28.2 kilometres. It is assumed the bird migration is perpendicular to one of the sides of the equilateral triangle area of Borssele. See figure A.1 as an illustration.

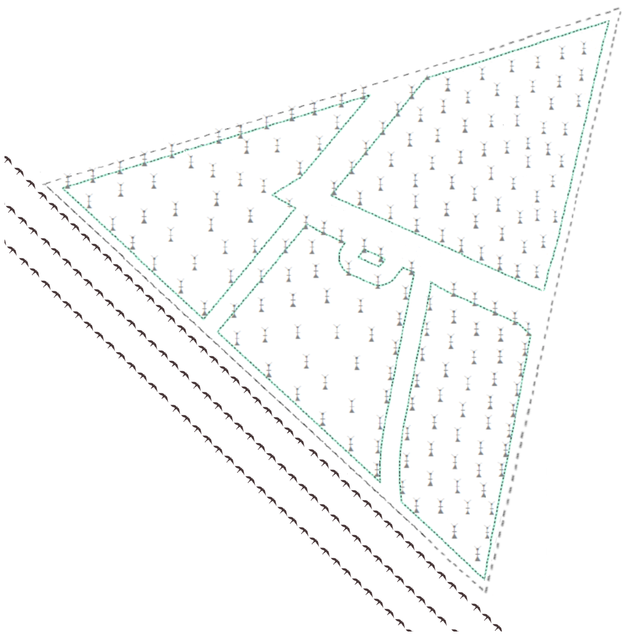

Figure A.1: Wind farm Borssele as an equilateral triangle (Appendix A)

Given that 500 birds migrate per kilometre per hour and assumed that Borssele has equal lengths of 28.2 kilometres, the following number of birds fly over Borssele per hour:

$$500\ [\frac{birds}{\frac{km}{h}}] * 28.2[km] = \textbf{14,100}\ [\frac{\textbf{birds}}{\textbf{h}}] \tag{A.1}$$

As the curtailment period lasts eight hours, the following number of birds are estimated to fly over the Borssele offshore wind farm:

$$14,100\ [\frac{birds}{h}] * 8\ [h] = \textbf{112,800 [birds]} \tag{A.2}$$

This indicates that during the eight-hour curtailment period, approximately 112,800 birds would fly over the Borssele offshore wind farm. In light of the aggregate percentage of prevented bird mortalities, which is estimated to be 0.14% according to Krijgsveld et al. (2009), the total number of bird mortalities prevented is:

$$112,800\ [birds] * 0.14\ [\%] = \textbf{158 [birds]} \tag{A.3}$$

It should be noted that this example is an extreme example. Curtailment of eight hours is a long period, a number of 500 birds/km/h is high and the 0.14% is a high percentage. To put the hypothetical scenario in perspective: According to Ferris (2022), 17 birds per wind turbine are killed, according to Zimmer (2024), an average of five birds per wind turbine are killed, according to Sanou (2024), 19 birds per wind turbine are killed. This is an average of 14 bird deaths per wind turbine per year. In this case for the offshore wind farm Borssele this would mean 2,422 bird deaths in one year. In this example the prevented bird deaths are approximately 6.5% of all the bird mortalities over a year in only eight hours. Nevertheless, in this scenario the Netherlands would initiate curtailment for the offshore wind farm Borssele. The curtailment procedure would, hypothetically, save 158 birds. During these eight hours of curtailment, the Netherlands are willing to curtail.

The question that follows is the magnitude of the CO_2 emissions generated by natural gas, the extra costs by using natural gas and lastly the costs per avoided bird deaths during the eight hours of curtailment. The Blauwwind site of the Borssele offshore wind farm generates approximately 3 TWh of energy every year (Borsboom, 2021; Wind & Waterworks, 2023). As Blauwwind's power generation is 731.5 MW, and Borssele's total power generation is 1.5 GW, approximately twice the amount of Blauwwind's energy generation, it is assumed that Borssele's total energy generation per year is 6 TWh. To keep the calculation simple it is assumed that Borssele generates a continuous amount of energy every hour. In the next equation the energy generation in one year is converted to power generation per day.

$$\frac{6.0\ [TWh]}{365\ [days]} = 0.0164\ [TWh] = \textbf{16.4 [GWh]} \tag{A.4}$$

It is assumed that Borssele generates a continuous amount of power on an hourly basis. Consequently, during periods of curtailment, the following amount of power is not produced:

$$\frac{16.4\ [GWh]}{24\ [h]} * 8\ [h] = \textbf{5.5 [GWh]} \tag{A.5}$$

This means that by curtailing Borssele for eight hours, 5.5 GWh worth of energy needs to be generated by natural gas. According to the Central Statistical Office (2024c), one m^3 of natural gas accounts for 35.17 MJ worth of energy. In order to determine the amount of natural gas required to produce 5.5 GWh of power, it is necessary to convert the units to ensure consistency. This is achieved by first converting the gigawatt-hours (GWh) to megajoules (MJ), as follows:

$$1\ [GWh] = 1\ [GW] * 1\ [hour] = 1,000,000,000\ [W] * 3,600\ [sec] = \textbf{3,600,000 [MJ]} \tag{A.6}$$

As one GWh of energy is equal to 3,600,000 MJ of power, then 5,5 GWh of energy is equal to:

$$3,600,000\ [MJ] * 5.5 = \textbf{19,800,000 [MJ]} \tag{A.7}$$

As mentioned, one m^3 of natural gas accounts for 35.17 MJ worth of energy, then 19,800,000 MJ equals:

$$\frac{19,800,000\ [MJ]}{35.17\ [\frac{MJ}{m^3}]} = \textbf{565,714}\ [\mathbf{m^3}] \tag{A.8}$$

According to the Environmental Protection Agency (2024) and Zijlema (2019) one m^3 emits approximately 1.9 kilograms of CO_2. Knowing the amount of m^3 of natural gas required, it is possible to determine the amount of kg of CO_2 that will be emitted:

$$565,714\ [m^3] * 1.9\ [\frac{kg}{m^3}] = 1,074,857\ [kg] \approx \textbf{1,075 [tons]} \tag{A.9}$$

Thus by curtailing for eight hours, assuming the energy production for a whole year is constant per hour, the Netherlands need to use 565,714 m^3, which results in approximately 1.1 million kilograms of CO_2, in order to meet the demand of energy which is not produced by the wind turbines. Over half a million m^3 of natural gas, and thus also 1.1 million kg of CO_2 seems like an absurd amount. Next, this will be put in perspective. According to the Central Statistical Office (2024b); Times (2024) the Netherlands have consumed 30 Billion m^3 of natural gas in 2023. This includes energy generation, industry, agriculture and the built environment. Of this 30 Billion m^3, 7.14 Billion m^3 was used for energy generation. This means that 565,714 m^3 compared to 7.14 Billion m^3 of gas is:

$$\frac{565,714\ [m^3]}{7,140,000,000\ [m^3]} * 100\% = \textbf{0.0079 \%} \tag{A.10}$$

So by curtailing for eight hours, assuming the energy production for a whole year is constant per hour, the Netherlands would use 0.0079% of their total electricity energy consumption of one year.

Knowing the amount of CO_2 emissions, and the number of birds saved, it is possible to determine how many tons of CO_2 the Netherlands is, hypothetically, willing to emit per saved bird:

$$\frac{1,074,857\ [kg]}{158\ [birds]} = 6806.3\ [\frac{kg}{bird}] \approx \textbf{6.8}\ [\frac{\textbf{tons}}{\textbf{bird}}] \tag{A.11}$$

This means that in this hypothetical scenario, the Netherlands are willing to emit 6.8 tons of CO_2 in order to save one bird. Note that this calculation is for 500 birds per kilometre per hour, this number is the threshold the Netherlands is currently curtailing for.

The next step is to determine how much the amount of 565,714 m^3 of natural gas costs. According to the Title Transfer Facility (2024), in the last 12 months the average gas price of natural gas was 34.545 €/MWh. As curtailment would mean a loss of 5.5 GWh, which equals to 5,500 MWh of energy, than this amount of energy is worth:

$$5,500\ [MWh] * 35.545\ [\frac{€}{MWh}] = €189,997.5 \approx \textbf{€190,000} \tag{A.12}$$

Consequently, the Netherlands would face a cost of €190,000 for a curtailment of eight hours. It should be noted that the procedure for measuring curtailment is likely to be more costly due to the additional costs associated with time and capital, given the involvement of multiple stakeholders. Nevertheless, taking this hypothetical scenario, it can be determined what one bird's life is worth:

$$\frac{190,000\ [\text{€}]}{158\ [birds]} = 1,203.1\ [\frac{\text{€}}{bird\ life}] \approx \mathbf{1200}\ [\frac{\text{€}}{\textbf{bird life}}] \tag{A.13}$$

Concluding, the Netherlands have a curtailment measurement procedure on offshore wind farms in the North Sea. This means that when the threshold of 500 birds per kilometre per hour is exceeded during migration periods and during the nights, curtailment of an offshore wind farm may be initiated. In this hypothetical scenario the offshore wind farm 'Borssele' is curtailed for eight consecutive hours due to a high migration flux of birds, namely the threshold of 500 birds per kilometre per hour. The Netherlands are willing to make the following trade-offs in this hypothetical scenario. The Netherlands are willing to 'pay' €1,200 for a single bird life. Consequently, this curtailment scenario will cost the Netherlands a total of €190,000. The Netherlands are willing to emit 6.8 tons of CO_2 in order to save one bird's life.

According to the Central Statistical Office (2024a), the life expectancy for women was 83.3 years, while men had a life expectancy of 80.3 years, which gives an average life expectancy in the Netherlands in 2023 of 81.8 years. As one 'hypothetical curtailment scenario loses' 1.80 DALYs, then the following number of hypothetical curtailment scenarios lose a human life:

$$\frac{81.8\ [years]}{1.80\ [DALYs]} = 45.4 \approx \mathbf{45} \tag{A.14}$$

This implies that if the Netherlands were to curtail 45 times as per the hypothetical curtailment scenario, the quantity of supplementary tons of CO_2 that would be emitted as gas-fired power plants are required to generate the equivalent amount of energy that would not be generated by offshore wind turbines.

Furthermore, as mentioned in equation 4.21, the average amount of $\frac{\text{€}}{DALYs}$ is €100.667, whereas the average life expectancy is 81.8 years. These values can therefore derive to the average amount a human life is worth as follows:

$$100,667[\frac{\text{€}}{DALY}] * 81.8\ [years] = \text{€}8,234,533 \approx \textbf{€8.23 million} \tag{A.15}$$

Going back to approximately 45 hypothetical curtailment scenarios being equal to one healthy average human life. One hypothetical curtailment scenario implies that a total of 158 birds are saved. The amount of 45 curtailment scenarios would imply that the following number of bird lives are saved:

$$45 * 158\ [birds] = \textbf{7,110 [birds]} \tag{A.16}$$

The question that arises is thus as follows:

"Ought we to be indifferent between saving 7,110 birds and one full healthy life of a human being?"

B

Hypothetical curtailment scenario 1,000 birds/km/h

"Imagine there are 1,000 birds per kilometre per hour migrating over the North Sea in the Netherlands. The decision-making process of curtailment in the Netherlands is initiated. The offshore wind farm 'Borssele' is curtailed for eight hours during the night, from 22:00 until 06:00. There is no peak demand. However, the loss of energy from the wind turbines needs to be compensated using natural gas in order to meet demand. This is necessary as grid operator TenneT needs to guarantee the stability of the high-voltage grid. There is a trade-off, namely more CO_2 emissions, but the prevention of bird deaths. How can we justify the curtailment?"

Note that for the hypothetical curtailment scenario, the vertical radar detection method is used, as described in chapter 4. According to Krijgsveld et al. (2009) 0.14% of all bird lives are saved when wind turbines are inactive, this means that one in 714 birds will collide with a wind turbine, as 714 * 0.014% = 1 bird. It should be noted that this is the aggregate percentage of both day- and night time, and measured during winter/autumn, nevertheless in this hypothetical curtailment scenario this value will be assumed.

In order to determine the number of birds that fly through the Borssele wind farm, it is first necessary to establish the size of Borssele. As mentioned before in section 4.4, wind farm Borssele consists of 173 wind turbines and has an area of 344 km^2. As seen in figure 4.3, Borssele is almost triangle shaped, to make calculations easier, it is assumed that Borssele's area is an equilateral triangle, meaning all sides are equal. Taking the area of Borssele of 344 km^2, then each side is equal to approximately 28.2 kilometres. It is assumed the bird migration is perpendicular to one of the sides of the equilateral triangle area of Borssele. See figure B.1 as an illustration.

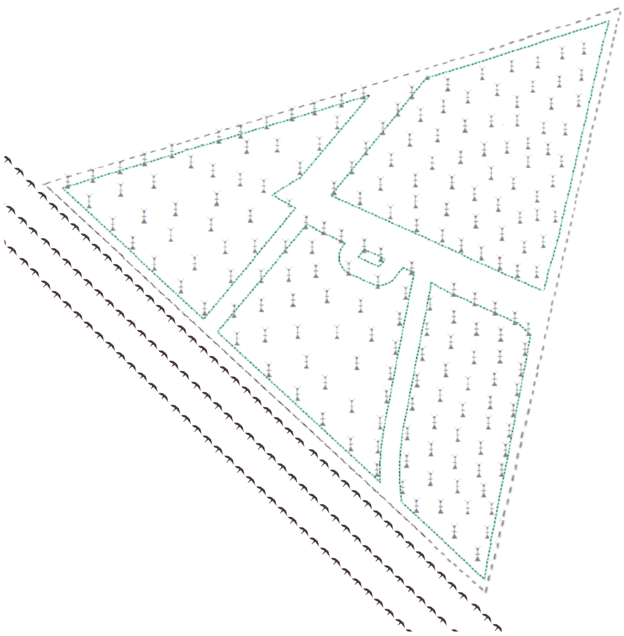

Figure B.1: Wind farm Borssele as an equilateral triangle (Appendix B)

Given that 1,000 birds migrate per kilometre per hour and assumed that Borssele has equal lengths of 28.2 kilometres, the following number of birds fly over Borssele per hour:

$$1,000\ [\frac{birds}{\frac{km}{h}}] * 28.2[km] = \mathbf{28{,}200}\ [\frac{\mathbf{birds}}{\mathbf{h}}] \tag{B.1}$$

As the curtailment period lasts eight hours, the following number of birds are estimated to fly over the Borssele offshore wind farm:

$$28,200\ [\frac{birds}{h}] * 8\ [h] = \mathbf{225{,}600\ [birds]} \tag{B.2}$$

This indicates that during the eight-hour curtailment period, approximately 225,600 birds would fly over the Borssele offshore wind farm. In light of the aggregate percentage of prevented bird mortalities, which is estimated to be 0.14% according to Krijgsveld et al. (2009), the total number of bird mortalities prevented is:

$$225,600\ [birds] * 0.14\ [\%] = \mathbf{316\ [birds]} \tag{B.3}$$

It should be noted that this example is an extreme example. Curtailment of eight hours is a long period, a number of 1,000 birds/km/h is high and the 0.14% is a high percentage. To put the hypothetical scenario in perspective: According to Ferris (2022), 17 birds per wind turbine are killed, according to Zimmer (2024), an average of five birds per wind turbine are killed, according to Sanou (2024), 19 birds per wind turbine are killed. This is an average of 14 bird deaths per wind turbine per year. In this case for the offshore wind farm Borssele this would mean 2,422 bird deaths in one year. In this example the prevented bird deaths are approximately 13% of all the bird mortalities over a year in only eight hours. Nevertheless, in this scenario the Netherlands would initiate curtailment for the offshore wind farm Borssele. The curtailment procedure would, hypothetically, save 316 birds. During these eight hours of curtailment, the Netherlands are willing to curtail.

The question that follows is the magnitude of the CO_2 emissions generated by natural gas, the extra costs by using natural gas and lastly the costs per avoided bird deaths during the eight hours of curtailment. The Blauwwind site of the Borssele offshore wind farm generates approximately 3 TWh of energy every year (Borsboom, 2021; Wind & Waterworks, 2023). As Blauwwind's power generation is 731.5 MW, and Borssele's total power generation is 1.5 GW, approximately twice the amount of Blauwwind's energy generation, it is assumed that Borssele's total energy generation per year is 6 TWh. To keep the calculation simple it is assumed that Borssele generates a continuous amount of energy every hour. In the next equation the energy generation in one year is converted to power generation per day.

$$\frac{6.0\ [TWh]}{365\ [days]} = 0.0164\ [TWh] = \mathbf{16.4\ [GWh]} \tag{B.4}$$

It is assumed that Borssele generates a continuous amount of power on an hourly basis. Consequently, during periods of curtailment, the following amount of power is not produced:

$$\frac{16.4\ [GWh]}{24\ [h]} * 8\ [h] = \mathbf{5.5\ [GWh]} \tag{B.5}$$

This means that by curtailing Borssele for eight hours, 5.5 GWh worth of energy needs to be generated by natural gas. According to the Central Statistical Office (2024c), one m^3 of natural gas accounts for 35.17 MJ worth of energy. In order to determine the amount of natural gas required to produce 5.5 GWh of power, it is necessary to convert the units to ensure consistency. This is achieved by first converting the gigawatt-hours (GWh) to megajoules (MJ), as follows:

$$1\ [GWh] = \ 1\ [GW] * 1\ [hour] = 1,000,000,000\ [W]\ *\ 3,600\ [sec] = \mathbf{3{,}600{,}000\ [MJ]} \tag{B.6}$$

As one GWh of energy is equal to 3,600,000 MJ of power, then 5,5 GWh of energy is equal to:

$$3,600,000\ [MJ] * 5.5 = \textbf{19,800,000 [MJ]} \tag{B.7}$$

As mentioned, one m^3 of natural gas accounts for 35.17 MJ worth of energy, then 19,800,000 MJ equals:

$$\frac{19,800,000\ [MJ]}{35.17\ [\frac{MJ}{m^3}]} = \textbf{565,714}\ [\mathbf{m^3}] \tag{B.8}$$

According to the Environmental Protection Agency (2024) and Zijlema (2019) one m^3 emits approximately 1.9 kilograms of CO_2. Knowing the amount of m^3 of natural gas required, it is possible to determine the amount of kg of CO_2 that will be emitted:

$$565,714\ [m^3] * 1.9\ [\frac{kg}{m^3}] = 1,074,857\ [kg] \approx \textbf{1,075 [tons]} \tag{B.9}$$

Thus by curtailing for eight hours, assuming the energy production for a whole year is constant per hour, the Netherlands need to use 565,714 m^3, which results in approximately 1.1 million kilograms of CO_2, in order to meet the demand of energy which is not produced by the wind turbines. Over half a million m^3 of natural gas, and thus also 1.1 million kg of CO_2 seems like an absurd amount. Next, this will be put in perspective. According to the Central Statistical Office (2024b); Times (2024) the Netherlands have consumed 30 Billion m^3 of natural gas in 2023. This includes energy generation, industry, agriculture and the built environment. Of this 30 Billion m^3, 7.14 Billion m^3 was used for energy generation. This means that 565,714 m^3 compared to 7.14 Billion m^3 of gas is:

$$\frac{565,714\ [m^3]}{7,140,000,000\ [m^3]} * 100\% = \textbf{0.0079 \%} \tag{B.10}$$

So by curtailing for eight hours, assuming the energy production for a whole year is constant per hour, the Netherlands would use 0.0079% of their total electricity energy consumption of one year.

Knowing the amount of CO_2 emissions, and the number of birds saved, it is possible to determine how many tons of CO_2 the Netherlands is, hypothetically, willing to emit per saved bird:

$$\frac{1,074,857\ [kg]}{316\ [birds]} = 3401.4\ [\frac{kg}{bird}] \approx \textbf{3.4}\ [\frac{\textbf{tons}}{\textbf{bird}}] \tag{B.11}$$

This means that in this hypothetical scenario, the Netherlands are willing to emit 3.4 tons of CO_2 in order to save one bird. Note that this calculation is for 1,000 birds per kilometre per hour, this number is twice the threshold the Netherlands is currently curtailing for. If the threshold is exceeded by zero, thus 500 birds per kilometre per hour, the Netherlands are still curtailing. However, the tons of CO_2 emitted per bird are doubled, thus 6.8 tons of CO_2 emitted per bird. Vice versa, if 2,000 birds are migrating per kilometre per hour, the tons of CO_2 per bird are halved, thus 1.7 tons of CO_2 per bird is emitted.

The next step is to determine how much the amount of 565,714 m^3 of natural gas costs. According to the Title Transfer Facility (2024), in the last 12 months the average gas price of natural gas was 34.545 €/MWh. As curtailment would mean a loss of 5.5 GWh, which equals to 5,500 MWh of energy, than this amount of energy is worth:

$$5,500\ [MWh] * 35.545\ [\frac{\text{€}}{MWh}] = \text{€}189,997.5 \approx \textbf{€190,000} \tag{B.12}$$

Consequently, the Netherlands would face a cost of €190,000 for a curtailment of eight hours. It should be noted that the procedure for measuring curtailment is likely to be more costly due to the additional costs associated with time and capital, given the involvement of multiple stakeholders. Nevertheless, taking this hypothetical scenario, it can be determined what one bird's life is worth:

$$\frac{190,000\ [€]}{316\ [birds]} = 601.3\ [\frac{€}{bird\ life}] \approx \mathbf{600}\ [\frac{\mathbf{€}}{\textbf{bird life}}] \tag{B.13}$$

Concluding, the Netherlands have a curtailment measurement procedure on offshore wind farms in the North Sea. This means that when a threshold of 500 birds per kilometre per hour is exceeded during migration periods and during the nights, curtailment of an offshore wind farm may be initiated. In this hypothetical scenario the offshore wind farm 'Borssele' is curtailed for eight consecutive hours due to a high migration flux of birds, namely 1,000 birds per kilometre per hour. The Netherlands are willing to make the following trade-offs in this hypothetical scenario. The Netherlands are willing to 'pay' €600 for a single bird life. Consequently, this curtailment scenario will cost the Netherlands a total of €190,000. The Netherlands are willing to emit 3.4 tons of CO_2 in order to save one bird's life.

According to the Central Statistical Office (2024a), the life expectancy for women was 83.3 years, while men had a life expectancy of 80.3 years, which gives an average life expectancy in the Netherlands in 2023 of 81.8 years. As one 'hypothetical curtailment scenario loses' 1.80 DALYs, then the following amount of hypothetical curtailment scenarios lose a human life:

$$\frac{81.8\ [years]}{1.80\ [DALYs]} = 45.4 \approx \mathbf{45} \tag{B.14}$$

This implies that if the Netherlands were to curtail 45 times as per the hypothetical curtailment scenario, the quantity of supplementary tons of CO_2 that would be emitted as gas-fired power plants are required to generate the equivalent amount of energy that would not be generated by offshore wind turbines.

Furthermore, as mentioned in equation 4.21, the average amount of $\frac{€}{DALYs}$ is €100.667, whereas the average life expectancy is 81.8 years. These values can therefore derive to the average number a human life is worth as follows:

$$100,667[\frac{€}{DALY}] * 81.8\ [years] = €8,234,533 \approx \textbf{€8.23 million} \tag{B.15}$$

Going back to approximately 45 hypothetical curtailment scenarios being equal to one healthy average human life. One hypothetical curtailment scenario implies that a total of 316 birds are saved. The amount of 45 curtailment scenarios would imply that the following number of bird lives are saved:

$$45 * 316\ [birds] = \textbf{14,220 [birds]} \tag{B.16}$$

The question that arises is thus as follows:

"Ought we to be indifferent between saving 14,220 birds and one full healthy life of a human being?"

C

New threshold of bird migration fluxes

In order to determine the new bird migration flux it should be determined first how many birds are flying over the offshore wind farm Borssele. First, it needs to be determined how many birds per curtailment scenario need to be saved:

$$\frac{19\ [birds]}{45\ [curtailment\ scenario]} = \mathbf{0.42} \frac{\textbf{birds saved}}{\textbf{curtailment scenario}} \tag{C.1}$$

The number of total bird flux can be calculated as follows:

$$\frac{0.42\ [birds]}{0.14\ [\%]} = \mathbf{302\ [birds]} \tag{C.2}$$

In order to determine the number of birds per hour the number needs to be divided by eight hours due to the curtailment period of this number of hours:

$$\frac{302\ [birds]}{8\ [hours]} = \mathbf{37.7}\ [\frac{\textbf{birds}}{\textbf{h}}] \tag{C.3}$$

The final step to determine the bird flux per kilometre per hour is to rephrase the birds per hour to birds per kilometre per hour:

$$\frac{37.7\ [\frac{birds}{h}]}{28.2\ [km]} = 1.36 \approx \mathbf{1.4}\ [\frac{\textbf{birds}}{\frac{\textbf{km}}{\textbf{h}}}] \tag{C.4}$$

Table C.1 shows what welfare ranges of bird ought to be in order to be indifferent between one human and a number of birds. The number of birds a person is indifferent to is depicted in the first column. In the second column the welfare range is stated, so for example, if a person is indifferent between 1 human and 100 birds, a person ought to believe one bird's welfare range is 0.0315. The third column is the needed bird flux for a hypothetical scenario in which the same number of hours is curtailed, thus 45 hypothetical curtailment scenarios are equivalent to one human life. Note that still some assumptions are made, such as the average life expectancy of a human and the life expectancy of a seagull is taken as the lifespan for birds in general. The most important assumption is assuming that a welfare range is the correct proxy to come to the conclusion that people ought to be indifferent between one human life and an exact number of birds.

Indifferent between	Positive welfare capacity of a bird	Corresponding bird flux
1 human and 1 bird	6.30	0.1 birds/km/h
1 human and 5 birds	1.258	0.4 birds/km/h
1 human and 10 birds	0.630	0.7 birds/km/h
1 human and **19 birds**	**0.332** (as section 4.7.1)	**1.4 birds/km/h**
1 human and 25 birds	0.252	1.8 birds/km/h
1 human and 50 birds	0.126	3.5 birds/km/h
1 human and 100 birds	0.0630	7.0 birds/km/h
1 human and 200 birds	0.0315	14 birds/km/h
1 human and 300 birds	0.0210	21 birds/km/h
1 human and 400 birds	0.0157	28 birds/km/h
1 human and 500 birds	0.0126	35 birds/km/h
1 human and 1,000 birds	0.00630	70 birds/km/h
1 human and 3,019 birds	0.00208	107 birds/km/h
1 human and 5,000 birds	0.00126	352 birds/km/h
1 human and **7,110 birds**	**0.00088** (as Appendix A)	**500 birds/km/h**
1 human and 10,000 birds	0.000630	703 birds/km/h
1 human and **14,220 birds**	**0.00044** (as Appendix B)	**1,000 birds/km/h**
1 human and **19,710 birds**	**0.00032** (as section 4.4)	**1,386 birds/km/h**
1 human and 50,000 birds	0.000126	3,516 birds/km/h
1 human and 100,000 birds	0.0000630	7,032 birds/km/h
1 human and 500,000 birds	0.0000126	35,162 birds/km/h
1 human and 1,000,000 birds	0.00000630	70,323 birds/km/h
1 human and ∞ birds	0.00	∞ birds/km/h

Table C.1: Welfare ranges indifferences with corresponding bird flux Appendix C

D

Background information of countries surrounding the North Sea

This section offers further insight into the countries around the North Sea. It provides data on the projected amount of gigawatts (GW) to be generated, the number of wind turbines or offshore wind farms to be constructed, and the extent of the existing offshore wind farms.

Offshore wind energy is expected to play a major role in achieving emission targets, especially for countries in the North Sea region. Offshore wind generation in the North Sea region will increase from 100-120 GW in 2030 to between 300-500 GW in 2050 (IEA, 2023; Santhakumar, Meerman, Faaij, Gordon, & Gusatu, 2024).

Belgium

Belgium currently has 12 operational offshore wind farms with a total capacity of 2.3 GW covering 225 km^2 (4C Offshore, 2024). Belgium is currently developing a second wind zone of 281 km^2 with a planned capacity of up to 3.5 GW. This results in a total offshore wind capacity between 5.35-5.7 by 2030 (IEA, 2022a). By 2040 Belgium aims to generate 8.0 GW from offshore wind farms (Pacheco, 2024).

Denmark

To date, Denmark has a capacity of 2.3 GW of offshore wind energy from 15 operational wind farms. Denmark aims to increase this capacity to 18 GW in 2030 and 35 GW in 2050 (IEA, 2023; 4C Offshore, 2024). It should be noted that Denmark's offshore wind capacity is located in both the North Sea and the Baltic Sea. No distinction is made between the two seas, this is just background information for the country of Denmark.

Germany

Germany currently has 30 operating offshore wind farms, located in both the North and Baltic Sea. Generated electricity from fixed bottom offshore wind farms in 2050: 31 GW (Santhakumar et al., 2024).

United Kingdom

The United Kingdom currently has 44 operational wind farms (4C Offshore, 2024). These wind farms currently produce 14.7 GW of electricity, accounting for 16% of the total energy consumption. In the 2020s alone, the UK plans to build 10 GW of capacity and by 2030 the UK aims to produce 50 GW of electricity (IEA, 2019; A. Tang, 2024). The UK is the European leader in offshore wind energy generation.

Netherlands

To date, the Netherlands has 10 operational offshore wind farms in the North Sea with a total capacity of 4.65 GW (4C Offshore, 2024). The size of the offshore wind farms ranges from 2 turbines to 150 turbines, with an electrical capacity of 19 MW to 1529 MW. The wind turbines are located between 11 and 60 kilometres from the coast. In 2023 alone, the Netherlands have built 48.2% of the energy capacity in the North Sea. The Netherlands aims to generate 11.5 GW by 2030, 50 GW by 2040 and 70 GW in 2050 (Netherlands Enterprise Agency, 2024).

Norway

To date, Norway has three operating offshore wind farms (4C Offshore, 2024). Norway is currently building the world's largest floating offshore wind farm consisting of 11 wind turbines with a capacity of 88 MW. Furthermore, Norway is planning to generate 12 GW and 30 GW of offshore wind capacity by 2030 and 2040 respectively. 30 GW accounts for almost all of Norway's electricity generation today (IEA, 2022b).

E

Using different DALYs per ton of CO_2

The data of table 4.2 is displayed from average $\frac{DALYs}{Ton\ of\ CO_2}$ from low to high. In this Appendix, the calculations for the minimum and maximum amount are derived. It would have been optimal for the magnitudes of the DALYs to be identical. The minimum amount is 0.00041 $\frac{DALYs}{Ton\ of\ CO_2}$, whereas the maximum amount is 0.0029 $\frac{DALYs}{Ton\ of\ CO_2}$. Both magnitudes will be assessed below.

Minimum amount of DALYs per ton of CO_2

Next, this information is compared with the hypothetical scenario earlier mentioned in section 4.4. In equation 4.9, it is derived that the amount of tons emitted from the curtailment scenario is 1,075 tons of CO_2. As the minimum amount of $\frac{DALYs}{Ton\ of\ CO_2}$ is 0.00041 according to Eckelman and Sherman (2017), and the amount of tons of CO_2 is 1,075, it can be determined how many DALYs the hypothetical curtailment scenario is responsible for assuming the data from Eckelman and Sherman is correct:

$$0.00041\ [\frac{DALYs}{Ton\ of\ CO_2}] * 1,075\ [tons\ of\ CO_2] = \mathbf{0.441}\ [\mathbf{DALYs}] \tag{E.1}$$

The hypothetical curtailment scenario is now responsible for the loss of 0.441 DALYs. Given the information that one curtailment scenario loses 0.441 DALYs, it can be determined how many hypothetical curtailment scenarios will be responsible for an entire human life. In order to derive the amount of hypothetical curtailment scenarios that are responsible for an entire human life, the life expectancy is needed. In this example, the life expectancy of the Netherlands is used.

According to the Central Statistical Office (2024a), the life expectancy for women was 83.3 years in 2023, while men had a life expectancy of 80.3 years in 2023, which gives an average life expectancy in the Netherlands in 2023 of 81.8 years. As one hypothetical curtailment scenario has a cost of 0.441 DALYs, then the following amount of hypothetical curtailment scenarios lose an entire human life:

$$\frac{81.8\ [years]}{0.441\ [DALYs]} = 185.6 \approx \mathbf{186\ [Curtailment\ scenarios]} \tag{E.2}$$

This implies that if the Netherlands were to curtail 186 times as per the hypothetical curtailment scenario an entire human life is lost. This is due to the quantity of supplementary tons of CO_2 that would be emitted as gas peaker plants are required to generate the equivalent amount of energy that would not be generated by offshore wind turbines to meet the energy demand. One hypothetical curtailment scenario also implies that a total of 438 birds are saved, derived in equation 4.3. The amount of 186 curtailment scenarios would therefore imply that the following number of bird lives are saved:

$$186 * 438\ [birds] = \mathbf{81{,}290\ [birds]} \tag{E.3}$$

In summary, in the hypothetical curtailment scenario, the data shows that an average of 1,386 birds are migrating per kilometre per hour for eight consecutive hours over the offshore wind farm Borssele. The offshore wind farm Borssele will be curtailed for these eight consecutive hours to save 438 birds from being struck by the offshore wind turbines. Gas peaker plants are used to meet the energy demand in the Netherlands, generating electricity that would otherwise be produced by the offshore wind farm Borssele. The use of gas peaker plants results in 1,075 tons of CO_2 emissions being released into the atmosphere. Consequently, 1,075 tons of CO_2 emissions result in losing 0,441 DALYs. Concluding, 186 hypothetical curtailment scenarios result in the loss of an entire, healthy, human life for the sake of the prevention of 81,290 bird mortalities.

Maximum amount of DALYs per ton of CO_2

Next, the maximum $\frac{DALYs}{Ton\ of\ CO_2}$ is used to derive the number of curtailment scenarios needed for the loss of an entire human life. The maximum amount is 0.0029 $\frac{DALYs}{Ton\ of\ CO_2}$.

This information is compared with the hypothetical scenario earlier mentioned in section 4.4. In equation 4.9, it is derived that the amount of tons emitted from the curtailment scenario is 1,075 tons of CO_2. As the maximum amount of $\frac{DALYs}{Ton\ of\ CO_2}$ is 0.0029 according to Romanello et al. (2023), and the amount of tons of CO_2 is 1,075, it can be determined how many DALYs the hypothetical curtailment scenario is responsible for assuming the data from Romanello et al. is correct:

$$0.0029\ [\frac{DALYs}{Ton\ of\ CO_2}] * 1,075\ [tons\ of\ CO_2] = \mathbf{3.12}\ [\mathbf{DALYs}] \tag{E.4}$$

The hypothetical curtailment scenario is now responsible for the loss of 3.12 DALYs. Given the information that one curtailment scenario loses 3.12 DALYs, it can be determined how many hypothetical curtailment scenarios will be responsible for an entire human life. In order to derive the amount of hypothetical curtailment scenarios that are responsible for an entire human life, the life expectancy is needed. In this example, the life expectancy of the Netherlands is used.

According to the Central Statistical Office (2024a), the life expectancy for women was 83.3 years in 2023, while men had a life expectancy of 80.3 years in 2023, which gives an average life expectancy in the Netherlands in 2023 of 81.8 years. As one hypothetical curtailment scenario has a cost of 3.12 DALYs, then the following amount of hypothetical curtailment scenarios lose an entire human life:

$$\frac{81.8\ [years]}{3.12\ [DALYs]} = 26.2 \approx \mathbf{26\ [Curtailment\ scenarios]} \tag{E.5}$$

This implies that if the Netherlands were to curtail 26 times as per the hypothetical curtailment scenario an entire human life is lost. This is due to the quantity of supplementary tons of CO_2 that would be emitted as gas peaker plants are required to generate the equivalent amount of energy that would not be generated by offshore wind turbines to meet the energy demand. One hypothetical curtailment scenario also implies that a total of 438 birds are saved, derived in equation 4.3. The amount of 26 curtailment scenarios would therefore imply that the following number of bird lives are saved:

$$26 * 438\ [birds] = \mathbf{11{,}388\ [birds]} \tag{E.6}$$

In summary, in the hypothetical curtailment scenario, the data shows that an average of 1,386 birds are migrating per kilometre per hour for eight consecutive hours over the offshore wind farm Borssele. The offshore wind farm Borssele will be curtailed for these eight consecutive hours to save 438 birds from being struck by the offshore wind turbines. Gas peaker plants are used to meet the energy demand in the Netherlands, generating electricity that would otherwise be produced by the offshore wind farm Borssele. The use of gas peaker plants results in 1,075 tons of CO_2 emissions being released into the atmosphere. Consequently, 1,075 tons of CO_2 emissions result in losing 3.12 DALYs. Concluding, 26 hypothetical curtailment scenarios result in the loss of an entire, healthy, human life for the sake of the prevention of 11,388 bird mortalities.