1. Introduction

While scientists became increasingly confident over the second half of the 20th century[1] that anthropogenic climate change[2] is happening and will have severe effects on human life on earth, for a long time studies have shown that great parts of the public still perceived there to be no consensus about the topic within the scientific community.[3]

There are multiple reasons why the public perception that basic questions about the anthropogenic climate change are not yet settled was sustainable for such a long time. On the one hand, in the past the issue of climate change has often been reported in a similar fashion as political debates: as a debate with good arguments on both sides, neglecting that it is not a question of opinions but of facts (Edwards, 1999). Thereby, a distorted picture about the degree of general agreement and disagreement among climate scientists is created (Boykoff and Boykoff, 2004; Washington and Cook, 2011). On the other hand, institutions and individuals that have an interest in discrediting climate

1 In this context, it is often said that there is a 97 % consensus among climate scientists about climate change, referring to a study done by Cook et al. (2013). Although there is some disagreement about the exact number, several other studies have shown that the overwhelming majority of publications in climate science journals do not question the anthropogenic climate change (e.g., Oreskes, 2004).

2 That is, the climate is changing due to external, human-caused forcing. Generally, forcing refers to a change in the energy budget of the planet, which can happen by nature, e.g., radiation from the sun or erupting volcanoes but also CO_2 emissions produced by humans.

3 Studies from the *Pew Research Center* show that the perception of climate change as a major threat to humanity in many countries has increased since 2013. The survey across 23 countries displays an increase from a median of 56 % in 2013 to 67 % in 2018 (Pew Research Center, 2019). However, studies from the same institute also show that in 2014 only 57 % of adult U.S. citizens were under the impression that there was consensus among scientists that climate change is happening (Pew Research Center, 2015).

scientists' research results have been shown to have invested large sums of money into climate-change critical research projects (Oreskes and Conway, 2010). This has artificially amplified their voices and given the false impression that there is no consensus at all among scientists concerning anthropogenic climate change.

Multiple psychological factors also play a role (Van Lange et al., 2018). After all, many policies to mitigate climate change are inconvenient to most of us. This makes it much more compelling to disregard scientific evidence. Furthermore, the scale of the problem might seem so overwhelming that it appears like one's individual actions will not have an impact anyway. Another contributing factor is that (at least in what is often referred to as the 'Western world') we are only just starting to see the effects of climate change. Heat waves, droughts, wildfires and warm winters have brought climate change to the forefront of social and political debates, in the last few years.

However, I will argue in this book that there is another underlying structural problem concerning public understanding of science that so far has rarely been discussed: how climate-change deniers benefitted from certain ideals about how science does and should operate, which are widespread in the public understanding of science. However, over the last few decades work of philosophers of science has shown that science, specifically when dealing with high complexity in the target system, such as climate science, cannot and more importantly need not hold up to these ideals.

Even though actual scientific practice is often far from these ideals, one reason that these ideals are so prevalent is because they are also frequently perpetuated by scientists themselves when communicating with the public. Thus, the discrepancies between these ideals and the everyday work of scientists often only become visible when science is dragged into the spotlight due to its social relevance.

The objective of the book is twofold:

1. Three ideals about science, which are perpetuated in the public's understanding of science and play reoccurring roles in public controversies about climate science, are investigated. It will be shown by example of climate science why science cannot but also does not have to life up to these ideals.
2. Under the assumption that these ideals cannot be referred to in order to assess which scientific research results to have confidence in, the aim is also

to provide another route, specifically for outsiders to the scientific community, to determine when it is justified to be (at least) sceptical about the claimed expertise of specific individuals.

I deliberately use the plural *ideals* here. For one, to stress that what I will examine in the following by no means constitute an exhaustive summary of these kinds of beliefs. I will assert that the ideals examined in this book make reoccurring appearances in the context of different controversies about climate change. For another, because it seems prudent to assume that these ideals are not exclusive to the public discourse about the reliability of climate science but also return in different compositions in other instances where scientific research affects public life, I would like to make it clear that these different aspects do not make up one coherent and full ideal that will be realised in its entirety wherever science meets public scrutiny.

In the following, I will examine three of these ideals as they manifest themselves in the case of controversies about climate science. They concern the role of values in science, the relationship between data and theory, and the handling of uncertainty. While in the public debate about climate change these ideals take a prominent and reoccurring role, they can also all be interpreted as signs of a wish for more simplicity in science. Proponents of these ideals argue that:

1. scientists should not 'spoil' scientific research with their values, instead, produce unbiased irrefutable facts.
2. a scientific theory or model can be easily proven or refuted by a comparison to irrevocable observational or experimental data.
3. and science should give clear yes- and no-answers, so uncertainties only mean that scientists need to try harder.

These assumptions, however, greatly underestimate the complexity of modern science and the systems examined. One might argue that, at least to some extent, no science can entirely fulfil the ideals outlined above. But as I hope to show in the next few chapters, in a case study of climate science, this holds particularly for those sciences dealing with highly complex systems. These sciences hit what Johannes Lenhard calls the *complexity barrier* (2019, pp. 89–131), where the complexity of the system impedes access to full analytical understanding. Simulations, as they are done extensively in these sciences, are, he argues, a way to circumvent these barriers, but they cannot overcome them.[4] The epistemic challenges coming from the complexity of the system make it distinctly evident that science functioning in such a simple and straightforward way as envisioned in these ideals is impossible. Considering this, the goal in the following is to show why science does not have to live up to these ideals.

To see how this will play out, let us first take a look at how these ideals are displayed in the public discussion of climate change: the first of these ideals of science states that science should be value-free (Chapter 3.1). The typical ideal of a 'man of science' is one who is fully detached from his personal beliefs on political or social issues in his work. While philosophers have discussed whether science can or even must uphold a separation between science and values since the early 20th century, the value-free ideal has been astonishingly persistent in the public perception of science as well as in science itself.

It seems reasonable to assume that this widespread perception of science as a fully value-free endeavour is also at the core of why it has been such as successful line of attack from climate-change denialists over the last few decades to frame climate change as a "hoax created by a conspiracy of supposedly greedy scientists, liberal politicians, and environmentalists" (Dunlap and Jacques, 2013, p. 713) and climate scientists having a personal "political agenda", as, for instance, former US President Donald Trump has done (BBC, 2018) or being "alarmists" (Medimorec and Pennycook, 2015) who overdramatise the situation (see also Brysse et al., 2013). Thus, it is implied that the scientists are influenced in an untoward way by their own 'leftist' values. Climate scientists also on occasion give the impression that they sometimes find themselves in the position where they feel like they have to defend themselves from these kinds of accusations (see e.g. Schmidt and Sherwood, 2015).[5]

4 Lenhard argues that the occurrence of the *complexity barriers* is not new to science. But historically, it was possible to overcome these without the help of computer simulations. As an example Lenhard cites the introduction of algebra in the 16th century (2019, p. 115).

5 For instance, at one of the high points of the attacks on climate scientists, Hans Joachim Schellnhuber, the then director of the *Potsdam Institute of Climate Impact Research* (PIK), pointed out in an interview that he drives a BMW, eats meat and is not a member of the *Green Party* (Evers et al., 2010). A somewhat paradoxical move from a scientist to call attention to the "value neutrality of his work by invoking certain values" (Leuschner, 2012a, p. 192). But Leuschner argues that Schellnhuber's declaration has to be inter-

The idea of the value-freeness of science in this context is often associated with the notion of *scientific objectivity*. Chapter 2.3 will show that the concept of scientific objectivity is not very well defined and has a variety of interpretations. Nevertheless, in the public understanding of science 'objective' science is often assumed to be value-free science. Thus, when climate science is attacked as being value-laden, it is commonly seen as not 'objective'. Only value-free science is considered to be objective and thereby good science.

As will be discussed in Chapter 3.1, philosophers of science have shown that science, specifically when its results have significant social and political implications, can never be guaranteed to be value-free. Nor does it have to be (Longino, 1990). Moreover, as Chapter 3.1.3 will show, the models used in climate science are commonly far too complex for climate scientists to consciously or inadvertently influence them in a specific direction furthering their personal social or political convictions.

The second ideal concerns the understanding of the relationship between experimentally acquired data und theory or, more specifically, theoretical models (Chapter 3.2). The common understanding of how the scientific process works is usually characterised in the following way: a scientist develops a theory or a hypothesis which then is tested by comparing it to data acquired by observation or experiment. Theories that cannot be proven by empirical data are to be disregarded immediately. In actual scientific practice, the relationship between the empirical and the theoretical is by no means that simple. At least since Thomas S. Kuhn published his hugely influential book *The Structure of Scientific Revolution* in 1962, there has been consensus among philosophers of science that scientists will usually need more than just one negative result of an experiment to overthrow a whole theoretical construct. Before Kuhn, philosophers such as Pierre Duhem (1906) and Willard Van Orman Quine (1951) also had argued that theories are underdetermined by empirical data. Furthermore, philosophers have established that observations are often (or even always) theory-laden. Norwood Russell Hanson (1958) is usually credited with having first clearly formulated the notion that our observations are influenced by theoretical background assumptions. In the context of highly complex computer models, philosophers have also argued that these models are not just theoretical constructs but also significantly data-laden (Edwards, 1999).

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preted as "desperate reaction to the climate skeptics' standard argument" (Leuschner, 2012a, p. 192) of climate science being inappropriately value-laden.

Increases in the complexity of the systems explored also mean an expanding complexity in the data to be handled. In climate science data is collected on a global scale. As will be further discussed in Chapter 3.2.3, observational data – for example, satellite data – in climate science is also heavily model-filtered (Edwards, 1999). Meaning that the 'raw' data not only has to be assembled but usually has to be processed in terms of filtering and homogenisation and the like before it is of any use to climate scientists. Hence, contrary to what is sometimes assumed, it does not suffice to gather some data from a few thermometers and then compare them to the results of the models. The observations as well as the models are laden with uncertainties. Nevertheless, climate-change deniers have repeatedly and very successfully argued that the disagreement between data sets and models does unequivocally show the models' failing (Lloyd, 2012).

A striking example of this is the infamous *Climategate scandal*, during which private emails between climate scientists from *Climatic Research Unit* at the University of East Anglia were leaked and the scientists, subsequently, accused of illicit data manipulations. In the emails the scientists were discussing using a "trick" to treat their data in order "to hide the decline" in tree-ring proxy data (Jones, 1999). This turned out to be a normal and well-established practice in the climate science community to counterbalance the so-called *divergence problem*.[6] Even though the incident was thoroughly investigated and the scientists later acquitted of any wrongdoing by several independent investigations, the media coverage gave the impression that there had been serious misbehaviour by the scientists in question (see also Leuschner, 2012b, pp. 39–47; Oxburgh et al., 2010).

An oversimplified view of the relationship between theory and data can effect actual climate policy. At the turn of the century climate-change sceptics have argued – quite successfully at the time even in front of the US congress – that an apparent discrepancy between models' predictions and data from satellite and weather balloons would show unequivocally that the climate models have been wrong and that, therefore, the models' prediction of temperature

6 To be more specific, the 'trick' here refers to a way of homogenising data so as to deal with the widely acknowledged problem of a "dramatic change in the sensitivity of hemispheric tree-growth to temperature forcing" (Briffa et al., 1998, p. 65) observed in the second half of the 20th century, that "if not recognized and accounted for, could lead to erroneous inferences about past and future climate changes" (Briffa et al., 1998, p. 66).

rise due to climate change have been vastly overestimated and no mitigating actions have to be taken (Edwards, 2010, pp. 413–418; Lloyd, 2012). However, instead of discarding the models many climate scientists questioned the adequacy of the particular data set. As Lloyd has pointed out with respect to this controversy, climate data ought not to be treated as "windows on the world, as reflections of reality, without any art, theory, or construction interfering with that reflection" (Lloyd, 2012, p. 392).

The third ideal that will be discussed relates to the expectation that science provides predictions with a clear yes-or-no-answer (Chapter 3.3). According to this view of science, uncertainties are a sign of premature science where the scientists have not done their job properly. The ability to make predictions has become a hallmark of modern science. Specifically, a scientific discipline which research has significant implications for society is expected by policymakers and the public at large to give distinct binary answers. So, when scientists voice uncertainty, it is often interpreted as no knowledge, not as knowledge to a certain degree.[7] This, of course, does not take into account that all scientific research is tainted by some degrees of uncertainty. Scientists are well aware that their work always has a preliminary character and might very well be overturned someday. Thus, this ideal is in stark contrast to what science actually can achieve.

In the public debate about climate change, this has manifested itself in the way climate-change sceptics have argued against taking mitigating measures. Uncertainties to some degree are presented as a sign that there is no evidence at all that anthropogenic climate change is happening, with the implication that there is no reason to act. The argument that the science on climate change is not yet settled (Howe, 2014) discounts, on the one hand, the high complexity of the climate system and, on the other hand, negates that, concerning the basic questions – for example, how increasing the amount of CO_2 in the atmosphere will lead to a global mean temperature rise – there is wide reaching consensus in the climate science community.

In situations that require urgent action, waiting for 'more certainty' comes, of course, at a certain cost. All in all, the question of how much certainty is

7 It has to be acknowledged here that in certain forms probability statements in science are generally accepted, even by a public audience. One might think, for instance, of quantum mechanics, where uncertainty is inherent to the non-deterministic quantum mechanical system. With a deterministic system, like the climate system, the expectation is often still that scientists deliver clear and precise research results.

required and at what stage to act is at best one of cost-benefit analyses. In the worst case, by the time the certainty is considered 'sufficient', it might be too late to act.

Thus, an insufficient public understanding of science has serious implication that go beyond the epistemic. In a case like climate change that has clear public and social significance, a lack of public understanding of how science actually works makes it easy for certain interest groups to undermine climate scientists when they raise legitimate concern about the threat of climate change. Instead the scientists are declared 'alarmists': that is, they are accused of "overinterpreting or overreacting to evidence of human impacts on the climate system" (Brysse et al., 2013). This makes it so dangerous to uphold these ideals. In doing so, science itself undermines its relevance to the public discourse:

> The danger is that holding science up to the wrong standard will diminish the value of what science discovers about nature, and could create an environment in which science is no longer consulted to inform policy. "The scientists can't give us a definitive answer, so why should we listen to them?" (Mitchell, 2009, pp. 118–119)

Still, from within the scientific community these simplistic ideals are quite often kept alive as a kind of 'useful fairy tale'. They underline the importance and infallibility of science. And after all, they "do not do any harm to the scientists unless policymaker start to believe that science is really so simple" (Collins, 2014, p. 24). This, however, can turn into a problem in those instances where the work of scientists is watched more closely than usual by the public.

Nevertheless, if we throw out these ideals, the question remains how can one then – specifically as outsiders to the scientific community – tell if the scientists and their work are trustworthy. In the following I will offer a different approach to this problem. Instead of resorting to either the virtues of the scientists or some distinct methodological approach that scientists follow, I will highlight the relevance of specialist tacit knowledge in science in general, which gains in relevance in the context of increasing complexity in science. Although tacit knowledge is at odds with the depiction of science in the aforementioned ideals, as it is commonly seen as something subjective and personal, I will argue that acknowledging this role of tacit knowledge, in fact, opens up a chance, even for outsiders to the scientific community, to assess at least to some degree whether or not to trust the work of the scientists. The argument, in short, is the following: the relevance of tacit knowledge also highlights the necessity of experience for expertise. Following Collins and Evans (2009), I will claim that this leads to a concept of scientific expertise that puts the experience gained by scientists while working in their specialist field front and centre. This definition of expertise is specifically useful in a situation where science is under distinct public scrutiny and researchers are confronted with criticism from individuals who are presented to the public as apparent 'experts' but who have never actually worked in the specific subject in question. As will be discussed further in Chapter 4, it can be shown that some of the most prominent 'experts' that climate sceptics have referred to in order to undermine climate science actually have never done any specific research in the field of climate science (Oreskes and Conway, 2010, p. 8). Further, I will argue that, if tacit knowledge plays such an important role in science, then the place where it is acquired, namely, the scientific institutions, has some specific relevance. The structures of these institutions luckily are much more accessible to an investigations, even for outsiders, than the models or other methods used by the scientists.

In regard to the structure of the following chapters, I will start with some preliminary remarks in the next one. The aim here is to introduce some recurring themes that will be relevant in the then following discussion of the above mentioned ideals about science: the epistemic challenges of highly complex systems, the distinction between the context of discovery and the context of justification and scientific objectivity. The *complexity* of the climate system and the resulting *additional epistemic challenges* are what makes the failure of these ideals so apparent. The distinction between *context of discovery and context of justification* is a constitutive element to two of these ideals (see Chapter 3.1 and 3.2). In the context of science the term *objectivity* has become almost synonymous with 'good science' and, therefore, different interpretations of *scientific objectivity* will be significant when discussing certain idealised representations of science.

Chapter 3 then will focus on an in-depth discussion of three prominent ideals about scientific methods and objectives in relation to climate science: value-freeness, a clear separation between theoretical and empirical work, and the claim that science has to provide clear, binary answers. Each subchapter in Chapter 3 corresponds to one of these ideals and is structured in a similar way. I will start with a short historical introduction how the specific ideal came into being. These subchapters are not supposed to recap the full history of these ideals. The point is rather to trace where these ideals have come from and how they have risen to prominence. After that a small subchapter will follow introducing one or two central philosophical concepts or issues that are of relevance in the context of the conflict of the ideals with scientific practice. The third and central part of every one of these chapters then is a discussion about how these ideals cannot be fulfilled in the context of climate science, but also why they do not have to. In the conclusion of Chapter 3 I will return to the concepts discussed in Chapter 2. A direct examination how they fare in the context of climate science will point to a way forward how to circumvent the problem that Chapter 3 leaves us with; that is, that these three ideals cannot be resorted to in order to assess the quality of scientific research. It will be shown that the increasing complexity gives tacit knowledge a more significant and more visible role in science.

Chapter 4 will discuss tacit knowledge in more detail. It will be argued that the epistemic challenges of complex climate simulations, particularly the difficulties of reaching "analytical understanding" (Lenhard and Winsberg, 2010), makes the reliance on tacit knowledge in science particular visible, but also grounds scientific research in the institutions and communities where this tacit knowledge is acquired and created. Further, a concept of expertise derived from tacit knowledge is introduced as an alternative to the failed ideals examined in Chapter 3.

Chapter 5 forms the conclusion and provides an outlook what all of this means for science, philosophy and society.