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Abstract

This deliverable is the final exam paper of the Phd Research Design to the mandatory PhD course Philosophy of Science at NTNU. The paper consists of two parts (individual assignment 2 and 3) and was approved for 10 ECTS which will be implemented in the PhD.

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Innhold

1 Philosophy of Science - Individual Assignment 2

Analysis and comments on the dissertation:

"Energy Efficiency in Data Centres and the Barriers to Further Improvements: An Interdisciplinary Investigation."

By Gemma Ann Brady

Thesis for Doctor of Philosophy as part of the Integrated PhD/MSc in Low Carbon Technologies at The University of Leeds. School of Chemical and Process Engineering.

1.1 Summary

Research context: Inter-disciplinary study of barriers to increased energy efficiency in data centers[1]. **Research topics:** Investigate industry opinions, attitudes towards and efforts made relating to energy use in the data centre sector to find out if there are any existing barriers that may prevent increased saving. Investigate the metrics (Power Utilization Effectiveness) and methodologies used to assess energy consumption and efficiency within data centres. Conduct an investigation into the energy use of server fans as a technological means of improving energy efficiency.

Theoretical) background: The author is leaning on the research field of "barriers to energy efficiency" with roots in rational-choice theory, which are (causally) explaining what technological, organizational and behavioral factors that hinders organizations in reducing their energy consumption.

Method: The research questions are investigated through three distinct methodological approaches. Industry survey with 11 semi-structured interviews with data center operators, colocation providers and engineering consultancies. Empirical study of the feasibility of the energy metric PUE by investigating open source material of energy use in an existing data center. Experimental study of equipment optimization of internal servers.

Main results: Costs, lack of communication between departments and split incentives are the main barriers that hinders further energy efficiency in data centers. The PUE metric is not a feasible measure for energy efficiency or for comparing data centers because it hides key parameters. The energy efficiency of internal server fans can theoretically be improved by applying water cooling or external fans.

Explicit knowledge claims: Increased energy efficiency can contribute to reduce human-induced climate change. There is a gap between the techno-economic potential of energy efficiency in data centres, and the

[1] Data centers are commercial server parks providing computation power and storage for customers.

actual energy use. The existence of barriers hinders adoption of energy efficiency measures. Revealing barriers can enable change through policies.

1.2 Conceptual formation

Key phenomena in this dissertation are *energy efficiency* and its operationalization through metrics and the conceptualization of *barriers* to causally explain why implementation of energy efficiency measures are *not* happening. Although the author claims to apply a "grounded theory" approach inspired by Glaser and Strauss (1968), new concepts are not constructed in the research process, and concepts and theories are pre-defined in previous research.

Energy efficiency:

Energy efficiency is a pre-defined concept for presenting relatively how much energy (electrical, chemical, mechanical, etc.) is needed to perform a specific task. The idea of the efficient use of energy arises due to the fact that processes lose energy thus leading to a lower energy output compared to the initial input (Brady, 2016, p. 54). The author starts with presenting the thermodynamic (physics) definition of energy efficiency which is the energy used by a system or process as a proportion of the useful (energy) output. Other operationalization's of energy efficiency (drawing on the work of Patterson (1996)), such as *energy intensity* places physical products as the denominator (i.e. energy used / to produce 1 ton of alumina) or even *economic* measurements which places revenue as the denominator (energy used / revenue). The author notes that one key challenge in operationalizing energy efficiency in data centers is the lack of definition and operationalization of "useful output" when it comes to "virtual work" which often is a complex combination of computational power, storage and communication between networks. The author presents and scrutinize different operationalization and metrics for energy efficiency in the search for the most feasible metrics for data centers (see below). A key function for the operationalization's of energy efficiency is *comparability*; to provide a measure to compare the energy efficiency of a system or process with itself (i.e. after installing new equipment) or with other, similar systems or processes (i.e. producing the same things). An important *function* of energy efficiency, the author argues, is to mitigate human induced climate change through reduced need for energy to produce equal (or more) products and services.

Power Utilization Effectiveness (PUE)

The author is leaning on a pre-defined metric, Power Utilization Effectiveness (PUE)[2], which is the industry standard to measure energy efficiency in data centers. The PUE is an operational definition (Sohlberg & Sohlberg, 2008, p. 132) based on the thermodynamic definition of energy efficiency described above. The metric calculates the energy efficiency of a data center as the total energy consumption of the data center as a proportion of the energy use of the IT equipment (total energy consumed / energy consumed by IT equipment), thus a value which will always be above the 1. In the absence of operationalized values for “useful virtual output” for data servers, this metric rests on the assumption that the power usage of the IT equipment best represents “useful work” and separates it from other energy consuming equipment in the data center (i.e. infrastructure providing cooling and lights). Thus, the lower the PUE (closer to the number 1), the more efficient the data center is perceived. The function of the concept is to assess the energy efficiency of the data center, to compare the energy efficiency between data centers (for marketing purposes) and as a tool to identify opportunities and verify changes and implementation of new equipment and methodology. The author sets out to verify the feasibility of this metric based on these functions.

Barriers and the energy efficiency gap:

The author leans heavily on the concept of (non-technical) ‘barrier’ to describe, classify and explain what hinders further implementation of energy efficiency operations concepts, methodologies or technologies. The author refers to the term energy efficiency gap which was first defined by Jaffe and Stavins in 1994 in order to describe the ‘paradox of gradual diffusion of apparently cost-effective energy-efficiency measures’ (Jaffe & Stavins, 1994). The energy efficiency gap is: *‘a gap between the opportunities for cost-effective energy efficiency investment identified in energy models and the levels actually seen in practice’* (Sorrell et al., 2000). Based on the assumption of an “energy efficiency gap” in the data center sector, the author identifies “state of the art” energy efficient technologies and methodologies and presents an “energy efficiency gap” of the data centre sector since state of the art technologies are not widely used. The author then leans on the concept of barriers to explain what factors that are causing this energy efficiency gap.

The conceptualization of barriers is interrelated to the concept of the energy efficiency gap above and is a pre-defined concept in the literature on energy efficiency addressing the non-technical factors that hinders the energy efficiency gap to be fulfilled. Thus, the concept of an “energy efficiency gap” is the deductive starting point for the research topic in this thesis; to investigate and reveal barriers for further energy efficiency in data centers. The author refers to the main categorization of barriers as technological,

[2] The Green Grid: Green Grid Data Center Power Efficiency Metrics: PUE and DCiE. White Paper #6

organizational and behavioral barriers (Cagno, Worrell, Trianni, & Pugliese, 2013). As the author claims; "*If energy efficiency is to be increased, then it is very important to understand the barriers that act against any efforts"* (Brady, 2016, p. 94). Thus, in the empirical investigation the author search for hindrances for increased energy efficiency in the interviews with respondents categorizing these in groups of barriers for example; risk aversion, awareness of information, communication between departments, different goal alignment, agreement with customers, costs etc. Thus, the concept of barriers are classifications with a strong theoretical foundation (Sohlberg & Sohlberg, 2008, p. 137).

Problems with the concepts

One problem with the concepts of energy efficiency and barriers is that they are both quite common in everyday vocabulary (Sohlberg & Sohlberg, 2008) and carries with them connotation which affect the precision level of the descriptions and explanations as will be elaborated under each concept below.

Energy efficiency

One problematic aspect with the use of *energy efficiency* in this thesis is that the concept is used in various ways and at different levels without clear-cut definitions. While the author discusses energy efficiency explicitly as a concept through its operationalized metrics, energy efficiency takes several forms and serves several functions in the dissertation such as; *definitions* and operationalized *metrics*, the *act* of actually reducing energy consumption by single components or larger systems, a *strategy* for mitigating human induced climate change (or enabling growth in the data center sector), and a *marketing tool or symbol* for competitive advantage. Thus, "energy efficiency" is much more than a tool to relatively measure energy use and output of a system. One problematic aspect of this imprecision of the concept surfaces in one of the main results, that the PUE metric is unfeasible since it doesn't represent actual energy efficiency which is the intended function, On the other hand, one could argue that actually because of these inaccuracies the PUE metric fulfils another function as a "marketing tool or symbol for competitive edge" even better (see page 7 for functional explanations in the thesis).

Another problematic aspect of using the concept "energy efficiency" inconsequently is that while some of the truth claims of some of the abovementioned "functions" for energy efficiency are unproblematic, others are controversial. Some scholars have criticized the taken-for granted connection between energy efficiency and climate mitigation, due to among other factors economic rebound effects and legitimization of economic growth (Shove, 2017). While effective climate mitigation requires "absolute" carbon reductions, energy efficiency measures only deals with "relative" reductions in energy use for the products used. To the authors defense, these truth-claims are not the topic of this thesis, but nevertheless they are used to legitimize the research topics.

Barriers and the energy efficiency gap

There is no lexical definition of 'barriers' are provided in this thesis, which is problematic since this is a central concept. The wording of the concept (or metaphor) "barrier" in everyday language has strong connotations to physical hindrances. Etymologically speaking this is also the original meaning of the word, stemming from the French word 'barrier' meaning doorway. The concept has found its way into several branches of social sciences to explain which social factors hinder wanted or unwanted events (i.e. accident causation), namely safety sciences (Reason, 1990), innovation research (i.e. Chesbrough, 2010) and most prominently in energy efficiency (Jaffe & Stavins, 1994). At the empirical level the barriers are either subtracted from stories (i.e. studies of accident causation because of breached barriers), or as responses to specific questions about hindrances which is the case in this thesis. One challenging aspect of the 'barrier' concept is evident in the questionnaire of this thesis, where the author asks the informants about 'what are the barriers for improved energy efficiency'. Thus there are no conceptual distinction between what the informant and researcher address as a barrier.

In the analytical work in this thesis, as well as the research field on barriers which the author refers to (Cagno et al., 2013), there is a process of *reification* of these abstract concepts. As identified by Sohlberg and Sohlberg (2008, p. 128) reifications are often applied as "causes" in causal chains, which also reflect the use of barriers for causal explanations in this thesis. For example, it can be problematic to view aspects such as 'communication', 'information' and 'awareness' as entities with causal power since it 'hides' information, and could just as well be understood as pre-requisites for implementing energy efficient technologies. The metaphorical and persuasive to the concept of barriers because of the connotation connection to 'physical hindrances' could enhance the reification of these abstract categories and provide the 'barriers' with even more causational weight. This can be problematic especially in cases where the original information through interview inherently more "rich in content" describing *why* and *to whom* something is a hindrance, in the process of conceptualization to a de-contextualized "barrier" are transposed to other contexts (the whole data center sector) and used as a causational factor to why something (energy efficiency) has not happened. Conceptualizing "lack of information" as a barrier, reduces a complex variable such as "information" to a binary state that a company either has or doesn't. Conceptualizing "communication between departments" as a barrier, hides the enabling opportunities of a company culture working towards energy efficiency, importance of trust and informal networks for knowledge sharing and decision-making.

1.3 Description/Inferences/Explanation/Theory

The explanations in this thesis includes inductive, deductive and functional inferences. While the analysis of the data center sector (as opposed to a larger economic system), the PUE metric and the experimental study of optimization of internal server fans has atomistic elements where only part of a system is under scrutiny (Sohlberg & Sohlberg, 2008, p. 103), the analysis also have ‘holistic’ aspects in the sense that the author claims it is valid for the data center sector and all use of the PUE metric, not just the individual cases; “*The methodology used in this chapter can be applied to other data centres, particularly those that employ direct air cooling*” (Brady, 2016, p. 166). This section below elaborates on some of these explanations and inferences in the thesis that were found to be particular interesting from a philosophy of science point of view; 1) barriers for increased energy efficiency in data centers, 2) the unfeasibility of the PUE metric and 3) reference to universal laws.

1) Barriers for increased energy efficiency in data centers

As argued above, even the wording of the research topic “barriers for increased energy efficiency in data centers” is based on the deductive starting point referred to by the author in the theory of “the energy efficiency gap”; the full potential of energy efficient technologies is not reached due to the presence of barriers. The theories and explanations of the “energy efficiency gap” rests on an assumption that all companies are purely driven by cost-optimization. Thus, the *movement* towards increased energy efficiency, is implicitly conceptualized as the aggregated results of rational choices in a neo-economic logic. Although not referred to in this theses, there is implicitly a strong connection to understanding human behavior as based by rational choices, which scholars fronted by scholars such as James Coleman (1990) and Jon Elster (in Delanty & Strydom, 2003). The basic assumption in rational choice perspectives are that people will act in a way which brings them benefits and will avoid acting in a way that does not bring them benefits (Benton & Craib, 2010, p. 85). This is mirrored in the main question and perceived energy efficiency paradox; *why doesn’t companies implement energy efficient measures when it is rational to do so*? The author transposes this theory to also be valid for data centers. The empirical work is both rationalistic since the deductive starting point is taken for granted, but also inductive and interpretive in the sense that it aims to map the perceived barriers through interviews with informants. While the barrier categories in the questionnaire are inspired by previous research on barriers for energy efficiency, new barrier categories emerge through the qualitative analysis – resulting in a list of barriers hindering energy efficiency measures in the data center sector.

One clear limitation to this theory (and interrelated methodological approach) is that in the author's active search for barriers contextual information can be overlooked. Human action and intention in this text are only conceptualized through barriers, translated into casual factors hindering further energy efficiency. By applying this framework *everything* that doesn't contribute towards increased energy efficiency will be conceptualized as a barrier. For example, while the author claims that human intentions and opinions are important point of the analysis such as "opinions towards energy efficiency in data centers" (Brady, 2016, p. 7), the analytical framework does not. Thus, the eventual lack of motivation will be conceptualized as a "barrier", not an evidence against the proclamation that organizations are inherently moving towards increased energy efficiency and the existence of a "gap". An interesting parallel here is, Hume's argument that causal links can never be observed directly but only by its effect (Benton & Craib, 2010, p. 19). Barrier perspectives actually tries the opposite; to explain causally *why something has not happened*, which may be even more problematic. Some scholars argue for a non-positivist causal explanation on human action, not relying on observations per se, but interpreting the behavior of rational agents (Keat & Urry, 1975, p. 156) and also Elster (in Delanty & Strydom, 2003) argues in this direction. Others, such as Benton & Craib (2010, p. 89) questions whether interpretive approaches are compatible with anything but the broadest sense of causality – a sense which perhaps covers up rather than illuminates significant differences and complexities, which is very relevant for the causal explanations of barriers.

2) Functional explanations: The unfeasibility of the PUE metric

In the technical description of the data center functional explanations are frequently used, and could easily be translated into Aristotelean "final cause" formulations (Sohlberg & Sohlberg, 2008, p. 205); "*Assuring effective of use IT equipment by removing heat is what cooling is for*". More interestingly, is the functional argumentation the author makes to claim that the PUE metric is in fact, not a feasible measure for energy efficiency in data centers. First, the author shows through measurements of an existing data center how key energy consuming components which are clearly not "useful virtual output" are represented in the denominator of the metric (i.e. lights over Ethernet). Second, through an experimental design of optimizing the server fans which is considered a part of the "IT equipment" thus the denominator in the PUE metric, the author shows that the metric will show worse energy efficiency although energy consumption is reduced while keeping the IT performance:

> *"By removing the internal fans and replacing them with an external one, the energy consumption is shifted to the supporting infrastructure rather than being included in the IT load. This causes an increase in the PUE to be noted. For example, the result of removing the internal fans completely*

caused an increase from 1,08 to 1,18 during the 10-minute stress test. This increase in PUE is despite the fact that energy overall performance has been reduced, 9 % in this case" (Brady, 2016, pp. 218–219).

Unfeasibility in this case is the mismatch between what the metric is supposed to measure, and what it actually measures, what information its suppose to provide and what it actually provides:

- While the metric provides an incentive for increase the efficiency for the supporting infrastructure, all energy efficiency measures on the IT equipment side (i.e. server fans) will result in worsening the PUE score of the facility.
- Data centers cannot be compared with the PUE without providing information on how this number was reached. Using the PUE as a 'competitive edge' towards other companies can actually provide an incentive for worse energy efficiency overall.

Thus, the author implicitly argues that the metric does not fulfill its intended *function* and even has several *dysfunctions* in Merton's terms (1968). Another way to look at it is that the 'unfeasability' of the PUE metric for the intended function, measure energy efficiency, actually makes it even better to fulfill another function, competitive advantage.

3) Reference to universal laws (deductive / inductive)

Another interesting aspect of this thesis are the references to universal "holistic" laws. Being an interdisciplinary thesis, the author lean on theories from natural sciences as well as social sciences. On the one hand the laws of thermodynamics are used to explain the transformation of energy by deductive reasoning. However, the author also refers to Moore's Law (Moore, 1965) as a universal law to legitimize the importance of energy efficiency in the sector due to the inevitable growth of transistors. While this law is presented in the same way as the laws of thermodynamics, its properties and inferences are quite unique. Moore's Law is a prediction that "integrated circuits would hold a two-fold increase in components (transistors) each year, as had been the trend from 1958 to 1965" (Brady, 2016, p. 14). This kind of explanations are predictive inductive inferences based on historical patterns of growth in transistors which led to predictive statements of the rate of future technology development. Parallels can be made to the problem of induction, first fronted by David Hume, that the lack of logical justification of causality and universal laws based on repetitive observation (Benton & Craib, 2010, p. 19). Although interestingly enough the prediction (with some minor deviations) held true for about 50 years, Moore's Law is now considered broken[3].

1.4 Falsification/Alternative interpretations

The author explicitly render the methodological approach open for scrutiny and replication for possible falsification. For example, the calculations of the PUE of the data center are transparent, the input numbers are open and available online and other researchers could apply the same mathematical models to reproduce (verify) or falsify the results. However, it can be noted that the truth-claims formulated in this thesis are not formulated in falsifiable terms, as fronted by Karl Popper (Popper in Delanty & Strydom, 2003, p. 46). Similarly, for the explorative study of optimizing internal server fans installing external fans, the experimental design and input measures, as well as the mathematical models used are possible to reproduce. An interesting aspect to discuss is the authors explanations of human behavior through barrier models. The author does not reflect upon alternative interpretations or falsification to the barrier models, reflecting Kuhn's notion of scientific work within a paradigm (Sohlberg & Sohlberg, 2008, p. 146). For the sake of this short paper we can separate between falsification *within* the research tradition (or paradigm) on barriers, and alternative interpretations rejecting or complementing this dominating framework within interdisciplinary energy research.

Falsification within the paradigm of barriers

Researchers could have visited the same data centers, asked the same questions and verified the results. Alternative explanations within the research tradition on barriers could be that other barriers are actually impacting the company's decisions more than the one suggested in the thesis, or the validity of transposing the results to other companies or industries could be conducted:

- Are the barriers suggested the root causes for not implementing energy efficiency measures, or are there additional barriers that could explain the results?
- Are the barriers presented in this study valid for other data centers? Are they valid for other industries (generalizability to barriers to energy efficiency)?

The thesis would in this case be scrutinized, while at the same time accepting the notion of an energy efficiency gap and the causality of barriers.

[3] https://www.technologyreview.com/s/601441/moores-law-is-dead-now-what/

Alternative interpretations to barriers

The underlying theory of the energy gap and barriers applies a linear view on innovation and economic behavior which has been much contested (i.e Hughes, 1983). Interesting insights could been gained in studies by not taking movement for granted, study successfully implemented energy efficiency measures and turning the question around; *why and how have they managed to establish these energy efficient solutions?* The most prominent alternative to neo-classical economics to study (and explain) technology development processes and economic behavior are theories on embeddedness (Granovetter, 1985) and works within the field of *Social Construction of Technology* (Bijker, Hughes, Pinch, & Douglas, 2012; Hughes, 1987) as well as actor-network theory (Latour, 1987). While barrier perspectives can be important to identify "problem areas", complementary social science research of organizational culture (and structure), contextual aspects of innovation and decision-making processes, science in action studies can provide great insight into how *energy efficiency* is constructed in various companies. However, since the qualitative methodology is strongly connected to the theoretical starting point (asking informants about which barriers that exists), it renders the task difficult for other researchers to re-interpret the data material from this thesis. Alternative interpretations would require alternative methodologies and descriptions for example through historical case studies or ethnographic field work on the process of deciding, designing and implementing energy efficiency measures accompanied by thick descriptions (Geertz, 1973).

1.5 Values and ethical considerations

The author explicitly covers ethical aspects in regards to treatment of informant data in the methodology section of the dissertation. Techniques for ensuring confidentiality of information and anonymity of respondents are carefully elaborated. Legitimization of the topic and research questions are explicitly placed within "human induced climate change" suggesting "energy efficiency" as a strategy for mitigating climate change. Another framing could potentially be to focus on solely the *cost reducing* aspects of energy efficiency, thus leaning on a different (and perhaps complementary) framing of what energy efficiency *solves*. The author strongly argues for the *applicability* of the research – which in opposition (or complementary) to research for the sake of knowledge, also can be considered a value. As Weber (Weber in Delanty & Strydom, 2003) writes about how objectivity in effect is impossible, and that every researcher will, based on his background and (cultural) values, choose to research *a part* of an event or social phenomena. This is because "the number and type of causes which have influenced any given event are always infinite […]", and thus "[…] only a part of concrete reality is interesting and significant to us". Thus, the focus on 'barriers' or hindrances for implementation of energy efficiency measures in itself can be regarded as a choice based on the researcher's value considerations.

1.6 Programmatic/Implicit position

The author does not claim any programmatic position in terms of paradigmatic, ontological or epistemological position. The implicit position(s) in this dissertation varies to some extent with the chapters revolves around the three research questions. The authors implicit position on ontology and epistemology surfaces clearly when the author is scrutinizing the PUE metric and conducting the experimental optimization of server fans. As the author claims; *"However, the metric does not show a true representation of energy efficiency in a data center, due to it not including the efficiency of the servers in their required operations"* (Brady, 2016, p. 187). The arguments in the thesis are close to realism as epistemology; both energy and output from a data center exists, and can be revealed through better metrics. This implies that the author acknowledge that a 'true representation' is possible to acquire through improved tools, implicitly placing the authors epistemological position close to that of realism as described by (Sohlberg & Sohlberg, 2008).

From an outsider view, it seems that the materialism and realism employed to scrutinize and validate the energy efficiency metric and experimental study of actual energy use of server fans, echoes also in the explanation of human (non)-action where 'barriers' are explicitly to be *revealed* through empirical analysis. The author does programmatically place the thesis methodological approach within "grounded theory" (Glaser & Strauss, 1968). However, the thesis does not introduce any novel concepts or construction of theory per se, although it contributes with new barrier categories within the situated research tradition. The theoretical conceptions from the "energy efficiency gap and barriers" is permeating the methodological design (i.e. research question, interview questionnaire) as well as the deductive starting point for analysis categorizing results in terms of barriers and building causal explanations. The thesis can thus implicitly be placed close to *rationalism* (Sohlberg & Sohlberg, 2008, p. 75), where the cornerstone argument is close to a Platonian axiom. The research tradition on barrier studies of energy efficiency can be regarded as a paradigm (Kuhn, 1970), where research is conducted in accordance with the accepted methodologies, concept and theories. Thus, the author strongly takes a 'cumulative' position towards the research field, with the aim adding to the existing knowledge base (Sohlberg & Sohlberg, 2008, p. 96) on barriers to energy efficiency in general, and data centers in particular.

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2 Philosophy of Science - Individual Assignment 3

Jens Petter Kirkhus Johansen

PhD in Sociology

2.1 Sociological studies of technology: In search for methodology

For this assignment I have chosen to focus on *methodology* for social studies of technology. More explicitly, how discussions in philosophy of science regarding constructivist studies of scientific facts and technology can provide inspiration and guidance for the methodological research design in sociological studies of technology. As a newly started PhD studying innovation processes of energy efficient technology and infrastructure in the Norwegian industry *in the making*, I have been on the search for methodological input for how to study the social construction of technology and especially how to treat material (or technical) objects in the case studies. Perspectives from *social construction of technology* (Bijker, Hughes, & Pinch, 1987; Hughes, 1983) and *actor-network theory* (Callon, 1984; Latour, 1987; Latour & Woolgar, 1979) provided a starting point in the search for theories, concepts and methodologies which can help 'open the black box' of technological development processes. However, in the course literature of philosophy of social science, the ontological and epistemological claims from these traditions have been largely criticized. In the following I will discuss some of the arguments, critique and response in this academic debate and how they can inspire methodological approaches for studying technology development processes.

The choice of topic partly derives from the fuming critique in (Benton & Craib, 2010, pp. 68–74) and almost complete dismissal of the concepts provided in this field of research by Bruno Latour (Latour, 1987). Benton and Craib's critique towards this reflexive turn mirrors several of the arguments put forward by Collins and Yearley (1992) in the "Epistemological Chicken" debate in Andrew Pickering anthology *Science as Practice and Culture* (1992) with responses from Callon and Latour (1992). It is not my objective (or wish) in this short assignment to mount a defense of the ontological or epistemological view on nature/society fronted by ANT scholars, nor fully accept the critique of this research tradition, but rather discuss how this academic debate about construction of scientific facts within philosophy of science, can provide sociologists studying technology with valuable tools, tips and guidance for *what to look for* in case studies.

2.2 From studying scientific facts to technology

Benton & Craib (2010, p. 68) situates the representatives of (early) actor-network theory, and most prominently Bruno Latour, within the broader *reflexive turn* in sociology; with its critique against the 'strong programme' and its supposedly unquestioning realist assumptions about society. Studies within the 'strong programme', showed the extent to which social processes of negotiation and consensus-formation were involved in the construction and authorization of scientific knowledge-claims (Benton & Craib, 2010, p. 62). The reflexive turn here implies sociologists should now also problematize the "sociological variables" such as the individual and collective actors, their interests and power relations, alliances and so on (Benton & Craib, 2010, p. 68). Asdal et al. (2001) describes ANT as a materialistic and expanded version of the semiotics, also called relationism or associativism, which studies how things are constructed as a result of their relations. This thinking challenge the way we see materiality, order, hierarchies between causal variables, as Michel Callon (1987, p. 84) argues: "right from the start, technical, scientific, social, economic, or political considerations have been inextricably bound up into an organic whole". Hence, the argument is in line with the sociology of scientific knowledge view of "construction" of scientific facts, but not only "social", also material objects participate in this construction. ANT instructs the researcher to identify the elements (network) which influence, creates or causes action. Or as put forward by Monteiro (2000, p. 72); "..to unpack the dynamic, socio-technical process unfolding over time that as a net result constructs reality and order". Callon (1987, p. 84) here argues that we must reconsider the prevailing thought [within innovation research] that the start of an innovation process is characterized by that the problems that must be solved are technical, and that economic, social, political and cultural aspects first become relevant at a later stage. The heterogeneity and complexity which can be seen at the end of a process are not progressively introduced in a linear innovation process (Callon, 1987).

Hanseth, Aanestad and Berg (2004) argues that ANT has also been a critique against technological determinism, where the intention was to study the construction of objects that are usually taken for granted and the boundaries between the social and the technical. With a similar objective, the research strand *social construction of technology* (SCOT), most notably fronted by Bijker and Pinch (1984) and Hughes (1983), attempted to describe the co-construction of scientific practice and technological innovation descriptive studies by investigating how different 'social groups' negotiate the design and operation principles of technological innovations. They also introduced the concepts of *interpretive flexibility* and *stabilization* to show the potential reversibility in design phases of what viewed as taken for granted technologies, and how one social group prevails over the others and the operation concepts.

The empirical research in both ANT and SCOT share several traits relevant for methodology for social studies of technology. They both rely on "thick descriptions" (Geertz, 1973) based on ethnographic (and anthropologically inspired) studies. These studies can also be coined as *descriptive oriented science studies* (Sohlberg & Sohlberg, 2008, p. 30) due to their object under scrutiny; scientific practices itself, as well as the non-explanatory descriptions often fronted by ANT. A method underlined by the proposed *anti-deterministic* goal of the research branches.

Both within ANT and SCOT the object for scientific inquiry transposed beyond the construction of scientific facts in the universities and laboratories into studying the emergence of specific technologies, innovation processes, infrastructures and large technological systems (i.e. Bijker et al., 1987). A common trait for these approaches was to put *technology* on the agenda of social studies, partly due to the paucity of studies of technologies within the traditional social sciences, and the lack of "not taking materiality seriously" (Bijker et al., 1987). Orlikowski (2009) argues in the same lines how 'pure' concepts of technology, organizations or society can lead to 'blind zones' when researching these phenomena, and that a network analysis that restricts itself to merely social relationships will fail to pick up how technology and materiality mediate the character of such relationships. Thomas Hughes (1983) understanding of sociotechnical systems and the metaphor of a "seamless web" of heterogeneous system components are permeating this research. In the preface of the newest edition of *the social construction of technological systems* Bijker and Pinch retrospectively argues:

> "Rather than taking an essentialist view of technologies and their contexts, we all agreed that describing the activities of actors-whether in the form of relevant social groups (SCOT), system builders (LTS), or actants (ANT)-was more interesting than a promethean history of technology that emphasized how heroic inventors and engineers stole great ideas about technology from the gods and gave them to mere mortals" (Bijker, Hughes, Pinch, & Douglas, 2012)

Thus, the ambition was both to present counter arguments for "pure" social explanations to technology development, but just as much avoid technological determinism. This has implications of how to study innovation processes. The 'black boxes' of technologies was to be open through sociological deconstruction, or to open open up the interpretive flexibility that a given technology provides (Asdal et al., 2001). Technological development is here understood as a heterogeneous process which can take many directions, is a result of interaction and negotiation between different social groups, more than a linear, stepwise process (Asdal et al., 2001, p. 29). Thus, ANT and SCOT, could be viewed just as much as a methodology rather than a theory.

2.3 Criticism and response

ANT has been heavily criticized since its origin, maybe most prominently the "Epistemological Chicken" debate between Collins and Yearley (1992) on the one side, and Callon and Latour (1992) on the other. An echo of this critique are fronted by Benton & Craib's (2010), directed to the attempt to break free from the dualistic concepts of nature and society (or humans and non-humans).

> Latour's key concepts for defining 'actants' are those of 'hybridity', 'quasi-object', 'quasi-subject', and so on. These terms get such meaning as they have only in terms of the *prior* understanding of what 'subjects', 'objects' and the 'pure' elements of the 'hybrid' are. Latour contravenes his own methodology in the very act of defining his most basic ideas (Benton & Craib, 2010, p. 71)

In other words, they argue that Latour' effort to dispense 'pure' concepts such as 'nature' or 'society' implicitly presupposes them. Another line of Benson and Craibs (2010) critique is the risk of resort to *anthropomorphism*, in explaining 'intentions' of material objects (i.e. the wind), or the insistency of given agency to nonhumans. Here the critique is partly semantically grounded, Latour's main argument of the independent casual power of material objects and its role in shaping the range of possible human responses is not under scrutiny (while this argument has not gone uncriticized either). Callon and Latours (1992) reside this critique in a setting of establishing a "metalanguage to talk about science in the making":

> "Of course our two articles would have been better if instead of using the same vocabulary for the two sides, we could have used an unbiased vocabulary. But is it our fault that it does not exist? If "enroll" smacks of anthropomorphism, and "attach" of zoomorphism? (Callon & Latour, 1992, p. 354)

This is also a consequence of applying (a radical version) of the symmetry principle (Bloor, 1991) in the strong programme (Benton & Craib, Bloor), or the "aim to generalize symmetry by treating all actants that are party to the scientific enterprise in the same manner" (Collins & Yearley, 1992, p. 322). Callon and Latour (1992, p. 353) responds to this with that "it does not mean that we wish to extend intentionality to things, or mechanism to humans, but only that with any one attribute we should be able to depict the other". While ANT and SCOT provides interesting arguments and examples of how objects partly *mediate* the range of possible human behavior in technical design processes, it is necessary to be aware of the possible *anthropomorphist* explanations.

Benton & Craib (Benton & Craib, 2010, p. 71) they argue that the terms which link humans to non-humans into seamless networks leads to “metaphorical excesses which carry little conviction”. This second argument strikes both the ANT and SCOT traditions. The response from Thomas Hughes (in Bijker et al., 2012) to this critique, is that whether questioning the fixed boundary between humans and nonhumans, or paying attention to the nontechnical aspects when studying the history of technical systems-all three approaches embraced the methodological principle of paying attention to how the borders between the social and the technical were drawn by actors, rather than assuming that these borders are pre-given and static. What can be drawn from this argument is that, even without taking an explicit (ontological) position, material objects should be payed attention to the analysis.

Benton & Craib (2010) also argue that ANT research (again exemplified by Latour) falls into of ‘defeatism’ in the sense of a cynicism towards technoscience and the power relations that form them. Other scholars critique takes the opposite stance, problematizing the ‘amoral’ or neutral stance on technology (Winner, 1993). Bijker and Pinch argues that this criticism assumes that only one form of criticism is available-by taking sides in a sociotechnical controversy (Bijker et al., 2012). SCOTS can still be political in all sorts of ways by pointing to the entanglement of humans and nonhumans, surely itself a principle that could lead to political action (Bijker et al., 2012, p. xxi). An interesting aspect of the ‘amorality’, can be found in a rather polemic article by Latour (2004) noting that the US Republicans strategists are using the same arguments as STS researchers objections to “neutral” and “final” science, to argue that the “human induced climate change” are *not settled* – which surely shows the political force of the arguments (although not the one he wants).

To include a concluding argument, Collins and Yearley (1992) also criticize ANT (and implicitly SCOT) scholars of lacking scientific expertise of the technologies or scientific facts under scrutiny – which, they argue, becomes a problem when the objects themselves takes places as “intentional” actants in the analysis (how can the sociologist Michel Callon describe the intentions of scallops, where a marine biologist can’t?). An interrelated argument to this is that the ANT approach is criticized in providing the analyst “too much power” for what is important in the network (Collins & Yearley, 1992), stating that the descriptions relies too much on judgement calls from the researchers. Callon and Latour (1992) tries to fend of this critique by arguing for the value for an ‘outsider view’ of scientific processes, and that it is exactly the task for social studies of science and technology. Underlying the debate here, there is an interesting methodological proposition I will come back to at the end of this dissertation.

2.4 Methodological inspiration for sociology of technology

The criticism from Benton & Craib (2010) must be viewed in connection with their comprehensive task of writing a short chapter on philosophy of social science and alternatives to empiricism and radical relativism. While this short assignment does not justify the extensive critique and response against ANT/SCOT research and knowledge claims, it can provide some proposals to how the academic debate in itself provide valuable methodological guidelines for social studies of technology. For students studying technological development processes, where the ontological, epistemological and theoretical position are not yet decided (or discovered), including my own PhD work, it is useful to apply arguments from both sides as a guidance for the methodology and case studies.

First of all, it is reassuring that there at least is (presumably) consensus that technology and technological development processes can be an interesting object of study for the social sciences. There also seem to be little debate regarding the value of investigating the interpretive flexibility or potential reversibility for what is later viewed as taken for granted facts or technical components. This guides the researcher to study design processes as well as controversies. While there are conflict regarding whether "symmetrical weight" should be granted to nonhumans as well as humans, how they *intent* or *cause* human behavior, case studies could very well investigate *how* technology *mediate* the range of possible human behavior without taking an explicit stance right away. Following the last argument, there is little conflict that social groups, intentions, power relations and alliances are important for technological innovations and should be studied – the controversy here concerns the 'groups that are not heard' (that being social groups in the eyes of the SCOT critics or nonhumans in the eyes of Latour). Applying "thick descriptions" (Geertz, 1973) to account for such controversies can yield rich data – as well as the possibility for falsifiability of descriptions and explanations. Collins & Yearley's (1992) precise critique of Michel Callon's (1984) work on scallops, and the academic discussion that followed would be difficult without the possibility to scrutinize Callon's empirical grounds. As a concluding argument, what I find inspiring about the debate regarding the impossibility to claim anything about a scientific practice without "expertise knowledge" of the phenomena under scrutiny very interesting. While I partly accept Callon and Latours (1992) argument, that it is valuable for 'outsiders' to study scientific practices (which is indeed one of the main objectives for philosophies of science) – Collins and Yearley (1992) has an interesting implicit methodological proposition here (although well hidden under the harsh critique of Michel Callon). As a social scientist studying practices of technology formation, there can be methodological strength in acquiring as comprehensive understanding of the technologies which are studied. This is not an argument for that we all should become “marine biologists”, but rather highlighting the potential of increasing the methodological possibilities and analytical precision level, if we understand the premises on which technologies are made, that be thermodynamics, industrial economics or basic mechanics. I believe this is a methodological proposition which could strengthen sociological explanations as well as contribute to interdisciplinary theory building on technology development processes.

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