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When Bioeconomy Policy Objectives (Fail To) Overlap: Rethinking the analysis of necessity to detect causal interdependencies among sustainable development goals in the Nordic bioeconomy strategy

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September 27, 2019

Abstract

Biomass is becoming a viable substitute for oil and petrochemicals within many industries as concerns over climate change deepen. But does novel biomass utilization enable countries to pursue other important policy objectives simultaneously with climate change mitigation? Theoretical answers to this question vary. Ecological modernization theory assumes that environmental and economic objectives are compatible or even mutually reinforcing, while degrowth theory calls our attention to potential trade-offs and compromises. The purpose of this paper is to probe whether set-theoretic methods offer new insights for this debate. The context of this study is the Nordic bioeconomy. In a sample of 82 cases of biomass utilization within the electricity, fuels, chemicals, and textile fiber industries, eight cases contribute to all core objectives in the Nordic bioeconomy strategy thus supporting ecological modernization theory's claim about compatibility. However, the analysis of necessity suggests that the policy objectives are not mutually reinforcing. The remaining 74 cases in the sample fail to contribute to either economic, social or environmental objectives. This indicates that degrowth theory's attention to compromises is also justified, although the analysis of necessity suggests that there are no systematic trade-offs. Thus, while both theoretical frameworks find empirical support, neither is able to fully capture the complexity of the bioeconomy transition.

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1 Introduction

In 2018, the Nordic Council of Ministers published the revised Nordic bioeconomy strategy (Nordic Council of Ministers, 2018). The term *bioeconomy* refers broadly to a society that relies on technologies for sustainable extraction of biomass for fossil substitution (Bugge et al., 2016). Substitution is a huge task as fossil resources penetrate our daily lives. Not only do we rely on fossils for electricity, heating, and fuel; oil and petrochemicals are central ingredients in electronics, wires, asphalt, cement, paint, detergents, plastics, textiles, cosmetics, pharmaceuticals, pesticides, and fertilizers. As a result of recent innovations, biomass is becoming a viable replacement for oil and petrochemicals within many industrial sectors (Sillanpää & Ncibi, 2017). The bioeconomy transition is thus beginning to take-off and it is a point of departure for pursuing several green and socio-economic policy objectives, such as climate change mitigation, environmental sustainability, competitiveness, jobs, rural development, health and food security (Dieckhoff et al., 2015; Fund et al., 2015). A coherent transition strategy ideally consists of policy objectives that enable rather than disable simultaneous pursuit. However, the green transition literature in general and the bioeconomy literature more specifically contain competing theoretical expectations on the transition's ability to reconcile policy objectives from so many domains of society. For instance, bioeconomy conceptualizations originating from ecological modernization theory assume compatibility between economic, social, and environmental objectives. From this perspective, the ability to deliver on the policy objectives in the Nordic strategy hinges on technological development, careful policy reform and correction of market failures. At the other end of the spectrum, degrowth theory argues that continued economic growth is an obstacle to long-term environmental sustainability, not because we might fail to increase resource efficiency, but because we might succeed and hereby induce rebound effects (Bugge et al., 2016; Priefer et al., 2017; Hausknost et al., 2017). Thus, from this perspective the Nordic bioeconomy policy objectives contradict each other, making the strategy incoherent. Instead of pursuing environmental and economic objectives simultaneously, policy makers must choose which objective to prioritize. In short, the two theoretical frameworks disagree on the extent to which bioeconomy policy objectives overlap.

This paper probes whether set-theoretic methods offer new insights in relation to this debate. Rather than hypothesis testing, set-theoretic methods can help uncover the specific contexts in which each theoretical framework offers explanatory power. Perhaps ecological modernization theory makes more sense than degrowth theory in relation to certain feedstocks, countries, or industries and vice versa. For instance, Lange and Nordregio (2018) suggests that reducing fuel emissions through fossil substitution was a flawed strategy that undermined support for biomass conversion from the outset (cf. the *food vs fuel* debate). Degrowth theory's focus on compromises and trade-offs seems highly relevant for this dilemma, while ecological modernization theory might have more leverage in relation to other kinds of biomass utilization. Given that ecological modernization theory and degrowth theory fundamentally disagree on the compatibility between environmental, economic and social policy objectives in the green transition, the following research question guides the analysis:

> Is it conceivable to simultaneously realize all policy objectives envisioned in the Nordic

bioeconomy strategy given the currently available technologies for biomass utilization?

Set-theoric methods have been applied to studies of the bioeconomy (Lucia & Kronsell, 2010; Huang & Huarng, 2015; Muench, 2015) and green transitions more broadly (Damonte, 2014; Tobin, 2017; Vinke-de Kruijf et al., 2018). These studies uncover the conditions that affect technology performance and the conditions that lead to adoption or successful implementation of green policy objectives. However, set-theoretic methods have yet to be applied in a study where the *interplay between policy objectives* is the focus of the analysis. This paper is a first step towards closing this gap in the literature. The reason this gap exists is mainly methodological; more specifically due the difficulty in detecting and modelling causal interdependencies among not only conditions and outcome, but among conditions themselves. In this regard, configurational and set-theoretic methods may have more to offer than regressional and interpretavist approaches. Nonetheless, within the set-theoretic literature scholars disagree on how to detect causal interdependencies; Baumgartner and Epple (2014) argue that Coincidence Analysis (CNA) is better equipped to do this than fuzzy-set Qualitative Comparative Analysis (fsQCA). In CNA, conditions are not considered mutually independent, and no condition needs to be defined as the primary outcome. This allows the researcher to uncover data structures characterized by causal chains and common causes. Baumgartner and Epple argue that QCA can achieve the same thing only by accepting contradictory assumptions about logical remainders, but this point is contested by (Thiem, 2015). The controversy between Baumgartner and Epple and Thiem centers on the use of logical remainders and the Quine-McCluskey algorithm of minimization, and therefore has implications for the analysis of *sufficiency*.

This debate sparked the idea of rethinking QCA's analysis of *necessity* as a tool for analyzing causal interdependencies among conditions. The procedure suggested in this paper is simple: Taking turns, each policy objective constitutes the outcome of interest. In short, five parallel analyses of necessity uncover whether some (configurations of) policy objectives act as contextual enablers or disablers in the pursuit of other policy objectives. If this approach was applied to the analysis of sufficiency, it would indeed introduce contradictory simplifying assumptions as argued by Baumgartner and Epple, but applying it to the analysis of necessity circumvents this issue. Thus, although the new approach of Alternating Necessity Tests does not solve the controversy, it nonetheless illustrates that analyses of necessity can be powerful tools for uncovering how context and sequence matters. If one objective is necessary for another, the latter can *only* occur when the former is fulfilled. Put differently, Alternating Necessity Tests can uncover the contexts in which different objectives are achievable, and thus provide valuable input in discussions about how to prioritize goals sequentially in order to reconcile environmental, economic and social objectives. Beyond its methodological contribution, this paper therefore has implications not only for the development of green transition theory, but also in a wider perspective, e.g. when planning how to comply with the United Nations' seventeen sustainable development goals (United Nations, 2015).

The scope of the analysis is contained to three Nordic countries (Denmark, Finland and Sweden) for which it was possible to obtain updated, dis-aggregated and comparable data. The units of analysis, i.e. the *sets*, are the policy objectives contained in the Nordic bioeconomy strategy (2018). In this analysis, the strategy is simplified to five objectives: climate change mitigation, sustainable resource management, employment opportunities, economically viable business models, and globally competitive bio-based industries. None of the policy objectives are considered the main outcome in the bioeconomy strategy. Instead, simultaneous goal fulfillment seems to be the measure of success, and the Nordic countries pursue this through different means, most notably technology, innovation, education and changes in behavior and norms. This analysis focuses only on the current state of technological performance and the extent to which technology systems for novel biomass utilization enable (simultaneous) fulfillment of the Nordic policy objectives. More specifically, the cases in this analysis (i.e. technologies developed for fossil substitution) are assessed according to how sustainable (SUS) and emission intensive they are (CLIM), while competitiveness (COMP), employment opportunities (JOB) and economic viability (ECON) are assessed at industry and commodity level in Denmark, Finland, and Sweden. Technologies are defined in broad terms, encompassing the value chain from cultivation, harvest, and pre-treatment to processing. One technology case is for instance the usage of food waste for electricity production, another is forest logging residues for bio-ethanol production (see all cases Table 1).

Section 2 presents theoretical considerations on the compatibility between bioeconomy policy objectives. The methodological techniques for data analysis and the approach to case selection, data collection, and calibration are laid out in section 3. Section 4 presents the results from the analysis of set-relations. Finally, section 5 concludes and offers suggestions for further research.

2 Theoretical and empirical points of departure: how do bioeconomy policy objectives interact?

The Nordic Bioeconomy Strategy aims at simultaneously fulfilling environmental, social and economic objectives. But is it possible to rely on sustainable feedstock while mitigating climate change, creating employment opportunities, adding economic value, and competing successfully on global markets? Theory and tentative empirical evidence provide no clear answer to this question. This section highlights how the pursuit of one objective might hinder or further the pursuit of other objectives contained in the Nordic Bioeconomy Strategy. The arguments below indicate that the bioeconomy transition is characterized by great complexity; not only should we expect both compatibility and compromises among sustainability goals, but the severity of these compatibilities and compromises might vary across industries, feedstocks and countries. Better knowledge about such contextual differences will increase our understanding of factors that stall or push the bioeconomy transition forward.

2.1 Pursuing climate change mitigation and employment: will the bioeconomy create green jobs?

Phasing out the use of fossil resources is necessary to curb greenhouse gas emissions (IPCC, 2018). However, bio-based alternatives often rely on intensive cultivation, long distance transportation, and complex refining technologies. In a life-cycle perspective, therefore, biomass utilization is not always the low-emission choice when it comes to for instance energy (Barth et al., 2016) or chemicals and plastics (Yates & Barlow, 2013). Greenhouse gas reduction is thus not only a question of replacing fossil-based products with renewable alternatives, but also a question of designing shorter and more circular value chains to maintain an acceptable energy balance (Cong & Termansen, 2016). The specific technology and feedstock affect the degree to which this is possible. Because biomass is geographically dispersed (as opposed to for instance oil deposits), local and decentralized processing is necessary in order to ensure small emissions. Consequently, Lewandowski (2018) argues in line with ecological modernization theory that climate change mitigation and employment are not only compatible objectives; the bioeconomy transition will actually boost rural and agricultural employment opportunities. However, considering that the European agricultural workforce is expected to decline by 28 per cent from 2017 to 2030 (Agriculture and Rural Development, 2017), it is unclear whether the bioeconomic employment boost will reverse or merely slow down the decline (for a discussion of regional employment effects, see for instance Næss-Schmidt et al., 2015).

It is also unclear whether bioeconomic employment opportunities are stable or only a short-term phenomenon. Halseth (2016) argues that they will be relatively stable because the incentive to outsource is not very urgent in the bioeconomy: bio-based industries depend on local biomass supply and are therefore much less footloose than other kinds of manufacturing. In contrast, Johnson and Altman (2014) do not expect the employment dynamics of the bioeconomy to be any different from those of the fossil economy. Bio-based industries might not outsource production, but they are oftentimes highly automated and mechanized, and much innovation is directed towards making bio-based production even less labor intensive (Knudsen & Haug, 2015). Therefore, due to rapid technological development, stable green employment opportunities might be scarce in a low-emission bioeconomy context, at least within industries that lend themselves to automation. Given such increasing resource efficiency (*relative decoupling*), production and consumption must increase at a similar pace to avoid unemployment (Arler et al., 2015). According to degrowth theory, it is difficult to see how technological development can improve quickly enough to keep emissions low in the face of growing production and consumption. Thus, a low-emission bioeconomy can accommodate stable employment opportunities and achieve *absolute decoupling* only as long as we work fewer hours.

2.2 Pursuing economic and environmental sustainability: can we create value from sustainable feedstock?

In ecological modernization theory, economic growth can be a co-driver of environmental harm and social injustice, but it is also part of the solution to environmentally and socially sustainable development. This framework argues that market forces can contribute to environmental efficiency if we manage to design reasonable legislation and tax regimes that take into account the true costs of emissions, pollution and environmental degradation (Arler et al., 2015). But we also need technologies that increase resource efficiency and rely on circular material flows. The *cascading principle* is a way to ensure this. This principle of production entails that multiple material needs can be met from the same feedstock, and that the highest possible value is gained at each stage of utilization. However, implementation of the cascading principle is currently inadequate according to de Besi and McCormick (2015). Depending on the feedstock in question, some kinds of novel biomass utilization are therefore associated with opportunity costs and not yet economically viable. According to ecological modernization theory, sustainable resource management will not take off until it is economically attractive. The right sequence for achieving triple bottom-line sustainability is therefore first economic growth, which enables investments in green technologies, which then render environmental sustainable production possible.

From the perspective of degrowth theory, cascading use of biomass is not in itself a solution. Improved resource efficiency is often offset by the increased consumption it allows; relative decoupling is not automatically followed by absolute decoupling. This is the challenge of the rebound effect (Figge et al., 2014). To avoid the rebound effect, we need to transform consumption behavior, life-styles and norms. Preserving the *stock* rather than maximizing the *flow* of the economy is crucial for sustainable development (Arler et al., 2015). Thus, economic growth is not seen as a precondition for environmentally sustainable resource management in degrowth theory. At macro scale, these two objectives are *ceteris paribus* incompatible in the long run.

2.3 Pursuing competitiveness: the bioeconomy in a global perspective

As the world population grows and demands ever more protein rich diets, biomass is a scarce resource already prior to the bioeconomy transition (Godfray & Garnett, 2014). Additional cultivation and land use changes might aggravate freshwater shortages, accelerate habitat change, challenge biodiversity, and disrupt ecosystem services (Hall et al., 2012). We will therefore have to change eating and consumption habits to reduce environmental pressures and ensure food security. From the perspective of ecological modernization theory, changes in consumption patterns create business opportunities for those actors that can supply the goods and services that conscious green consumers demand. However, increasing capital intensity coupled with lacking support for piloting and demonstration of sustainable biomass technologies constitute obstacles for meeting demand and feed into investor insecurities (Leoussis & Brzezicka, 2017). Consequently, Scarlat et al. (2015) argues that many sustainable bio-technologies have yet to reach a stage of market maturity where they are economically viable and able to compete with cheap fossil alternatives.

Policy reforms might mitigate this problem and enable a competitive advantage. However, global competitiveness is difficult to reconcile with climate change mitigation, which relies not only on fossil substitution, short/circular value chains and less long-distance export, but also on technology transfer to developing countries. Technology transfer should enable receiving countries to leapfrog into a new stage of low-emission technological development (Brezis et al., 1993). The Paris Agreement emphasizes the need for rapid technology transfer (Nations, 2015), and a new regime for intellectual property rights has been a highly contested topic in international climate negotiations (de Coninck & Sagar, 2015). For developed countries, the dilemma consists in the fact that developing countries with low labor cost might be able to outperform them in supplying green commodities and services. According to Lange et al. (2016, p.22), these dynamics are already visible in the global bioeconomy context; up-scaling of bio-based industries takes place outside Europe, but relies on technologies developed inside Europe. Consequently, developed countries may struggle to maintain a competitive edge in the presence of accelerating technology transfer. From the perspective of degrowth theory, it is unclear *when* or *if* and at what *strength* a rebound effect will kick in when developing countries leapfrog towards new stages of cleaner production. It is also unclear whether globally distributed technological development could foster more local self-reliance and autarky, which again might reduce the need for long-distance trade and thus make the very notion of competitiveness redundant. In short, degrowth theory has ambiguous expectations regarding the consequences of pursuing competitiveness in a bioeconomy context.

The arguments above show ambiguous prospects for simultaneously pursuing all policy objectives. Whereas ecological modernization theory sees economic growth as a precondition for environmentally sustainable development, degrowth theory does not theorize on the importance of sequence. From the perspective of degrowth theory, we should expect consistent trade-offs between policy objectives across the entire bioeconomy no matter the industry, feedstock or country in question. Trade-offs are also conceivable from the perspective of ecological modernization theory due to market or policy failures in relation to particular technologies. If such failures are difficult to correct, 'sub-optimal' technologies could simply be avoided or employed in way in which they balance each other's strengths and weaknesses. Analyzing whether degrowth theory or ecological modernization theory is the most fruitful point of departure for understanding the Nordic bioeconomy requires a method that can deal with complex interaction between all five policy objectives. This is difficult to achieve via regression based models, but set-theoretic methods, on the other hand, can do exactly this. The following section introduces the methodological framework in more detail.

3 Materials and methods

In set-theory, a *set* defines a group of cases that share a characteristic, for instance *the set of competitive bio-based industries*. If the Nordic countries want to pursue competitiveness, they should utilize biomass primarily in industries that are *members* of this set. The analytical task is to uncover whether these industries overlap with the set of industries that e.g. generate employment opportunities. If so, it is possible to pursue both policy objectives. In order to analyze such dynamics, the analytical model used in this paper consists of five sets that correspond to policy objectives in the Nordic bioeconomy strategy. Analysis of set-relations does not rely on probability theory like quantitative methods. Instead, it relies on the mathematical foundations of set-theory, Boolean algebra and logic of propositions. Boolean algebra's basic operators are logical AND (*intersection*), logical OR (*disjunction*), and logical NOT (*negation*). By combining the basic Boolean operators, it is possible to calculate complex set-relations. This is what Schneider and Wagemann (2012) refer to as *QCA as a technique*. These calculations are based on standardized algorithms and can be performed by a range of different sofware options (for an overview, see Thiem & Duşa, 2013a). This analysis relies on the Venn, QCA, and SetMethods packages in R (version 3.6.0) developed by Dusa (2019, 2018) and Oana and Schneider (2018).

The analysis of set-relations procedes in two steps. In the first descriptive step, all cases are mapped in a Venn diagram that summarizes the case distribution and shows all logically possible configurations of sets. Put differently, the Venn diagram uncovers the general pattern of compatibility and compromise among policy objectives as some configurations contain several cases, while others are empty. This enables a discussion of the two theories' competing assumptions on how to reconcile environmental, economic and social sustainability. The next step is a search for necessary conditions. If a *negated* condition is necessary for another condition, actors face a trade-off between policy objectives. For instance, if absence of employment opportunities is necessary for competitiveness in bio-based industries (∼JOB←COMP), fulfilling both objectives is difficult. Thus, the analysis of necessity enables a discussion of sequence and strategy coherence. Technically, the Alternating Necessity Tests are performed with the *QCAfit* and *superSubset* commands using a consistency threshold of 0.9 covering disjunctions of maximum two conditions[1].

3.1 Case selection

The technology cases have been selected from the EU Commission Joint Research Center (JRC) database *LCA Results for Bio-based Commodities* (Giuntoli et al., 2018). This database is a collection of attributional life-cycle impact assessments of 380 biomass technologies in a cradle-to-gate scope. The database does not constitute the entire relevant population of bio-technologies, but the predominance of electricity and fuel technologies make it somewhat representative of the bioeconomy in general, as innovation and funding have mainly been directed towards bioenergy (Golembiewski et al., 2015). However, purposeful case selection rather than representativeness is the ideal in QCA, and generalizations beyond the scope conditions of the case sample are therefore restricted.

The case sample was built the following way: First, *EU* and *North Sea* were set as geographical filters. Then, all technologies not related to fossil substitution were excluded (e.g. food, feed, and furniture). Lack of data availability across all databases used in this analysis meant that some technologies had to be excluded, e.g. technologies related to bio-based construction materials, pharmaceuticals, plastics, and rubber. Next, cases were excluded if they relied on feedstock not native to the Nordic countries (e.g. imported eucalyptus or rice). This left a selection of 22 technologies within the industries of bio-electricity (9) and bio-fuels (13) and bio-based chemicals (5). Fossil substitution

[1] See the entire R script in the appendix.

occurs within other industries as well. The potential for fossil substitution is huge within textile industry. Synthetic fossil-based fibers made up approximately 70 per cent of global textile production in 2015, corresponding to more than 60 megatons (Antikainen et al., 2017).Therefore, three cases of man-made cellulosic fibers for textile production were added to the sample. Note that JRC's LCA-database does not include data on textile fibers. Instead, data was drawn from the cradle-to-gate LCA study by Shen et al. (2012). This yields a case sample of 82 unique cases, see Table 1.

Table 1: Case sample

Case ID	Case name	Country
Elec1	Electricity_dairy cow slurry	DEN, FIN, SWE
Elec2	Electricity_biowaste	DEN, FIN, SWE
Elec3	Electricity_food waste	DEN, FIN, SWE
Elec4	Electricity_wheat straw	DEN, FIN, SWE
Elec5	Electricity_wood industry residues	DEN, FIN, SWE
Elec6	Electricity_agricultural residues	DEN, FIN, SWE
Elec7	Electricity_forest loggin residues	DEN, FIN, SWE
Elec8	Electricity_poplar	DEN, FIN, SWE
Elec9	Electricity_stemwood	DEN, FIN, SWE
Biodiesel1	Biodiesel_microalgae	DEN, FIN, SWE
Biodiesel2	Biodiesel_used cooking oil	DEN, FIN, SWE
Biodiesel3	Biodiesel_animal fat	DEN, FIN, SWE
Biodiesel4	Biodiesel_rapeseed	DEN, FIN, SWE
Biodiesel5	Biodiesel_sunflower seed	DEN, FIN, SWE
Bioethanol1	Bioethanol_forest logging residues	FIN, SWE
Bioethanol2	Bioethanol_wheat straw	FIN, SWE
Bioethanol3	Bioethanol_black liqour	FIN, SWE
Bioethanol4	Bioethanol_poplar	FIN, SWE
Bioethanol5	Bioethanol_giant reed	FIN, SWE
Bioethanol6	Bioethanol_cereal mix	FIN, SWE
Bioethanol7	Bioethanol_maize	FIN, SWE
Bioethanol8	Bioethanol_sugar beet	FIN, SWE
Chemi1	Chemi_1.3 propanediol	DEN, FIN, SWE
Chemi2	Chemi_lactic acid	DEN, FIN, SWE
Chemi3	Chemi_acetic acid	DEN, FIN, SWE
Chemi4	Chemi_succinic acid	DEN, FIN, SWE
Chemi5	Chemi_adipic acid	DEN, FIN, SWE
Fiber1	Fiber_viscose	DEN, FIN, SWE
Fiber2	Fiber_modal	DEN, FIN, SWE
Fiber3	Fiber_tencel	DEN, FIN, SWE

Note that there is no data on the bioethanol industry in Denmark in the JRC databases. Therefore, only 22 cases are assessed in the Danish context, while all 30 are assessed in the Finnish and Swedish contexts.

3.2 Data collection and set-calibration

Each technology in the sample was assigned membership scores in the five sets in the model. In fuzzy-set QCA, set-membership is a matter of both *degree* and *kind*. Set-scores range from zero to one. Cases that get a score of one are full members of the set, meaning that they are empirical representations of the analytically relevant characteristic. A score of zero means that a case is not among the cases that share this characteristic. Variation between these thresholds is analytically relevant in set-theory, while variation beyond is irrelevant (Schneider & Wagemann, 2012). The fuzzy score 0.5 marks the point of maximum ambiguity. Above this threshold, cases are more members than non-members, and vice-versa. Cases can take on any value in between the three qualitative thresholds. Transforming raw data into set-scores is known as *calibration*. Calibration requires careful definition of the qualitative thresholds (0, 0.5 and 1) in relation to the indicator that is used for measurement. Ideally, thresholds should be external to the data at hand and based on theory, empirical knowledge, or common sense. Using external criteria to define the qualitative thresholds ensures that analytical results have sound theoretical justification and are not purely data driven. Robustness of QCA results depends, among other things, on how sensitive solution terms are to changes in the qualitative thresholds, in particular the 0.5 cross-over value. The upper and lower threshold affect analytical results less.

In addition to the LCA database, two recently published JRC databases are the main data sources for set-calibration as they constitute the most comprehensible source of information on the European bioeconomy. The database *BioSams for EU Member States* is a social accounting matrix (Mainar Causapé et al., 2018). It covers transactions between all agents in the economy for the year 2010 (most recent data). It offers data on highly disaggregated bio-based industries and commodities in all EU28 member states. The database *Job and Wealth in the Bioeconomy* provides data at industry level (Ronzon et al., 2018). Industry level data is usually disaggregated according to NACE codes. However, NACE codes do not enable researchers to distinguish for instance the bio-based chemical industry from the chemical industry in general. Therefore, JRC uses expert assessments to estimate the size of bio-based industries in relation to their parent industries. These shares are then used to calculate value-added, turnover and persons employed in bio-based industries. As the assessment of bio-based shares is still a work in progress, there might be data gaps. One such data gap is the absence of bio-ethanol cases in the Danish context. Additional data is drawn from the Nordic Statistics database. Data was downloaded in January 2019[2]. The remaining parts of this section describe the indicators, thresholds, and methods used in the calibration of the five sets.

3.2.1 The set of technologies with potential for climate change mitigation (CLIM)

Climate change mitigation is a multifaceted concept, although often it simply refers to reducing greenhouse gas emissions. The indicator Global Warming Potential (GWP100) is a standard measure for the amount of greenhouse gasses a commodity emits (Giuntoli et al., 2016). The higher the GWP,

[2] In the a appendix, the raw data is available in Table 1, and the calibrated data in Table 2.

the larger the emissions (measured in CO2 equivalents). For all technologies in the sample, the midpoint between the maximum and minimum GWP value is extracted from the LCA-database as the raw data. The guiding principle for the calibration is whether the bio-based commodity has a lower GWP than the fossil alternative it replaces. From 2021, EU regulations require that bioenergy emits 70 per cent less greenhouse gas than the legally defined fossil fuel comparator in order to be eligible for public financial support (Commission, 2017; Giuntoli et al., 2017). Consequently, 54.9 gCO2eq/MJ and 28.2 gCO2eq/MJ constitutes the GWP of the fossil alternatives for bioelectricity and biofuels, respectively. PlasticsEurope calculates the GWP of petrochemicals and polymers in a Western European context. Among the petrochemicals, HDPE has the smallest GWP (1.9 kgCO2eq/kg product), and the best performing fiber polymer is PP with a GWP of 2.0 kgCO2eq/kg product (Yates & Barlow, 2013). Consequently, 1.9 and 2 constitute the GWP of the fossil alternatives for biochemicals and bio-based textile fibers. The calibration thresholds are defined in relation to a GWP ratio:

$$GWP_{ratio} = \frac{GWP_{bio}}{GWP_{fossil}} \tag{1}$$

When this ratio yields the value of 1, the bio-based commodity emits as much greenhouse gas as its fossil alternative. This value therefore constitutes the threshold for full exclusion. Negative values on the GWP ratio are possible because some bio-based production processes consume rather than emit CO2. Zero therefore constitutes the threshold for full inclusion, and 0.5 constitutes the cross-over threshold. Using these thresholds, the GWP ratio values are transformed into fuzzy scores by the method direct standard logistic calibration.

3.2.2 The set of sustainable feedstocks (SUS)

In this analysis, technologies are considered sustainable if they rely on feedstock that neither threatens food security nor contributes to resource depletion in terms of land, freshwater, and biodiversity. As these dimensions are closely interlinked, the fuzzy scale is based on the following arguments. Marine algae, fungi and bacteria rely on almost no land and freshwater resources (Sillanpää & Ncibi, 2017). They are thus fully within the set (1.00) of sustainable feedstocks. Waste streams such as household organic waste, municipal solid waste, industrial waste, sludge and slurry are almost fully within the set (0.80) since utilizing these waste streams requires few land and freshwater resources. Another feedstock is residues such as stalks, branches, leaves, straws and fruit pits. Increased demand for residues may escalate cultivation of mother-crops that are themselves land and freshwater intensive. In addition, residues perform several ecosystem services such as maintaining soil carbon levels and preventing soil erosion, so they can only be removed and utilized to a limited extent (Priefer et al., 2017). The fuzzy score 0.6 reflect that residues are more in the set than out, but to a lesser extent than waste streams. Below the 0.5 cross-over threshold we find virgin terrestrial feedstocks. Forestry based feedstock is given the score 0.40. Although boreal forests require no irrigation, fertilizers or pesticides, they are intensive in terms of land use (Antikainen et al., 2017). Agricultural feedstock is intensive both in terms of land use, freshwater, fertilizers and pesticides[3] (Garnett et al., 2013), and therefore gets a score 0.20. Fully out of the set is feedstock that constitute foodstuff, for instance maize.

3.2.3 The set of industries with employment opportunities (JOB)

Many bio-based industries are on a path towards automation and mechanization, so even if bio-based production increases in absolute terms, we might not expect significant employment growth within these industries. Hence, development in labor intensity at industry level is used as a proxy for estimating employment opportunities. It is calculated using the formula:

$$Development\ in\ labor\ intensity = \frac{\triangle\ turnover}{\triangle\ employment} \tag{2}$$

Data on turnover and number of employed persons in bio-based industries from 2012 to 2015 is extracted from the database Jobs and Wealth in the Bioeconomy. If turnover increases more than employment, an industry is becoming less labor intensive. In other words, when the fraction yields positive values it indicates decreasing employment potential. Accordingly, this set is calibrated as a negative end-point concept (Thiem & Duşa, 2013b). Zero marks the cross-over threshold; at this value, labor intensity remains stable. As decreasing labor intensity is the general trend in the Nordic economies, bio-based industries are considered non-members of the set only if their labor intensity decreases more than the Nordic average. Accordingly, the threshold for full exclusion is 0.074 (Statistics, 2018a, 2018b). The inverse, -0.074, constitutes the threshold for full inclusion. Using these thresholds, the raw scores are transformed to fuzzy scores through direct logistical calibration.

3.2.4 The set of economically viable business models (ECON)

A central aspect of the bioeconomy transition is to mitigate resource depletion by switching to a renewable resource base. Many renewable resources are largely untapped, for instance marine biomass, residues and waste streams. These feedstocks represent an entirely new resource base and thus provide added value for society. However, novel bio-technologies relying on terrestrial virgin resources must compete with existing industries to obtain feedstock. Therefore, opportunity cost in relation to the utilization of feedstock is used as a proxy when assessing whether bio-based business models are economically viable. To estimate opportunity cost, data on the average value added per employee during the years 2012-2015 (measured in million €) is extracted from the Jobs and Wealth database. The indicator for opportunity costs is calculated as the difference in value added between novel and conventional sectors competing for the same feedstock using the formula:

[3] at least conventional non-organic agricultural feedstock

$$Opportunity\ cost = \frac{VA_{novel}}{employee} - \frac{VA_{conventional}}{employee} \quad (3)$$

At the value of zero, there is no opportunity cost in novel utilization of the feedstock compared to conventional utilization, but no added value either. This value therefore defines the lower calibration threshold. Positive values indicate *absence* of opportunity cost, i.e. novel utilization is viable compared to conventional utilization. However, novel biomass utilization also needs to be viable in relation to the economy in general in order to attract investments. The average value added per employee throughout the Nordic economies – 0.082 million € (Statistics, 2018c, 2018a) – therefore serves as the cross-over threshold. The upper calibration threshold is set at three times this value, i.e. 0.246 million €. An added value of this size should significantly contribute to reducing investors' risk perceptions and making bio-based business models economically viable. However, as this threshold is somewhat arbitrary, robustness tests are performed using 0.2 and 0.3 as alternative thresholds (see appendix). Again, direct logical calibration is used to transform raw scores into fuzzy scores.

3.2.5 The set of competitive bio-based industries (COMP)

The indicator Revealed Comparative Advantage (RCA) is a standard measure of how competitive a national industry is in the international markets. In Balassa's classic variant, RCA is calculated using the formula:

$$RCA = \frac{Commodity\ share\ of\ national\ export\ value}{Commodity\ share\ of\ international\ trade\ value} \quad (4)$$

RCA scores above 1 indicate a comparative advantage, while scores below 1 indicate a disadvantage (JRC, 2018; French, 2017). Take for example the Danish bio-chemical industry. In 2010, the export value of bio-chemical commodities constituted 0.83 per cent of total Danish export value. For EU28, the value of the bio-chemical industry constituted 0.81 percent of total export value. This yields an RCA value of 0.83/0.81=1.02, meaning that the Danish bio-chemical industry had a slight revealed advantage compared to bio-chemical industries in other EU28 member states. The data used in this example was extracted from the BioSams database, which also contains data on the other bio-based industries analyzed in this study. As RCA scores above 1 indicate a comparative advantage, the value of 1 marks the cross-over calibration threshold. Zero marks the lower threshold. Both mathematically and theoretically, the RCA indicator has no upper limit. The upper calibration threshold is set at the value of 2 to distinguish industries that are sufficiently competitive. Using these thresholds (0, 1, and 2), the RCA scores are transformed to fuzzy values using direct logistical calibration[4].

[4]Note that unlike the other JRC databases, textiles are not separated from apparel and leather in the BioSams database. This may influence estimations of the revealed comparative advantage of the textile industry, although it is impossible to say in which direction.

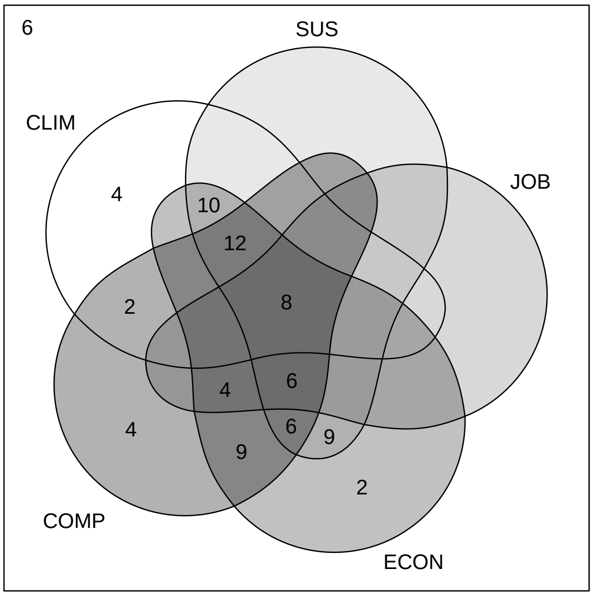
4 Results and discussion

This section presents and discusses the results of the analyses of set-relations. Robustness checks are available in the Appendix.

4.1 The pattern of compromise and compatibility

Figure 1 displays the case distribution. The numbers in the Venn diagram indicate how many cases (if any) that inhabit each intersection. Cases are included in the count if their set-scores pass the 0.5 threshold. Put differently, the Venn diagram is a crisp representation of the 32 logically possible policy combinations of policy overlap. In the middle of the diagram, all sets overlap. A case inhabiting this area enables simultaneous pursuit of all policy objectives. Fewer policy objectives overlap when a cases sits further away from the core.

Figure 1: Case distribution: technology performance in relation to the Nordic policy objectives



The diagram is constructed using the Venn package in R (Dusa, 2018)

Full overlap seems to be the exception rather than the rule. Only eight out of 82 cases inhabit the center space where they contribute to all five policy objectives. These cases are bioelectricity based on dairy cow slurry, food waste, wheat straw and agricultural residues in Finland and Sweden, respectively. Put differently, these four technologies rely on sustainable feedstock, belong to industries that compete successfully on international markets, add economic value without opportunity cost and have potential to mitigate climate change and create employment opportunities. No compromise between policy objectives is necessary if these technologies are employed in the Finnish or Swedish contexts. In the Danish context, the same technologies lack employment potential and therefore do not inhabit the middle of the Venn diagram. In fact, all cases lack employment opportunities in the Danish context, indicating that the pace of automation might be faster here than in the Finnish and Swedish bio-based industries. The case distribution in Figure 1 is skewed towards the lower left corner of the diagram (COMP and ECON). Globally, competitiveness and economic growth are the most frequently pursued policy objectives in bioeconomy strategies (Dieckhoff et al., 2015; Fund et al., 2015). Taking this into perspective, it is not surprising to find a skewed case distribution in which developed technologies often serve these goals. However, it suggests a need for innovation if the Nordic countries wish to pursue a more balanced palette of policy objectives, as envisioned in the bioeconomy strategy, especially relating to (rural) employment opportunities.

As biomass access varies across the Nordic countries, national policies focus on different types of feedstock and areas of utilization. Denmark has focused quite narrowly on bioenergy from agricultural feedstock, while Finland and Sweden have focused on utilizing forestry based feedstock for chemical, material and energy purposes (Lange et al., 2016). It is therefore worth noticing the six cases that sit in the diagram's upper left corner. They are non-members of *all* sets in the model. These cases are biodiesel based on rapeseed and sunflower seed in the Danish and Finnish contexts, and tencel fibers in the Finnish and Swedish contexts[5]. Put differently, the six cases match the national focus areas, but implementing them would paradoxically contribute to none of the objectives in the Nordic bioeconomy strategy.

Both the compatibility assumption in ecological modernization theory and the compromise assumption in degrowth theory are thus reflected empirically in the case sample, although they apply to different sectors, feedstocks and countries. The compatibility assumption holds true for four electricity cases in Finland and Sweden, while the compromise assumption holds true for two bio-diesel cases in Denmark and Finland and one textile fiber case in Finland and Sweden. Neither theoretical framework offers unequivocal explanatory power for those 68 cases that sit somewhere in between full overlap and complete non-membership. This suggests that green transition theory in general might have some blind spots when applied to the bioeconomy.

Figure 1 represents only a snapshot of the Nordic bioeconomy at a point in time where the transition is still in an early phase. Over time, innovation might change technologies' (in)ability to contribute to the five different policy objectives. According to a survey among green inventors, the expected time frame for piloting, demonstrating and up-scaling biotechnological innovations range from four to twenty years (Lange et al., 2016). Given the complex and ambiguous theoretical expectations (cf. section 2), it is difficult to hypothesize on the direction in which the case distribution might change within this relatively short time frame, i.e. whether policy overlap will increase (cases will come to congregate around the core), or decrease (case distribution will be skewed towards single sets in the Venn diagram or even drift towards the periphery). To shed more light on the case distribution, an analysis of necessity can uncover how sequence matters when pursuing the five policy objectives. If some objectives (or configurations hereof) are necessary conditions for other policy objectives,

[5] see Table 2 in the appendix

Table 2: Analyses of necessity: consistency scores

	Outcomes				
Enablers	CLIM	SUS	JOB	ECON	COMP
CLIM		0.613	0.484	0.454	0.458
SUS	0.757		0.756	0.673	0.620
JOB	0.300	0.379		0.367	0.394
ECON	0.744	0.892	**0.969**		0.855
COMP	0.661	0.724	**0.917**	0.753	
∼CLIM		0.588	0.671	0.643	0.646
∼SUS	0.490		0.590	0.509	0.583
∼JOB	0.796	0.795		0.735	0.690
∼ECON	0.415	0.349	0.299		0.345
∼COMP	0.490	0.513	0.277	0.423	
JOB+ECON		**0.903**			
SUS+ECON					**0.908**
COMP+SUS				**0.927**	
∼CLIM+SUS				**0.908**	

Coverage scores and relevance of necessity scores are available in the appendix.

policy makers will know the contexts in which different objectives are achievable. Put differently, they will know which objectives to prioritize and in which sequence to fulfill them in order to achieve more policy overlap. Conversely, if negated sets appear as necessary contextual conditions, these objectives are not merely incompatible when using particular technologies, but constitute trade-offs consistently across the Nordic bioeconomy. Increased overlap will be difficult to achieve in such circumstances.

4.2 How context and sequence matters

The results of the five analyses of necessity are displayed in Table 2. Consistency scores indicate the degree to which a condition is a perfect superset of an outcome. Only two single conditions pass the 0.9 consistency threshold: ECON←JOB and COMP←JOB. However, since the JOB set is quite skewed, these relations of necessity are probably merely trivial. Coverage and relevance scores and XY-plots support this interpretation (see appendix). The first finding to take away from Table 2 is therefore that single conditions neither enable nor disable one another other. Thus, there is no clear conclusion in terms of strategy coherence - the Nordic bioeconomy strategy does not pursue objectives that are directly incompatible, but neither does it pursue objectives that enable each other. However, this picture changes when we look at disjunctions rather than single sets (disjunctions are conditions connected by logical OR/+).

Four disjunctions pass the consistency threshold. Two disjunctions (∼CLIM+SUS←ECON and SUS+ECON←COMP) are rejected as necessary conditions due to skewedness and/or many logically contradictory cases (see appendix). Thus, only two disjunctions are deemed relevant for substantive interpretation. The superset relation JOB+ECON←SUS covers cases of fuel, chemicals, and electricity from all three countries and has no logically contradictory cases (coverage 0.673, RoN 0.582), see Figure 2, while the superset relation COMP+SUS←ECON covers cases of fuels and chemicals from all three countries and has some logically contradictory cases (coverage 0.851, RoN 0.702), see Figure 3. However, in Boolean algebra it is always possible to find consistent supersets by connecting ever more single conditions via logical OR. Therefore, even if parameters of fit are fine, disjunctions should be rejected as necessary conditions unless they constitute functional equivalents of some theoretically meaningful higher order construct (Schneider & Wagemann, 2012; Schneider, 2019). The remaining part of this section discusses whether that is the case. The discussion is accompanied by necessity plots (Figure 2 and 3). All cases that fall below the diagonal in a necessity plot are consistent with the claim of necessity. Cases that fall above the diagonal have different implications depending on the quadrant in which they sit. Cases above the diagonal in the lower left quadrant are irrelevant for the statement of necessity since they do not display the outcome. Cases above the diagonal in the upper left quadrant logically contradict the statement of necessity, since the outcome is present without the allegedly necessary condition being present. Cases above the diagonal in the upper right corner deviate from the statement of necessity, meaning that they are inconsistent, but not true logical contradictions.

4.2.1 JOB+ECON←SUS: Growth as a necessary context condition for sustainability

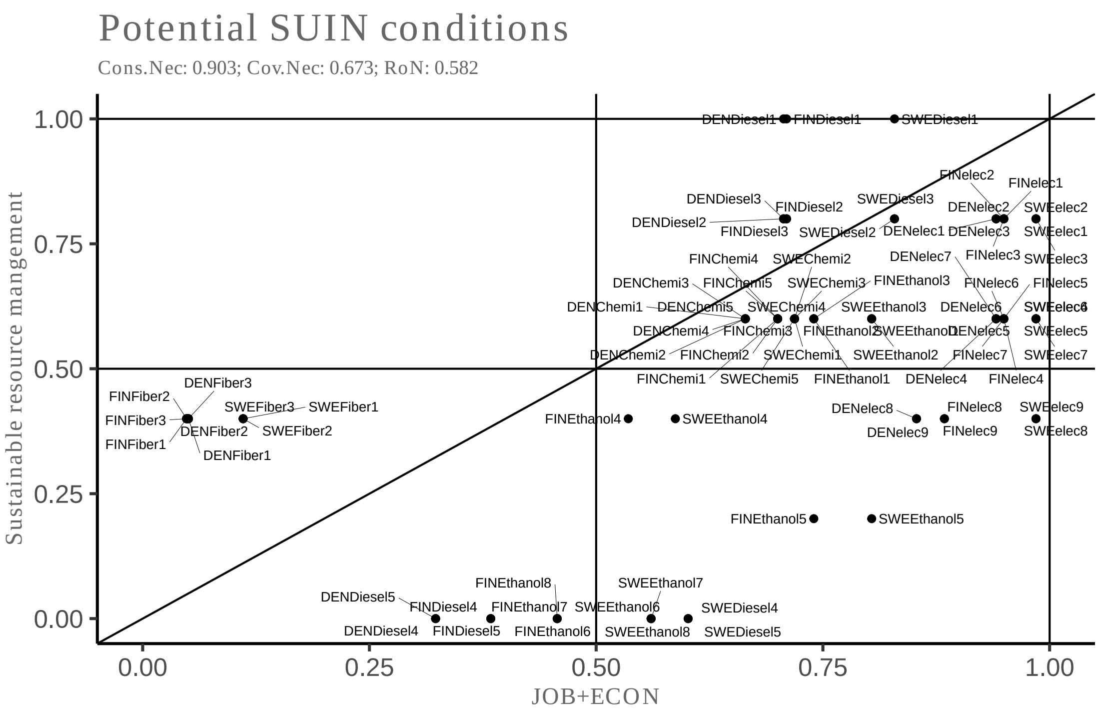
This disjunction states that relying on bio-based sectors with stable employment potential OR economically viable business models is necessary for realizing sustainable resource management. The theory section highlighted that stable employment opportunities are difficult to reconcile with the pursuit of economically viable business models. This disjunction indicates that as long as biomass utilization contributes to one or both of these objectives[6], sustainable resource management is possible. Note that we cannot be sure that biomass utilization in such sectors will indeed be sustainable, as *sufficient* conditions for sustainable resource management are not uncovered in this analysis.

From the perspective of degrowth theory, the disjunction JOB+ECON is hard to make sense of. According to degrowth theory, sustainable resource management is possible if we work fewer hours and abstain from pursuing economic growth. JOB+ECON←SUS suggests something else entirely, namely that we need to pursue employment opportunities or create economically viable business models *before* we can achieve sustainability. This pattern seems to align better with the assumptions in ecological modernization theory. JOB and ECON can be interpreted as functional equivalents of the higher order construct *growth*. Although growth encompasses more elements than just employment and viable business models, these are definitely two important ones. Because the higher order construct is meaningful from the perspective of ecological modernization theory, the disjunction JOB+ECON is accepted as a necessary context for sustainable resource management in the Nordic bioeconomy. However, the ecological modernization interpretation has some blind spots; although no

[6]The Boolean OR is an *inclusive* OR, not an *exclusive* OR.

cases logically contradict the superset relation, some cases are left unexplained while others deviate.

Figure 2: Necessity plot for sustainable resource management

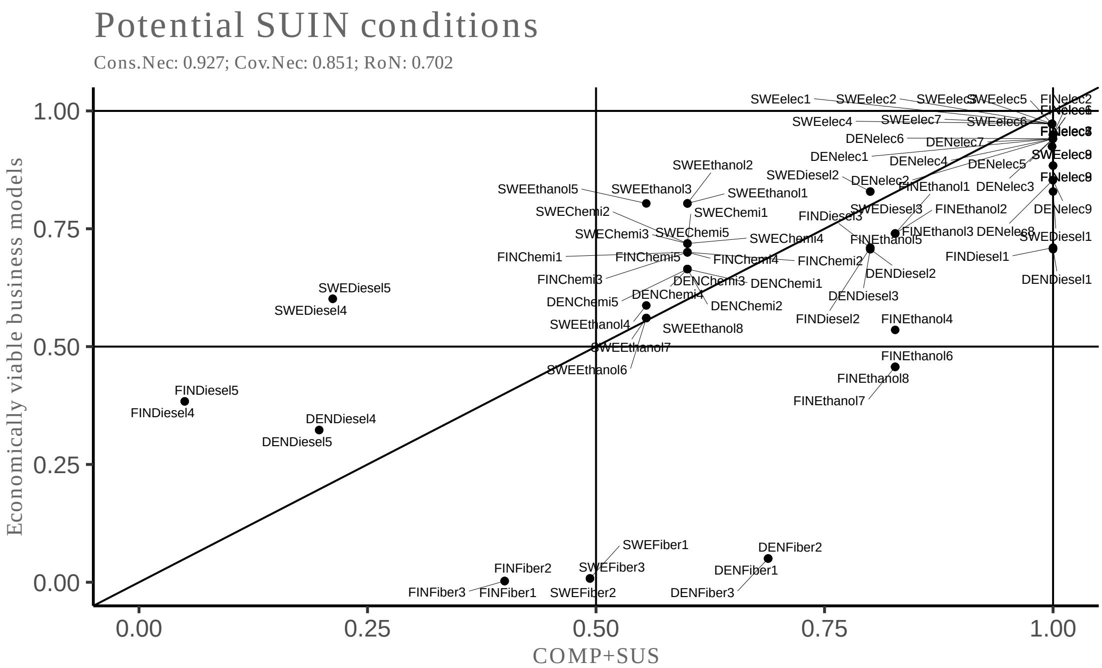


The textile fiber cases do not display the outcome (SUS) as they rely on virgin feedstock (forestry pulp), and they are therefore not among the cases explained. The ecological modernization interpretation suggests that until these sectors can create stable employment opportunities or generate more value added than sectors competing for the same feedstock (primarily the paper industry), they will have a hard time attracting investments and innovative technologies for utilizing non-virgin feedstock instead. The three cases of microalgae biodiesel (Diesel1) deviate notably from the statement of necessity. These are the only cases in the sample that have full membership in the sustainability set, meaning that the feedstock does not undermine food security or rely on land, freshwater, fertilizers or pesticides. The microalgae cases also contribute to economic growth (set-membership in JOB+ECON > 0.5); the socio-economic and environmental policy objectives are therefore compatible when it comes to the marine bioeconomy, but they seem to be related in another way than in the terrestrial bioeconomy. Future research could explore these dynamics.

4.2.2 COMP+SUS←ECON: Rebound effects in the context of global green consumer demand?

This disjunction states that utilizing biomass within industries that are competitive OR rely on sustainable feedstock is necessary for having economically viable business models. The theory section highlighted that some kinds of novel biomass utilization are characterized by high opportunity costs due to inadequate implementation of the cascading principle, and many sustainable technologies are not yet able to compete with cheap fossil alternatives. Figure 3 shows nonetheless that many cases contribute to realizing sustainable resource management, competitiveness and economically viable business models. If competitiveness and sustainable resource management are interpreted as functional equivalents of the higher order construct *green consumer demand*, ecological modernization theory offers a useful framework for interpretation: As long as bio-based industries contribute to satisfying global green consumer demand, economically viable business models are possible. This claim is rather trivial. However, it is interesting that the claim is not universal; there are quite a few inconsistent cases as well as two cases that logically contradict the claim of necessity. These two cases (Swedish rapeseed and sunflower biodiesel) are economically viable, but do *not* satisfy global green consumer demand. Ecological modernization theory would find it problematic that some unsustainable technologies are economically viable, but it is merely a sign of market failure or policy failure, which can and should be corrected.

Figure 3: Necessity plot for economically viable business models



Degrowth theory offers a fruitful point of departure for understanding the inconsistent cases in Figure 3. All the cases above the diagonal in the upper right corner are economically viable, but because COMP+SUS is a *subset* rather than a *superset* of ECON for these cases, economically viable business models seem to be *creating* green consumer demand, rather than *responding* to it[7]. This could be an indication that a supply-side rebound effect is at play, most noticeably within the Nordic biochemical industries. By developing new, profitable ways of producing chemicals using local bio-based feedstock, these chemicals become more accessible. Therefore, demand and consumption might increase, off-setting the initial gain in emission efficiency.

5 Conclusions

The Nordic countries pursue multiple policy objectives in the joint Nordic bioeconomy strategy. According to ecological modernization theory, we should expect that social, environmental and economic objectives are compatible. Degrowth theory, on the other hand, points our attention toward compromises and trade-offs between objectives. By answering the research question, the empirical results provide support for both theoretical frameworks: Given the currently available technologies for biomass utilization, simultaneous pursuit of all five policy objectives *is* possible as expected by ecological modernization theory. However, it occurs rarely and is restricted to the bio-electricity industries in Finland and Sweden. Eight cases in a sample of 82 technologies mitigate climate change and rely on sustainable feedstock while simultaneously belonging to industries that create employment opportunities, add economic value and compete successfully on global markets. This kind of overlap did not occur within the industries of fuels, chemicals and textiles; and in Denmark not at all.

Six cases forfeited all five policy objectives, which is a finding even more extreme than expected by degrowth theory. Nonetheless, many technologies are relevant to employ if actors are satisfied with pursuing two to three policy objectives simultaneously. If these ”sub-optimal” technologies are employed in a balanced way, Nordic countries might still be able to pursue all five policy objectives even though just eight individual technologies enable policy overlap. However, such a balancing act might be difficult to achieve since the case distribution is skewed towards serving the goals of competitiveness and economic viability, while only a few cases serve the goals of sustainable resource management and stable employment opportunities. As emphasized by van den Bergh (2017) in his delineation of agrowth theory, this balancing act may nonetheless be necessary in order to overcome the politically unproductive polarization between green growth and degrowth discourses.

The Alternating Necessity Tests revealed that this polarization might anyway be misguided: No negated conditions (single or SUIN [8]) appeared as necessary conditions for the other policy objectives. This does not mean that degrowth theory is wrong when drawing our attention towards compromises. It means only that these compromises seem to occur inconsistently and unsystematically across the Nordic bioeconomy rather than being strict trade-offs between particular policy goals. No non-negated conditions appeared necessary either, indicating that the Nordic bioeconomy strategy is

[7] Future research could test this claim in an analysis of sufficiency

[8] **S**ufficient, but **U**nnecessary part of a condition that is in itself **I**nsufficient, but **N**ecessary for an outcome (Schneider & Wagemann, 2012).

fairly coherent and not self-contradictory. This coherence might change or disappear if the objectives in the bioeconomy strategy are revised. For instance, climate mitigation was recently downplayed in the political and academic bioeconomy debates at the COP24 in Katowice (Lange & Nordregio, 2018), while food security gained emphasis. Future research could assess whether such a composition of strategic goals would be more coherent and enable a higher degree of overlap than the current strategic framework does.

When the search for necessary conditions was expanded to cover disjunctions, ecological modernization theory offered the most fruitful point of departure for interpretation. The first disjunction suggests that economic growth is necessary for sustainable resource management. This indicates that the Nordic bioeconomy transition needs to unfold in a specific sequence in order to achieve environmental sustainability. The second disjunction suggests that green consumer demand is necessary for creating economically viable business models. However, degrowth theory could not be ignored in relation to the second disjunction, since it enabled a meaningful interpretation of inconsistent cases: namely as possible signs of a rebound effect. Even though rebound effects only encompass some technologies within a few industries and not the Nordic bioeconomy as a whole, they are critical and should not be neglected. Put differently, degrowth theory's precautionary stance is an important contribution to the otherwise well-founded optimism in the Nordic bioeconomy discourse. Green transition theories that can incorporate both growth and degrowth aspects, as for example van den Bergh's agrowth theory, seem relevant to develop further in order to grasp the scope conditions within which we can pursue either aspect.

The fact that set-theoretic methods enabled a very nuanced conclusion testifies to the methods' increasing importance and usefulness in political environmental science. Not only was it possible to capture variations across countries, industries and feedstocks, it was also possible to identify cases that constitute theoretical blind spots. Thus, set-theoretical methods are useful points of departure for potentially refining and revising green transition theory. That being said, this paper constitutes only a first step towards this aim as set-relations are not necessarily causal. In order to make convincing causal claims and subsequently refine theory, the set-theoretic multi-method literature argues that relations of sufficiency and necessity should be substantiated through in-depth case studies (Beach, 2018; Schneider & Rohlfing, 2016, 2013). A case study of the Nordic biochemical industry is relevant in this regard, since it is uncertain what sets this industry apart from the remaining industries in the sample. Explaining why rebound effects seem to appear here is an important avenue for future research. While degrowth theory convincingly explains the psychological and market mechanisms that trigger rebound effects, the theory has yet to elaborate on the scope conditions in which these mechanisms are most likely to occur in a bioeconomy context.

In this study, data limitations meant that some bioeconomy industries were not included in the analysis, for instance bio-pharmaceuticals, construction materials and plastics. In addition, technologies relying on marine biomass were underrepresented. It is therefore unclear whether the same pattern of compromises and compatibilities are present in these parts of the Nordic bioeconomy. Uncovering this is also an important area for future research.

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Appendix to the analysis
When Bioeconomy Policy Objectives (Fail To) Overlap

September 27, 2019

Contents

1 Raw data

Table 1: Raw scores

	GWP_ratio	SUS	JOB_raw	ECON_raw	COMP_raw
DENelec1	-3,616	0,800	0,634	0,236	3,864
DENelec2	1,295	0,800	0,634	0,236	3,864
DENelec3	0,003	0,800	0,634	0,236	3,864
DENelec4	0,353	0,600	0,634	0,236	3,864
DENelec5	0,821	0,600	0,634	0,236	3,864
DENelec6	0,272	0,600	0,634	0,236	3,864
DENelec7	1,287	0,600	0,634	0,236	3,864
DENelec8	1,485	0,400	0,634	0,180	3,864
DENelec9	1,286	0,400	0,634	0,180	3,864
DENDiesel1	1,366	1,000	0,157	0,131	0,523
DENDiesel2	0,246	0,800	0,157	0,131	0,523
DENDiesel3	0,369	0,800	0,157	0,131	0,523
DENDiesel4	1,495	0,000	0,157	0,061	0,523
DENDiesel5	1,278	0,000	0,157	0,061	0,523
DENChemi1	-0,007	0,600	0,161	0,120	1,117
DENChemi2	0,105	0,600	0,161	0,120	1,117
DENChemi3	1,447	0,600	0,161	0,120	1,117
DENChemi4	0,605	0,600	0,161	0,120	1,117
DENChemi5	1,447	0,600	0,161	0,120	1,117
DENFiber1	-0,125	0,400	0,095	0,000	1,269
DENFiber2	0,015	0,400	0,095	0,000	1,269
DENFiber3	0,550	0,400	0,095	0,000	1,269
FINelec1	-3,616	0,800	-0,022	0,245	5,855
FINelec2	1,295	0,800	-0,022	0,245	5,855
FINelec3	0,003	0,800	-0,022	0,245	5,855
FINelec4	0,353	0,600	-0,022	0,245	5,855
FINelec5	0,821	0,600	-0,022	0,245	5,855
FINelec6	0,272	0,600	-0,022	0,245	5,855
FINelec7	1,287	0,600	-0,022	0,245	5,855
FINelec8	1,485	0,400	-0,022	0,195	5,855
FINelec9	1,286	0,400	-0,022	0,195	5,855
FINDiesel1	1,366	1,000	0,045	0,132	0,000
FINDiesel2	0,246	0,800	0,045	0,132	0,000
FINDiesel3	0,369	0,800	0,045	0,132	0,000

Table 1 continued from previous page

	GWP_ratio	SUS	JOB_raw	ECON_raw	COMP_raw
FINDiesel4	1,495	0,000	0,045	0,069	0,000
FINDiesel5	1,278	0,000	0,045	0,069	0,000
FINEthanol1	0,377	0,600	0,053	0,140	1,532
FINEthanol2	0,273	0,600	0,053	0,140	1,532
FINEthanol3	0,365	0,600	0,053	0,140	1,532
FINEthanol4	0,725	0,400	0,053	0,090	1,532
FINEthanol5	1,018	0,200	0,053	0,140	1,532
FINEthanol6	1,599	0,000	0,053	0,077	1,532
FINEthanol7	1,720	0,000	0,053	0,077	1,532
FINEthanol8	1,046	0,000	0,053	0,077	1,532
FINChemi1	-0,007	0,600	0,027	0,129	0,514
FINChemi2	0,105	0,600	0,027	0,129	0,514
FINChemi3	1,447	0,600	0,027	0,129	0,514
FINChemi4	0,605	0,600	0,027	0,129	0,514
FINChemi5	1,447	0,600	0,027	0,129	0,514
FINFiber1	-0,125	0,400	0,075	-0,084	0,338
FINFiber2	0,015	0,400	0,075	-0,084	0,338
FINFiber3	0,550	0,400	0,075	-0,084	0,338
SWEelec1	-3,616	0,800	-0,105	0,281	3,320
SWEelec2	1,295	0,800	-0,105	0,281	3,320
SWEelec3	0,003	0,800	-0,105	0,281	3,320
SWEelec4	0,353	0,600	-0,105	0,281	3,320
SWEelec5	0,821	0,600	-0,105	0,281	3,320
SWEelec6	0,272	0,600	-0,105	0,281	3,320
SWEelec7	1,287	0,600	-0,105	0,281	3,320
SWEelec8	1,485	0,400	-0,105	0,222	3,320
SWEelec9	1,286	0,400	-0,105	0,222	3,320
SWEDiesel1	1,366	1,000	0,076	0,170	0,554
SWEDiesel2	0,246	0,800	0,076	0,170	0,554
SWEDiesel3	0,369	0,800	0,076	0,170	0,554
SWEDiesel4	1,495	0,000	0,076	0,105	0,554
SWEDiesel5	1,278	0,000	0,076	0,105	0,554
SWEEthanol1	0,377	0,600	0,083	0,161	1,075
SWEEthanol2	0,273	0,600	0,083	0,161	1,075
SWEEthanol3	0,365	0,600	0,083	0,161	1,075
SWEEthanol4	0,725	0,400	0,083	0,102	1,075

Table 1 continued from previous page

	GWP_ratio	SUS	JOB_raw	ECON_raw	COMP_raw
SWEEthanol5	1,018	0,200	0,083	0,161	1,075
SWEEthanol6	1,599	0,000	0,083	0,096	1,075
SWEEthanol7	1,720	0,000	0,083	0,096	1,075
SWEEthanol8	1,046	0,000	0,083	0,096	1,075
SWEChemi1	-0,007	0,600	0,013	0,134	0,483
SWEChemi2	0,105	0,600	0,013	0,134	0,483
SWEChemi3	1,447	0,600	0,013	0,134	0,483
SWEChemi4	0,605	0,600	0,013	0,134	0,483
SWEChemi5	1,447	0,600	0,013	0,134	0,483
SWEFiber1	-0,125	0,400	0,052	-0,052	0,991
SWEFiber2	0,015	0,400	0,052	-0,052	0,991
SWEFiber3	0,550	0,400	0,052	-0,052	0,991

2 Calibrated data

Table 2: Calibrated data matrix

	CLIM	SUS	JOB	ECON	COMP	NAME
DENelec1	1,000	0,800	0,000	0,941	1,000	Electricitydairy cow slurry
DENelec2	0,009	0,800	0,000	0,941	1,000	Electricitybiowaste
DENelec3	0,949	0,800	0,000	0,941	1,000	Electricityfood waste
DENelec4	0,704	0,600	0,000	0,941	1,000	Electricitywheat straw
DENelec5	0,131	0,600	0,000	0,941	1,000	Electricitywood industry residues
DENelec6	0,793	0,600	0,000	0,941	1,000	Electricityagricultural residues
DENelec7	0,010	0,600	0,000	0,941	1,000	Electricityforest loggin residues
DENelec8	0,003	0,400	0,000	0,853	1,000	Electricitypoplar
DENelec9	0,010	0,400	0,000	0,853	1,000	Electricitystemwood
DENDiesel1	0,006	1,000	0,002	0,707	0,197	Dieselmicroalgae
DENDiesel2	0,817	0,800	0,002	0,707	0,197	Dieselused cooking oil
DENDiesel3	0,684	0,800	0,002	0,707	0,197	Dieselanimal fat
DENDiesel4	0,003	0,000	0,002	0,323	0,197	Dieselrapeseed
DENDiesel5	0,010	0,000	0,002	0,323	0,197	Dieselsunflower seed
DENChemi1	0,952	0,600	0,002	0,664	0,585	1.3 propanediol
DENChemi2	0,911	0,600	0,002	0,664	0,585	lactic acid
DENChemi3	0,004	0,600	0,002	0,664	0,585	acetic acid
DENChemi4	0,350	0,600	0,002	0,664	0,585	succinic acid
DENChemi5	0,004	0,600	0,002	0,664	0,585	adipic acid
DENFiber1	0,975	0,400	0,022	0,050	0,688	Fibreviscose
DENFiber2	0,946	0,400	0,022	0,050	0,688	Fibremodal
DENFiber3	0,427	0,400	0,022	0,050	0,688	Fibretencel
FINelec1	1,000	0,800	0,708	0,950	1,000	Electricitydairy cow slurry
FINelec2	0,009	0,800	0,708	0,950	1,000	Electricitybiowaste
FINelec3	0,949	0,800	0,708	0,950	1,000	Electricityfood waste
FINelec4	0,704	0,600	0,708	0,950	1,000	Electricitywheat straw
FINelec5	0,131	0,600	0,708	0,950	1,000	Electricitywood industry residues
FINelec6	0,793	0,600	0,708	0,950	1,000	Electricityagricultural residues
FINelec7	0,010	0,600	0,708	0,950	1,000	Electricityforest loggin residues
FINelec8	0,003	0,400	0,708	0,884	1,000	Electricitypoplar
FINelec9	0,010	0,400	0,708	0,884	1,000	Electricitystemwood
FINDiesel1	0,006	1,000	0,142	0,710	0,050	Dieselmicroalgae
FINDiesel2	0,817	0,800	0,142	0,710	0,050	Dieselused cooking oil
FINDiesel3	0,684	0,800	0,142	0,710	0,050	Dieselanimal fat

Table 2 continued from previous page

	CLIM	SUS	JOB	ECON	COMP	NAME
FINDiesel4	0,003	0,000	0,142	0,384	0,050	Dieselrapeseed
FINDiesel5	0,010	0,000	0,142	0,384	0,050	Dieselsunflower seed
FINEthanol1	0,674	0,600	0,110	0,740	0,827	Ethanolforest logging residues
FINEthanol2	0,792	0,600	0,110	0,740	0,827	Ethanolwheat straw
FINEthanol3	0,689	0,600	0,110	0,740	0,827	Ethanolblack liqour
FINEthanol4	0,210	0,400	0,110	0,535	0,827	Ethanolpoplar
FINEthanol5	0,045	0,200	0,110	0,740	0,827	Ethanolgiant reed
FINEthanol6	0,002	0,000	0,110	0,457	0,827	Ethanolcereal mix
FINEthanol7	0,001	0,000	0,110	0,457	0,827	Ethanolmaize
FINEthanol8	0,039	0,000	0,110	0,457	0,827	Ethanolsugar beet
FINChemi1	0,952	0,600	0,255	0,700	0,193	1.3 propanediol
FINChemi2	0,911	0,600	0,255	0,700	0,193	lactic acid
FINChemi3	0,004	0,600	0,255	0,700	0,193	acetic acid
FINChemi4	0,350	0,600	0,255	0,700	0,193	succinic acid
FINChemi5	0,004	0,600	0,255	0,700	0,193	adipic acid
FINFiber1	0,975	0,400	0,048	0,003	0,125	Fibreviscose
FINFiber2	0,946	0,400	0,048	0,003	0,125	Fibremodal
FINFiber3	0,427	0,400	0,048	0,003	0,125	Fibretencel
SWEelec1	1,000	0,800	0,985	0,972	0,999	Electricitydairy cow slurry
SWEelec2	0,009	0,800	0,985	0,972	0,999	Electricitybiowaste
SWEelec3	0,949	0,800	0,985	0,972	0,999	Electricityfood waste
SWEelec4	0,704	0,600	0,985	0,972	0,999	Electricitywheat straw
SWEelec5	0,131	0,600	0,985	0,972	0,999	Electricitywood industry residues
SWEelec6	0,793	0,600	0,985	0,972	0,999	Electricityagricultural residues
SWEelec7	0,010	0,600	0,985	0,972	0,999	Electricityforest loggin residues
SWEelec8	0,003	0,400	0,985	0,925	0,999	Electricitypoplar
SWEelec9	0,010	0,400	0,985	0,925	0,999	Electricitystemwood
SWEDiesel1	0,006	1,000	0,047	0,829	0,212	Dieselmicroalgae
SWEDiesel2	0,817	0,800	0,047	0,829	0,212	Dieselused cooking oil
SWEDiesel3	0,684	0,800	0,047	0,829	0,212	Dieselanimal fat
SWEDiesel4	0,003	0,000	0,047	0,601	0,212	Dieselrapeseed
SWEDiesel5	0,010	0,000	0,047	0,601	0,212	Dieselsunflower seed
SWEEthanol1	0,674	0,600	0,036	0,804	0,555	Ethanolforest logging residues
SWEEthanol2	0,792	0,600	0,036	0,804	0,555	Ethanolwheat straw
SWEEthanol3	0,689	0,600	0,036	0,804	0,555	Ethanolblack liqour
SWEEthanol4	0,210	0,400	0,036	0,587	0,555	Ethanolpoplar

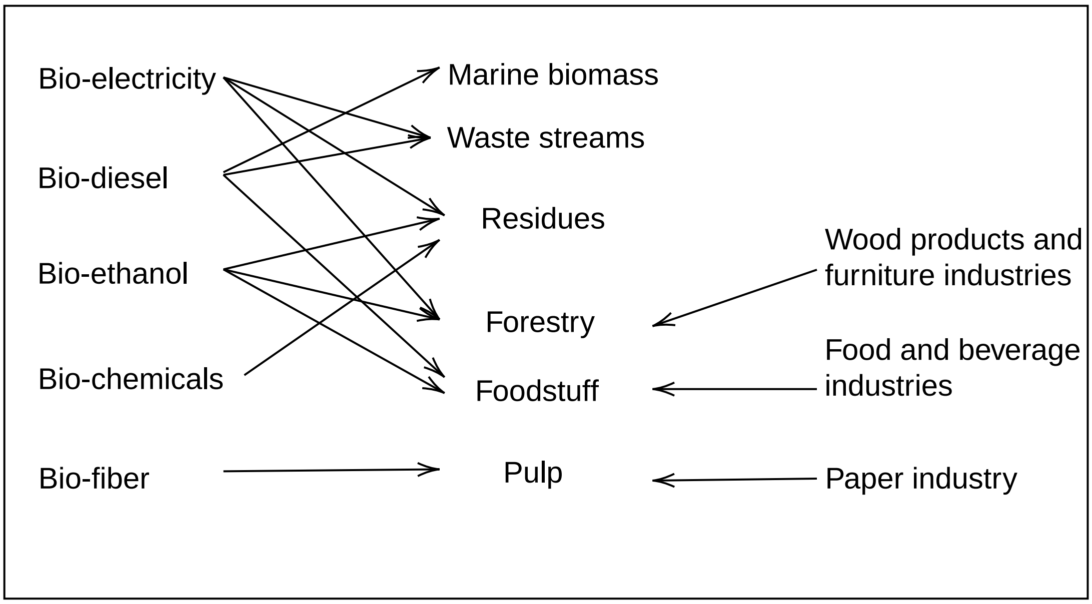
Table 2 continued from previous page

	CLIM	SUS	JOB	ECON	COMP	NAME
SWEEthanol5	0,045	0,200	0,036	0,804	0,555	Ethanolgiant reed
SWEEthanol6	0,002	0,000	0,036	0,561	0,555	Ethanolcereal mix
SWEEthanol7	0,001	0,000	0,036	0,561	0,555	Ethanolmaize
SWEEthanol8	0,039	0,000	0,036	0,561	0,555	Ethanolsugar beet
SWEChemi1	0,952	0,600	0,374	0,719	0,179	1.3 propanediol
SWEChemi2	0,911	0,600	0,374	0,719	0,179	lactic acid
SWEChemi3	0,004	0,600	0,374	0,719	0,179	acetic acid
SWEChemi4	0,350	0,600	0,374	0,719	0,179	succinic acid
SWEChemi5	0,004	0,600	0,374	0,719	0,179	adipic acid
SWEFiber1	0,975	0,400	0,111	0,008	0,493	Fibreviscose
SWEFiber2	0,946	0,400	0,111	0,008	0,493	Fibremodal
SWEFiber3	0,427	0,400	0,111	0,008	0,493	Fibretencel

3 Industries competing for feedstock

Figure 1 shows the feedstock that the different technologies rely on, and the industries with which they compete to obtain this feedstock.

Figure 1: Which industries compete for the same feedstock?



4 Analysis of necessity

Table 3 through 7 present additional parameters of fit - coverage and relevance of necessity - as a supplement to Table 2 in the article.

Table 3: Analysis of necessary conditions for the outcome CLIM

Conditions	Consistency	Coverage	Relevance
SUS	0.757	0.613	0.711
JOB	0.300	0.484	0.849
ECON	0.744	0.454	0.464
COMP	0.661	0.458	0.553
~SUS	0.490	0.417	0.643
~JOB	0.796	0.444	0.383
~ECON	0.415	0.535	0.820
~COMP	0.490	0.505	0.750

Table 4: Analysis of necessary conditions for the outcome SUS

Conditions	Consistency	Coverage	Relevance
CLIM	0.613	0.757	0.853
JOB	0.379	0.756	0.922
ECON	0.892	0.673	0.591
COMP	0.724	0.620	0.639
~CLIM	0.588	0.514	0.593
~JOB	0.795	0.548	0.433
~ECON	0.349	0.556	0.827
~COMP	0.513	0.654	0.811
JOB+ECON	**0.903**	0.673	0.582

Table 5: Analysis of necessary conditions for the outcome COMP

Conditions	Consistency	Coverage	Relevance
CLIM	0.458	0.661	0.806
SUS	0.620	0.724	0.775
JOB	0.394	0.917	0.972
ECON	0.855	0.753	0.657
~CLIM	0.646	0.660	0.676
~SUS	0.583	0.715	0.786
~JOB	0.690	0.555	0.437
~ECON	0.345	0.642	0.855
SUS+ECON	**0.908**	0.740	0.582

Table 6: Analysis of necessary conditions for the outcome ECON

Conditions	Consistency	Coverage	Relevance
CLIM	0.454	0.744	0.847
SUS	0.673	0.892	0.898
JOB	0.367	0.969	0.989
COMP	0.753	0.855	0.823
∼CLIM	0.643	0.745	0.735
∼SUS	0.509	0.708	0.782
∼JOB	0.735	0.671	0.512
∼COMP	0.423	0.714	0.839
COMP+SUS	**0.927**	0.851	0.702
∼CLIM+SUS	**0.908**	0.774	0.530

Table 7: Analysis of necessary conditions for the outcome JOB

Conditions	Consistency	Coverage	Relevance
CLIM	0.484	0.300	0.669
SUS	0.756	0.379	0.605
ECON	**0.969**	0.367	0.427
COMP	**0.917**	0.394	0.526
∼CLIM	0.671	0.294	0.501
∼SUS	0.590	0.311	0.604
∼ECON	0.299	0.239	0.735
∼COMP	0.277	0.177	0.644

5 Robustness checks

Robustness of QCA results can be assessed along different dimension. Hug (2013) stresses measurement error and data reliability. These issues are discussed briefly in Section 3 in the article. Skaaning (2011) emphasizes how changes in case selection and model specification may alter results. Apart from CLIM and SUS, the conditions in the model were initially operationalized along several dimensions. In the final model, however, all conditions are operationalized along a single dimension to align with set-theoretic logic and make substaintial interpretation simpler. This caused membership scores in JOB to be skewed towards zero, while membership scores in the other sets remained quite stable.

Schneider et al. (2019) argue that robustness tests in QCA must stay true to the fundamental nature and principles of set-theory, and not merely mimic robustness tests known to standard quantitative methods. Consequently, it is relevant to assess whether parameters of fit change considerably when altering calibration thresholds, raw consistency levels, and case selection, and whether different choices lead to solution terms that are no longer in a subset relation with one another. Since this paper only performs the analysis of necessity, there are no solution terms to be checked (as solution terms relate to the analysis of sufficiency). Parameters of fit are therefore the focus of robustness checks. More specifically, the sensitivity towards changes in calibration thresholds is tested, while no tests are performed for sensitivity towards changes in raw consistency levels or case selection. The reason is that 0.9 is a fairly undisputed consistency threshold in analyses of necessity as opposed to analyses of sufficiency, where lower thresholds are usually accepted, and where changes in thresholds potentially affects the minimization procedure and the ensuing solution terms.

The choice of upper calibration threshold for ECON had weak theoretical foundations. Therefore, the robustness check is to assess sensitivity when changing the upper threshold for ECON to 0.3 and 0.2, respectively. Lowering the calibration threshold to 0.2 (i.e. allowing more cases to reach full set-membership) changed the consistency score in the analysis of single necessary conditions. ECON now appears as a necessary condition for sustainable resource management (consistency 0.903). Coverage (0.643) and relevance (0.522) are non-trivial, which only strengthens ecological modernization theory's argument that sequence matters and that economic performance precedes sustainable resource management. Neither lowering or raising the upper calibration threshold changed the analysis of necessary disjunctions (i.e. SUIN conditions).

6 R-script for replication of the analysis

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# # Script for analysis and replication ----
# Paper: When Bioeconomy Policy Objectives (Fail To) Overlap. Working paper Compasss.org
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# R version 3.6.0 (2019-04-26) -- "Planting of a tree"

#Packages ====
library(SetMethods)      #version 2.4.1
library(QCA)             #version 3.4
library(devtools)        #version 2.0.1
library(cna)             #version 2.2.0
library(venn)            #version 1.7
library(xtable)          #version 1.8-3
library(dplyr)           #version 0.8.0.1



#Developer version of SetMethods package also used:
install_github("nenaoana/SetMethods")

#Setting working directory
setwd("C:/Users/au278415/Desktop/QCA_Bio")

#Clearing workspace
rm(list = ls())


########### Preparing the data ###################################


# (1) Calibration of conditions ====
#Importing raw uncalibrated data
BIO_RAW <- read.csv("BIO_RAW2019.csv",
                    row.names=1,
                    sep=";",
                    dec=",",
                    header=TRUE)

head(BIO_RAW)

#Note that condition SUS is calibrated qualitatively,
#and is therefore not included in the raw data.

#### (1.a) CLIM ----
#Case distribution of raw scores
hist(BIO_RAW$GWP_ratio,
     xlab="GWP_ratio",
     main=paste("Histogram of raw CLIM scores"))


#Thresholds
```

```
  #Lower: 1
  #Cross-over: 0.5
  #Upper: 0

#Calibration
CLIM_fz <- calibrate(BIO_RAW$GWP_ratio,
                     type="fuzzy",
                     thresholds=c("e=1, c=0.5, i=0"))

#Plotting raw against calibrated scores
plot(BIO_RAW$GWP_ratio,CLIM_fz)


#### (1.b) JOB ----

#Case distribution
hist(BIO_RAW$JOB_raw,
     xlab="JOB_raw",
     main=paste("Histogram of raw JOB scores"))

#Thresholds (negative end-point concept)
  #Lower: 0.074
  #Cross-over: 0.0
  #Upper: -0.074

#Calibration
JOB_fz <- calibrate(BIO_RAW$JOB_raw,
                    type="fuzzy",
                    method="direct",
                    thresholds=c("e=0.074,c=0.0,i=-0.074"))
JOB_fz

#Plotting raw scores against calibrated values
plot(BIO_RAW$JOB_raw,JOB_fz)


#### (1.c) ECON ----

#Case distribution
hist(BIO_RAW$ECON_raw,
     xlab="ECON_raw",
     main=paste("Histogram of raw ECON scores"))


#Calibration thresholds:
  #Lower=0
  #Cross-over= 0.082 (Nordic average)
  #Upper=0.246 (3*Nordic average)

  ECON_fz <- calibrate(BIO_RAW$ECON_raw,
                     type="fuzzy",
                     thresholds=c(0.0,0.082,0.246))

  #Plotting raw scores against calibrated scores
  plot(BIO_RAW$ECON_raw, ECON_fz)
```

```
#### (1.d) COMP ====
  #Case distribution of raw scores
  hist(BIO_RAW$COMP_raw,
       xlab="Revealed comparative advantage",
       main=paste("Histogram of raw COMP scores"))

  #Calibration thresholds
  #Lower=0
  #Cross-over=1
  #Upper= 2


#Calibration
COMP_fz <- calibrate(BIO_RAW$COMP_raw,
                     type="fuzzy",
                     thresholds=c(0,1,2))



#Plotting raw scores against fuzzy scores
plot(BIO_RAW$COMP_raw, COMP_fz)


#### Adding the calibrated conditions to the dataframe ====

BIO_RAW$CLIM <- CLIM_fz
BIO_RAW$JOB <- JOB_fz
BIO_RAW$ECON <- ECON_fz
BIO_RAW$COMP <- COMP_fz

head(BIO_RAW)


#### Exporting the calibrated data matrix ####
write.csv(BIO_RAW, file="BIO_fz")

###################################################################

#Importing the calibrated data matrix ----
BIO <- read.csv("BIO_fz_2019.csv",
                sep=";", row.names=1,dec=",")

  # (2) Checking the data ====
  head(BIO)
  summary(BIO)
  names(BIO)
  rownames(BIO)

  # (2.a) Analyzing skewedness ====
  skew.check(BIO[,c(1,2,3,4,5)])

  # Check which cases, if any, have == 0.5
  which(BIO == 0.5, arr.ind = TRUE)
```

```
  # (2.b) Case names ----
    #CLIM
    skewedCLIM <- as.numeric(BIO$CLIM>0.5)
    rownames(subset(BIO,skewedCLIM>0.5))
    #41 cases

    #SUS
    skewedSUS <- as.numeric(BIO$SUS>0.5)
    rownames(subset(BIO,skewedSUS>0.5))
    #49 cases

    #JOB
    skewedJOB <- as.numeric(BIO$JOB>0.5)
    rownames(subset(BIO,skewedJOB>0.5))
    #16 cases - only Swedish and Finnish cases, no Danish

    #ECON
    skewedECON <- as.numeric(BIO$ECON>0.5)
    rownames(subset(BIO,skewedECON>0.5))
    #65 cases

    #COMP
    skewedCOMP <- as.numeric(BIO$COMP>0.5)
    rownames(subset(BIO,skewedCOMP>0.5))
    #49 cases

  # (2.c) Histograms of the calibrated conditions ====
  hist(BIO$CLIM,
       xlab="CLIM",
       main=paste("Histogram of CLIM scores"))

  hist(BIO$SUS,
       xlab="SUS",
       main=paste("Histogram of SUS scores"))

  hist(BIO$JOB,
       xlab="JOB",
       main=paste("Histogram of JOB scores"))

  hist(BIO$ECON,
       xlab="ECON",
       main=paste("Histogram of the ECON scores"))

  hist(BIO$COMP,
       xlab="ECON",
       main=paste("Histogram of COMP scores"))



############ Analysis of set-relations ######################

#### (3) Venn diagram mapping the case distribution ====
NORDIC_v <- read.csv("Nordic_venn.csv",sep=";", dec=",",row.names=1)
Venn_NORD2 <- venn(NORDIC_v,
                   snames="CLIM,SUS,JOB,ECON,COMP",
                   zcolor=c("white","gray70", "gray50", "gray20","black"),
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                   ilabels=FALSE,
                   opacity=0.3,
                   size=15,
                   cexil=1,
                   cexsn=1,
                   borders=TRUE)

#Saving the plot
ggsave("Venn_NORD2.pdf", device = "pdf")


#### (4) Analysis of necessity - single conditions ----
  # (4.a) Single conditions necessary for COMP? ====
  nec_COMP <- QCAfit(BIO[,c(1,2,3,4)],
                     BIO$COMP,
                     necessity=TRUE)

  nec_COMP #No single conditions pass the 0.9 consistency threshold
  #ECON comes close (0.855), but RoN is quite low (0.657)

  #Plotting potential necessary condition ECON for outcome COMP
  xy.plot("ECON","COMP",BIO,
          main="Necessity plot of ECON and COMP",
          xlab="Economically viable business models",
          ylab="Competitive biobased industries",
          necessity=TRUE,
          jitter=TRUE,
          font="sans",
          fontsize = 3,
          fontface="plain")
  # Quite a few logically contradictory cases
  #And ECON was skewed towards 1.

  #Conclusion: no condition is considered necessary for the outcome COMP

  # (4.a) Single conditions necessary for JOB? ====
  nec_JOB <- QCAfit(BIO[,c(1,2,4,5)],
                    BIO$JOB,
                    necessity=TRUE)

  nec_JOB
  #JOB set quite skewed - necessary conditions trivial

  # (4.c) Single conditions necessary conditions for CLIM? ====
  nec_CLIM <- QCAfit(BIO[,c(2,3,4,5)],
                     BIO$CLIM,
                     necessity=TRUE)

  nec_CLIM

  #No necessary conditions

  # (4.d) Single conditions necessary conditions for SUS? ====

  nec_SUS <- QCAfit(BIO[,c(1,3,4,5)],
                    BIO$SUS,
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```
                  necessity=TRUE)

  nec_SUS

  #Plotting potential necessary condition ECON for outcome SUS
  xy.plot("ECON","COMP",BIO,
          main="Necessity plot of ECON and SUS",
          xlab="Economically viable business models",
          ylab="Sustainable resource management",
          necessity=TRUE,
          jitter=TRUE,
          font="sans",
          fontsize = 3,
          fontface="plain")

  #many logically contradictory cases

  # (4.e) Single conditions necessary conditions for ECON? ====

  nec_ECON <- QCAfit(BIO[,c(1,2,3,5)],
                     BIO$ECON,
                     necessity=TRUE)

  nec_ECON



#### Analysis of necessity - SUIN conditions ----

  # (4.f) SUIN conditions for COMP? ====
  SUIN_COMP <- superSubset(BIO, outcome="COMP",
                           neg.out=FALSE,
                           conditions=c("CLIM", "SUS", "JOB", "ECON"),
                           relation="nec",
                           incl.cut=0.9,
                           ron.cut = 0.5,
                           use.tilde = TRUE,
                           depth=2)


  SUIN_COMP
  #SUS+ECON passes the 0.9 threshold,
  #but RoN is  low.

  #Plotting potential SUIN conditions for the outcome COMP
  SUIN1 <- pmax(BIO$SUS,BIO$ECON)
  BIO$SUIN1 <- SUIN1

  xy.plot("SUIN1","COMP",BIO,
          main="Potential SUIN conditions",
          xlab="SUS+ECON",
          ylab="Competitive biobased industries",
          necessity=TRUE,
          jitter=TRUE,
          font="sans",
          fontsize = 2.5,
```

```
        fontface="plain")

#SUS+ECON does not constitute a higher order construct

#Conclusion: no SUIN conditions for the outcome COMP

# (4.g) SUIN conditions for CLIM? ====
SUIN_CLIM <- superSubset(BIO, outcome="CLIM",
                         neg.out=FALSE,
                         conditions=c("COMP", "SUS", "JOB", "ECON"),
                         relation="nec",
                         incl.cut=0.9,
                         ron.cut = 0.5,
                         use.tilde = TRUE,
                         depth=2)


SUIN_CLIM

# (4.h) SUIN conditions for SUS? ====
SUIN_SUS <- superSubset(BIO, outcome="SUS",
                        neg.out=FALSE,
                        conditions=c("COMP", "CLIM", "JOB", "ECON"),
                        relation="nec",
                        incl.cut=0.9,
                        ron.cut = 0.5,
                        use.tilde = TRUE,
                        depth=2)


SUIN_SUS

# Plotting potential SUIN conditions for the outcome SUS
SUIN2 <- pmax(BIO$JOB,BIO$ECON)
BIO$SUIN2 <- SUIN2

xy.plot("SUIN2","SUS",BIO,
        main="Potential SUIN conditions",
        xlab="JOB+ECON",
        ylab="Sustainable resource mangement",
        necessity=TRUE,
        jitter=TRUE,
        font="sans",
        fontsize = 2.5,
        fontface="plain")


# (4.i) SUIN conditions for JOB? ====
SUIN_JOB <- superSubset(BIO, outcome="JOB",
                        neg.out=FALSE,
                        conditions=c("COMP", "CLIM", "SUS", "ECON"),
                        relation="nec",
                        incl.cut=0.9,
                        ron.cut = 0.5,
                        use.tilde = TRUE,
                        depth=2)
```

```


  SUIN_JOB

  # (4.j) SUIN conditions for ECON? ====
  SUIN_ECON <- superSubset(BIO, outcome="ECON",
                           neg.out=FALSE,
                           conditions=c("COMP", "CLIM", "SUS", "JOB"),
                           relation="nec",
                           incl.cut=0.9,
                           ron.cut = 0.5,
                           use.tilde = TRUE,
                           depth=2)


  SUIN_ECON


  # Plotting potential SUIN conditions for the outcome ECON
  SUIN3 <- pmax(BIO$COMP,BIO$SUS)
  BIO$SUIN3 <- SUIN3

  xy.plot("SUIN3","ECON",BIO,
          main="Potential SUIN conditions",
          xlab="COMP+SUS",
          ylab="Economically viable business models",
          necessity=TRUE,
          jitter=TRUE,
          font="sans",
          fontsize = 2.5,
          fontface="plain")

  # Plotting potential SUIN conditions for the outcome ECON
  SUIN4 <- pmax(1-BIO$CLIM,BIO$SUS)
  BIO$SUIN4 <- SUIN4

  xy.plot("SUIN4","ECON",BIO,
          main="Potential SUIN conditions",
          xlab="~CLIM+SUS",
          ylab="Economically viable business models",
          necessity=TRUE,
          jitter=TRUE,
          font="sans",
          fontsize = 2.5,
          fontface="plain")

  #Analysis of necessity for negated outcomes performed but not shown in this appendix.

#### Conclusion on the analysis of necessity ####
  #No single conditions are non-trivilially necessary for other conditions
  #Four disjunctions cross the consistency threshold as necessary conditions,
  #but only two of them are relevant for substantial theoretical interpretation
  #XY-plots guide the theoretical interpretation of SUIN conditions.
  #SUIN conditions must be functional equivalents of a theoretically meaningful higher-order construct,
  #to be accepted as necessary conditions.
```

```
  #Global green consumer demand as a higher-order construct necessary for ECON
  pimplot(data=BIO,
          results=SUIN_ECON,
          outcome="ECON",
          necessity=TRUE,
          all_labels=FALSE,
          jitter=TRUE)

  #Economic growth as a higher-order construct necessary for SUS
  pimplot(data=BIO,
          results=SUIN_SUS,
          outcome="SUS",
          necessity=TRUE,
          all_labels=TRUE,
          jitter=TRUE)

#### (5) Robustness check ----
# (5.a) Recalibrating ECON - does it alter the results considerably? ====
  #The robustness check includes no repetition of the Venn diagram,
  #since since this diagram is only sensitive to alterations in the cross-over calibration threshold.
  #The robustness checks is relevant for the search for necessary single and SUIN conditions.

  #Original upper threshold: 0.246
  #Alternative upper tresholds: 0.2 and 0.3

  #Recalibration
  ECON_fz_rob1 <- calibrate(BIO_RAW$ECON_raw,
                            type="fuzzy",
                            thresholds=c(0,0.082,0.2))
  ECON_fz_rob2 <- calibrate(BIO_RAW$ECON_raw,
                            type="fuzzy",
                            thresholds=c(0,0.082,0.3))

  #Plotting raw scores against calibrated scores
  plot(BIO_RAW$ECON_raw, ECON_fz_rob1)
  plot(BIO_RAW$ECON_raw, ECON_fz_rob2)


  #Adding re-calibrated conditions to the dataframe for robustness check
  BIO$ECON_fz_rob1 <- ECON_fz_rob1 #column 10
  BIO$ECON_fz_rob2 <- ECON_fz_rob2 #column 11


# (5.b)Repeating the analysis of necessity using the alternative calibration thresholds ####
  # (5.c) Single conditions necessary for COMP? ####
  nec_COMP_rob1 <- QCAfit(BIO[,c(1,2,3,10)],
                     BIO$COMP,
                     necessity=TRUE)

  nec_COMP_rob1 #No necessary conditions

  nec_COMP_rob2 <- QCAfit(BIO[,c(1,2,3,11)],
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```
                          BIO$COMP,
                          necessity=TRUE)

nec_COMP_rob2 #No necessary conditions



# (5.d) Single conditions necessary for JOB? ####
nec_JOB_rob1 <- QCAfit(BIO[,c(1,2,10,5)],
                  BIO$JOB,
                  necessity=TRUE)

nec_JOB_rob1 # ECON_fz_rob1 consistent, but trivial

nec_JOB_rob2 <- QCAfit(BIO[,c(1,2,11,5)],
                       BIO$JOB,
                       necessity=TRUE)

nec_JOB_rob2 # ECON_fz_rob2 consistent, but trivial

# (5.e) Single conditions necessary conditions for CLIM? ####
nec_CLIM_rob1 <- QCAfit(BIO[,c(2,3,10,5)],
                   BIO$CLIM,
                   necessity=TRUE)

nec_CLIM_rob1 #No necessary conditions

nec_CLIM_rob2 <- QCAfit(BIO[,c(2,3,11,5)],
                        BIO$CLIM,
                        necessity=TRUE)

nec_CLIM_rob2 #No necessary conditions


# (5.f) Single conditions necessary conditions for SUS? ####

nec_SUS_rob1 <- QCAfit(BIO[,c(1,3,10,5)],
                  BIO$SUS,
                  necessity=TRUE)

nec_SUS_rob1 #ECON_fz_rob1 necessary for SUS

#Plotting potentially necessary condition
xy.plot("ECON_fz_rob1","SUS",BIO,
        main="Robustness check: necessity plot of ECON and SUS",
        xlab="Economically viable business models, upper threshold: 0.2",
        ylab="Sustainable resource management",
        necessity=TRUE,
        jitter=TRUE,
        font="sans",
        fontsize = 3,
        fontface="plain")

#No logically contradictory cases
#A few individually irrelevant and deviant cases

```

```
nec_SUS_rob2 <- QCAfit(BIO[,c(1,3,11,5)],
                       BIO$SUS,
                       necessity=TRUE)

nec_SUS_rob2 #No necessary conditions

# (5.g) SUIN conditions for COMP? ====
SUIN_COMP_rob1 <- superSubset(BIO, outcome="COMP",
                         neg.out=FALSE,
                         conditions=c("CLIM", "SUS", "JOB", "ECON_fz_rob1"),
                         relation="nec",
                         incl.cut=0.9,
                         ron.cut = 0.5,
                         use.tilde = TRUE,
                         depth=2)


SUIN_COMP_rob1
#SUS+ECON_fz_rob1 passes the 0.9 threshold,
#but RoN is  low, and SUS+ECON does not constitute a higher-order construct.

SUIN_COMP_rob2 <- superSubset(BIO, outcome="COMP",
                              neg.out=FALSE,
                              conditions=c("CLIM", "SUS", "JOB", "ECON_fz_rob2"),
                              relation="nec",
                              incl.cut=0.9,
                              ron.cut = 0.5,
                              use.tilde = TRUE,
                              depth=2)


SUIN_COMP_rob2
#SUS+ECON_fz_rob2 passes the 0.9 threshold,
#but RoN is  low and SUS+ECON does not constitute a higher-order construct.

# (5.h) SUIN conditions for CLIM? ====
SUIN_CLIM_rob1 <- superSubset(BIO, outcome="CLIM",
                         neg.out=FALSE,
                         conditions=c("COMP", "SUS", "JOB", "ECON_fz_rob1"),
                         relation="nec",
                         incl.cut=0.9,
                         ron.cut = 0.5,
                         use.tilde = TRUE,
                         depth=2)


SUIN_CLIM_rob1 #no combinations with ron,cut=0.5

SUIN_CLIM_rob2 <- superSubset(BIO, outcome="CLIM",
                              neg.out=FALSE,
                              conditions=c("COMP", "SUS", "JOB", "ECON_fz_rob2"),
                              relation="nec",
                              incl.cut=0.9,
                              ron.cut = 0.5,
                              use.tilde = TRUE,
                              depth=2)
```

```r


SUIN_CLIM_rob2 #no combinations with ron,cut=0.5

# (5.j) SUIN conditions for SUS? ====
SUIN_SUS_rob1 <- superSubset(BIO, outcome="SUS",
                        neg.out=FALSE,
                        conditions=c("COMP", "CLIM", "JOB", "ECON_fz_rob1"),
                        relation="nec",
                        incl.cut=0.9,
                        ron.cut = 0.5,
                        use.tilde = TRUE,
                        depth=2)


SUIN_SUS_rob1

SUIN_SUS_rob2 <- superSubset(BIO, outcome="SUS",
                             neg.out=FALSE,
                             conditions=c("COMP", "CLIM", "JOB", "ECON_fz_rob2"),
                             relation="nec",
                             incl.cut=0.9,
                             ron.cut = 0.5,
                             use.tilde = TRUE,
                             depth=2)


SUIN_SUS_rob2 #no combinations with ron,cut=0.5


# (5.j) SUIN conditions for JOB? ====
SUIN_JOB_rob1 <- superSubset(BIO, outcome="JOB",
                        neg.out=FALSE,
                        conditions=c("COMP", "CLIM", "SUS", "ECON_fz_rob1"),
                        relation="nec",
                        incl.cut=0.9,
                        ron.cut = 0.5,
                        use.tilde = TRUE,
                        depth=2)


SUIN_JOB_rob1

SUIN_JOB_rob2 <- superSubset(BIO, outcome="JOB",
                             neg.out=FALSE,
                             conditions=c("COMP", "CLIM", "SUS", "ECON_fz_rob2"),
                             relation="nec",
                             incl.cut=0.9,
                             ron.cut = 0.5,
                             use.tilde = TRUE,
                             depth=2)


SUIN_JOB_rob2
```

Script_appendix.R

References

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