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Rethinking Islands and their Models in Sustainable Energy Planning: How Inclusive Local Perspectives Improve Energy Planning Globally

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ABSTRACT

This work contemplates and defines the role of modelling renewable energy, especially on islands, in the transition to sustainable and highly renewable energy systems. It addresses the Paris Agreement by potentially including 80,000 islands with their locally limited and globally relevant role in energy planning. To achieve global targets, also islands need to contribute, yet with limited possibilities and support but with increasing attention. With a particular focus on three case studies, this work highlights general perspectives of islands, their limitations but also their potentials, and the understanding we can gain from them to address energy planning is a smart way. Therefore, the concepts of smart energy systems and islands are elaborated and combined, as well as put into new theoretical context of transition and multi-level governance. This is achieved by looking into the energy system analysis and modelling done on the case studies. This critically reflects on the renewable energy demonstrations and modelling *of* and *on* islands; and when including perspectives *from* and working *with* the islands, it benefits both islanders and planners in the energy transition. The collaboration with and creation of model islands supports future research and the fight against climate change in a sustainable way.

Keywords

Smart energy systems;
Modelling islands;
Energy system analyses;
Sustainable energy planning;

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1. Introduction

With the Paris Agreement from 2015 promoting the transition to cleaner energy, lower emissions and higher efficiencies, all backing countries are required to contribute in light of their circumstances to smarter energy production and consumption [1]. Thereby to support the agreement, islands, who are at the edges of both maps and energy networks either as sub-national jurisdiction or independent island state, are to apply the same global trends. While being at the forefront of climate change due to predicted sea level rise [2], however, the global and national climate actions might not always be realisable at the island level.

At the same time, the required shift for the energy transition is possible, especially for smaller economies, due to their rapid and dynamic ways of adapting their more compact territories [3]. While mainly discussed in the context of small nations, the same possibilities might exist with islands. With energy historically often supplied centrally, and future supply more decentralised, the explanation might be with local energy supply and system optimisation. Furthermore, this enables local sector integration and coordination of the energy transition [4–6].

European and national policies define renewable energy and cross-border interconnection shares for countries as a whole [7] without the much-needed consideration of limitations found in their local municipalities or islands [8]. Likewise, research has been done in cities and on regional or national level, reflecting on how they can follow and contribute to national and

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global guidelines [9,10]. This context implies that not one region should be viewed as being above another region but also that resources must be shared horizontally. In general, it has been argued that the different levels should aim at sustaining themselves while playing a part in larger plans, such as cities in a national perspective [10] or urban and rural regions collaborating [11].

The same applies to islands, but to some extent, they might be limited in this regard due to the natural isolation caused by water, which in contrast could offer a resource not only to the island communities. To address the integration of islands in a smarter way, strategic energy planning raises the issue of energy planning viewpoints and contextual inclusion by suggesting a re-evaluation of coordination needs [8,12]. Institutional and regulatory framework conditions and central support are lacking, while expectations for local action persist.

Besides decentralising the framework conditions, there is a global trend towards the inclusion of more decentralised technical solutions like wind turbines, solar collectors, hydro or biomass energy as resources. Examining this further, we must address not only the electricity sector but also heating, cooling, transport and industry. In light of the transition away from central, large-scale power production using on-demand fossil fuels towards decentralised, renewable technologies, the intermittency of the energy production from the latter is a recurring issue [13]. A resulting future energy system that strives to achieve high renewable energy shares is referred to under the concept of 'smart energy systems' [14].

The investigation of aligning islands with smart energy trends and planning practices can be approached through models and modelling. While islands themselves can be considered models of larger (energy) systems, most things can be illustrated in a theoretical way through modelling in island mode. Examples where islands are used as case studies for energy planning include the use of La Gomera island for weather analysis [15], Tomia Island for the evaluation of PV [16], or Sulawesi Island for hydropower planning [17]. The size of islands and their natural limitations provide an opportunity for testing these practices through observation and evaluation to examine both the alignment of islands with trends and their relevance for other regions. In particular, new technological additions to an energy system, such as renewable energy technologies and their impacts, could be studied through island models, as they provide a natural modelling setting. Yet, similar to the use of islands and models, energy plans are suggested to be re-evaluated to contribute to energy planning approaches through better understanding and sensemaking [18].

Smart energy systems can be modelled both in island mode and in interconnection with surrounding energy systems. The former modelling mode restricts energy trade to other areas and focuses on self-sufficiency and local system balancing. Even though island mode causes a restriction in terms of electricity transmission, it is also described as informative regarding supply assessment, where balancing of supply and demand must be solved within system boundaries [19]. In order to further question the use of models, there is the potential that they may be misunderstood, undervalued or deemed irrelevant for various reasons, which limits the use of models and advises caution, for example when presenting them to municipal stakeholders [20].

Despite the potential role of islands for smart energy systems and their understanding and development, islands face a certain neglect at the political level, not the least in Denmark, a country with 52% of the population living on large - and another 8% on small - islands [21]. When further looking into the example of Denmark, where the latest Danish climate agreement on energy for 2021-2030 elaborates on the opportunities of artificial 'energy islands' [22], it does little to include actual islands in the national agreement – not as models, nor for testing or acknowledging potential differences [23].

The current research gap identified in literature and politics is supported by an advanced search of key terms in scientific publications on ScienceDirect. It reveals that 13% of the search results for the phrase 'Danish energy system' include 'island', while the same share is only 6% in the non-Danish context, despite a global island population of 10% [2]. For 'Energy planning', the results are 21% compared to 11%, which show a significance of islands in research, though a small discrepancy can still be made out here besides the lack of island inclusion on a political level.

When looking further into the existing 'Danish island energy system' literature, a trend can be noticed towards the use of 'cases', 'models', or 'tests' (97% of search results), as well as 'technology' (70%); this trend supports the claim that islands are often used for testing and modelling technologies. Yet, we see less literature on the use of 'strategy', 'implementation', 'market', or 'policy' (avg. 43%). This indicates a lack in further use of potentials from island energy research and a misaligned role of islands in energy planning. [24]

A potential light on the Danish horizon in this regard is the appointment of Samsø as the Danish renewable energy island in 1997, when the Minister for Energy and Environment stated, 'Through Samsø, we can create a striking international demonstration project and exhibition window for Danish energy technology' [25]. How Samsø became a pioneer community on energy projects despite its total population below 4,000 inhabitants has been elaborated in [26]. Samsø has also been mentioned in recent publications in regards to reaching energy autonomy [27] and the importance of local characteristics prior to energy system analyses [28], but the trend of evaluating energy in a smart way applies to islands in general. This could enable a better energy democracy and help develop and understand energy systems better.

Finally, recent developments in renewable energy, efficiency, and infrastructure, as well as faster and overall smarter responses to the Paris Agreement indicate the need and possibility for global smart energy, in which islands are not to be left out and to which islands could contribute well [29].

1.1. Research Objective

In order to achieve the targets of the Paris Agreement through smart energy systems on a global scale and to continue developing our understanding of these systems, islands should not be excluded in energy planning, despite usually being located at the edges of the map. However, for islands to follow and apply similar energy developments as their continental counterparts requires a more detailed understanding of ongoing developments, possible challenges, and future opportunities of islands and their models as part of a holistic energy policy approach.

A recent review identifying approaches in energy system modelling points towards advances but also increased complexity in the field, highlighting challenges in representation and understanding of models [30]. Another review on bottom-up energy system models supports this trend by pointing out the discrepancy of insular applications applied on country level and vice versa [31]. This indicates insufficient understanding of advanced island modelling and suggests a rethinking of island models in sustainable energy planning.

This paper addresses an investigation of islands that on the one hand follows, aligns with and learns from the global trends and national targets in energy planning. On the other hand, it looks in the opposite direction of islands as laboratories to contribute to energy planning. These two perspectives are evaluated along the line of publications by the author over the past three years [32–36], as well as recent developments and trends globally, as well as locally. This addresses the presented research and policy gap, not only in Denmark, but globally, by emphasising the potential role of islands on the global scale by moving away from seeing a world *with* islands to a world *of* islands as part of sustainable energy transitions. This underlines the idea that islands 'must have an important role to play in our society' [37].

To solve the puzzle of transitioning to smart energy on both nation and global level, the resulting research objective addresses the following question: *What role can islands and modelling of renewable energy on islands play in sustainable energy planning?* In order to answer this, it is important to analyse how modelling renewable energy islands are understood, approached and potentially improved through perspectives on, from and with islands.

Section 2 addresses the research question by presenting the theoretical and analytical framework, including three case studies and related publications that are evaluated in particular and set into a novel theoretical context. The resulting perspectives for islands discuss and answer the research question in Section 3, which presents the results of evaluating the role of modelling renewable energy islands. Section 4 adds a discussion on current and future smart energy trends involving islands; and Section 5 offers a final conclusion on the role of island in smart energy and energy transitions.

2. Methodology

The role of islands is evaluated in both a theoretical and analytical way, combined to answer the research objective in Section 3. The first section presents the potential role of islands and island modelling in a theoretical approach and the latter presents the analyses conducted and their analytical meaning to reflect on it.

2.1. Theoretical framework

The combination of smart energy trends with models and planning is in the following referred to as smart energy planning. To introduce islands into this concept of innovation leads to the consideration of islands to represent a certain niche in energy planning research with a potential impact on a larger scale. A way to illustrate this is shown in the multi-level transition theory, as adapted in Figure 1 [38], highlighting how island

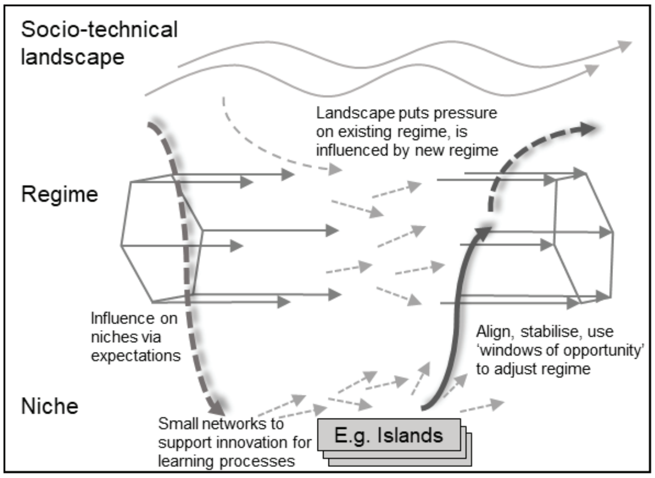

Figure 1: Adaptation to multi-level transition theory and islands as a part of niche innovations, based on [38]

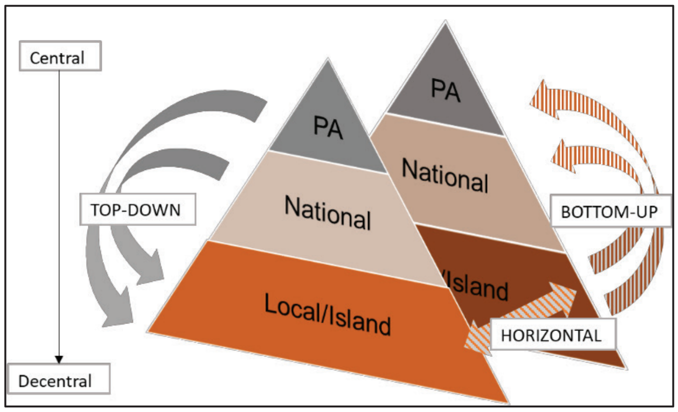

Figure 2: Vertical (top-down or bottom-up) and horizontal coordination in multi-level governance between Paris Agreement (PA) and island level, based on [41]

perspectives can be important pieces of the energy transition, not only in Denmark but also globally. The underlying processes referred to in this theory that are happening across the globe have a common denominator in societal changes, such as climate change requiring action in energy planning, leading to socio-technical transitions [38].

With islands having potential for experimenting and modelling, niche innovations can be explored in transparent and controlled island settings. The transition to renewables and the potential role of islands therefore present a potential window of opportunity for novelties [38,39]. Despite their individuality, islands are likely to succeed in the push for socio-technical transition, as they are 'seriously engaging society based on place specific issues' [40]. The resulting perspectives when seeing and modelling islands as niches are, firstly, from an outside view as 'modelling of islands', secondly, when looking close-up at the niches as 'modelling on islands', and thirdly, the insights into modelling through and 'from islands', as illustrated by the arrows in Figure 1.

The already established need to re-evaluate the coordination between different institutional levels to enable local experimentation and strategic energy planning might yet require additional consideration in regards to islands [8,12]. Where transition theory frames the different levels of influence in innovation, multi-level governance allows for a qualitative analysis of governance. In the comparison of the different aspects of multi-level governance and influence, Figure 2 emerges. Through transition theory, islands can be considered local niches with currently little power or influence, following national and international top-down advice, such as resulting from the Paris Agreement. However, horizontal alignments and bottom-up action is limited despite their increased significance for strategic energy planning [12]. This happens in parallel across the globe or within the EU, with the same guidelines at the top-level influencing development on lower levels vertically and in various, often insufficiently coordinated ways.

Whether focusing on energy systems or islands, transitions or governance, modelling combines the trends and concerns above presented by contributing to niche innovation or governance decision-making in both quantitative and qualitative ways. The term 'model' refers to both something ideal to look up to and something used for experimentation and replication elsewhere. While the latter might initially be intended in energy research, the former appears with increasing frequency throughout the research on this topic. Besides the potential of innovation in transition theory, the need for experimentation has also been mentioned in the literature, where local experiments are suggested and enabled through modelling, leading to the development of new understandings [42].

2.2. Analytical framework

The discussion of modelling islands requires models to work with; hence, the use of case studies is discussed for that purpose. The case studies where renewable energy has been analysed within smart island energy systems are part of the Horizon 2020 SMart IsLand Energy system (SMILE) [43] project. The SMILE project involves a number of partners in investigating three cases, namely Samsø in Denmark, Orkney in the United Kingdom and Madeira in Portugal, and their ways of transitioning to renewable energy through smart technology demonstrations. Publications made during the project result in the research on modelling of renewable energy on islands, as it is based on related publications on Samsø [32,33], Samsø and Orkney [34], on all three cases [35], and especially for Madeira [36]; yet also questioning their role in global energy planning and transitions.

In this research, case studies support modelling under specific conditions by providing living laboratories. While neither an evaluation of the 80,000 globally inhabited islands, nor the 2,700 European or 72 Danish ones is done nor required, the evaluation on the specific case studies permit an evaluation to some extent nonetheless in the following, as similarities can be pointed out.

Creating models in island mode or testing technology in an island setting allows for a certain predictability and establishes boundaries for the model, which increases transparency and the potential for learning. There are two modelling types to discuss in the context of energy transition: optimisation and simulation. They are differentiated by their endogenous versus exogenous characteristics, as well as their computed versus user-chosen inputs to the model, respectively. Unlike optimisation, where the solution is predefined, simulation models the various consequences of different additions to the system, resulting in user-specified – thereby controlled – scenario making. Examples of optimisation models include Homer or Balmorel, while simulation models include energyPRO and EnergyPLAN. [44]

Hence, simulations can be understood as descriptive rather than prescriptive. Decisions must be made consciously and potentially in dialogue with stakeholders, which makes the modelling process with simulation models more complicated, yet also more inclusive and contextual. The relevance of simulation is further established by addressing the innovative aspect of islands as niches, which thereby supports the analysis of the role of islands.

EnergyPLAN is a suitable modelling tool for smart energy systems and the corresponding technological evaluations. The modelling tool is developed by Aalborg University [45]. Besides incorporating sustainable energy resources and the technical simulation strategy to address the efficient use of renewable energy, socio-economic costs including investments and operation costs are also analysed with EnergyPLAN. Furthermore, environmental considerations can be reflected in its inclusion of CO_2 emissions, of which a reduction directly addresses the Paris Agreement. Finally, in addition to including social perspectives in the simulations, EnergyPLAN enables individual units to be tested, including at household levels, completing the analytical framework for sustainable energy planning. [46,47]

Both the concept of smart energy systems, as well as specific research on islands has been studied with EnergyPLAN for the islands of Samsø, Orkney and Madeira, which is put into the theoretical framework presented in Section 2.1. Furthermore, these analyses are re-evaluated on the base of the different perspectives through Figures 1 and 2, leading up to the result in the following section. Hence, besides the case studies being analysed in the publications [32–36] in regards to energy and environmental indicators, like CO_2, renewable energy the self-sufficiency shares, the development of the island models in regards to sustainable energy planning is qualitatively assessed. This is evaluated from low to high by the number of sectors integrated and the inclusiveness of island perspectives, as well as the overall complexity within the topics of the publications and their perception in comparison with each other.

This goes in line with the suggestion that modelling of technical scenarios is not the final step in energy planning and that additional steps can be considered, for example, the use of the results and the related development of possible implementation strategies across different institutions. The purpose of modelling is to also highlight certain aspects of reality and 'to assist in the design, planning and implementation of future energy systems' [44]. This can be applied through energy market and policy design, which is addressed in the discussion of modelling islands in technical and institutional terms.

Islands may present suitable places for experimenting and learning. However, theories suggest a strategic alignment of innovation and governance across all areas and levels. This paper highlights the potentials and limits of modelling renewable energy for islands through energy system analysis and the case studies, as evaluated in the publications [32–36], as well as beyond. Furthermore, the following combination with transition theory and governance adds new perspectives to the areas of investigation and contributes to the understanding of sustainable energy planning by rethinking the role of islands and their models within.

3. Resulting inclusion of islands in energy planning

Combined with the analyses in and of the publications [32–36], the theoretical framework indicates different perspectives when modelling renewable energy islands to further develop smart energy planning. The first one is illustrated through transition theory by landscape and regime influence on niches and top-down governance, resulting in 'modelling *of* islands'. The second perspective can be found when addressing the innovation within the niches and horizontal governance, allowing 'modelling *on* islands'. And the third perspective presents the influence of islands to other levels in transition theory through bottom-up action, which elaborates 'modelling *from* islands', as further discussed and illustrated in the following paragraphs and figures.

'Modelling of islands' illustrates how islands are suitable for evaluating renewable energy technologies for various reasons and as done with EnergyPLAN in [32–36], yet there are also limitations. The setting of islands simplifies the often complex energy system research through their natural borders, small scales and transparency. Modelling renewable energy for islands not only addresses the need for decentralisation and local energy transition by evaluating technologies on islands as seen from an outside view, but it also provides information for other areas, on both national and global scale, hence, islands can be seen as laboratories. Modelling renewable energy is addressed through the model of Samsø in relation to evaluating PV and batteries [32], for heat pumps and storage [33], as well as for thermal and electrical storages in comparison [34].

However, replicability is critical, and the context of an island test setting usually shapes and defines the modelling and results; thus, island models are very location-specific and this requires special attention. The perspective of the modelling *of* islands explains this situation, as guidance and initiatives normally follow top-down processes aiming to experiment with and implement renewable energy technology locally, yet from a central viewpoint. The innovation potential is thereby limited, as illustrated by the multi-level perspective in transition theory, where landscapes overshadow niche innovation, and as shown through weaknesses in central governance without the often-claimed local coordination. While experimenting, testing and evaluating renewable technologies on islands still provide quantitative feedback, the suitability of the respective technologies for islands, and vice versa, must be considered; hence, more qualitative discussions are sought.

'Modelling on islands' improves the modelling potential through its acknowledgement and additional inclusion of island conditions. Hereby, replicability, which was previously limited by location-specific island models, can be addressed by comparing several case studies. Furthermore, the quality of modelling improves by considering local conditions on islands, including two [34] and three [35] islands, as well as an increased level of details and scenarios. This introduces an additional understanding of how decentralisation can become more effective and how cross-border coordination in energy planning can be not only technical but also procedural and collaborative.

The second perspective on modelling islands thereby illustrates how local conditions help understand and utilise what the island models are theoretically intended for, namely to test and show how decentralisation can be achieved and replicated. By modelling *on* islands, niche innovations become more explorative and competitive, while horizontal alignment strengthens vertical governance. Additionally, local coordination helps islanders and others at the bottom level in terms of energy governance. The learnings from collaboration and coordination on islands support smart energy planning with qualitative inputs. Also, the knowledge of the individuality and similarities between energy systems indicates that solutions to energy transitions are neither simple nor singular but depend on the context.

'Modelling from islands' includes insights from the modelling *of* islands, as well as perspectives *on* islands, and thereby presents how to make modelling work *from* and through island perspectives, adding the third angle to the islands' role in smart energy planning. The strategic context consideration is proven to be most helpful, whereby not only technical and local aspects but also institutional alignment with energy markets and policy gain importance for local energy system planning [36]. The complexity should be balanced with the simplicity of modelling. Yet new qualitative knowledge can be best achieved by including most aspects, bringing the models to the highest level of quality and usability. While replication also becomes more complex, understanding certain aspects of individuality and transcendent solutions suitable for many islands offers a new way to use the learnings. In particular, self-sufficiency is a potential that should be explored not only in the context of islands but also to help other energy systems understand the value of local energy system optimisation.

The resulting bottom-up influence from niche innovation and through vertical governance presents islands and their models with a wide-reaching impact and higher power than is initially attributed to them. The learnings from islands can thereby influence existing understandings and institutions on national and global levels and reconfigure current regimes and landscapes. Thus, giving this power to islands through bottom-up action and coordination benefits not only islands locally but also central stakeholders through the knowledge gained and actions accomplished in a decentralised manner, when island are not only considered laboratories.

The three perspectives and the development of the corresponding publications increase the complexity of island modelling as qualitatively assessed and overall perceived through increasingly complex data, as also other qualities and content increase relatively. As illustrated by Figure 3, this covers the share of self-sufficiency, local focus, sector integration, CO_2 emission reductions, and renewable energy shares. While self-sufficiency is addressed only to a limited extent in the early publications, as shown in 'Modelling of islands', it significantly shapes the publications when looking at 'Modelling on islands', and especially when 'Modelling from islands'.

Furthermore, the initial focus is global or European in the first two publications [32,33], while the focus in the later publications is directed more directly toward the local islands and their conditions, like the specific local focus on Madeira in [35]. Also, smart energy system's sector integration is not addressed much in the early publications (one out of five sectors in [31]), where the analyses focus rather on certain technologies and sectors; however, it gains more attention in the following publications and steps. Where first the electricity sector was primarily addressed, adding heating/cooling enables better understanding of the energy system in later publications [34,35].

The final perspective presents a technically and institutionally feasible fully-renewable energy system, taking all sectors into account [36]. This development of the island modelling is also reflected in the CO_2 emission reductions, which are highest in the later publications, compared to earlier ones; cf. 27% in [32], 66% in [35], and 98% in [36], which is in line with the renewable energy share increases, thereby addressing the Paris Agreement better with elaborated modelling. Figure 3 illustrates this relative share and the differences of the qualities of smart energy planning increasing throughout the addressed perspectives, as based on the evaluation and comparison of the selected publications. While it illustrates overall enhancements throughout the steps, it is further indicating areas for improvement, even when modelling with perspectives from islands.

The analytical approach above is further supporting and used in the theoretical framework. With the increased complexity and various additional perspectives of modelling renewable energy islands, it can be concluded that modelling should be done *with* islands in future smart energy systems, as it provides qualitative value on top of quantitative data. For that, the other perspectives *of, on* and *from* islands and the overall learnings are acknowledged, combined and included.

Both quantitative experiments and qualitative knowledge on and from islands can influence and offer a benefit on the global scale. While some individuality must be recognised, similarities also support the understanding and help identify transcendent recommendations from the modelling. By doing so, the need for self-sufficiency as well as cross-border collaboration, either technically or theoretically, can be evaluated accordingly. Concluding, islands in the context of modelling can be

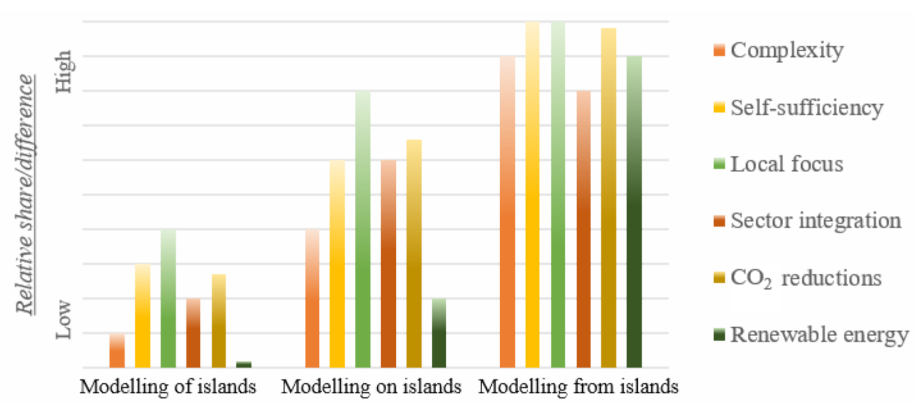

Figure 3: Relative increase of complexity and content when adding perspectives of [32,33], on [34,35] and from islands [36]; based on [41]

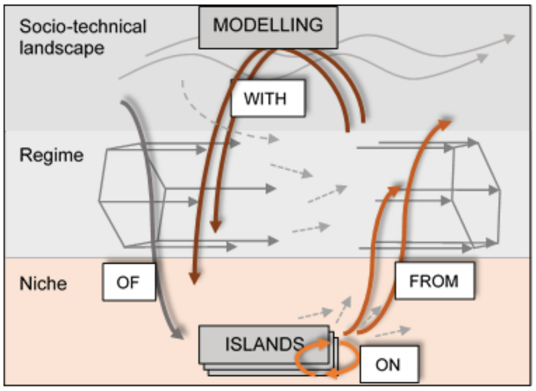

Figure 4: Modelling with islands in transition theory – transformed understanding on all levels [41]

Figure 5: Modelling with islands – through acknowledging multiple perspectives in multi-level governance in a Danish example, based on [41]

seen as lighthouses rather than only laboratories when approached in a smart way, by including the above-mentioned aspects and acknowledging their importance in the transition rather than merely for their capacity for experimentation.

When put into the context of transition theory, Figure 4 emerges, including the theoretical reflections on modelling *of*, *on*, *from* and *with* islands. Existing socio-technical landscapes and regimes require and influence niche innovation, however, enabling the additional local inclusion and strengthening of the innovation can benefit them in return through qualitative learnings on and from islands, including individual social, environmental and economic aspects.

The opportunities offered by 'modelling *with* islands' result in knowledge and adjustments for landscapes and regimes, which finally enables the transition towards future energy systems that combat climate change. Therefore, the adjusted levels from this point onward can allow for a better inclusion of islands with increased influence and understanding on the landscape and regime levels, as well as an impact on future niche innovations to come. Through Figure 4, islands are presented as niches for innovation, but also the support, understanding and learning of islands transform the multi-level perspective of the energy transition. Where control from higher levels once prevailed, the importance of supporting guidance and freedom is now presented.

The summary of the multi-level governance perspectives results in Figure 5, which combines all levels and directions of vertical and horizontal influence; cf. Figure 2. Instead of one-sided influence, a combination of top-down coordination, horizontal alignment and bottom-up action is suggested. This hybrid governance aligns with the requirement of central coordination and decentralised action in smart, strategic energy planning by addressing the similarities and differences, allowing for a better understanding of the results when working with islands in terms of tests, demonstrations and innovation.

Figure 5 shows the influence on islands from central governance and national plans, the options in between islands, and the influence of islands on the Danish exemplary capitol. It also illustrates islands as central and corner pieces of a puzzle, which can become more transpart in this approach of sustainable energy planning for an island country like Denmark.

4. Discussion

In light of the impending task of reducing fossil fuel demands and increasing sustainable energy shares, islands are not to be overlooked or disregarded as they play an important role in decentralisation. The contribution from each country to the Paris Agreement in light of their circumstances, hence, should be inclusive of their islands and perspectives. This also aligns with the centralised-decentralised coordination of locally available renewable energy sources and includes the environmental, economic and social aspects found locally.

By re-evaluating and combining the options of both cross-sector and cross-border optimisation in a new way for islands, and by acknowledging the local needs and limits, islands can not only contribute quantitatively but can add new qualitative knowledge to smart energy planning and energy transitions. Overall, the new understanding of islands contributes to better understanding of energy system modelling and energy impact analysis, where the different perspectives of modelling can be discussed.

Island modelling addresses the geographical context not only by aligning the available resources with demands in other locations, but especially by including the remote areas of consumption at the edges of our energy networks. This makes islands a rather central piece in the energy system, despite being far from political centres. Differences between islands and mainlands still need to be acknowledged, such as limited infrastructure and industrial energy demands, but also additional seasonal demands and resources particular to islands. If modelling is done with islands, it addresses these areas of concern and limits the continental view towards them, creating a more inclusive and strategic island-mainland relation.

The case studies can be reconsidered with a limited representation of the world's 80,000 islands, as generalisation as well as quantitative and qualitative insights were presented as targets for case study research. While the work with renewable energy islands as lighthouses provides these quantitative and qualitative insights, the generalisation and a common solution for islands cannot be presented. Although Samsø, Orkney, and Madeira provide insight, they do not represent global perspectives, or even Danish, Scottish or Portuguese ones, completely. However, they do provide, along with the energy system analysis of, and the scenario work with, their different energy systems, three valuable perspectives *on* and *from* islands and within their limitations.

Where the EnergyPLAN models of current and short-term scenarios should include the latest data to the best extent possible, also challenges and changes, for example in island demographics, should be included in future scenarios, indicating energy system impacts beyond the technical aspects. This can be summarised as a new way of strategic contextual energy planning that is especially relevant to islands due to their isolation; although others may also benefit from the approach through new understanding. Instead of simply serving as test-beds to be exploited, islands might actually 'lend credibility to innovation activities' [40], where limitations result in resilience. This further investigation in the use of models and plans, by applying EnergyPLAN or other approaches, is hereby addressed and contributes to better understanding, as suggested [18].

The importance of self-sufficiency and resilience has also been highlighted in recent events with the barriers to international trade and reliance thrown up by the Covid-19 situation. This suggests that local resilience is important, especially, but not exclusively, for islands. While many areas of concern can be mentioned in this regard, smart energy planning and the importance of local energy system optimisation is one of them, ranging from optimising the current situations to future ones where more remote work may be seen on islands [48–50].

Likewise, the understanding and presentation of islands as lighthouses, rather than only as laboratories, can support this in future energy policy. Concrete research could be aimed at the island mode in energy policy, such as finding deviating policies for small or isolated markets. Following the discussion on presenting renewable energy islands as lighthouses also in politics, a reflection of artificial 'energy islands' and the reconsideration of their definition and purpose is suggested. As introduced in the Danish climate agreement [22,23], energy islands refer to the artificially yet-to-be-developed islands in the North and Baltic Seas. Even though energy islands might not represent decentralisation in the perspective presented throughout the analysis of island models in this paper, similar conditions exist, including resource and research potentials.

Furthermore, limited research and development have been observed in the field of marine renewable energy [51] besides the development of offshore wind farms and future energy islands [23]. Even though islands comprise only 1.5% of the Earth's surface [2], their potential for modelling and learning also suggests that future research should focus more on marine energy sources and demands. Studies indicate marine energy to contribute up to 23% to the world's electricity demand [52,53], additionally demonstrating the relevance of islands. However, it is not just coastal communities and islands that could benefit from both the resources and the understanding from modelling with islands emerging from this.

While the share of the population living on Danish islands is close to the global average, other countries, like Germany, have a much smaller share; nevertheless, islands should be similarly included. Programs on the international, regional or national level, such as *Small Islands Organisation* (SMILO), *Northsea Interreg* or the German *Island and Hallig Conference,* are already making use of this and could be further researched and elaborated in energy planning [2,54]. This could result in not only a replication potential of renewable energy solutions on other islands but also an up-scaling of those to the mainland in the respective countries. This shows the global scale of the local possibilities and the value of islands, since it is the scale that ultimately matters [3].

5. Conclusion

Understanding the potentials of islands is presented as a research gap in smart energy transitions and sustainable energy planning. While theoretical perspectives indicate a role in transition theory and multi-level governance, recent research shows different levels of understanding and new perspectives emerging. When analysing islands in past research, in ongoing political and local developments and in future needs of smart energy transitions, modelling renewable energy islands presents an important role for islands to play.

Modelling *of* islands enables the evaluation of renewable energy technologies in an island setting, but with an outside view *of* islands. Modelling *on* islands addresses the limitations of the outside view and improves the modelling by including and comparing local conditions *on* islands. Modelling *from* islands elaborates the potentials of island modelling by adding contextual and institutional aspects through perspectives *from* islands and islanders. Discussing these three perspectives adds new reflections of the edges of both countries and research, concluding that modelling islands should be done *with* islands, from which both energy planners and islanders benefit. [41]

This research thereby contributes to a new understanding of islands as places for niche innovation through transition theory by considering all perspectives, and adds transparency to energy planning coordination through multi-level governance, including horizontal and bottom-up actions. This changes the way energy planning can be understood and made more sustainable by discussing the quantitative and qualitative importance of islands and island models as well as the understanding of self-sufficiency and cross-border developments. This results in islands being given a role that is worth recognising and contributes to the coordination and strengthening of energy systems, collaboration across borders, innovation, and independence. This benefits energy planning by being inclusive of island views and limits, resulting in a reduction of emissions and limiting climate change through islands on a global scale. Hence, not only countries like Denmark, but also other nations with islands should see themselves as countries *of* islands, attributing more importance to their islands than them simply being seen as additions to these countries.

The resulting recommendation of acknowledging the versatile role of islands answers the research question: Modelling islands contributes to sustainable energy planning and energy transitions with potentials for coordination, collaboration, innovation, and island mode optimisation with a global impact. This is achieved when the modelling is done *with* islands. With the answer to the research question thereby given, it opens up possibilities for further research. Therefore, modelling islands is discussed as contributing to research and new understandings of energy system modelling, energy policy, energy islands, marine development, and resilience.

Concluding, the energy of islands contributes to the understandings of smart energy and sustainable energy planning. This is achieved by islands playing a well-represented part in energy planning and energy being an important part of islands. Islands provide a place for innovation and collaboration, as supported by theory, and overall, by improving the modelling of renewable energy. Instead of only working with island models, we can see them as model islands. Having a closer look at islands presents them as lighthouses on the edge and ready for the energy transition. Including islands and their models in global energy transitions thereby addresses the Paris Agreement and the fight against climate change through greenhouse gas reductions and the decentralisation of sustainable energy in a smart way.

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