Status and perspectives on 100% renewable energy systems

Hansen, Kenneth; Breyer, Christian; Lund, Henrik

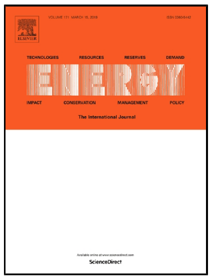
Published in:
Energy

DOI (link to publication from Publisher):
10.1016/j.energy.2019.03.092

Publication date:
2019

Document Version
Accepted author manuscript, peer reviewed version

Citation for published version (APA):
Hansen, K., Breyer, C., & Lund, H. (2019). Status and perspectives on 100% renewable energy systems. *Energy*, *175*, 471-480. https://doi.org/10.1016/j.energy.2019.03.092



Status and Perspectives on 100% Renewable Energy Systems

Kenneth Hansen, Christian Breyer, Henrik Lund

PII: S0360-5442(19)30496-7

DOI: 10.1016/j.energy.2019.03.092

Reference: EGY 14928

To appear in: *Energy*

Received Date: 14 February 2019

Accepted Date: 16 March 2019

Status and Perspectives on 100% Renewable Energy Systems

Authors: Kenneth Hansen[a], Christian Breyer[b], Henrik Lund[c]*

[a] Aalborg University, Department of Planning, A. C. Meyers Vænge 15, 2450 Copenhagen, Denmark

[b] Lappeenranta University of Technology, Skinnarilankatu 34, Lappeenranta, 53850, Finland

[c] Aalborg University, Department of Planning, Rendsburggade 14, 9000 Aalborg, Denmark

*Corresponding author: lund@plan.aau.dk

Highlights:

- Research in design of 100% renewable energy has increased
- Energy is the leading forum for 100% RES research
- Holistic cross-sectoral analysis is becoming state-of-the-art
- There is a future need for linking the local and the global level

Abstract:

This article shows that research in the design of 100% renewable energy systems in scientific articles is fairly new but has gained increasing attention in recent years. In total, 180 articles published since 2004 have been identified and analysed. Many of these articles have a predominant focus on the electricity sector. However, an increasing number of studies apply a cross-sectoral holistic approach on the entire energy system. Most studies analyse energy systems for the final 100% renewable state, while a small, though increasing, number also investigate energy transition pathways; how to reach the target. Europe, and thereafter the US and Australia, are well researched, while other parts of the world lack behind, and there is a focus on individual country studies. Henceforward, there is a need for applying a cross-sectoral holistic approach as well as coordinating individual country studies with the global context.

Keywords: 100% renewable energy, Smart Energy Systems, Energy Scenarios, Energy Systems Analysis

Nomenclature

AR6	6th assessment report of the IPCC
BECCS	bioenergy carbon capture and storage
BECCU	bioenergy carbon capture and utilisation
CO_2	carbon dioxide
CSP	concentrating solar thermal power
DACCS	direct air carbon capture and storage
DACCU	direct air carbon capture and utilisation
ESM	energy system model
IAM	integrated assessment model
IPCC	Intergovernmental Panel on Climate Change
NA	North Africa
PV	solar photovoltaics
R&D	research and development
RE	renewable energy
RES	renewable energy systems

SAARC South Asian Association for Regional Cooperation
SR1.5 special report on Global warming of 1.5⁰C
SSA Sub-Saharan Africa
UN United Nations

Introduction

Climate action is urgent as presented by the IPCC's Special report on 1.5°C global warming stating that climate change impacts are worse than expected [1]. In 2017, human-induced warming reached approximately 1°C above pre-industrial levels, leading to severe climate change impacts. Changes are therefore required. The Paris Agreement of 2015 presents global ambitions to achieve a balance between anthropogenic emissions by sources and removals of sinks of greenhouse gases in the second half of this century. The ambition in the agreement is to maintain the increase in global average temperature to well below 2°C above pre-industrial levels and pursue efforts to limit the temperature to 1.5°C [2]. The total cumulative emissions up to that time represent a key to achieving this target and it has been estimated that stabilizing atmospheric greenhouse gas concentrations would result in continued warming [1,3].

One solution to meet these ambitions is to reduce the emissions from fossil fuels by deploying large-scale renewable energy (RE) supply in energy systems. This corresponds to UN's Sustainable Development Goal no. 7 working for affordable and clean energy for all with the aim to substantially increase the share of renewable energy in the global energy mix by 2030 [4]. Moreover, 100% renewable energy systems could also contribute to the fulfilment of Sustainable Development Goals no. 6 (clean water and sanitation), no. 9 (industry, innovation and infrastructure), no. 11 (sustainable cities and communities), no. 12 (responsible production and consumption) and no. 13 (climate action).

This paper focuses on the state of research within high-renewable energy systems to accommodate these ambitions and combat climate change.

In recent years, renewable solar photovoltaics (PV) and wind energy technologies have experienced radical cost reductions. PV account for the highest change in cost [5] due to improved efficiencies, material costs, economies of scale as well as public and private R&D [6,7]. The PV cost reduction trends are expected to continue further in the future [8] and similar trends can be found for wind power technologies and CSP [9]. Several studies conclude that wind and PV technologies are cost-competitive with traditional fossil fuel energy generation costs today [10–13].

Currently, the 100% RE concept is gaining momentum among a variety of stakeholders. Examples exist in Sweden where the ambition is to achieve zero net emissions of greenhouse gases by 2045 [14] and in Denmark where the target is to achieve zero net emissions by 2050 at the latest [15]. Furthermore, numerous countries aim at 100% renewable electricity by 2045 or 2050 including Bangladesh, Barbados, Cambodia, Colombia, Ethiopia, Ghana, Mongolia, Vietnam, Hawaii and California [16]. Already today, a few countries supply almost all electricity from renewable sources (mainly hydropower) such as Norway and Costa Rica [16], whereas some countries, such as Uruguay, have been the first to achieve this target in a mix of renewables [17]. Similarly, several cities have committed to 100% renewable energy by 2050 for the total energy consumption. These cities include Copenhagen in Denmark (2050), Frankfurt and Hamburg in Germany (2050), Malmö and Växjö in Sweden (2030), Oxford Country in Australia (2050), Vancouver in Canada (2050) and The Hague in The Netherlands (2040) [16]. A similar trend exists among larger companies such as IKEA, BMW and Walmart and technology companies such as Google, Apple, Sony, eBay and Facebook among many others, and even the first company from the inner core of the fossil energy business, Wärtsilä, that has committed to 100% renewable electricity [18].

In this perspective, the article first scrutinizes the status of current 100% RE systems (RES) research in terms of research focus, methods and typical regions considered. Second, gaps in 100% RES research are identified, while the third section establishes priorities for future 100% RES research. Finally, some reflections are presented.

The current status of 100% RES research

No uniform definition of 100% RE systems exists which is witnessed across the published literature. In many cases, studies focusing solely on the electricity sector label the transition as 100% RE, while other researchers focus on the entire energy system (also including heating/cooling, transport, and industry). These definitions influence the overall methods and findings. In this perspective paper, both types of studies are considered to obtain a comprehensive overview of the current research. A minimum threshold value of 95% RE is applied to the studies and only peer-reviewed journal articles are included. A total of 181 studies have been reviewed to form the insights of this perspective [19–199].

The 100% RE topic is a rather recent research field as illustrated in Figure 1, which lists all 181 publications according to their publication year. The trend indicates growing interest in the topic with very few studies published before 2009 contrasting the recent years with more than 15 studies published annually since 2014. The publications peak in 2017 and 2018 with more than 40 studies each.. It should be noticed that the first quantitative 100% RE analysis found by the authors is published in 1975 by Sorensen [200] [ref], and it took about 30 years to take up again this very early 100% RE system research with nowadays methodology.

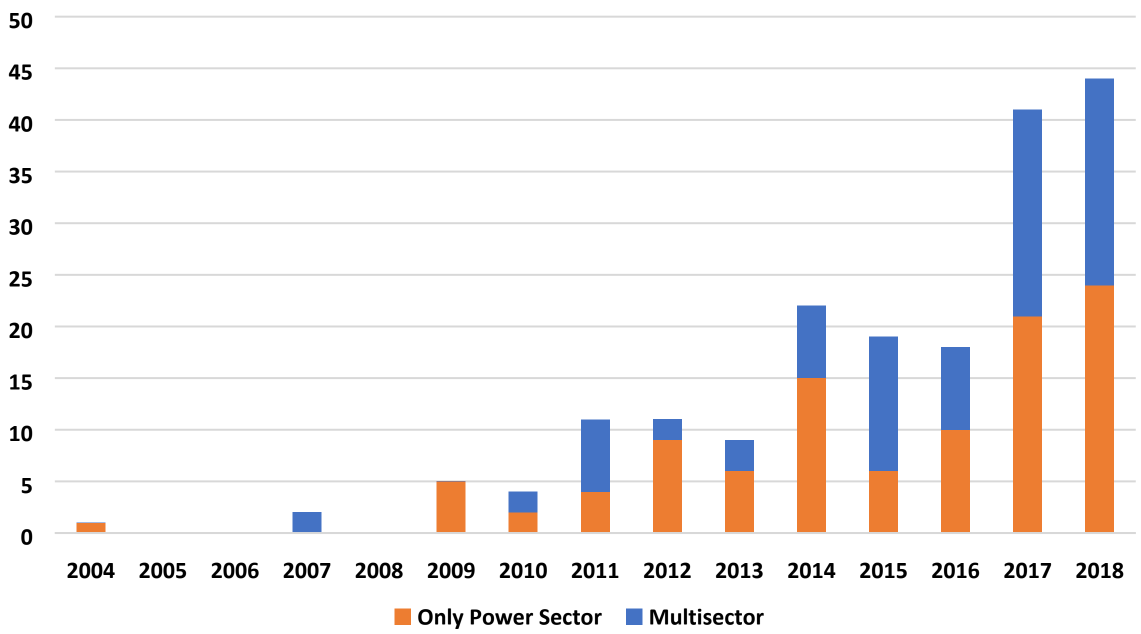


Figure 1: Number of 100% RE studies for countries, regions and globally according to their publication year

As shown in Figure 2, until now research has been published in a variety of academic journals, which proves the mainstreaming of the topic and the introduction into various research disciplines. The most common journal for 100% RE studies is Energy (45 publications), followed by Energy Policy (17 publications), Applied Energy (17 publications), Renewable Energy (15 publications) and Energy Procedia (15 publications). 80 additional articles on the topic have been published in more than 40 other journals combined. One observation is that Energy Policy historically published many articles on the topic of 100% RE, but this has decreased significantly in recent years (2 in 2009, 1 in 2010, 2 in 2011, 4 in 2012, 6 in 2013, 0 in 2014, 0 in 2015, 1 in 2016, 1 in 2017 and 0 in 2018).

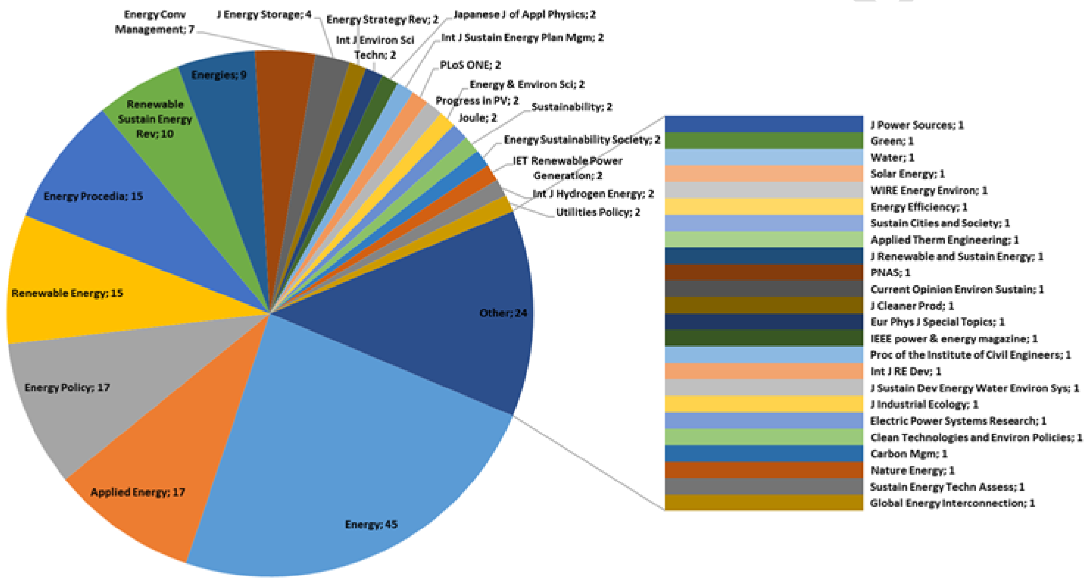


Figure 2: Number of 100% RE studies for countries, regions and globally according to the publishing journal.

Recently, 100% RE was mentioned for the first time in the IPCC SR1.5 report on 1.5°C global warming stating that the current studies "could, provided their assumptions prove plausible, expand the range of 1.5°C pathways" [1], page 112. This is a major milestone to realize that the Integrated Assessment Models (IAMs) can be complemented by sector-specific analysis about, e.g., 100% RE scenarios.

Research has focused on selected regions of the world as indicated in Acknowledgement illustrating the spread across regions. The region with largest attention is Europe, where research covers more than the electricity sector, but still not all sectors. In addition, Australia and the US are well researched, but mainly in terms of the electricity sector. Overall, national studies are most common with less focus on global levels or areas smaller than a national scale. Some islands are in focus in terms of 100% RE, in particular in Europe. Europe is also the only world region for which trans-national studies have been carried out on a broader and regular base, in some research also including North Africa, which has been triggered by the DESERTEC vision [201]. This is also based on the dissertation of Gregor Czisch [202], which represents the first peer-reviewed research on a multi-national 100% RE system.

A large number of studies using Energy System Models (ESMs) prove the viability of performing hourly energy modelling as a core methodology in the light of large-scale integration of variable renewable resources such as supplied by wind and PV generation. This enables an optimized use of technologies reflecting their resource complementarity and storage options hour-by-hour in current energy systems and in scenarios of future energy system trajectories. The hourly resolution permits modelling of energy system flexibility in a sufficient level of detail, mainly involving storage (same location but different times), grids (same time but different locations), dispatchable renewables (hydro reservoirs and bioenergy), demand response and sector coupling. This level of detail is typically not possible when temporal resolutions are limited to time slices and annual energy balancing [203]. Overcoming this limitation enables 100% RE studies to show the economic validity in terms of a relevant cost potential, but also the technical feasibility since all hours of a year are considered [204]. Some models have the aim to identify optimal solutions, but from a more theoretical point of view. In a broader planning and policy support perspective, it has also been discussed if the concept of optimal solutions makes sense [205], including how to handle the significant uncertainties aligned with future fuel end electricity market price predictions [206].

Until now, the research has also displayed analyses of a comparably broad technological portfolio, which is significant considering the long time horizon towards 2050 in most studies. Hence, technologies uncommon to the existing energy systems can be modelled and their roles in 100% RE systems can be determined.

The majority of the reviewed studies find that 100% RE is possible from a technical perspective, while only few publications argue against this [76,78,207,208]. The studies conclude that 100% RE is possible within the electricity sector, while other studies find that it is technically achievable for all sectors in a long-term perspective [44,77,80,92,97,120,134,137,138,175]. A large variety of technologies and measures are proposed for this transition. There is a growing base of open science activities among 100% RE researchers [209], mainly driven by researchers in Europe.

With a growing tendency in recent years, an increasing number of researchers underline the importance of applying a holistic cross-sectoral approach to the design of 100% renewable energy systems - also known as a smart energy systems approach. As shown in [210], the number of papers aligned to this concept has increased significantly in recent years. The assumption is that the best solutions can be found only if one focuses on the synergies between the sectors. On one hand, the transport and industry as well as the heating and cooling sectors need input from the electricity sector. On the other hand, these sectors can provide more affordable energy storage solutions to the integration of wind and solar power production [211] and also more operational flexibility [125], which reveals the value added by sector coupling.

The value of cross-border integration is increasingly investigated with multi-node models to show that the cooperation between neighbouring countries is a further means to achieving flexibility across a larger geographic entity, which allows a more efficient utilization of infrastructure and capacities of energy conversion and storage technologies [36,51,125]. A very limited number of studies are available which could reveal the separated value of cross-sectoral integration versus cross-border integration and a final cross-sectoral-border integration [212].

Which gaps can be identified

Certain gaps have been identified in the current research on 100% RE as described in this section.

The most researched energy sector in the 100% RE literature is the electricity sector, which is part of almost all studies and is the sole energy sector analysed in numerous cases (See figure 4). Conversely, less focus is placed on other energy sectors, even though these might be responsible for similar energy demands and emissions. For example, few studies investigate the transport sector and, in even rarer cases, all transport modes are considered (road, rail, marine, aviation). Many studies that include only transport incorporate the road mode, which is motivated by a final energy share of the road mode of about 80% in the current transport sector structure. However, this may change in the future due to challenges to directly electrify marine and aviation modes [213]. Moreover, the heating and cooling sectors gain little attention despite the fact that these sectors in some cases exceed the final energy demands of the electricity sector. 50% of the total final energy demand in Europe is either heating or cooling [214], which translates to about 30% primary energy demand for the heat sector [215]. This is also a consequence of the low efficiencies of thermal power plants leading to a high primary energy share of the present electricity sector. Additionally, a few studies thoroughly analyse the industrial sectors (in particular feedstock for steel, chemicals, cement, etc.) and the potential for direct carbon removal. The carbon dioxide removal technologies are, however, mostly in their infancy [1], but a broad literature base has been created [216–218], which should enable a fast integration into existing models.

The reasons for the predisposed focus can only be speculated but might be due to more straightforward solutions in the electricity sector (integration of mature renewable resources) compared to, e.g., the transport sector, as well as competences within the research field or the distribution of research grants. The reasons for sub-sector analyses in general may also be historical, since these sectors, to a wide extent, have been operated separately from one another in the current system based on fossil fuels. However, in a future 100% renewable energy system, they need to be much more coordinated and integrated. For the same reason, this should have a high priority in the research of 100% renewable energy solutions.

Other research topics that have not been comprehensively researched regarding 100% RE are sector-coupling studies with more sectors for different world regions, Power-to-X studies (fuels, chemicals, metal refining, etc.) and requirements for future energy grids. The latter is relevant because of the large increase in variable electricity sources that will challenge the existing electricity grids. Hence, it is pertinent to analyse transmission and distribution grids in more detail in scenarios with broad electrification of large parts of the energy demand. Moreover, the impact of the energy transition and sector coupling on other energy grids, such as gas grids, district heating networks and potential hydrogen and carbon dioxide grids requires more investigation.

In addition, the literature has a predominant focus either on supply side solutions such as the integration of further renewable energy sources or on the integration of technologies to enhance the energy system efficiency. These could be storage technologies, transmission grid options [96], integration of efficient technologies such as heat pumps, electric vehicles and reverse osmosis desalination [219], or power-to-fuels and power-to-chemicals to respect sustainable biomass limits in all-sector 100% RE scenarios. Less focus is placed on demand side solutions such as reducing energy demands at the consumer side to reduce the need for energy supply. Some studies indicate that demand side reductions are vital for transitioning to 100% RE systems in all sectors while remaining within sustainable resource limits [141,220]. Studies have introduced and applied methodologies to identify optimal balances between savings and production measures [221,222].

The geographical distribution of the research is, as previously described, limited to certain world regions. Less tradition for 100% RE research exists in regions such as South America, Sub-Saharan Africa, Eurasia, Northeast Asia, Southeast Asia and India/South Asia that have been scarcely researched. This limited research creates less support for decision-makers when developing future high renewable policies. The 100% RE studies to a large degree focus on national studies, particularly in the regions of origin of the researchers. Moreover, almost no global studies are carried out with energy system analysis, using the features of high temporal and hourly resolutions. No single study exists for the world in high regional resolution for all sectors, in full hourly resolution and describing energy transition pathways. The first studies conducted can cover parts of the desired profile, as summarized in Table 1.

ESMs in global-local resolution in an all-sector approach may be able to fill the gap of the comprehensive country-based studies and the much rougher description of IAMs to enable energy system models for 100% RE to contribute more effectively to tackling climate change. More ambitious research on the pathway options is needed, as claimed by Creutzig et al. [223] and Breyer et al. [125], reflecting high renewable energy shares. This is particularly important for the next IPCC AR6, as 100% RE system results were acknowledged, but not yet considered on a broader scale in the recent IPCC SR1.5 [1].

Table 1: Global highly renewable energy system studies indicating the level of covering the desired aspects. Latest versions of articles of the respective groups are listed.

	Model	Model type	Temporal resolution	Sectors	Pathway	Regions	Electricity exchange among regions	Energy trade among regions	RE share in 2050	long-term	Remark
Jacobson et al. [168]	LOADMATCH, GATOR-GCMOM	optimisation	hourly	all	overnight	20	no	no	100%	100 %	1
Teske et al. [24]	Mesap/PlaNet	simulation	annual	all	transition	10	no	no	100%	100 %	2
Breyer et al. [224]	LUT model	optimisation	hourly	power	transition	145	partly	no	99.7%	100 %	
Löffler et al. [173]	GENeSYS-MOD	optimisation	time slices	power, heat, transport	transition	10	no	fuels	100%	100 %	
Pursiheimo et al. [225][	VTT-TIMES	optimisation	time slices	all	transition	13	no	no	84.1%	84.1 %	3
Deng et al. [191]	Ecofys	simulation	annual	all	transition	1	no	no	95.0%	95%	
Sgouridis et al. [226]	NETSET	simulation	annual	all	transition	1	no	no	90.7%	98.3 %	4

1 industrial feedstock is missing
2 non-energy use of 9620 TWh_{th} still fossil
3 model is unable to defossiliate non-energetic industrial demand
4 remaining non-renewable is nuclear energy

Looking at the global distribution of studies as well as at the lack of global studies fulfilling all requirements, there seems to be a need for coordinating the individual city, country and regional studies and identifying how they fit into an overall solution with neighbouring countries and ultimately the rest of the world. Only few papers have addressed the principle of this problem [50]. Most studies focus on 100% RE analyses in the overnight approach, which may lack information to policy-makers and energy system planners in terms of how and by when to transition from the current state to a 100% RE system. In contrast to the overall picture, most global studies describe transition pathways as shown in Table 1.

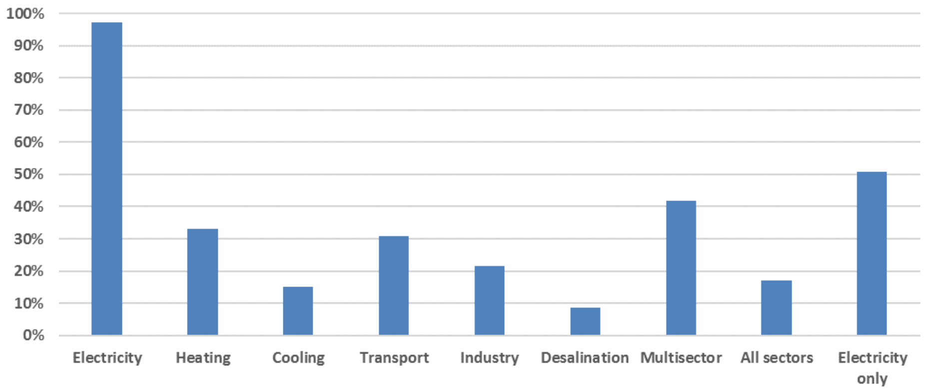


Figure 3: 100% RE studies according to their inclusion of different sectors.

Perspectives for future 100% RES research insights

Based on the current status and the identified research gaps, certain insights should be prioritized for future 100% RE research.

The research of future 100% RE mainly prioritise the mix of flexibilities for hosting high RE shares. A variety of solutions have been suggested such as developing optimal mixes of RE supply to accommodate temporality issues, demand response solutions, supply side management of dispatchable renewables, sector coupling, grid extensions and energy storage. However, these solutions have rarely been analysed in combination and therefore it is appropriate to focus on the optimal mix of these solutions in a 100% RE system. Other imminent challenges relate to the degree of centralized versus decentralized elements in 100% RE systems. This issue concerns both the decentralization of the energy supply (PV and wind power), the role of various energy grids (electricity, thermal and gas grids) and the role of the individual consumer/prosumer. Consequently, ownership structures will change, but have rarely been the focus of 100% RE studies. In addition, all-sector integrated global-local models also need to be able to describe the regional and international trade of fuels and chemicals to supplement the domestic supply, which effectively adds an international dimension to the discussion of decentralization versus centralization.

Moreover, research priority should be given to combining the design of future 100% RE systems with the available resource potentials within and across regions. For example, certain regions are affluent in hydropower, biomass, wind or solar resources, but could possibly benefit from exchanging resources with neighbouring regions. Hence, regions with limited renewable resources will also have the possibility to carry out a full RE transition. Finally, the integration of renewable resource potentials should be combined with changes to energy demands to ensure that these align.

One final priority concerns the feasibility of future 100% RE systems for various regions. Most studies find that it is technically probable to carry out a 100% RE transition (at least in certain sectors), but less consistency exists regarding the economic feasibility of this transition. In some studies, authors argue that it will be extremely costly (and technically infeasible) to perform this 100% RE transition [75,207,208], while other researchers find that it is both technically and economically feasible [143,145,150,224,227]. These studies typically differ in terms of geographical regions and analysis assumptions for future technology efficiencies and prices, and therefore more streamlined research is needed.

Biophysical limits require more consideration in 100% RE system research. This goes beyond the complex limits for bioenergy [150,228,229], since net energy analyses should be considered to a larger extent [226]. In addition, assessments should be made of the material demand for the energy transition, since the current energy system based on fossil energy fuels will be replaced by a system that is mainly based on metal resources.

A key contribution of 100% renewable ESMs could be to the development of future IPCC defossilisation pathways. ESMs with higher resolutions than IAMs could recalculate the technical feasibility of suggested pathways. Furthermore, IAMs do not account in sufficient detail for energy system flexibility effects, which is an area of expertise within ESMs. These measures might include BECCU (BioEnergy with Carbon Capture and Utilization) or DACCU (Direct Air Capture with Carbon Utilization), more described as Power-to-X. In addition, negative CO_2 emissions, based on BECCS and DACCS (storage instead of utilization) is a field to which ESMs can contribute with a deeper energy system understanding of these climate change mitigation options, which may be needed [1]. All energy system modelling, independent of ESMs or IAMs, should take care of sustainability guardrails [203].

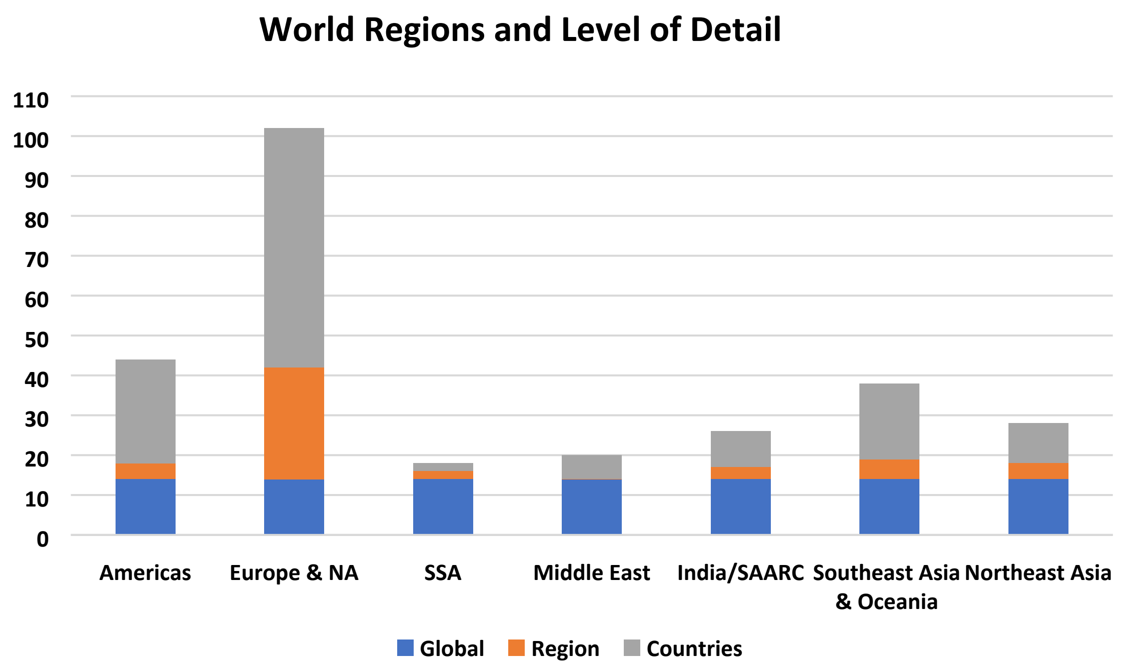


Figure 4: Number of publications according to world regions and level of detail in the 100% RE studies. NA: North Africa, SSA: Sub-Saharan Africa, SAARC: South Asian Association for Regional Cooperation.

Conclusions

The research field of 100% RE was established around the mid-2000s and has been referenced in an increasing number of articles since the early-2010s. In recent years, the 100% RE research field has provided scientific insights for policy-making, which is reflected by a fastly growing number of countries, states, cities and companies now committed to 100% RE targets. The best researched region in the world is Europe which is covered by more than half of all identified articles, followed by the US and Australia. The articles are published in various journals, led by *Energy*. The great majority of all publications highlights the technical feasibility and economic viability of 100% RE systems. State-of-the-art in 100% RE modelling applies a full hourly methodology with the aim to capture the various forms of flexibility to achieve optimized energy system solutions. This is increasingly complemented by a broad portfolio of energy technologies.

An increasing number of articles cover several energy sectors, overcoming the limited view of only the power sector. This reflects the integration of future energy systems and the increasingly important role of electricity in all energy sectors. More emphasis is required in 100% RE research on the full transport sector, industrial feedstock, power-to-X technologies, carbon dioxide removal options, and sector coupling. Major regions and countries in the world are not yet well covered by 100% RE research, such as South America, Sub-Saharan Africa, Eurasia, Northeast Asia, Southeast Asia and India/South Asia, which may be a substantial bottleneck for effective policy-making.

Several energy system models have been established for modelling global 100% RE research, but only few models have yet been developed to such extent that they can describe all required sectors and features in a sufficient level of detail and they have not been applied to the global level. Energy system models may be further progressed to be coupled with integrated assessment models for a more comprehensive and multi-disciplinary understanding of defossilisation pathways to the benefit of all involved communities and stakeholders.

Acknowledgement

The work presented in this paper is partly a result of the research project RE-Invest - Renewable Energy Investment Strategies, grant number 6154-00022B, which has received funding from Innovation Fund Denmark.

References

[1] Allen M, Coninck H de, Dube OP, Hoegh-Guldberg O, Jacob D, Jiang K, et al. Technical Summary. In: Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the th. 2018.

[2] UN FCCC. Adoption of the Paris Agreement. Paris, France: 2015.

[3] Steffen W, Rockström J, Richardson K, Lenton TM, Folke C, Liverman D, et al. Trajectories of the Earth System in the Anthropocene. Proc Natl Acad Sci 2018;115:8252–9. doi:10.1073/PNAS.1810141115.

[4] United Nations. Transforming our world: the 2030 Agenda for Sustainable Development. New York, USA: 2015.

[5] Trancik JE, Cross-Call D. Energy Technologies Evaluated against Climate Targets Using a Cost and Carbon Trade-off Curve. Environ Sci Technol 2013;47:6673–80. doi:10.1021/es304922v.

[6] Kavlak G, McNerney J, Trancik JE. Evaluating the causes of cost reduction in photovoltaic modules. Energy Policy 2018;123:700–10. doi:10.1016/J.ENPOL.2018.08.015.

[7] Breyer C, Birkner C, Meiss J, Goldschmidt JC, Riede M. A top-down analysis: Determining photovoltaics R&D investments from patent analysis and R&D headcount. Energy Policy 2013;62:1570–80. doi:10.1016/J.ENPOL.2013.07.003.

[8] Comello S, Reichelstein S, Sahoo A. The road ahead for solar PV power. Renew Sustain Energy Rev 2018;92:744–56. doi:10.1016/J.RSER.2018.04.098.

[9] IRENA. Renewable Power Generation Costs in 2017. Abu Dhabi: 2018.

[10] Lazard. Lazard's levelized cost of energy analysis - version 11.0. 2017.

[11] IRENA. Renewable Energy in District Heating and Cooling - A sector roadmap for REMAP. 2017.

[12] Pujari SN, Cellere G, Falcon T, Hage F, Zwegers M, Bernreuter J, et al. International Technology Roadmap for Photovoltaic (ITRPV). 2018.

[13] Kaizuka I, Masson G, Nowak S, Brunisholz M, Cambie C, Serra G, et al. Trends 2018 in photovoltaic applications. 2018.

[14] Swedish social democratic party, The Moderate Party, The Swedish Green Party, The Centre Party, The Christian Democrats. , the Swedish Green Party, the Centre Party and the Christian Democrats. 2016.

[15] The Danish Government, Social Democracy, The Danish People's Party, The Red-green Alliance, The Alternative, The Social Liberal Party, et al. Energy Agreement of 29 June 2018. 2018.

[16] REN21. Renewable 2018 - Global status report - data pack. Paris, France: 2018.

[17] International Energy Agency. Total Primary Energy Supply (TPES) by source 2018.

[18] RE100. RE100 2019.

[19] Mason IG, Page SC, Williamson AG. Security of supply, energy spillage control and peaking options within a 100% renewable electricity system for New Zealand. Energy Policy 2013;60:324–33. doi:10.1016/J.ENPOL.2013.05.032.

[20] Fthenakis V, Mason JE, Zweibel K. The technical, geographical, and economic feasibility for solar energy to supply the energy needs of the US. Energy Policy 2009;37:387–99. doi:10.1016/J.ENPOL.2008.08.011.

[21] Mason IG, Page SC, Williamson AG. A 100% renewable electricity generation system for New Zealand utilising hydro, wind, geothermal and biomass resources. Energy Policy 2010;38:3973–84.

[22] Elliston B, MacGill I, Diesendorf M. Least cost 100% renewable electricity scenarios in the Australian National Electricity Market. Energy Policy 2013;59:270–82. doi:10.1016/j.enpol.2013.03.038.

[23] Child M, Nordling A, Breyer C. The impacts of high V2G participation in a 100% renewable åland energy system. Energies 2018;11. doi:10.3390/en11092206.

[24] Teske S, Pregger T, Simon S, Naegler T. High renewable energy penetration scenarios and their implications for urban energy and transport systems. Curr Opin Environ Sustain 2018;30:89–102. doi:10.1016/j.cosust.2018.04.007.

[25] Heide D, von Bremen L, Greiner M, Hoffmann C, Speckmann M, Bofinger S. Seasonal optimal mix of wind and solar power in a future, highly renewable Europe. Renew Energy 2010;35:2483–9. doi:10.1016/j.renene.2010.03.012.

[26] Heide D, Greiner M, von Bremen L, Hoffmann C. Reduced storage and balancing needs in a fully renewable European power system with excess wind and solar power generation. Renew Energy 2011;36:2515–23. doi:10.1016/j.renene.2011.02.009.

[27] Schlachtberger DP, Becker S, Schramm S, Greiner M. Backup flexibility classes in emerging large-scale renewable electricity systems. Energy Convers Manag 2016;125:336–46. doi:10.1016/j.enconman.2016.04.020.

[28] Battaglini A, Lilliestam J, Haas A, Patt A. Development of SuperSmart Grids for a more efficient utilisation of electricity from renewable sources. J Clean Prod 2009;17:911–8. doi:10.1016/j.jclepro.2009.02.006.

[29] Tranberg B, Schwenk-Nebbe LJ, Schäfer M, Hörsch J, Greiner M. Flow-based nodal cost allocation in a heterogeneous highly renewable European electricity network. Energy 2018;150:122–33.

doi:10.1016/j.energy.2018.02.129.

[30] Andresen GB, Rodriguez RA, Becker S, Greiner M. The potential for arbitrage of wind and solar surplus power in Denmark. Energy n.d. doi:http://dx.doi.org/10.1016/j.energy.2014.03.033.

[31] Jensen TV, Greiner M. Emergence of a phase transition for the required amount of storage in highly renewable electricity systems. Eur Phys J Spec Top 2014;223:2475–81. doi:10.1140/epjst/e2014-02216-9.

[32] Becker S, Frew BA, Andresen GB, Jacobson MZ, Schramm S, Greiner M. Renewable build-up pathways for the US: Generation costs are not system costs. Energy 2015;81:437–45. doi:10.1016/j.energy.2014.12.056.

[33] Lund H, Mathiesen B V. Energy system analysis of 100% renewable energy systems-The case of Denmark in years 2030 and 2050. Energy 2009;34:524–31. doi:10.1016/j.energy.2008.04.003.

[34] Rodriguez RA, Dahl M, Becker S, Greiner M. Localized vs. synchronized exports across a highly renewable pan-European transmission network. Energy Sustain Soc 2015;5:1–9. doi:10.1186/s13705-015-0048-6.

[35] Frew BA, Jacobson MZ. Temporal and spatial tradeoffs in power system modeling with assumptions about storage: An application of the POWER model. Energy 2016;117:198–213. doi:10.1016/j.energy.2016.10.074.

[36] Schlachtberger DP, Brown T, Schramm S, Greiner M. The benefits of cooperation in a highly renewable European electricity network. Energy 2017;134:469–81. doi:10.1016/j.energy.2017.06.004.

[37] Schlachtberger DP, Brown T, Schäfer M, Schramm S, Greiner M. Cost optimal scenarios of a future highly renewable European electricity system: Exploring the influence of weather data, cost parameters and policy constraints. Energy 2018;163:100–14. doi:10.1016/j.energy.2018.08.070.

[38] Elliston B, Riesz J, MacGill I. What cost for more renewables? The incremental cost of renewable generation - An Australian National Electricity Market case study. Renew Energy 2016;95:127–39. doi:10.1016/j.renene.2016.03.080.

[39] Riesz J, Elliston B. Research and deployment priorities for renewable technologies: Quantifying the importance of various renewable technologies for low cost, high renewable electricity systems in an Australian case study. Energy Policy 2016;98:298–308. doi:10.1016/j.enpol.2016.08.034.

[40] Lund H, Duić N, Krajačić G, Graça Carvalho M d. Two energy system analysis models: A comparison of methodologies and results. Energy 2007;32. doi:10.1016/j.energy.2006.10.014.

[41] Lund H. Renewable energy strategies for sustainable development. Energy 2007;32. doi:10.1016/j.energy.2006.10.017.

[42] Alberg Østergaard P, Mathiesen BV, Möller B, Lund H. A renewable energy scenario for Aalborg Municipality based on low-temperature geothermal heat, wind power and biomass. Energy 2010;35:4892–901. doi:10.1016/j.energy.2010.08.041.

[43] Lund H. The implementation of renewable energy systems. Lessons learned from the Danish case. Energy 2010;35:4003–9.

[44] Ćosić B, Krajačić G, Duić N. A 100% renewable energy system in the year 2050: The case of Macedonia. Energy 2012;48:80–7. doi:10.1016/J.ENERGY.2012.06.078.

[45] Østergaard PA, Lund H. A renewable energy system in Frederikshavn using low-temperature

geothermal energy for district heating. Appl Energy 2011;88. doi:10.1016/j.apenergy.2010.03.018.

[46] Liu W, Lund H, Mathiesen BV, Zhang X. Potential of renewable energy systems in China. Appl Energy 2011;88. doi:10.1016/j.apenergy.2010.07.014.

[47] Lund H, Andersen AN, Østergaard PA, Mathiesen BV, Connolly D. From electricity smart grids to smart energy systems - A market operation based approach and understanding. Energy 2012;42:96–102. doi:10.1016/j.energy.2012.04.003.

[48] Mathiesen BV, Lund H, Connolly D. Limiting biomass consumption for heating in 100% renewable energy systems. Energy 2012;48. doi:10.1016/j.energy.2012.07.063.

[49] Thellufsen JZ, Lund H. Energy saving synergies in national energy systems. Energy Convers Manag 2015;103. doi:10.1016/j.enconman.2015.06.052.

[50] Thellufsen JZ, Lund H. Roles of local and national energy systems in the integration of renewable energy. Appl Energy 2016;183:419–29. doi:10.1016/J.APENERGY.2016.09.005.

[51] Thellufsen JZ, Lund H. Cross-border versus cross-sector interconnectivity in renewable energy systems. Energy 2017;124:492–501. doi:10.1016/j.energy.2017.02.112.

[52] Child M, Breyer C. The Role of Energy Storage Solutions in a 100% Renewable Finnish Energy System. Energy Procedia, vol. 99, 2016, p. 25–34. doi:10.1016/j.egypro.2016.10.094.

[53] Child M, Haukkala T, Breyer C. The role of solar photovoltaics and energy storage solutions in a 100% renewable energy system for Finland in 2050. Sustain 2017;9. doi:10.3390/su9081358.

[54] Schlott M, Kies A, Brown T, Schramm S, Greiner M. The impact of climate change on a cost-optimal highly renewable European electricity network. Appl Energy 2018;230:1645–59. doi:10.1016/j.apenergy.2018.09.084.

[55] Elliston B, Diesendorf M, MacGill I. Simulations of scenarios with 100% renewable electricity in the Australian National Electricity Market. Energy Policy 2012;45:606–13. doi:10.1016/j.enpol.2012.03.011.

[56] Kroposki B, Johnson B, Zhang Y, Gevorgian V, Denholm P, Hodge B-M, et al. Achieving a 100% Renewable Grid: Operating Electric Power Systems with Extremely High Levels of Variable Renewable Energy. IEEE Power Energy Mag 2017;15:61–73. doi:10.1109/MPE.2016.2637122.

[57] Maïzi N, Mazauric V, Assoumou E, Bouckaert S, Krakowski V, Li X, et al. Maximizing intermittency in 100% renewable and reliable power systems: A holistic approach applied to Reunion Island in 2030. Appl Energy 2018;227:332–41. doi:10.1016/j.apenergy.2017.08.058.

[58] Krakowski V, Assoumou E, Mazauric V, Maïzi N. Reprint of Feasible path toward 40–100% renewable energy shares for power supply in France by 2050: A prospective analysis. Appl Energy 2016;184:1529–50. doi:10.1016/j.apenergy.2016.11.003.

[59] Oyewo AS, Aghahosseini A, Bogdanov D, Breyer C. Pathways to a fully sustainable electricity supply for Nigeria in the mid-term future. Energy Convers Manag 2018;178:44–64. doi:10.1016/j.enconman.2018.10.036.

[60] Lawrenz L, Xiong B, Lorenz L, Krumm A, Hosenfeld H, Burandt T, et al. Exploring energy pathways for the low-carbon transformation in India—a model-based analysis. Energies 2018;11. doi:10.3390/en11113001.

[61] Wänn A, Connolly D, Gallachóir BÓ. Investigating 100% renewable energy supply at regional level using scenario analysis. Int J Sustain Energy Plan Manag 2014;3:31–2. doi:10.5278/ijsepm.2014.3.3.

[62] Zappa W, Junginger M, van den Broek M. Is a 100% renewable European power system feasible by 2050? Appl Energy 2019:1027–50. doi:10.1016/j.apenergy.2018.08.109.

[63] Alexander MJ, James P. Role of distributed storage in a 100% renewable UK network. Proc Inst Civ Eng Energy 2015;168:87–95. doi:10.1680/ener.14.00030.

[64] Alexander MJ, James P, Richardson N. Energy storage against interconnection as a balancing mechanism for a 100% renewable UK electricity grid. IET Renew Power Gener 2015;9:131–41. doi:10.1049/iet-rpg.2014.0042.

[65] Bačeković I, Østergaard PA. A smart energy system approach vs a non-integrated renewable energy system approach to designing a future energy system in Zagreb. Energy 2018;155:824–37. doi:10.1016/j.energy.2018.05.075.

[66] Jacobson MZ, Howarth RW, Delucchi MA, Scobie SR, Barth JM, Dvorak MJ, et al. Examining the feasibility of converting New York State's all-purpose energy infrastructure to one using wind, water, and sunlight. Energy Policy 2013;57:585–601. doi:10.1016/j.enpol.2013.02.036.

[67] Guenther M, Ganal I, Bofinger S. A 100% Renewable Electricity Scenario for the Java-Bali Grid. Int J Renew Energy Dev 2018;7:13–22. doi:10.14710/ijred.7.1.13-22.

[68] Hess D, Wetzel M, Cao K-K. Representing node-internal transmission and distribution grids in energy system models. Renew Energy 2018;119:874–90. doi:10.1016/j.renene.2017.10.041.

[69] Lund H. Renewable heating strategies and their consequences for storage and grid infrastructures comparing a smart grid to a smart energy systems approach. Energy 2018;151. doi:10.1016/j.energy.2018.03.010.

[70] Selosse S, Garabedian S, Ricci O, Maïzi N. The renewable energy revolution of reunion island. Renew Sustain Energy Rev 2018;89:99–105. doi:10.1016/j.rser.2018.03.013.

[71] Vidal-Amaro JJ, Sheinbaum-Pardo C. A transition strategy from fossil fuels to renewable energy sources in the mexican electricity system. J Sustain Dev Energy, Water Environ Syst 2018;6:47–66. doi:10.13044/j.sdewes.d5.0170.

[72] Hamilton NE, Howard BS, Diesendorf M, Wiedmann T. Computing life-cycle emissions from transitioning the electricity sector using a discrete numerical approach. Energy 2017;137:314–24. doi:10.1016/j.energy.2017.06.175.

[73] McPherson M, Karney B. A scenario based approach to designing electricity grids with high variable renewable energy penetrations in Ontario, Canada: Development and application of the SILVER model. Energy 2017;138:185–96. doi:10.1016/j.energy.2017.07.027.

[74] Pursiheimo E, Holttinen H, Koljonen T. Path toward 100% renewable energy future and feasibility of power-to-gas technology in Nordic countries. IET Renew Power Gener 2017;11:1695–706. doi:10.1049/iet-rpg.2017.0021.

[75] Trainer T. Can renewables meet total Australian energy demand: A "disaggregated" approach. Energy Policy 2017;109:539–44. doi:10.1016/j.enpol.2017.07.040.

[76] Trainer T. Can Australia run on renewable energy? The negative case. Energy Policy 2012;50:306–14. doi:10.1016/j.enpol.2012.07.024.

[77] Delucchi MA, Jacobson MZ. Providing all global energy with wind, water, and solar power, Part II: Reliability, system and transmission costs, and policies. Energy Policy 2011;39:1170–90. doi:10.1016/J.ENPOL.2010.11.045.

[78] Trainer T. Can Europe run on renewable energy? A negative case. Energy Policy 2013;63:845–50. doi:10.1016/j.enpol.2013.09.027.

[79] Zhao G, Guerrero JM, Jiang K, Chen S. Energy modelling towards low carbon development of Beijing in 2030. Energy 2017;121:107–13. doi:10.1016/j.energy.2017.01.019.

[80] Dominkovic DF, Bacekovic I, Cosic B, Krajacic G, Puksec T, Duic N, et al. Zero carbon energy system of South East Europe in 2050. Appl Energy 2016;184:1517–28. doi:10.1016/j.apenergy.2016.03.046.

[81] Kötter E, Schneider L, Sehnke F, Ohnmeiss K, Schröer R. Sensitivities of power-to-gas within an optimised energy system. Energy Procedia, vol. 73, 2015, p. 190–9. doi:10.1016/j.egypro.2015.07.670.

[82] Kötter E, Schneider L, Sehnke F, Ohnmeiss K, Schröer R. The future electric power system: Impact of Power-to-Gas by interacting with other renewable energy components. J Energy Storage 2016;5:113–9. doi:10.1016/j.est.2015.11.012.

[83] Petrović SN, Karlsson KB. Residential heat pumps in the future Danish energy system. Energy 2016;114:787–97. doi:10.1016/j.energy.2016.08.007.

[84] Procter AC, Kaplan PÖ, Araujo R. Net Zero Fort Carson: Integrating Energy, Water, and Waste Strategies to Lower the Environmental Impact of a Military Base. J Ind Ecol 2016;20:1134–47. doi:10.1111/jiec.12359.

[85] Yue C-D, Chen C-S, Lee Y-C. Integration of optimal combinations of renewable energy sources into the energy supply of Wang-An Island. Renew ENERGY 2016;86:930–42. doi:10.1016/j.renene.2015.08.073.

[86] Jost D, Speckmann M, Sandau F, Schwinn R. A new method for day-ahead sizing of control reserve in Germany under a 100% renewable energy sources scenario. Electr Power Syst Res 2015;119:485–91. doi:10.1016/J.EPSR.2014.10.026.

[87] Khoie R, Yee VE. A forecast model for deep penetration of renewables in the Southwest, South Central, and Southeast regions of the United States. Clean Technol Environ Policy 2015;17:957–71. doi:10.1007/s10098-014-0848-y.

[88] Jacobson MZ, Delucchi MA, Ingraffea AR, Howarth RW, Bazouin G, Bridgeland B, et al. A roadmap for repowering California for all purposes with wind, water, and sunlight. Energy 2014;73:875–89. doi:10.1016/j.energy.2014.06.099.

[89] Nunes P, Farias T, Brito MC. Enabling solar electricity with electric vehicles smart charging. Energy 2015;87:10–20. doi:10.1016/j.energy.2015.04.044.

[90] Šare A, Krajačić G, Pukšec T, Duić N. The integration of renewable energy sources and electric vehicles into the power system of the Dubrovnik region. Energy Sustain Soc 2015;5. doi:10.1186/s13705-015-0055-7.

[91] Hong S, Bradshaw CJA, Brook BW. Nuclear power can reduce emissions and maintain a strong economy: Rating Australia's optimal future electricity-generation mix by technologies and policies. Appl Energy 2014;136:712–25. doi:10.1016/j.apenergy.2014.09.062.

[92] Hooker-Stroud A, James P, Kellner T, Allen P. Toward understanding the challenges and opportunities in managing hourly variability in a 100% renewable energy system for the UK. Carbon Manag 2014;5:373–84. doi:10.1080/17583004.2015.1024955.

[93] Ridjan I, Mathiesen BV, Connolly D. Synthetic fuel production costs by means of solid oxide electrolysis cells. Energy 2014;76:104,113. doi:10.1016/j.energy.2014.04.002.

[94] Sáfián F. Modelling the Hungarian energy system – The first step towards sustainable energy planning. Energy 2014;69:58–66. doi:10.1016/j.energy.2014.02.067.

[95] Child M, Bogdanov D, Breyer C. The Baltic Sea region: Storage, grid exchange and flexible electricity generation for the transition to a 100% renewable energy system. Energy Procedia, vol. 155, 2018, p. 390–402. doi:10.1016/j.egypro.2018.11.039.

[96] Child M, Bogdanov D, Breyer C. The role of storage technologies for the transition to a 100% renewable energy system in Europe. Energy Procedia, vol. 155, 2018, p. 44–60. doi:10.1016/j.egypro.2018.11.067.

[97] Hansen K, Mathiesen BV, Skov IR. Full energy system transition towards 100% renewable energy in Germany in 2050. Renew Sustain Energy Rev 2019;102:1–13. doi:10.1016/J.RSER.2018.11.038.

[98] Haas J, Cebulla F, Nowak W, Rahmann C, Palma-Behnke R. A multi-service approach for planning the optimal mix of energy storage technologies in a fully-renewable power supply. Energy Convers Manag 2018;178:355–68. doi:10.1016/J.ENCONMAN.2018.09.087.

[99] Krewitt W, Teske S, Simon S, Pregger T, Graus W, Blomen E, et al. Energy [R]evolution 2008—a sustainable world energy perspective. Energy Policy 2009;37:5764–75. doi:10.1016/J.ENPOL.2009.08.042.

[100] Matsuo Y, Endo S, Nagatomi Y, Shibata Y, Komiyama R, Fujii Y. A quantitative analysis of Japan's optimal power generation mix in 2050 and the role of CO2-free hydrogen. Energy 2018;165:1200–19. doi:10.1016/J.ENERGY.2018.09.187.

[101] Zapata S, Castaneda M, Jimenez M, Julian Aristizabal A, Franco CJ, Dyner I. Long-term effects of 100% renewable generation on the Colombian power market. Sustain Energy Technol Assessments 2018;30:183–91. doi:10.1016/J.SETA.2018.10.008.

[102] Selosse S, Ricci O, Garabedian S, Maïzi N. Exploring sustainable energy future in Reunion Island. Util Policy 2018;55:158–66. doi:10.1016/J.JUP.2018.10.006.

[103] Tarroja B, Shaffer BP, Samuelsen S. Resource portfolio design considerations for materially-efficient planning of 100% renewable electricity systems. Energy 2018;157:460–71. doi:10.1016/J.ENERGY.2018.05.184.

[104] Pfeifer A, Dobravec V, Pavlinek L, Krajačić G, Duić N. Integration of renewable energy and demand response technologies in interconnected energy systems. Energy 2018;161:447–55. doi:10.1016/J.ENERGY.2018.07.134.

[105] Esteban M, Portugal-Pereira J, Mclellan BC, Bricker J, Farzaneh H, Djalilova N, et al. 100% renewable energy system in Japan: Smoothening and ancillary services. Appl Energy 2018;224:698–707. doi:10.1016/J.APENERGY.2018.04.067.

[106] Hess D. The value of a dispatchable concentrating solar power transfer from Middle East and North Africa to Europe via point-to-point high voltage direct current lines. Appl Energy 2018;221:605–45. doi:10.1016/J.APENERGY.2018.03.159.

[107] Wang C, Dargaville R, Jeppesen M. Power system decarbonisation with Global Energy Interconnection – a case study on the economic viability of international transmission network in Australasia. Glob Energy Interconnect 2018;1:507–19. doi:10.14171/J.2096-5117.GEI.2018.04.011.

[108] Bode C, Schmitz G. Dynamic Simulation and Comparison of Different Configurations for a Coupled Energy System with 100 % Renewables. Energy Procedia 2018;155:412–30. doi:10.1016/J.EGYPRO.2018.11.037.

[109] Ikäheimo J, Kiviluoma J, Weiss R, Holttinen H. Power-to-ammonia in future North European 100 % renewable power and heat system. Int J Hydrogen Energy 2018;43:17295–308. doi:10.1016/J.IJHYDENE.2018.06.121.

[110] Blakers A, Luther J, Nadolny A. Asia Pacific Super Grid – Solar electricity generation, storage and distribution. GREEN 2012;2:189. doi:10.1515/green-2012-0013.

[111] Dranka GG, Ferreira P. Planning for a renewable future in the Brazilian power system. Energy 2018;164:496–511. doi:10.1016/J.ENERGY.2018.08.164.

[112] Huber M, Roger A, Hamacher T. Optimizing long-term investments for a sustainable development of the ASEAN power system. Energy 2015;88:180–93. doi:10.1016/j.energy.2015.04.065.

[113] Jacobson MZ, Delucchi MA, Bazouin G, Bauer ZAF, Heavey CC, Fisher E, et al. 100% clean and renewable wind, water, and sunlight (WWS) all-sector energy roadmaps for the 50 United States. Energy Environ Sci 2015;8:2093–117. doi:10.1039/c5ee01283j.

[114] Bussar C, Moos M, Alvarez R, Wolf P, Thien T, Chen H, et al. Optimal Allocation and Capacity of Energy Storage Systems in a Future European Power System with 100% Renewable Energy Generation. Energy Procedia 2014;46:40–7. doi:10.1016/J.EGYPRO.2014.01.156.

[115] Bussar C, Stöcker P, Cai Z, Moraes L, Alvarez R, Chen H, et al. Large-scale integration of renewable energies and impact on storage demand in a european renewable power system of 2050. Energy Procedia, vol. 73, 2015, p. 145–53. doi:10.1016/j.egypro.2015.07.662.

[116] Grossmann WD, Grossmann I, Steininger KW. Solar electricity generation across large geographic areas, Part II: A Pan-American energy system based on solar. Renew Sustain Energy Rev 2014;32:983–93. doi:10.1016/j.rser.2014.01.003.

[117] Rasmussen MG, Andresen GB, Greiner M. Storage and balancing synergies in a fully or highly renewable pan-European power system. Energy Policy 2012;51:642–51. doi:10.1016/j.enpol.2012.09.009.

[118] Palzer A, Henning H. A comprehensive model for the German electricity and heat sector in a future energy system with a dominant contribution from renewable energy technologies – Part II: Results. Renew Sustain Energy Rev 2014;30:1019–34.

[119] Pleßmann G, Erdmann M, Hlusiak M, Breyer C. Global Energy Storage Demand for a 100% Renewable Electricity Supply. Energy Procedia 2014;46:22–31. doi:10.1016/J.EGYPRO.2014.01.154.

[120] Child M, Breyer C. Vision and initial feasibility analysis of a recarbonised Finnish energy system for 2050. Renew Sustain Energy Rev 2016;66:517–36. doi:10.1016/j.rser.2016.07.001.

[121] Breyer C, Bogdanov D, Komoto K, Ehara T, Song J, Enebish N. North-East Asian Super Grid: Renewable energy mix and economics. Jpn J Appl Phys 2015;54. doi:10.7567/JJAP.54.08KJ01.

[122] Bogdanov D, Breyer C. North-East Asian Super Grid for 100% renewable energy supply: Optimal mix of energy technologies for electricity, gas and heat supply options. Energy Convers Manag 2016;112:176–90. doi:10.1016/j.enconman.2016.01.019.

[123] Gulagi A, Bogdanov D, Breyer C. A cost optimized fully sustainable power system for Southeast Asia and the Pacific Rim. Energies 2017;10. doi:10.3390/en10050583.

[124] De Barbosa LSNS, Bogdanov D, Vainikka P, Breyer C. Hydro, wind and solar power as a base for a 100% renewable energy supply for South and Central America. PLoS One 2017;12. doi:10.1371/journal.pone.0173820.

[125] Breyer C, Bogdanov D, Gulagi A, Aghahosseini A, Barbosa LSNS, Koskinen O, et al. On the role of solar photovoltaics in global energy transition scenarios. Prog Photovoltaics Res Appl 2017;25:727–45. doi:10.1002/pip.2885.

[126] De Souza Noel Simas Barbosa L, Orozco JF, Bogdanov D, Vainikka P, Breyer C. Hydropower and Power-to-gas Storage Options: The Brazilian Energy System Case. Energy Procedia, vol. 99, 2016, p. 89–107. doi:10.1016/j.egypro.2016.10.101.

[127] Pleßmann G, Blechinger P. How to meet EU GHG emission reduction targets? A model based decarbonization pathway for Europe's electricity supply system until 2050. Energy Strateg Rev 2017;15:19–32. doi:10.1016/J.ESR.2016.11.003.

[128] Gulagi A, Bogdanov D, Fasihi M, Breyer C. Can Australia power the energy-hungry asia with renewable energy? Sustain 2017;9. doi:10.3390/su9020233.

[129] Aghahosseini A, Bogdanov D, Breyer C. A techno-economic study of an entirely renewable energy-based power supply for North America for 2030 conditions. Energies 2017;10. doi:10.3390/en10081171.

[130] Aghahosseini A, Bogdanov D, Ghorbani N, Breyer C. Analysis of 100% renewable energy for Iran in 2030: integrating solar PV, wind energy and storage. Int J Environ Sci Technol 2018;15:17–36. doi:10.1007/s13762-017-1373-4.

[131] Gulagi A, Choudhary P, Bogdanov D, Breyer C. Electricity system based on 100% renewable energy for India and SAARC. PLoS One 2017;12. doi:10.1371/journal.pone.0180611.

[132] Lu B, Blakers A, Stocks M. 90–100% renewable electricity for the South West Interconnected System of Western Australia. Energy 2017;122:663–74. doi:10.1016/j.energy.2017.01.077.

[133] Gils HC, Simon S. Carbon neutral archipelago – 100% renewable energy supply for the Canary Islands. Appl Energy 2017;188:342–55. doi:10.1016/j.apenergy.2016.12.023.

[134] Connolly D, Lund H, Mathiesen B V, Leahy M. The first step towards a 100% renewable energy system for Ireland. Appl Energy 2011;88:502–7.

[135] Turner GM, Elliston B, Diesendorf M. Impacts on the biophysical economy and environment of a transition to 100% renewable electricity in Australia. Energy Policy 2013;54:288–99. doi:10.1016/j.enpol.2012.11.038.

[136] Moeller C, Meiss J, Mueller B, Hlusiak M, Breyer C, Kastner M, et al. Transforming the electricity generation of the Berlin-Brandenburg region, Germany. Renew Energy 2014;72:39–50. doi:10.1016/j.renene.2014.06.042.

[137] Mathiesen BV, Lund H, Connolly D, Wenzel H, Østergaard PA, Möller B, et al. Smart Energy Systems for coherent 100% renewable energy and transport solutions. Appl Energy 2015;145:139–54. doi:10.1016/j.apenergy.2015.01.075.

[138] Child M, Nordling A, Breyer C. Scenarios for a sustainable energy system in the Åland Islands in 2030. Energy Convers Manag 2017;137:49–60. doi:10.1016/j.enconman.2017.01.039.

[139] Blakers A, Lu B, Stocks M. 100% renewable electricity in Australia. Energy 2017;133:471–82. doi:10.1016/j.energy.2017.05.168.

[140] Pleßmann G, Blechinger P. Outlook on South-East European power system until 2050: Least-cost decarbonization pathway meeting EU mitigation targets. Energy 2017;137:1041–53. doi:10.1016/j.energy.2017.03.076.

[141] Connolly D, Lund H, Mathiesen BV. Smart Energy Europe: The technical and economic impact of one potential 100% renewable energy scenario for the European Union. Renew Sustain Energy Rev 2016;60:1634–53. doi:10.1016/j.rser.2016.02.025.

[142] Jacobson MZ, Delucchi MA, Cameron MA, Frew BA. Low-cost solution to the grid reliability problem with 100% penetration of intermittent wind, water, and solar for all purposes. Proc Natl Acad Sci U S A 2015;112:15060–5. doi:10.1073/pnas.1510028112.

[143] Elliston B, MacGill I, Diesendorf M. Comparing least cost scenarios for 100% renewable electricity with low emission fossil fuel scenarios in the Australian National Electricity Market. Renew Energy 2014;66:196–204. doi:10.1016/j.renene.2013.12.010.

[144] Becker S, Rodriguez RA, Andresen GB, Schramm S, Greiner M. Transmission grid extensions during the build-up of a fully renewable pan-European electricity supply. Energy 2014;64:404–18. doi:10.1016/j.energy.2013.10.010.

[145] Connolly D, Mathiesen BV. A technical and economic analysis of one potential pathway to a 100% renewable energy system. Int J Sustain Energy Plan Manag 2014;1:7–28. doi:10.5278/ijsepm.2014.1.2.

[146] Steinke F, Wolfrum P, Hoffmann C. Grid vs. storage in a 100% renewable Europe. Renew Energy 2013;50:826–32. doi:10.1016/j.renene.2012.07.044.

[147] Hart EK, Jacobson MZ. The carbon abatement potential of high penetration intermittent renewables. Energy Environ Sci 2012;5:6592–601. doi:10.1039/c2ee03490e.

[148] Hart EK, Jacobson MZ. A Monte Carlo approach to generator portfolio planning and carbon emissions assessments of systems with large penetrations of variable renewables. Renew Energy 2011;36:2278–86. doi:10.1016/j.renene.2011.01.015.

[149] Mathiesen BV, Lund H, Karlsson K. 100% Renewable energy systems, climate mitigation and economic growth. Appl Energy 2011;88. doi:10.1016/j.apenergy.2010.03.001.

[150] Jacobson MZ, Delucchi MA, Bauer ZAF, Goodman SC, Chapman WE, Cameron MA, et al. 100% Clean and Renewable Wind, Water, and Sunlight All-Sector Energy Roadmaps for 139 Countries of the World. Joule 2017;1:108–21. doi:10.1016/J.JOULE.2017.07.005.

[151] Huber M, Weissbart C. On the optimal mix of wind and solar generation in the future Chinese power system. Energy 2015;90:235–43. doi:10.1016/j.energy.2015.05.146.

[152] Gils HC, Scholz Y, Pregger T, Luca de Tena D, Heide D. Integrated modelling of variable renewable energy-based power supply in Europe. Energy 2017;123:173–88. doi:10.1016/j.energy.2017.01.115.

[153] Eriksen EH, Schwenk-Nebbe LJ, Tranberg B, Brown T, Greiner M. Optimal heterogeneity in a simplified highly renewable European electricity system. Energy 2017;133:913–28. doi:10.1016/j.energy.2017.05.170.

[154] Ghorbani N, Aghahosseini A, Breyer C. Transition towards a 100% Renewable Energy System and the Role of Storage Technologies: A Case Study of Iran. Energy Procedia 2017;135:23–36. doi:10.1016/J.EGYPRO.2017.09.484.

[155] Child M, Breyer C, Bogdanov D, Fell H-J. The role of storage technologies for the transition to a 100% renewable energy system in Ukraine. Energy Procedia 2017;135:410–23. doi:10.1016/J.EGYPRO.2017.09.513.

[156] Fernandes L, Ferreira P. Renewable energy scenarios in the Portuguese electricity system. Energy 2014;69:51–7. doi:10.1016/j.energy.2014.02.098.

[157] Gulagi A, Bogdanov D, Breyer C. The Demand For Storage Technologies In Energy Transition Pathways Towards 100% Renewable Energy For India. Energy Procedia 2017;135:37–50. doi:10.1016/J.EGYPRO.2017.09.485.

[158] Gulagi A, Bogdanov D, Breyer C. The role of storage technologies in energy transition pathways towards achieving a fully sustainable energy system for India. J Energy Storage 2018;17:525–39. doi:10.1016/j.est.2017.11.012.

[159] Kies A, Schyska B, Thanh Viet D, Von Bremen L, Heinemann D, Schramm S. Large-Scale Integration of Renewable Power Sources into the Vietnamese Power System. Energy Procedia, vol. 125, 2017, p. 207–13. doi:10.1016/j.egypro.2017.08.188.

[160] Foyn THY, Karlsson K, Balyk O, Grohnheit PE. A global renewable energy system. A modelling exercise in ETSAP/TIAM. Appl Energy 2011;88:526–34. doi:10.1016/j.apenergy.2010.05.003.

[161] Gils HC, Simon S, Soria R. 100% Renewable energy supply for Brazil-The role of sector coupling and regional development. Energies 2017;10. doi:10.3390/en10111859.

[162] Caldera U, Breyer C. Impact of Battery and Water Storage on the Transition to an Integrated 100% Renewable Energy Power System for Saudi Arabia. Energy Procedia, vol. 135, 2017, p. 126–42. doi:10.1016/j.egypro.2017.09.496.

[163] Caldera U, Breyer C. The role that battery and water storage play in Saudi Arabia's transition to an integrated 100% renewable energy power system. J Energy Storage 2018;17:299–310. doi:10.1016/j.est.2018.03.009.

[164] Kilickaplan A, Bogdanov D, Peker O, Caldera U, Aghahosseini A, Breyer C. An energy transition pathway for Turkey to achieve 100% renewable energy powered electricity, desalination and non-energetic industrial gas demand sectors by 2050. Sol Energy 2017;158:218–35. doi:10.1016/j.solener.2017.09.030.

[165] Hall M, Swingler A. Initial perspective on a 100% renewable electricity supply for Prince Edward Island. Int J Environ Stud 2018;75:135–53. doi:10.1080/00207233.2017.1395246.

[166] Sadiqa A, Gulagi A, Breyer C. Energy transition roadmap towards 100% renewable energy and role of storage technologies for Pakistan by 2050. Energy 2018;147:518–33. doi:10.1016/j.energy.2018.01.027.

[167] Krajacic G, Duic N, Carvalho M da G. How to achieve a 100% RES electricity supply for Portugal? Appl Energy 2011;88:508–17.

[168] Jacobson MZ, Delucchi MA, Cameron MA, Mathiesen B V. Matching demand with supply at low cost in 139 countries among 20 world regions with 100% intermittent wind, water, and sunlight (WWS) for all purposes. Renew Energy 2018;123:236–48. doi:10.1016/J.RENENE.2018.02.009.

[169] Hohmeyer OH, Bohm S. Trends toward 100% renewable electricity supply in Germany and Europe: a paradigm shift in energy policies. WILEY Interdiscip Rev Environ 2015;4:74–97. doi:10.1002/wene.128.

[170] Liu H, Andresen GB, Greiner M. Cost-optimal design of a simplified highly renewable Chinese electricity network. Energy 2018;147:534–46. doi:10.1016/j.energy.2018.01.070.

[171] Rodríguez RA, Becker S, Andresen GB, Heide D, Greiner M. Transmission needs across a fully renewable European power system. Renew Energy 2014;63:467–76. doi:http://dx.doi.org/10.1016/j.renene.2013.10.005.

[172] Rodriguez RA, Becker S, Greiner M. Cost-optimal design of a simplified, highly renewable pan-

European electricity system. Energy 2015;83:658–68. doi:10.1016/j.energy.2015.02.066.

[173] Löffler K, Hainsch K, Burandt T, Oei P-Y, Kemfert C, Von Hirschhausen C. Designing a model for the global energy system-GENeSYS-MOD: An application of the Open-Source Energy Modeling System (OSeMOSYS). Energies 2017;10. doi:10.3390/en10101468.

[174] Teske S, Pregger T, Simon S, Naegler T, Graus W, Lins C. Energy [R]evolution 2010-a sustainable world energy outlook. Energy Effic 2011;4:409–33. doi:10.1007/s12053-010-9098-y.

[175] Meschede H, Child M, Breyer C. Assessment of sustainable energy system configuration for a small Canary island in 2030. Energy Convers Manag 2018;165:363–72. doi:10.1016/j.enconman.2018.03.061.

[176] Khoodaruth A, Oree V, Elahee MK, Clark WW. Exploring options for a 100% renewable energy system in Mauritius by 2050. Util Policy 2017;44:38–49. doi:10.1016/j.jup.2016.12.001.

[177] Frew BA, Becker S, Dvorak MJ, Andresen GB, Jacobson MZ. Flexibility mechanisms and pathways to a highly renewable US electricity future. Energy 2016;101:65–78. doi:10.1016/j.energy.2016.01.079.

[178] Esteban M, Zhang Q, Utama A. Estimation of the energy storage requirement of a future 100% renewable energy system in Japan. Energy Policy 2012;47:22–31. doi:10.1016/j.enpol.2012.03.078.

[179] Simon S, Naegler T, Gils HC. Transformation towards a renewable energy system in Brazil and Mexico-Technological and structural options for Latin America. Energies 2018;11. doi:10.3390/en11040907.

[180] Barasa M, Bogdanov D, Oyewo AS, Breyer C. A cost optimal resolution for Sub-Saharan Africa powered by 100% renewables in 2030. Renew Sustain Energy Rev 2018;92:440–57. doi:10.1016/j.rser.2018.04.110.

[181] Bogdanov D, Farfan J, Sadovskaia K, Fasihi M, Child M, Breyer C. Arising role of photovoltaic and wind energy in the power sector and beyond: Changing the Northeast Asian power landscape. Jpn J Appl Phys 2018;57. doi:10.7567/JJAP.57.08RJ01.

[182] Oyewo AS, Farfan J, Peltoniemi P, Breyer C. Repercussion of large scale hydro dam deployment: The case of congo Grand Inga hydro project. Energies 2018;11. doi:10.3390/en11040972.

[183] Esteban M, Portugal-Pereira J. Post-disaster resilience of a 100% renewable energy system in Japan. Energy 2014;68:756–64. doi:10.1016/j.energy.2014.02.045.

[184] Solomon AA, Bogdanov D, Breyer C. Solar driven net zero emission electricity supply with negligible carbon cost: Israel as a case study for Sun Belt countries. Energy 2018;155:87–104. doi:10.1016/j.energy.2018.05.014.

[185] Laslett D, Carter C, Creagh C, Jennings P. A large-scale renewable electricity supply system by 2030: Solar, wind, energy efficiency, storage and inertia for the South West Interconnected System (SWIS) in Western Australia. Renew Energy 2017;113:713–31. doi:10.1016/j.renene.2017.06.023.

[186] Howard BS, Hamilton NE, Diesendorf M, Wiedmann T. Modeling the carbon budget of the Australian electricity sector's transition to renewable energy. Renew Energy 2018;125:712–28. doi:10.1016/j.renene.2018.02.013.

[187] Raunbak M, Zeyer T, Zhu K, Greiner M. Principal mismatch patterns across a simplified highly renewable European electricity network. Energies 2017;10. doi:10.3390/en10121934.

[188] Jacobson MZ, Cameron MA, Hennessy EM, Petkov I, Meyer CB, Gambhir TK, et al. 100% clean and renewable Wind, Water, and Sunlight (WWS) all-sector energy roadmaps for 53 towns and cities in

North America. Sustain Cities Soc 2018;42:22–37. doi:10.1016/j.scs.2018.06.031.

[189] Budischak C, Sewell D, Thomson H, Mach L, Veron DE, Kempton W. Cost-minimized combinations of wind power, solar power and electrochemical storage, powering the grid up to 99.9% of the time. J Power Sources 2013;225:60–74. doi:10.1016/J.JPOWSOUR.2012.09.054.

[190] Akuru UB, Onukwube IE, Okoro OI, Obe ES. Towards 100% renewable energy in Nigeria. Renew Sustain Energy Rev 2017;71:943–53. doi:10.1016/j.rser.2016.12.123.

[191] Deng YY, Blok K, van der Leun K. Transition to a fully sustainable global energy system. Energy Strateg Rev 2012;1:109–21. doi:10.1016/j.esr.2012.07.003.

[192] Heuberger CF, Mac Dowell N. Real-World Challenges with a Rapid Transition to 100% Renewable Power Systems. Joule 2018;2:367–70. doi:10.1016/j.joule.2018.02.002.

[193] Cabrera P, Lund H, Carta JA. Smart renewable energy penetration strategies on islands: The case of Gran Canaria. Energy 2018;162:421–43. doi:10.1016/j.energy.2018.08.020.

[194] Duić N, Da Graça Carvalho M. Increasing renewable energy sources in island energy supply: Case study Porto Santo. Renew Sustain Energy Rev 2004;8:383–99. doi:10.1016/j.rser.2003.11.004.

[195] Krajačić G, Duić N, Carvalho M d. G. H<inf>2</inf>RES, Energy planning tool for island energy systems - The case of the Island of Mljet. Int J Hydrogen Energy 2009;34:7015–26. doi:10.1016/j.ijhydene.2008.12.054.

[196] Bačelić Medić Z, Ćosić B, Duić N. Sustainability of remote communities: 100% renewable island of Hvar. J Renew Sustain Energy 2013;5. doi:10.1063/1.4813000.

[197] Nikolic D, Tereapii T, Lee WY, Blanksby C. Cook Islands: 100% Renewable Energy in Different Guises. Energy Procedia, vol. 103, 2016, p. 207–12. doi:10.1016/j.egypro.2016.11.274.

[198] Krajačić G, Duić N, Zmijarević Z, Mathiesen BV, Vučinić AA, da Graça Carvalho M. Planning for a 100% independent energy system based on smart energy storage for integration of renewables and CO2 emissions reduction. Appl Therm Eng 2011;31:2073–83. doi:10.1016/J.APPLTHERMALENG.2011.03.014.

[199] Praene JP, David M, Sinama F, Morau D, Marc O. Renewable energy: Progressing towards a net zero energy island, the case of Reunion Island. Renew Sustain Energy Rev 2012;16:426–42. doi:10.1016/j.rser.2011.08.007.

[200] Sørensen B. Energy and Resources. Science (80-) 1975;189:255 LP-260. doi:10.1126/science.189.4199.255.

[201] The DESERTEC Foundation. THE DESERTEC-ATLAS n.d.

[202] Czisch G. Szenarien zur zukünftigen Stromversorgung - Kostenoptimierte Variationen zur VersorgungEuropas und seiner Nachbarn mit Strom auserneuerbaren Energien. University of Kassel, 2005.

[203] Child M, Koskinen O, Linnanen L, Breyer C. Sustainability guardrails for energy scenarios of the global energy transition. Renew Sustain Energy Rev 2018;91:321–34. doi:10.1016/J.RSER.2018.03.079.

[204] Brown TW, Bischof-Niemz T, Blok K, Breyer C, Lund H, Mathiesen BV. Response to 'Burden of proof: A comprehensive review of the feasibility of 100% renewable-electricity systems.' Renew Sustain Energy Rev 2018;92. doi:10.1016/j.rser.2018.04.113.

[205] Lund H, Arler F, Østergaard PA, Hvelplund F, Connolly D, Mathiesen B, et al. Simulation versus Optimisation: Theoretical Positions in Energy System Modelling. Energies 2017;10:840.

doi:10.3390/en10070840.

[206] Lund H, Sorknæs P, Mathiesen BV, Hansen K. Beyond sensitivity analysis: A methodology to handle fuel and electricity prices when designing energy scenarios. Energy Res Soc Sci 2018;39:108–16. doi:10.1016/J.ERSS.2017.11.013.

[207] Trainer T. Some problems in storing renewable energy. Energy Policy 2017;110:386–93. doi:10.1016/j.enpol.2017.07.061.

[208] Heard BP, Brook BW, Wigley TML, Bradshaw CJA. Burden of proof: A comprehensive review of the feasibility of 100% renewable-electricity systems. Renew Sustain Energy Rev 2017;76:1122–33. doi:10.1016/j.rser.2017.03.114.

[209] Pfenninger S, Hirth L, Schlecht I, Schmid E, Wiese F, Brown T, et al. Opening the black box of energy modelling: Strategies and lessons learned. Energy Strateg Rev 2018;19:63–71. doi:10.1016/J.ESR.2017.12.002.

[210] Lund H, Østergaard PA, Connolly D, Mathiesen BV. Smart energy and smart energy systems. Energy 2017. doi:10.1016/j.energy.2017.05.123.

[211] Lund H, Østergaard PA, Connolly D, Ridjan I, Mathiesen BV, Hvelplund F, et al. Energy Storage and Smart Energy Systems. Int J Sustain Energy Plan Manag 2016;11:3–14. doi:10.5278/ijsepm.2016.11.2.

[212] Brown T, Schlachtberger D, Kies A, Schramm S, Greiner M. Synergies of sector coupling and transmission reinforcement in a cost-optimised, highly renewable European energy system. Energy 2018;160:720–39. doi:10.1016/J.ENERGY.2018.06.222.

[213] Breyer C, Khalili S, Bogdanov D. Solar Photovoltaic Capacity Demand for a Sustainable Transportation Sector to Fulfil the Paris Agreement by 2050. Prog Photovoltaics Res Appl 2019;In Press. doi:10.1002/pip.3114.

[214] Fleiter T, Elsland R, Rehfeldt M, Steinbach J, Reiter U, Catenazzi G, et al. Profile of heating and cooling demand in 2015. Heat Roadmap Europe Deliverable 3.1; 2017.

[215] Ram M, Bogdanov D, Aghahosseini A, Gulagi A, Oyewo AS, Child M, et al. Global Energy System based on 100% Renewable Energy – Energy Transition in Europe Across Power, Heat, Transport and Desalination Sectors. Berlin, Germany: 2018.

[216] Fuss S, Lamb WF, Callaghan MW, Hilaire J, Creutzig F, Amann T, et al. Negative emissions—Part 2: Costs, potentials and side effects. Environ Res Lett 2018;13:063002. doi:10.1088/1748-9326/aabf9f.

[217] Bui M, Adjiman CS, Bardow A, Anthony EJ, Boston A, Brown S, et al. Carbon capture and storage (CCS): the way forward. Energy Environ Sci 2018;11:1062–176. doi:10.1039/C7EE02342A.

[218] Creutzig F, Breyer C, Hilaire J, Minx J, Peters G, Socolow RH. The mutual dependence of negative emission technologies and energy systems. Energy Environ Sci 2019. doi:10.1039/C8EE03682A.

[219] Caldera U, Bogdanov D, Afanasyeva S, Breyer C. Role of Seawater Desalination in the Management of an Integrated Water and 100% Renewable Energy Based Power Sector in Saudi Arabia. Water 2018;10. doi:10.3390/w10010003.

[220] Mathiesen BV, Lund H, Hansen K, Ridjan I, Djørup S, Nielsen S, et al. IDA's Energy Vision 2050. A Smart Energy System strategy for 100% renewable Denmark. Aalborg: 2015.

[221] Lund H, Thellufsen JZ, Aggerholm S, Wichtten KB, Nielsen S, Mathiesen BV, et al. Heat Saving Strategies in Sustainable Smart Energy Systems. Int J Sustain Energy Plan Manag 2014;04:3–16.

doi:10.5278/ijsepm.2014.4.2.

[222] Hansen K, Connolly D, Lund H, Drysdale D, Thellufsen JZ. Heat Roadmap Europe: Identifying the balance between saving heat and supplying heat. Energy 2016;115:1663–71. doi:10.1016/j.energy.2016.06.033.

[223] Creutzig F, Agoston P, Goldschmidt JC, Luderer G, Nemet G, Pietzcker RC. The underestimated potential of solar energy to mitigate climate change. Nat Energy 2017;2:17140.

[224] Breyer C, Bogdanov D, Aghahosseini A, Gulagi A, Child M, Oyewo AS, et al. Solar photovoltaics demand for the global energy transition in the power sector. Prog Photovoltaics Res Appl 2018;26:505–23. doi:10.1002/pip.2950.

[225] Pursiheimo E, Holttinen H, Koljonen T. Inter-sectoral effects of high renewable energy share in global energy system. Renew Energy 2018. doi:10.1016/J.RENENE.2018.09.082.

[226] Sgouridis S, Csala D, Bardi U. The sower's way: quantifying the narrowing net-energy pathways to a global energy transition. Environ Res Lett 2016;11:094009. doi:10.1088/1748-9326/11/9/094009.

[227] Dominković DF, Bačeković I, Ćosić B, Krajačić G, Pukšec T, Duić N, et al. Zero carbon energy system of South East Europe in 2050. Appl Energy 2016;184. doi:10.1016/j.apenergy.2016.03.046.

[228] Lund H. Renewable Energy Systems : A Smart Energy Systems Approach to the Choice and Modeling of 100% Renewable Solutions. vol. 2. Burlington, USA: Academic Press; 2014.

[229] Hof C, Voskamp A, Biber MF, Böhning-Gaese K, Engelhardt EK, Niamir A, et al. Bioenergy cropland expansion may offset positive effects of climate change mitigation for global vertebrate diversity. Proc Natl Acad Sci 2018;115:13294 LP-13299. doi:10.1073/pnas.1807745115.