energies

MDPI

Article

Economic Feasibility of Energy Supply by Small Modular Nuclear Reactors on Small Islands: Case Studies of Jeju, Tasmania and Tenerife

Sanghyun Hong * and **Barry W. Brook**

College of Science & Engineering, University of Tasmania, Private Bag 55, Hobart 7001, Australia; Barry.brook@utas.edu.au

* Correspondence: Sanghyun.hong@utas.edu.au

Received: 28 August 2018; Accepted: 27 September 2018; Published: 28 September 2018

Abstract: Small modular nuclear reactors (SMRs) offer the promise of providing carbon-free electricity and heat to small islands or isolated electricity grids. However, the economic feasibility of SMRs is highly system-dependent and has not been studied in this context. We selected three case-study islands for such an evaluation: Jeju, Tasmania and Tenerife based on their system complexity. We generated 100,000 electricity-mix cases stochastically for each island and examined the system-level generation-cost changes by incrementing the average generation cost of SMRs from USD$60 to 200 MWh^{-1}. SMRs were found to be economically viable when average generation cost was <$100 MWh^{-1} for Jeju and <$140 MWh^{-1} for Tenerife. For Tasmania the situation was complex; hydroelectric power is an established competitor, but SMRs might be complementary in a future "battery of the nation" scenario where most of the island's hydro capacity was exported to meet peak power demand on the mainland grid. The higher average generation cost of SMRs makes it difficult for them to compete economically with a fossil fuel/renewable mix in many contexts. However, we have demonstrated that SMRs can be an economically viable carbon-free option for a small island with a limited land area and high energy demand.

Keywords: small modular reactors; renewable; small island; micro grid; isolated grid

1. Introduction

Decarbonizing electricity generation is fundamental for limiting the mean global temperature increase to the levels proposed in the Paris Agreement (<2 °C above pre-industrial by 2100). The countries that ratified the Paris Agreement have widely varying decarbonization policies, energy histories and future development constraints. Many national-level pathways seek to pursue a combination of the expansion of variable renewable sources (e.g., wind, solar) along with a substantial backup supply from gas or hydroelectric power [1]. Some countries have a plan to depend on, or expand, their existing nuclear fleet or deploy fossil-fueled power stations equipped with carbon capture and sequestration (CCS). Although the extent to which increasing the share of variable renewable energy sources can reduce the share of fossil fuels effectively compared with nuclear power is strongly debated [2,3], it seems inevitable that variable renewable energy sources will meet a significant fraction of electricity demand in many future national-level electricity grids.

However, physical constraints (e.g., limited land area) becomes a major hurdle for the expansion of variable renewable energy sources for geographically bounded areas, such as the 87,000 inhabited small islands worldwide, where >740 million people currently live [4]. Given that the globally averaged per-capita electricity consumption now exceeds 3 MWh p.a. [5], the total annual electricity consumption of small island inhabitants is ~2250 TWh [5]. Currently, fossil generators such as diesel- or steam-powered turbines are the major sources of electricity, due to their compact footprint [6].

Small modular reactors (SMR) have been proposed in recent energy discussions as a potential way to address such issues in micro grids. Six different 'types' of SMRs (based on broad categorizations of >50 designs) are under development or construction globally [7]. Land-based light water reactors are the most mature technology, which has historically been adopted for monolithic nuclear reactor technologies. One SMR unit with 30 MWe of power output (CAREM) is currently under construction in Argentina (CNEA, Argentina), and South Korea (KAERI, South Korea) is developing 100 MWe reactors (SMART). For isolated regions where fundamental infrastructure and accessible land area (e.g., small islands, polar bases, etc.) are limited, marine-based light water reactors are an alternative option. In this context, the Russian Federation (OKBM Afrikantov, Russia) is building a 70 MWe floating reactor (KLT-40S). For more efficient electricity generation, high temperature (≥750 °C) gas-cooled reactors have been developed [8]. One such unit, with 210 MWe of power output (high-temperature gas-cooled (HTGR) pebble-bed generation IV reactor, HTR-PM), is being constructed in China (INET, Tsinghua University). Other types of SMRs under development include fast-neutron spectrum reactors, molten salt reactors and small-heat-pipe reactors [7].

Some recent work has assessed optimal electricity-generation mixes on small islands in the context of their economic and geographical constraints [4,6], and have also explored opportunities for alternative systems such as electric vehicles and energy storage [9,10]. However, these studies have, in general, focused on a varying range of renewable-only solutions for small islands, and neglected to consider any role for small modular reactors (SMR) (i.e., nuclear power plants with <300 MWe; [11]), whether it be exclusive to, or in synergy with, renewable-energy supply. Complicating the matter is the wide differences in renewable-energy potential, available land area and electricity demand patterns across small islands, making it difficult to draw any high-level conclusions on the economic feasibility of SMRs in this context.

To redress this gap in knowledge, we sought to covered virtually all possible electricity-generation scenarios for three strategically selected small islands: Jeju (South Korea), Tasmania (Australia), and Tenerife (Spain), based on 100,000 possible energy mixes for each island, covering the full gamut of renewables, SMR nuclear, and fossil fuels with CCS. We then analyzed the system-level economic costs, greenhouse-gas emissions and land use by the simulated share of SMRs, variable renewable energy sources and fossil fuels, to determine optimal outcomes for each representative case studies, and to draw more general conclusions about the potential role of SMRs in helping to meet low-carbon energy supply on small islands.

2. Methodology

2.1. Three Islands

We selected three small islands to represent the diversity of scenarios facing small islands globally, such as energy demand, potential renewable energy sources, land area and system complexity (e.g., transmission to the mainland). The three were Jeju in South Korea, Tasmania in Australia and Tenerife in Spain (Table 1). Critically, all had sufficient historical and current data available on which to base a robust modelling exercise. Jeju island is the smallest among the three by area, and Tasmania the largest. Tenerife has the largest population but the lowest annual and demand peak and has no transmission connection to any mainland grid and has a large influx of tourists annually. Tasmania, by contrast, has the lowest population of the three but the highest annual and demand peak, but is connected to mainland Australia by a recently built transmission line. Jeju island relies on its long-established connection to the mainland for over half of its supply (57.6%). Hydroelectric power is the main source of electricity for Tasmania, and fossil fuels (e.g., diesel, gas) for Tenerife.

Table 1. Three case-study islands (Jeju, Tasmania and Tenerife), giving their geographical location, land area, population, peak and annual demand, annual renewable and fossil-fuel supply shares, and transmission-connection to the mainland grid.

	Jeju	Tasmania	Tenerife
Latitude	33° N	42° S	28° N
Longitude	126° E	147° E	16° E
Area (km^2)	1849	68,401	2034
Population	604,771	515,000	889,936
Transmission (MW)	400 (from mainland to Jeju)	500 (bidirectional)	None
Peak (MW)	921	1721	569
Demand (GWh)	5422	10,527	3530
Renewables (GWh)	714 (wind)	8038 (hydro) 1063 (wind)	62 (wind)
Fossil fuels (GWh)	2410	794	3488

2.2. Data

We sourced input data from local sources for each case-study island. We obtained hourly electricity-demand profiles for each island from its own system operator: Korea Power Exchange [12] for Jeju, Australian Energy Market Operator (AEMO) [13] for Tasmania, and Red Eléctrica de España [14] for Tenerife, along with hourly electricity-generation profiles for wind and solar photovoltaic. We divided the generation profile by the peak generation to obtain the hourly generation profile per unit of capacity (1 MW). We obtained the levelized cost of each electricity-generation source from the same sources for Jeju [12] and Tenerife [14], and a report published by the Bureau of Resources and Energy Economics [15] for Tasmania.

Land area came from various published sources: Hernandez et al. [16] for a typical solar photovoltaic plant, a National Renewable Energy Laboratory (NREL) report [17] for onshore wind power, and print report on the size of a new solar thermal power plant in South Australia [18] (Table 2). We did not include the land requirements of conventional power plants since this is not relevant to the capacity of a power plant, and a GW-scale power plant can fit into a negligibly small land-area (<0.01 km^2) [19]. We also did not include the land requirement of hydroelectric power, since we only included currently operating hydroelectric power plants. We collected greenhouse-gas emissions of each source from a published report for Tasmania [20], greenhouse-gas emission inventories from Korea Power Exchange (KPX) [12] and data from the Electric Power Statistics Information System (EPSIS) [21] for Jeju. Greenhouse-gas emissions for each source for Tenerife came from public generation and emission data from Red Eléctrica de España [14].

Table 2. Land-use, greenhouse-gas emissions and average generation cost of each energy-generation source for the three case-study islands: Jeju, Tasmania and Tenerife.

Criteria	Power Plant	Jeju	Tasmania	Tenerife
land use (km^2 MW^{-1})	solar photovoltaic (pv)	0.025	0.025	0.025
	onshore wind	0.33	0.33	0.33
	solar thermal		0.04	
emissions (kg MWh^{-1})	coal	823	880	
	gas	362	519	
	oil			
	biomass	600	491	
cost (USD$ MWh^{-1}) *	solar pv	60, 80	212, 264	98.5, 137.7
	onshore wind	200, 350	111, 122	62.5, 81.2
	offshore wind		130, 225	
	solar thermal		295, 361	
	coal	80, 120	84, 94	
	gas	120, 150	81, 93	134.3, 204.4
	oil			104.3, 130.17
	biomass	120, 150	75, 160	
	hydro		75, 85	
	transmission	200, 250	150, 200	
	nuclear	60, 80	94, 99	100, 200

* Average generation costs of each source include both maximum and minimum levels.

2.3. Modelling

We included fossil fuels (e.g., coal, oil, gas), variable renewable energy sources (e.g., wind, solar photovoltaic, concentrated solar thermal), and dispatchable renewable sources (e.g., biomass, hydroelectric power) and nuclear power in our simulation study. We selected different generation options for each case-study island based on its economic viability and available land area (for future deployments of renewables). For Jeju, we included onshore wind, solar photovoltaic, biomass, coal, gas and nuclear power; for Tasmania, we included onshore and offshore wind, solar photovoltaic, concentrated solar thermal, coal, gas, biomass, hydroelectric and nuclear; for Tenerife, we included onshore wind, solar photovoltaic, gas, oil and nuclear.

We evaluated generation costs, required land area and greenhouse-gas emissions at the system level. We multiplied the average unit cost (USD$ MWh^{-1}) and greenhouse-gas emission (kg MWh^{-1}) and scaled up appropriately to estimate annual generation costs and emissions. A similar approach was used to estimate required land area based on scaling of the per-unit footprint (in km^2 MW^{-1}). Although the generation costs of variable renewables are highly volatile, being strongly dependent on the correlation between demand and generation, we assumed fixed generation costs for the sake of the model simplicity. Energy storage, such as electrochemical batteries, can reduce cost volatility to an extent [22], and so annual average generation costs will likely converge to a certain price. Since SMR nuclear is not yet widely commercialized, its electricity generation cost is unknown. We analyzed the economic feasibility of SMRs by incrementing the average generation cost (i.e., bidding price) across the range $US 60 to 200 MWh^{-1}.

We also added a reference case that nuclear power was not introduced, along with three cost variations: (1) low renewable-energy costs (e.g., technology improvement, subsidies); (2) low renewable-energy and high fossil-fuel costs (e.g., carbon tax); and (3) low renewable-energy and high fossil-fuel costs but with no priority dispatch given to variable renewable energy sources.

We stochastically produced 100,000 sets of capacity mixes for each case study. To distribute capacity mixes across all possible combinations within an island, including some extreme cases such as where one source dominates the entire capacity, we divided the system-level capacity range into 100 sections. The minimum capacity was set at 0 and the maximum total capacity set to five times the peak demand. The number of cases for each section was selected using a beta distribution, so as to allocate fewer scenarios to extreme cases and a larger probability density to more plausible intermediate cases. Power output capacity of each source ranged between 0 and the adjusted maximum capacities (peak demand divided by a source's capacity factor). This flexible approach allowed us to encompass all potential capacity mixes.

We multiplied the stochastically generated capacity mixes of a variable renewable source with its hourly generation profile (per unit of capacity) to obtain the generation profiles of variable renewable sources. For conventional-energy sources, we allocated the expected annual generation (capacity multiplied by a source's capacity factor and hours in a year) to each hour in proportion to the required generation. For the sake of model simplicity, we ignored the complications associated with balancing system-level sub-hourly demand. The electricity-supply dispatch order followed a merit order, whereby the source with the lowest average generation cost was dispatched first and the highest last. Variable renewable energy sources such as wind, solar photovoltaic and concentrated solar power had a priority over the other conventional sources in the dispatch order. This allowed for the maximal feasible use of variable renewable energy sources relative to other conventional sources. To select capacity mixes that ensure system reliability, we screened generation-mix cases for those that generated sufficient electricity for the demand of each hour, while also ensuring that total generation did not exceed 120% of annual demand.

3. Results

3.1. Jeju

The maximum share of onshore wind power in Jeju is only 60.0% of the total electricity demand, and that of solar photovoltaic is 36.7% (Figure 1). The system-level average generation cost decreases as wind expands, but it increases with the size of the solar photovoltaic share. Increases in the use of gas, biomass and inflows through the interconnector increase the average generation cost. Nuclear power has economic and environmental advantages over the other low-carbon sources in this case study, whilst the average generation cost is <$100 MWh^{-1}.

To achieve the maximum share of onshore wind power, 46.5% of the total land area of Jeju (1849 km^2) needs to be converted. Given that the current protected area (land reserved for nature conservation) in Jeju is 409 km^2, and it will increase to 639 km^2 [23], land area is the main constraint to further expansion of variable renewable energy sources in Jeju. Gas becomes a relatively low-emission source when nuclear power is excluded from the mix, or the average generation cost of nuclear power exceeds $100 MWh^{-1}. Inflows from mainland South Korea allow for reductions in emissions and land use but lead to increases in annual cost. Regardless of economic viability, nuclear power offers the only realistic zero emission source in Jeju. However, the South Korean government has proposed to phase out nuclear power [24,25]; in this situation, onshore wind power and greater inflows from the mainland would need to be the main sources of future electricity supply in a decarbonized Jeju.

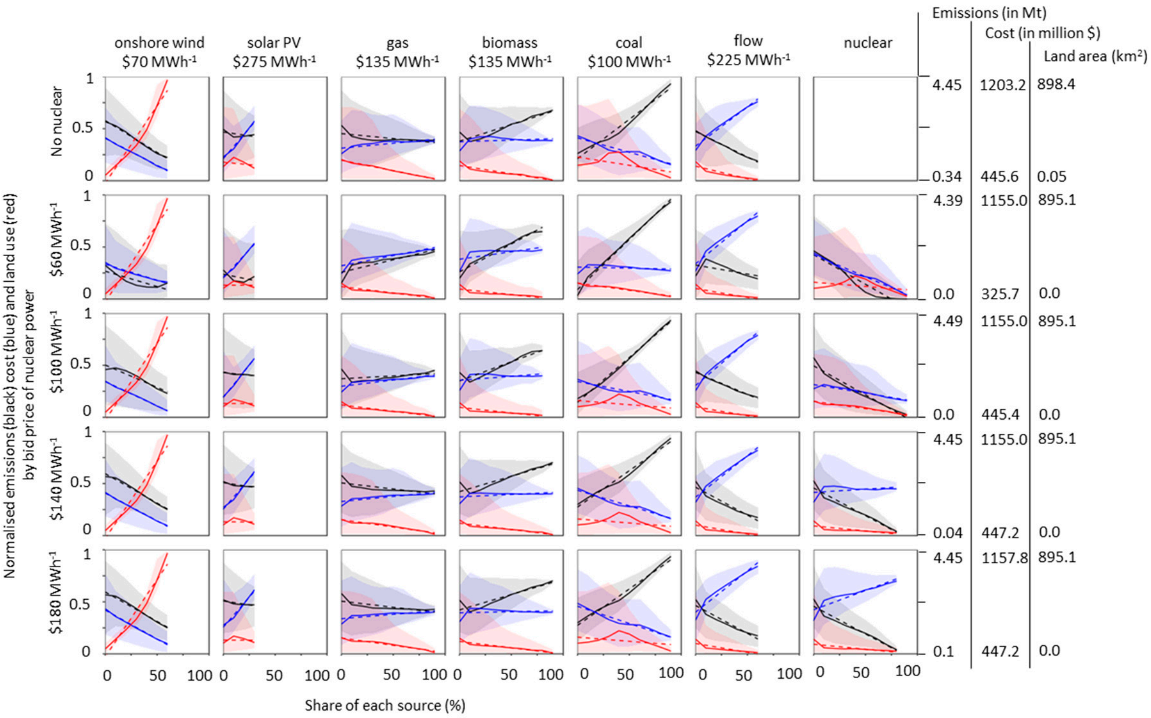

Figure 1. Jeju example: greenhouse-gas emissions (black) cost (blue) and land use (red) and its median for each section (continuous) based on incremental 5% changes in the share of each source of total annual generation, along with regression graphs (dotted) by the share of each electricity source. Each plot is redrawn from the same output to display the changes by share of each source.

3.2. Tenerife

Either onshore wind or solar photovoltaic power alone could not meet the entire electricity demand of Tenerife (Figure 2). Furthermore, a maximal combination of onshore wind and solar photovoltaics failed to achieve zero emissions if nuclear power is not included in the generation mix. If nuclear power is included (<$100 MWh^{-1}), solar photovoltaic reached its minimum greenhouse-gas emission levels (in terms of the average of each section) prior to reaching its maximum possible generation share. Land requirement had a strong positive (and exponential) correlation with the share of onshore wind, while other sources were negatively correlated. Increases in the share of onshore wind power decreased the system-level average generation cost, while increases in the share of solar photovoltaic increased the cost.

Since a combination of onshore wind power and solar photovoltaics failed to provide sufficient electricity, nuclear power must be included in Tenerife's electricity mix if decarbonization is to be achieved. However, if the average generation cost of nuclear power is higher than either gas or oil, then an increase in nuclear shares will inevitably increase the system-level generation cost. The average generation-cost changes of nuclear power did not affect the economic feasibility of variable renewable energy sources due to its priority dispatch.

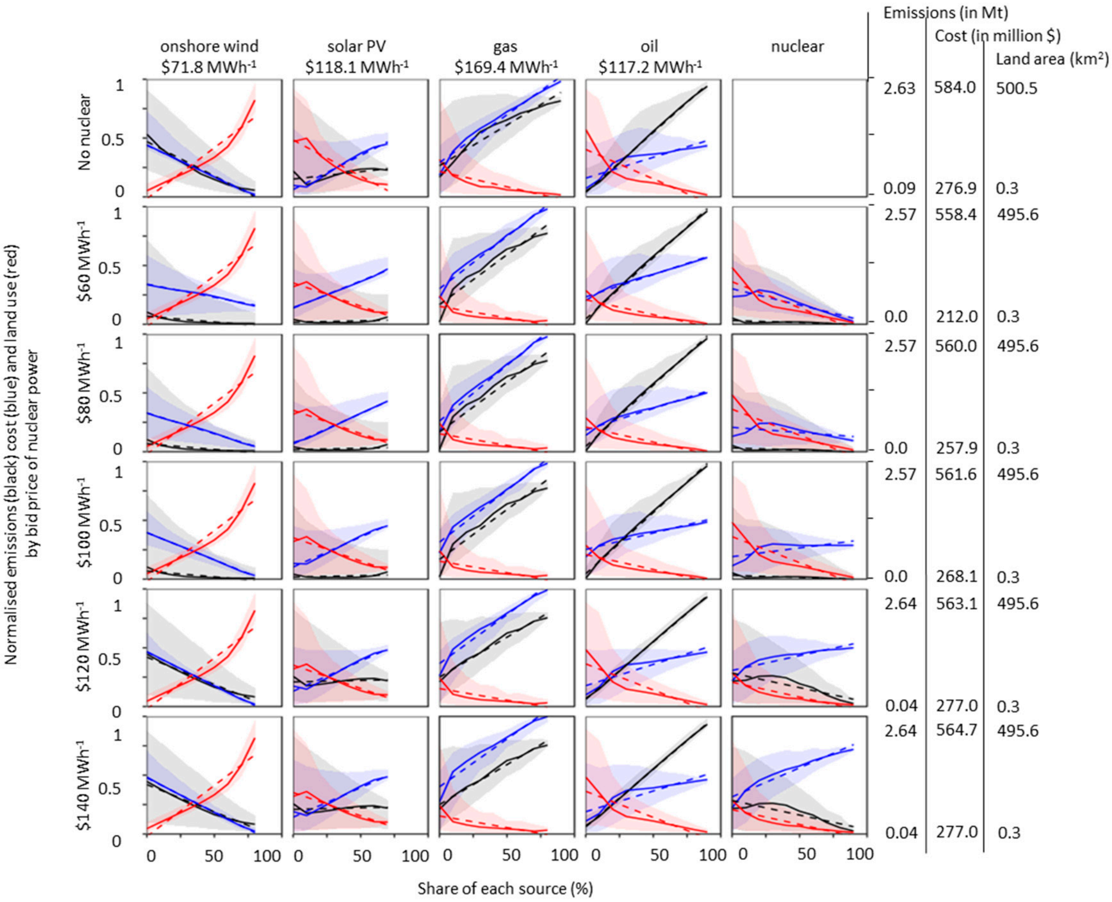

Figure 2. Tenerife example: greenhouse-gas emissions (black) cost (blue) and land use (red) and its median for each section (continuous) based on incremental 5% changes in the share by each source of total annual generation, along with regression graphs (dotted) showing the share of each electricity source. Each plot is redrawn from the same output to display the changes by share of each source.

3.3. Tasmania

Tasmania has sufficient combined onshore and offshore wind potential to theoretically cover all of its energy demand (Figure 3), due to its relatively larger land area and lower population density compared with Jeju and Tenerife. However, despite the land area, the solar-based systems (photovoltaic and thermal) cannot provide sufficient electricity. Such an expansion of variable renewable energy would require <2.5% of the island's total land area but would increase the system-level generation cost. Nuclear would only be competitive if the average generation cost is <$80 MWh^{-1}. Existing hydroelectric power with its low average-generation cost is the major competitor to nuclear power. Coal, gas and biomass failed to provide any electricity in the stochastic scenarios due to the large capacity of existing hydro. Any dispatchable power that is more expensive than existing hydro cannot compete economically in Tasmania. However, SMRs might provide baseload electricity for Tasmania if the "battery of the nation" scenario in which existing hydro capacity in Tasmania becomes a virtual/physical energy storage to provide peak power for mainland Australia [26].

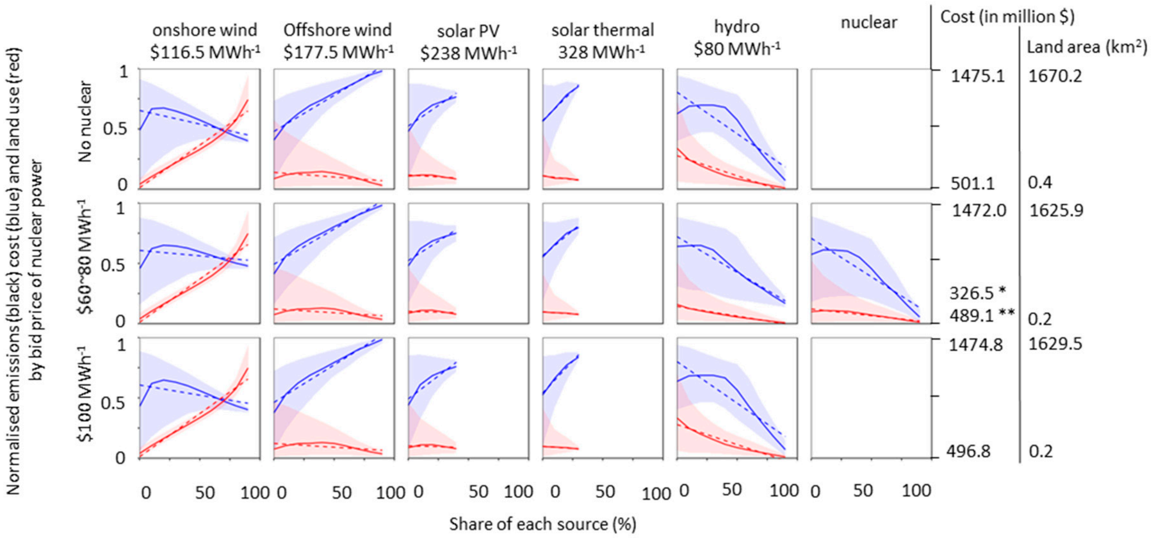

Figure 3. Tasmania example: cost (blue) and land use (red) and its median for each section (continuous) based on incremental 5% changes in the share of each source of total annual generation, along with regression graphs (dotted) showing the share of each electricity source. Each plot is redrawn from the same output to display the changes by share of each source. Note that the current greenhouse-gas emissions from electricity generation are 0 in Tasmania owing to its near-exclusive reliance on hydroelectric power (if inter-connector trading to the mainland is disregarded). * Minimum generation cost when the average generation cost of nuclear power is \$60 MWh^{-1}. ** Minimum generation cost when the average generation cost of nuclear power is \$80 MWh^{-1}.

3.4. Variation: Low Renewable, High Fossil-Fuel Costs and No Priority Dispatch

Increasing the share of solar photovoltaic, gas and oil increases the system-level generation cost in all the studied islands (Figure 4). The lower generation costs of variable renewable energy sources act to diminish the economic competitiveness of nuclear power and fossil fuels. However, such growth will potentially increase the system-level generation cost on these islands because backup generation from fossil fuels is required to cover shortfalls in variable-renewable output.

We did not attempt to estimate the required backup capacity due to changes in the correlations between demand and variable-renewable generation patterns. However, the lower the correlations and higher the penetration of variable renewables, the more the backup capacity requirement rises [27,28]. In the worst case, equal amounts of backup and installed capacity of variable renewables is required to prevent electricity supply discontinuities when the sun does not shine, and the wind does not blow. Increasing the share of onshore wind power increased the simulated system-level generation costs when renewables' priority dispatch is withdrawn, and the generation cost is then higher than nuclear power, due to large amounts of spilt generation.

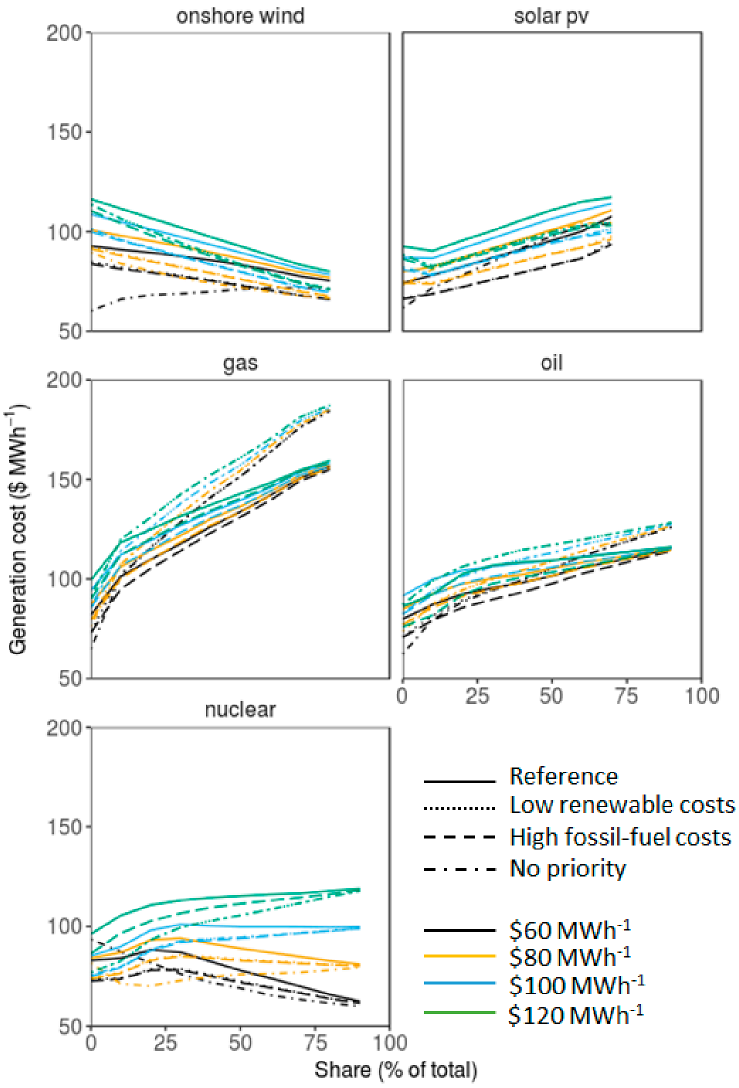

Figure 4. Tenerife example: the median value of each section of the generation costs of each source with respect to incremental changes in the average generation cost of nuclear power, from \$60 to 120 MWh^{-1}. Illustrated are four generation variations: (1) reference case, (2) low renewable cost, (3) low renewable and high fossil-fuel cost, (4) no dispatch priority to renewables on the low renewable and high fossil-fuel cost case.

4. Conclusions

On small islands with limited renewable resources and high population densities, such as Jeju and Tenerife, variable renewable energy cannot generate sufficient electricity supply to meet demand due to the physical limitations of the available land area. Although they are carbon-free, an electricity system that relies principally on variable renewable energy cannot achieve complete decarbonization due to the needs for backup sources (e.g., gas, oil and coal) [29,30]. By comparison, nuclear power could theoretically achieve a 100% carbon-free grid on such islands while minimizing land requirements and annual costs on electricity generation. Small modular reactors, which have a lower overnight capital cost and potential for deployment of distributed units, might prove to be more practical in this context compared to the currently commercial gigawatt-scale 'monolith' plants (e.g., the 1100 MWe AP1000 and 1600 MWe European Pressurized Reactor, EPR) [31].

The average generation cost which can guarantee economic feasibility of nuclear power differs across the three case-study islands. Nuclear power proved to be economically feasible when its supply cost was lower than other conventional sources (i.e., non-variable energy sources), but did not compete directly with variable renewables in our simulations due to our imposed dispatch rules that deliberately favoured wind and solar. We also found that if technology-neutral regulation environments (e.g., a straight carbon tax) are provided to decarbonize a power grid, then nuclear power has economic advantages over variable renewables. Specifically, our analysis showed that nuclear reactors with an electricity output of <300 MWe (i.e., small modular reactors) are economically feasible in a small island setting. The '*n*th-of-a-kind' cost of SMRs is anticipated to be well below \$100 MWh^{-1} of electricity output [11] which is lower than the threshold cost that SMRs would need to meet to be economically viable in all three cases. Our result is thus aligned with other research that argues for SMRs being an economically suitable technology to service micro grids with an average power demand of between 1 to 3 GWe [32,33].

To realize the maximum economic benefits from SMRs, however, some challenges remain. An initial order of a large number of modules will probably be required, to create the market conditions favourable for the establishment of a production and export facility for SMRs and for development of comprehensive management and safety plans, such as spent-fuel management strategies, evacuation plans and monitoring schedules along with requirements for a technology-neutral regulatory environment [11,34]. For Jeju in South Korea, a country where nuclear power is one of the main sources of electricity and continues to be being actively constructed, these issues are not major concerns. Conversely, for Tasmania in Australia, where nuclear power is legally prohibited, regulatory barriers are the first problem to overcome. In their favour, all three countries already have favourable financial and economic levels, infrastructure and regulatory frameworks in energy and radiation-protection sectors [34].

A smaller-sized, factory-based manufacturing process using standardized components, coupled with the clustering of multiple units of SMRs within 'energy parks', can potentially reduce the long-run construction cost and shorten the delivery period [31,32]. Moreover heat production from SMRs (an inevitable by-product of the Carnot cycle of heat engines that is exploited today in fossil-fuel-powered combined heat-and-power units in Europe), if aligned with district heating systems (>100 °C) in cold climates, or else the provision of evaporative or reverse osmosis desalination services in tropical islands, could generate other economically attractive revenue streams [32,35–38]. High-temperature thermal output of advanced reactor technologies can be used for other industrial purposes, such as petroleum refining (>300 °C), hydrogen production (>400~600 °C) [39,40], coal gasification (>800 °C) and blast furnace steel making (>900 °C) processes [7].

In summary, we examined the economic feasibility of small modular reactors for three case-study islands: Jeju, Tasmania and Tenerife. Using a probabilistic approach, we demonstrated that SMRs are not only economically viable, but also environmentally friendly, for small islands. We also confirmed that the limited land area of a small island with large populations is the main barrier to expanding the share of variable renewable resources. As such, we argue that a level playing field, in terms of a technology-neutral regulatory environment, needs to be provided to achieve the greatest economic and environmental benefits of SMRs on islands.

Author Contributions: All authors contribute equally to this work.

Funding: This research was funded by Australian Research Council grant FL160100101 to Barry W. Brook.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. International Energy Agency (IEA). *World Energy Outlook 2016*; International Energy Agency: Paris, France, 2016.
2. York, R.; McGee, J.A. Does Renewable Energy Development Decouple Economic Growth from CO_2 Emissions? *Socius* **2017**, *3*. [CrossRef]

3. Hansen, J.P.; Narbel, P.A.; Aksnes, D.L. Limits to growth in the renewable energy sector. *Renew. Sustain. Energy Rev.* **2017**, *70*, 769–774. [CrossRef]
4. Howe, E.; Blechinger, P.; Cader, C.; Breyer, C. Analyzing drivers and barriers for renewable energy integration to small islands power generation–tapping a huge market potential for mini-grids. In Proceedings of the 2nd International Conference on Micro Perspectives for Decentralized Energy, Berlin, Germany, 27 February 2013.
5. IEA. Statistics. Available online: http://www.iea.org/statistics/ (accessed on 16 February 2018).
6. Szabó, S.; Kougias, I.; Moner-Girona, M.; Bódis, K. Sustainable Energy Portfolios for Small Island States. *Sustainability* **2015**, *7*, 12340–12358. [CrossRef]
7. IAEA. Advances in Small Modular Reactor Technology Developments. Available online: https://aris.iaea.org/publications/smr-book_2018.pdf (accessed on 13 September 2018).
8. Fukaya, Y.; Goto, M. Sustainable and safe energy supply with seawater uranium fueled HTGR and its economy. *Ann. Nucl. Energy* **2017**, *99*, 19–27. [CrossRef]
9. Blechinger, P.; Seguin, R.; Cader, C.; Bertheau, P.; Breyer, C. Assessment of the Global Potential for Renewable Energy Storage Systems on Small Islands. *Energy Procedia* **2014**, *46*, 294–300. [CrossRef]
10. Díaz, A.R.; Ramos-Real, F.J.; Marrero, G.A.; Perez, Y. Impact of Electric Vehicles as Distributed Energy Storage in Isolated Systems: The Case of Tenerife. *Sustainability* **2015**, *7*, 15152–15178. [CrossRef]
11. Lokhov, A.; Cameron, R.O.N.; Sozoniuk, V. OECD/NEA Study on the economics and market of small reactors. *Nucl. Eng. Technol.* **2013**, *45*, 701–706. [CrossRef]
12. Korea Power Exchange. Korea Power Exchange. Available online: https://www.kpx.or.kr/eng/index.do (accessed on 20 June 2018).
13. AEMO. Generation and Load. Available online: https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Data/Market-Management-System-MMS/Generation-and-Load (accessed on 20 June 2018).
14. Red Eléctrica de España. Home | Red Eléctrica de España. Available online: http://www.ree.es/en (accessed on 20 June 2018).
15. Syed, A. *The Australian Energy Assessment (AETA) 2013 Model Update*; BREE: Canberra, Australia, 2018.
16. Hernandez, R.R.; Hoffacker, M.K.; Murphy-Mariscal, M.L.; Wu, G.C.; Allen, M.F. Solar energy development impacts on land cover change and protected areas. *Proc. Natl. Acad. Sci. USA* **2015**, *112*, 13579–13584. [CrossRef] [PubMed]
17. Denholm, P.; Hand, M.; Jackson, M.; Ong, S. *Land Use Requirements of Modern Wind Power Plants in the United States*; NREL/TP-6A2-45834; National Renewable Energy Laboratory (NREL): Golden, CO, USA, 2009.
18. Novak, L. South Australia energy plan: Port Augusta will be home to new $650 million solar thermal power plant. *Adelaide Now*, 14 August 2017.
19. Brook, B.W.; Bradshaw, C.J.A. Key role for nuclear energy in global biodiversity conservation. *Conserv. Biol.* **2015**, *29*, 702–712. [CrossRef] [PubMed]
20. Clean Energy Regulator. Electricity Sector Emissions and Generation Data 2016–2017. Available online: http://www.cleanenergyregulator.gov.au/NGER/National%20greenhouse%20and%20energy%20reporting%20data/electricity-sector-emissions-and-generation-data/electricity-sector-emissions-and-generation-data-2016-17 (accessed on 10 June 2018).
21. EPSIS. Electric Power Statistics Information System. Available online: http://epsis.kpx.or.kr/epsisnew/selectEkifBoardList.do?menuId=090140&boardId=003140 (accessed on 10 June 2018).
22. Zakeri, B.; Syri, S. Value of energy storage in the Nordic Power market—Benefits from price arbitrage and ancillary services. In Proceedings of the 2016 13th International Conference on the European Energy Market (EEM), Porto, Portugal, 6–9 June 2016; pp. 1–5.
23. Lee, S. 환경부, 한라산국립공원 4.3배 확대 추진, 내년 확정 (Translation: Ministrry of Environment Decided to Expand the Protect Area in Jeju). Available online: http://www.jejusori.net/?mod=news&act=articleView&idxno=199650 (accessed on 28 June 2018).
24. Hong, S.; Brook, B.W. A nuclear- to-gas transition in South Korea: Is it environmentally friendly or economically viable? *Energy Policy* **2018**, *112*, 67–73. [CrossRef]
25. Hong, S.; Brook, B.W. At the crossroads: An uncertain future facing the electricity-generation sector in South Korea. *Asia Pac. Policy Stud.* **2018**, *5*, 522–532. [CrossRef]
26. Hydro Tasmania. Battery of the Nations. Available online: https://www.hydro.com.au/clean-energy/battery-of-the-nation (accessed on 28 August 2018).

27. Ueckerdt, F.; Brecha, R.; Luderer, G. Analyzing major challenges of wind and solar variability in power systems. *Renew. Energy* **2015**, *81*, 1–10. [CrossRef]
28. Voorspools, K.R.; D'Haeseleer, W.D. An analytical formula for the capacity credit of wind power. *Renew. Energy* **2006**, *31*, 45–54. [CrossRef]
29. Hong, S.; Bradshaw, C.J.A.; Brook, B.W. Evaluating options for sustainable energy mixes in South Korea using scenario analysis. *Energy* **2013**, *52*, 237–244. [CrossRef]
30. Hong, S.; Qvist, S.; Brook, B.W. Economic and environmental costs of replacing nuclear fission with solar and wind energy in Sweden. *Energy Policy* **2018**, *112*, 56–66. [CrossRef]
31. Nian, V. Technology perspectives from 1950 to 2100 and policy implications for the global nuclear power industry. *Prog. Nucl. Energy* **2018**, *105*, 83–98. [CrossRef]
32. Locatelli, G.; Bingham, C.; Mancini, M. Small modular reactors: A comprehensive overview of their economics and strategic aspects. *Prog. Nucl. Energy* **2014**, *73*, 75–85. [CrossRef]
33. Islam, M.R.; Gabbar, H.A. Study of small modular reactors in modern microgrids. *Int. Trans. Electr. Energy Syst.* **2015**, *25*, 1943–1951. [CrossRef]
34. Black, G.; Taylor Black, M.A.; Solan, D.; Shropshire, D. Carbon free energy development and the role of small modular reactors: A review and decision framework for deployment in developing countries. *Renew. Sustain. Energy Rev.* **2015**, *43*, 83–94. [CrossRef]
35. Alonso, G.; Vargas, S.; del Valle, E.; Ramirez, R. Alternatives of seawater desalination using nuclear power. *Nucl. Eng. Des.* **2012**, *245*, 39–48. [CrossRef]
36. Orhan, M.F.; Dincer, I.; Naterer, G.F.; Rosen, M.A. Coupling of copper–chloride hybrid thermochemical water splitting cycle with a desalination plant for hydrogen production from nuclear energy. *Int. J. Hydrogen Energy* **2010**, *35*, 1560–1574. [CrossRef]
37. Ohashi, H.; Sato, H.; Goto, M.; Yan, X.; Sumita, J.; Tazawa, Y.; Nomoto, Y.; Aihara, J.; Inaba, Y.; Fukaya, Y.; et al. A Small-Sized HTGR System Design for Multiple Heat Applications for Developing Countries. *Int. J. Nucl. Energy* **2013**. [CrossRef]
38. Mantero, G.; Lomonaco, G.; Marotta, R. Nuclear desalination: An alternative solution to the water shortage. *Glob. J. Energy Technol. Res. Updat.* **2014**, *1*, 57–70.
39. Castagnola, L.; Lomonaco, G.; Marotta, R. Nuclear systems for hydrogen production: State of art and perspectives in transport sector. *Glob. J. Energy Technol. Res. Updat.* **2014**, *1*, 4–18.
40. Dincer, I. Green methods for hydrogen production. *Int. J. Hydrogen Energy* **2012**, *37*, 1954–1971. [CrossRef]