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Energy scenarios for the Faroe Islands: A MCDA methodology including local social perspectives

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ABSTRACT

Planning for the decarbonisation of island energy systems is both crucial and fraught with complexities. The process to develop and evaluate these plans needs to encompass not only technical and economic specifics but each plan’s impacts on the environment and local inhabitants must also be considered. This inclusive planning involves multiple criteria and requires a means of handling them. In this paper a series of potential future energy systems are generated with the EnergyPlan software for the Faroe Islands before these systems are assessed using a set of criteria covering their environmental, social, technical and economic aspects. These criteria are used by two multi-criteria approaches, along with actual weights obtained from local stakeholders, to rank the energy systems. It is found that there is a clear shift in rankings towards systems employing offshore technologies due to the inclusion of social criteria specifically fitted to the Islands’ resident’s preferences. This shift, however, was not sufficient for these offshore scenarios to outperform other scenarios that performed well on the other criteria. These findings indicate there is likely value in terms of local acceptance for transition planning on the Islands in adjusting to include greater quantities of offshore technologies in future energy strategies.

1. Introduction

Geographic islands are well-positioned to make the most of the transition to renewable energy. They often find they are already in possession of sufficient renewable energy potential to more than cover their needs, if they can only take advantage of it. The barriers to using these local sources of energy vary, ranging from concerns about economic and technical viability to worries about local environmental and social impacts. This paper seeks to expand the understanding of geographic islands’ positions and concerns while also helping local planners in the transition to renewable sources through the use of an integrated decision platform on the Faroe Islands. The work in this paper assesses the environmental, social, technical and economic concerns of different energy scenarios on the Faroe Islands and provides a ranking of solutions through the use of Multi-Criteria Decision Analysis (MCDA) and real stakeholders’ preferences. The key innovations of this paper for islands, and global energy transition planning, are:

- The central incorporation of social perspectives into the energy planning for the Faroe Islands via explicit elicitation of criteria weights of local stakeholders.
- The establishment and integration of a composite social criterion that can identify and weigh the potential impacts of each of the proposed RES technologies using the perspectives of Faroe Islands’ residents.
- The assessment of the potential usefulness and value of new renewable technologies such as tidal, offshore wind and pumped hydro to the transition of the isolated Faroe Islands energy system.
- The identification of the direct impact the inclusion of local social considerations can have on the selection of RES technology mixes when planning for energy transition.

The structure of the paper is as follows; Chapter 2 provides a literature review introducing prior studies of islands’ energy transition along with the concepts and applications of environmental, technical, economic and social evaluation. Further, relevant MCDA methods and applications are presented. Chapter 3 describes the overall methodology applied, from scenario generation and elicitation of criteria weights until scenario ranking, along with a note on the selected tools and

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Nomenclature

CEEP	Critical Excess Electricity Production
DM	Decision Maker
EU	European Union
MCDA	Multi-Criteria Decision Analysis
PV	Photovoltaic
REACT	Renewable Energy for Self-Sustainable Island Communities

methods used for each step. Once the framework and tools used have been described, Chapter 4 introduces the Faroe Islands' energy scenarios to be assessed and concludes with the presentation of the analyses' results along with sensitivity analyses of the scenarios' ranking. Chapter 5 includes a discussion of the results and is followed in Chapter 6 with the conclusions on the paper's findings.

2. Literature review

Islands have begun looking ahead to futures where they transition away from fossil fuel reliant energy systems to systems based on non-fossil renewables. This decarbonisation of islands' energy systems has been examined using wide-scale studies on the potential of renewable energy sources (RES) to replace fossil fuels or increase energy independence on islands more generally [1]. Research has focused on decarbonisation and its planning issues on specific islands in Italy [2,3], Greece [4–7], France [8], the Philippines [9], India [10], Finland [11] and Mauritius [12], amongst others.

While this decarbonisation of islands' energy systems is almost unquestionably beneficial to the environment as a whole, the local impacts of the new systems must still be analysed. While the environmental impacts of many renewable energy sources appear small they cannot, and should not, be ignored. Different methods of measuring the environmental impacts of renewable projects exist, ranging from detailed, albeit complicated and relatively time-consuming, life-cycle assessments (LCA) [13] to simpler and faster examinations of a system's estimated greenhouse gas emissions [2,4,8].

The technical, economic, environmental and social elements of a new energy system can be captured by the use of MCDA methods that are a means of supporting the often complex process of making energy and environmental strategic choices [14]. Planners find themselves confronted with many different options with various criteria and MCDA methods give these planners a way to effectively manage them [15,16].

MCDA has been used in several studies exploring decarbonisation of energy systems. It is used to evaluate energy system decarbonisation scenarios in cities [17] to develop and evaluate feasible energy scenarios for a small community in Germany [18] as well as to analyse different energy scenarios for small scale, off-grid locations in Canada [19]. MCDA has also been used for energy planning on islands. On the island of Crete in Greece it has been used to assist local decision makers in regional renewable energy planning [5] and as part of a methodology for the sustainable siting of offshore wind turbines there [20]. On the Greek island of Ikaria, MCDA was applied to evaluate a wind-hydro project [4]. On the Italian island of Corsica, MCDA was used in solar PV plant project selection [21], while on the island of Salina it was used to evaluate wind power configurations [22]. On the island of San Andrés in Columbia it was used to assess different energy alternatives [23] and on the island nation of Sri Lanka it was used to help evaluate the country's energy generation alternatives [24].

3. Methodology

Energy planning for the decarbonisation of islands around the globe should, and to be successful must, encompass all relevant local conditions and stakeholders. The plans developed for consideration should ideally include a range of the options in search of the best possible energy projects' portfolio for an island. The evaluation of these options by local island planners for the conditions identified should be done in as systematic and transparent way as possible and stakeholders need to have an opportunity to weigh-in on which of these conditions are the most pressing. To ensure the above steps all occur, in this paper's analysis of the Faroe Islands potential energy system futures, a modified version of a methodological framework for integrated energy planning of islands developed in the Renewable Energy for self-sustAinable island CommuniTies (REACT) Horizon 2020 project [25] is used. This model was first described in [26] and [27] before being applied in [28].

The first step of the methodology is the gathering of the data for the island, or islands, being evaluated. The data gathered in the first step is then used to create technically feasible scenarios. The economic, social and environmental characteristics of the scenarios are then analysed in the third step of the framework. The fourth step gathers all the information provided in the earlier steps to conduct a MCDA of the scenarios. This step also includes the elicitation of weights of the criteria from local stakeholders. Scenarios are then ranked in accordance to their performance in the MCDA. The final step is the conversion of the ranked solutions into concrete project proposals.

In this work, the energy scenarios generated for evaluation are created using the EnergyPLAN software [29]. EnergyPLAN is used for regional to national technical, economic and environmental planning for energy systems [30,31]. The software allows users to enter hourly supply and demand data to simulate the hourly dynamics within an energy system over a period of one year. The tool was developed in conjunction with the Smart Energy Systems concept [32,33], which argues for energy efficiency through energy savings and sector integration. Therefore, one of the key strengths of the tool is its capability to model the synergies that can be obtained by linking the different energy-consuming sectors of society, including power, heating, cooling, transportation, and industry while viewing them as a coherent energy system [34]. EnergyPLAN is a deterministic simulation tool. As such, the tool is not useful for finding one optimal solution to a problem, but rather it is better suited for generating a variety of scenarios, which can be compared, analysed and combined in order to design an integrated strategy. The scenarios' technical performances were derived from outputs of the EnergyPlan software.

The scenarios' financial performances are evaluated using LCOE and total discounted scenario costs. A sensitivity analysis is also conducted on key values for the considered technologies to determine their impacts. In addition, the impacts of uncertainty on the variables used in the economic analysis of the proposed systems, such as initial investment costs, has been evaluated using the Monte Carlo method. Monte Carlo analysis uses random sampling from a given set of inputs to perform repeated iterations of a process or calculation to provide a distribution of the potential results and the likelihood a specific range of results will occur. The distribution provided, rather than a single value, gives users a clearer understanding of the impacts uncertainties have on a given indicator [35,36].

The environmental assessment is done using outputs from the EnergyPLAN software's annual CO_2 emissions calculations and land use data gathered from literature review. The social assessment is conducted using job creation values and a combined social impact score based on the scenarios' technologies' visual, noise and land use impacts using data found in literature.

The PROMETHEE methods of MCDA [37] have been chosen for use in this analysis. The PROMETHEE methods are outranking methods of MCDA that are based on the modelling of the pairwise comparisons of scenarios. They are suited to decisions that include both qualitative and quantitative data as well as those with many decision makers and criteria. These methods generally require less information from decision makers than others and allow the user to remain closer to the decision problem [16,38].

Additionally, the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method has also been applied. The TOPSIS method is based on the principle that for a choice to be a good alternative, its distance from the best solution should be as short as possible and its distance from the worst solution as long as possible [39]. This method is considered to be more accessible to decision makers as its processes and logic are regarded as both straightforward and mathematically simple [40].

The criteria that are used for the MCDA analyses in the present paper fall with the main category types of economic, environmental, technical and social [41,42]. The weights given these criteria are also important and greatly impact the results [43,44]. The weighting of the criteria is done in consultation with relevant local stakeholders to further ensure that the real local perspectives are actually captured in the analysis. The stakeholders included have provided their weights for the criteria used and include Faroe Islands representatives from the environmental agency, the power production and distribution company, an environmental group and a local resident.

4. Case study

4.1. The Faroe Islands

Compared to mainland communities, the inhabitants of islands have lived in much more clearly delineated environmental boundaries with more limited farming and energy opportunities. Islands' geographic isolation, however, has not kept them from a growing reliance on the mainland economies and supports [45,46] or protected them from the threat of global climate change. Resident's isolation and acute awareness of, and dependence on, their local environment create strong connections to place [47]. The Faroe Islands, an archipelago located in the northern Atlantic Ocean, are no exception to this. The Islands are dependant on local agriculture and fishing but tourism's impacts and non-local ownership are both increasing. Further, the islands' residents show strong connections to their islands' environments and express concern for how that environment is changed [48].

The Faroe Islands are a self-governing part of Denmark, see Fig. 1, and have a population of just over 50,000 that is spread unevenly over the islands. Nearly 90% of the islands' population is connected on the same electricity grid but the southernmost island of Suðuroy has a separate grid that serves most of the remaining population. Other isolated systems exist on the islands to service smaller settlements. Electricity on the Islands is currently produced through a combination of fossil (about 100 MW) and renewable sources (about 62 MW) [49].

Space heating on the islands is primarily from oil burners and in 2016 made up 24% of the imported oil usage [51]. District heating has been present in the capital of Tórshavn since the beginning of the 1990′s and the district heat is derived primarily from a waste incineration plant while large boilers service peak demand and back-up [52]. The Island's power company, SEV, has a stated goal of achieving a "100% green electrical energy onshore by 2030." Furthermore, there are incentives in place to encourage Faroese consumers to purchase heat pumps and electric vehicles while the district heating system is also being expanded [53].

A number of researchers have studied the conversion of the Faroe Islands' energy system to renewable sources. These studies looked at a single island [54] or more broadly [51,53] and their primary focus was on the techno-economic optimization of the new system. This paper expands upon previous research by including district heating in energy planning and expanding the scope of consideration by looking beyond just technical and economic optimization to also critically assess environmental and social feasibility in order to propose an integrated energy strategy for the future, whereas at the same time the preferences of real stakeholders have been included in the MCDA exercise. In particular, the social element has been neglected to the detriment of the islands' transition to renewable energy, as shown by the uncertain future ahead of different onshore wind power parks due to social resistance and bureaucracy. In 2018, the local power company declared a goal of adding about 150 MW of wind turbine capacity by 2030. According to that plan, 48 MW should be implemented by 2021 [55]. Since then, however, only 6 MW have been installed, while two defined projects with a combined capacity of 30 MW are delayed due to a mix of complaints about the proposed projects, disputes between stakeholders and slow bureaucracy

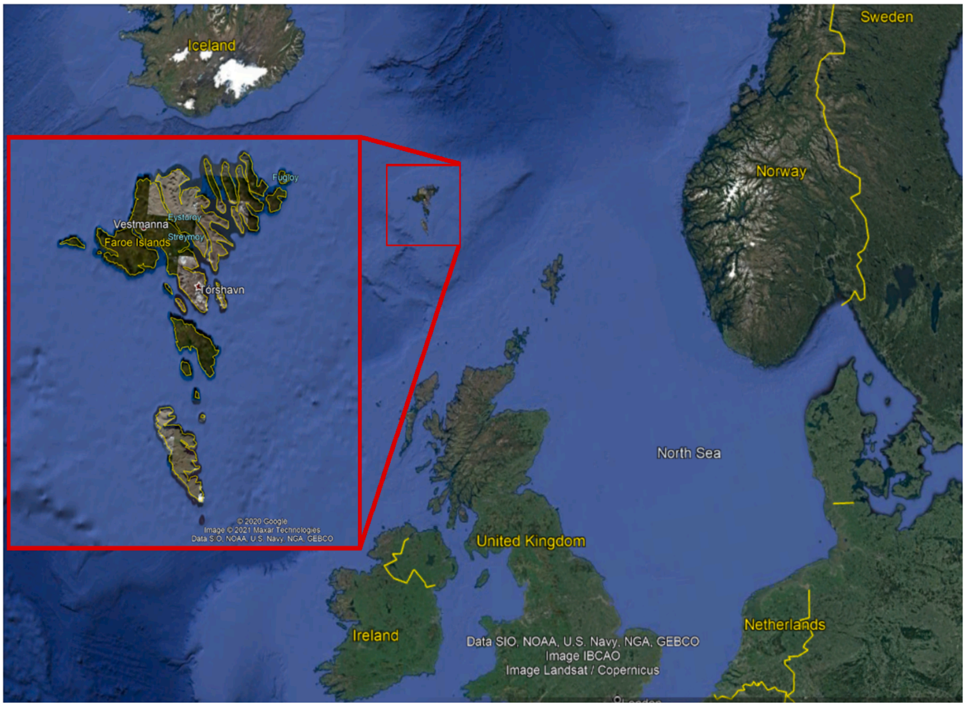

Fig. 1. Placing the Faroe Islands, inset in red [50].

[56,57].

4.1.1. *Energy scenarios*

Different technical scenarios were developed for the Faroe Islands based on the goal of achieving 100% green electrical energy production by 2030 along with greater electrification of transport, industry and heating. This section describes the key characteristics of these scenarios and some of the main energy system-related assumptions. First, the 2020 Reference case is presented, followed by five 2030 scenarios.

2020 Reference case

Firstly, a 2020 Reference energy system is modelled and serves as the base data. Table 1 below presents the scenario’s assumed energy demands and installed power producing capacities. The demand data for the 2020 Reference scenario is projected based on historical demand data from 2019, collected from Statistics Faroe Islands [58], and assumes an average growth corresponding to the average growth of the previous 10 years. The usage of 2019 data as the baseline to model rather 2020′s was due to the CoVid-19 pandemic skewing the demand profile of 2020.

Scenario 1: Current Trajectory

The first 2030 scenario, the Current trajectory, is a replication of the conclusions of some of the papers and reports which have been published by the transmission system operator (TSO), SEV, and the Faroese authorities. Therefore, this scenario largely reflects how the TSO and the authorities currently envision the future of the Faroese energy system, which is to have 100% RES in the electricity, heating, and on-land transportation sectors. The remaining scenarios are variations on this current trajectory scenario.

Scenario 2: 30% Heat savings

This scenario assumes an increased effort to implement heat savings. These heat savings are realized through improvements to the building envelope, such as improved insulation, windows, ventilation, and are to be implemented as part of the regular maintenance and renovation of buildings as such improvements have been found to less cost effective if done on their own [67,68]. These improvements result in a 30% lower heating demand in both district and individual heating. After implementing the savings, the wind turbine capacity is reduced until the required power plant operation is similar to the Current trajectory scenario.

Scenario 3: Tidal

Although tidal energy is still not widely considered a commercially ready technology, and its related costs are highly uncertain, it could potentially provide a valuable contribution to the Faroese power mix, since the conditions for harvesting tidal energy have been found to be ideal [69]. This scenario explores the potential role of tidal energy in a decarbonised Faroese energy system. The scenario includes significant tidal capacities, while the wind turbine capacity is reduced until the required power plant operation is similar to the Current trajectory scenario.

Table 1
Energy demands and installed power production capacities included in the 2020 reference scenario.

Demands	Electricity demand [GWh]		
	-Regular electricity demand	365	[59]
	- Heat pumps	12	[60]
	-Transportation	1	[60,61]
	Total:	**378**	
	Heating demand [GWh]		
	- Individual heating	530	[60]
	- District heating	34	[60,62]
	Total:	**563**	
	Fuel for transportation [GWh]		
	- Petrol	135	[63]
	- Diesel	376	[63]
	- Navigation	1508	[63]
	Total:	**2019**	
	Industry [GWh]		
	- Oil	**143**	[63]
Installed capacities	**Power production [kW]**		
	- Power Plants	100,000	[64]
	- CHP	1500	[65]
	- Hydro	38,300	[66]
	- Wind	22,650	[59]
	- PV	246	[64]
	Total:	**162,696**	

Scenario 4: Hydro

Hydro plants are a highly reliable way of generating electricity, however, these plants have vast environmental footprints, especially if they are constructed with large dams. For this reason, there is a strong social resistance against building more hydro plants or expanding existing dams in the Faroe Islands [70]. Nevertheless, due to the technology’s ability to provide system stability, it is relevant to identify how an increase in hydro energy can contribute to decarbonising the energy system. This scenario therefore explores these potentials by increasing hydro turbine capacity, as well as dam and pump capacities, while wind turbine installed capacity is reduced until the required power plant operation is similar to the Current trajectory scenario.

Scenario 5: Offshore wind

The Faroe Islands have vast wind resources, ideal for wind turbines. Thus, onshore wind is normally viewed as the main technology to generate renewable energy on the islands. However, due to the limited size of the islands, there are not many suitable locations for placing wind turbines in a manner where they do not disturb nearby inhabitants. At this very early stage of wind turbine implementation there is already resistance to further wind power deployment [56,57]. Therefore, the option and potential of placing the wind turbines out at sea is becoming increasingly relevant to explore. This scenario highlights the role of offshore wind turbines in the future Faroese energy system. A significant amount of offshore wind capacity is implemented in the scenario, while onshore wind is reduced until the required power plant operation is similar to the Current Trajectory scenario.

Table 2 below summaries of the proposed 2030 scenarios and their characteristics.

The table below presents the technical characteristics of the scenarios, including their demands, their technology mix and their annual energy production inputs in the EnergyPlan software.

4.2. *Technical data and results*

The technical impacts of the scenarios were evaluated using the criteria of critical excess electricity production (CEEP) and peak demand, both obtained from the EnergyPLAN software. CEEP in EnergyPLAN is the amount of produced electricity greater than local demand and the capacity of transmission lines out of the system. As the Faroe Islands have no transmission lines connecting them to external grids CEEP is simply production above local demand. Therefore, this excess

Table 2
Overview and summary of the proposed scenarios.

#	Scenario	Description
1	**Current trajectory**	Based on the latest plans and goals by the Faroese Government and the TSO, as presented in [53, 65, 71]
2	**30% heat savings**	Building on top of the Current trajectory scenario, 30% heat savings are implemented, while wind turbine installed capacity has been reduced accordingly
3	**Tidal**	Building on top of the Current trajectory scenario, tidal capacity is added, while wind turbine capacity is reduced accordingly
4	**Hydro**	Building on top of the Current trajectory scenario, assuming an expansion of the hydro reservoir, and reducing wind turbine capacities accordingly
5	**Offshore wind**	Building on top of the Current trajectory, adding offshore wind capacity, and reducing onshore wind capacities accordingly

Table 3
Selected technical energy scenarios for the Faroe Islands.

Sector	Category	Technology	2020 Reference	2030 Current Trajectory	2030 Savings	2030 Tidal	2030 Hydro	2030 Offshore Wind
Electricity	Annual electricity demands (GWh)	Regular electricity demand	363	445	445	445	445	445
		Electrification of industry	0	133	133	133	133	133
		Transmission and distribution losses	36	44	44	44	44	44
		Electric vehicles	1	206	206	206	206	206
		Individual heat pumps	6	190	133	190	190	190
		District heating heat pumps and electric boilers	0	16	9	16	16	16
	Renewable energy capacities (kW)	Wind Onshore	22,650	258,000	224,000	121,000	186,000	43,650
		Wind Offshore	0	0	0	0	0	180,000
		PV	246	81,000	81,000	81,000	81,000	81,000
		Tidal	0	0	0	76,000	0	0
		Hydro turbines	38,300	130,300	130,300	130,300	140,000	130,300
	Thermal plant capacities (kW)	Condensing power plants	100,000	100,000	100,000	100,000	100,000	100,000
		CHP Electric Capacity	1500	1500	1500	1500	1500	1500
	Storage capacities	Storage capacity of dams (MWh)	12,130	12,130	12,130	12,130	28,130	12,130
		Pump Back Capacity (kW-e)	0	74,000	74,000	74,000	100,000	74,000
		Energy Storage capacity (MWh)	0.7	3.7	3.7	3.7	3.7	3.7
		Charge/discharge capacity (kW)	2300	12,000	12,000	12,000	12,000	12,000
	Annual electricity generation (GWh/year)	Wind Onshore	94	1399	1215	656	1009	237
		Wind Offshore	0	0	0	0	0	1062
		PV	0	54	54	54	54	54
		Tidal	0	0	0	280	0	0
		Hydro	111	184	178	181	282	200
		Battery discharge	0.1	0.0	0.0	0.1	0.0	0.1
		Power Plants	195	8	8	6	7	8
		CHP	7	3	3	4	4	2
		CEEP/Curtailment	0	534	415	73	146	433
Heating	**Annual heating demands (GWh/year)**	Individual heating demand	560	570	399	570	570	570
		District heating demand	54	91	69	91	91	91
	Individual heating production (GWh)	Individual Oil boilers	541	0	0	0	0	0
		Individual Heat pumps	19	570	399	570	570	570
	District heating capacities	Waste incineration (kJ/s)	11,000	11,000	11,000	11,000	11,000	11,000
		CHP (kJ/s)	1490	1490	1490	1490	1490	1490
		Heat pumps (kWe)	0	5960	4437	5960	5960	5960
		Boilers (kJ/s)	5000	28,608	21,298	28,608	28,608	28,608
		Electric boilers (kJ/s)	0	10,000	10,000	10,000	10,000	10,000
	District heating production (GWh)	Waste incineration	70	67	67	67	67	67
		CHP	7	3	3	3	4	2
		Heat pumps	0	66	34	64	64	66
		Boilers	4	1	0	2	1	1
		Electric boilers	0	0	0	0	0	0
		DH losses	33%	33%	33%	33%	33%	33%
Industry	**Fuel for industrial processes (GWh)**	Diesel	148	0	0	0	0	0
Transport	**Fuel for transportation (GWh)**	Petrol	132	0	0	0	0	0
		Diesel	370	0	0	0	0	0

production needs to be regulated in some manner, such as through additional storage or curtailment.

Peak demand was determined by adding together all electricity demands in the system for each hour of the year, identifying the hour(s) with the highest electricity demand. It includes electricity needed for heat pumps, both those used for domestic and district heating, charging of EVs and batteries, electric boilers, flexible heating demand, pumped hydro pumping needs along with standard electricity demands.

4.3. *Financial data and results*

Key economic data for the installed energy systems was primarily derived from the Danish Energy Agency's technology catalogues for Individual Heating [72], Generation of Electricity and District Heating [73] and Energy Storage [74]. Financial data not available from the catalogues, primarily on tidal production, were obtained from [75]. An interest rate of 5% was applied and the technology lifetimes used varied for each technology following the values noted by [72–74].

A sensitivity analysis of the key financial and production parameters by technology type for each scenario was done to analyse the impacts on the scenarios economic and technical criteria. The scenario's investment costs were adjusted by ± 20% in 5% increments for each scenario. The same was done for the scenarios' productions.

Additionally, a Monte Carlo risk analysis of the different included technologies was conducted for each scenario. This analysis applied a 10% level of risk and 20,000 possible variations of the key economic inputs used to calculate the LCOEs within a range of ± 25% to provide frequency distributions. The distributions were found to fall within the ranges considered by the applied sensitivity analyses.

4.4. *Social data and results*

The social impacts of the scenarios were analysed using two criteria, job creation and a combined social scoring based on the scenarios' technologies' visual, noise and land use impacts.

Direct job creation figures were calculated using employment factors for each considered energy production technology using those found in [76] and [77]. Only job values for the installation and operations have been used as none of the technologies considered in the scenarios can be manufactured locally. Additionally, the construction and installation job factors from these sources were standardized to jobs per installed capacity following the methodology used by [78] and [79], amongst others. Using this method, the job-years per installed capacity employed in a technology's construction provided by [76] and [77] were multiplied by the ratio of total construction time to the technology's useful life, as provided by the Danish Energy Agency's technology catalogues. In the case of tidal power, wave technology's useful life was used as no lifetime was provided for tidal technologies in the catalogue.

The combined social scoring applied in this study is based on a social impact assessment where the renewable generation technologies' impact magnitudes on social acceptance are qualitatively assessed. The technologies assessed, impacts and their magnitudes are shown in Table 4 below. The grading scale used in this assessment was between 0 and 3, corresponding to a scale of no impact to major impact. Similar qualitative methods have been applied to assess social impacts in other studies, especially those applying a MCDA method, where direct quantitative assessment is impractical to implement using either a literature review [80–83] and/or expert evaluations [84–86]. The values assessed for each of these technologies are visibility, noise and impacts to how the land can be used relative to before their construction.

The qualitative values for the impact types listed for hydropower, onshore wind, offshore wind, solar PV and tidal technologies were derived from analysis of relevant literature. Special consideration is given to the results of a study on Faroese residents' landscape values, development preferences and their related narratives as found by a survey conducted on the Islands in [48] to more closely reflect local rather than more general views on the involved technologies.

Hydropower's visual and noise impacts, including pumped hydro, are generally considered minor. Yet significant issues related to displacement and river damage are well documented [87,88]. In the case of the Faroe Islands, hydropower was found in [48] to have the lowest percentage of supporting to opposing development preferences (39% to 61%). Furthermore, in narrative analysis it was specifically noted as causing too much damage to rivers and the land and that other renewable technologies should be pursued instead.

Onshore wind's visual, noise and land use impacts are well documented [87,89,90]. In the case of the Faroe Islands, onshore wind power was found in [48] to have a much more positively split percentage of supporting to opposing development preferences (67% to 33%) than hydropower. In narrative analysis its description is mixed and it is noted as having disadvantages, but being worth it, or being unattractive and that other technologies should be pursued instead.

Offshore wind's visual, noise and land use impacts are nearly as well documented as those for onshore wind [87,91,92]. In the case of the Faroe Islands, offshore wind power was not directly evaluated for development preference [48]. However, in narrative analysis offshore technologies were suggested to be preferable to onshore technologies.

Table 4
Technology social impacts.

Technology	Impact	Magnitude	Scale
Hydro	Visual	Minor/Moderate	1.5
	Noise	Minor	1
	Land use change	Major	3
Wind – Onshore	Visual	Moderate/Major	2.5
	Noise	Minor/Moderate	1.5
	Land use change	Moderate	2
Wind – Offshore	Visual	Minor	1
	Noise	Minor/none	0.5
	Land use change	Minor/none	0.5
PV	Visual	Minor/Moderate	1.5
	Noise	N/A	0
	Land use change	Moderate	2
Tidal	Visual	Minor/None	0.5
	Noise	None	0
	Land use change	Minor/None	0.5

Solar PV's noise impacts are non-existent following construction, though visual and land use impacts can be more significant [87,93,94]. In all considered scenarios, the solar PV installed capacity is greater than what reasonably can be installed on rooftops and as such large scale PV parks are envisaged. This choice of park versus rooftop deployment may influence the perception of the scale of solar PV's impacts [95]. In the case of the Faroe Islands, PV power was not directly evaluated for development preferences [48] but in narrative analysis solar technologies were noted positively.

Unlike the other technologies being assessed, tidal power's visual, noise and land impacts are relatively unstudied [87,91,96]. Tidal power's visual and noise impacts are expected to be negligible as are its land use impacts, though there may arise some conflict with the local fish farming industry or from the placement of onshore transformer stations. Tidal power was not directly evaluated for development preferences by [48], but in narrative analysis it was suggested as an alternative to onshore energy technologies.

The scores assigned for each technology for their visual, noise and land use change impacts were applied to each scenario's technologies based on a scenario's installed capacity relative to the maximum installed capacity of that technology across the scenarios. The scoring for each of the technologies' impacts is shown in Table 4 above. The total technology impact score for each scenario is a sum of all technologies scores for each scenario. The total score values can be found in Table 5.

4.4. Environmental data and results

The environmental impacts of the scenarios were evaluated using the criteria of land use and the scenario's yearly CO_2 emissions. Land use was determined per square metre from the Danish Technology Catalogue values [72,74] with the exception of hydro storage capacity increase. Values for reservoir size increase were found for the Faroe Islands using [97]. Further, land use was determined only for the onshore technologies. Note that land use here, a quantitative measure, is not the same as the land use change impact, a qualitative measure, used above to evaluate social impacts.

Yearly CO_2 emission values were found from EnergyPLAN for each scenario and then compared to the reference year scenario's emissions to determine the amount of change. CO_2 emissions are calculated in EnergyPLAN by multiplying fuel consumption by fuel emission data.

4.5. Results for all scenarios

The results for all criteria evaluated are presented in Table 5 below. All criteria are to be minimized except the Jobs criterion.

4.6. MCDA data and results

The methodology of the analysis used was explained to the selected stakeholders from the Islands. Each of the scenarios above were described to the stakeholders as were the types of criteria and what each measured. This process was conducted over the telephone/teleconference and via email due to the prevailing CoVid-19 situation at the time.

As part of this process the stakeholders were asked to give their inputs on the Islands' future energy system development. The stakeholders were then given the criteria used (Table 5), and asked to distribute 100 points across them to indicate each's relative level of importance to them for a future energy system [98–100]. It was explained to the stakeholders that these weights represented their varying preferences and understandings of their islands' energy transition and would be used

Table 5
Criteria results' summary.

		CT	Savings	Tidal	Hydro	Offshore	Unit
Environmental	CO_2 Emissions/year	15.4	15.3	14.9	14.9	14.9	Kt
	Land use	121	119	114	151	110	Hectare
Economic	LCOE	428.73	451.03	654.84	479.01	475.28	DKK/MWh
	Lifetime investment cost	5468	5334	7534.6	6334	7005	Millions of DKK
Technical	CEEP	121,927	93,893	15,558	32,173	97,570	MWh
	Peak demand	288	262	258	249	265	MW
Social	Jobs	302	286	377	299	359	Jobs/MW
	Technology social impact	20.1	19.2	17.6	20.2	16.6	Dimensionless (Min 0- Max 25)

to identify their preferred energy scenario. Further, the stakeholders were encouraged to explain their weighting choices.

4.6.1. PROMETHEE results

Using the weights obtained from these stakeholders, different rankings were found using the PROMETHEE II method. Fig. 2 shows the respective rankings found from the weights provided by the SEV, the FNU, the Environmental protection agency representative (EA) and the resident, respectively. In addition, a ranking using the average of the stakeholders' weights (AW) for each criteria is also provided as is ranking using equal weights for all criteria (Equal).

It is apparent that there is no general agreement between the stakeholders as to which scenarios are the most preferred. The FNU stakeholder's preferences placed less emphasis on the economic and technical criteria which resulted in the Tidal and Offshore scenarios ranking highest. The SEV representative slightly preferred the Offshore over the Savings while and the EA representative clearly preferred the Hydro. The residents' concern for price, through LCOE, placed the Current Trajectory and Savings scenarios in the top ranks.

What can be seen from the overall results is that the views of the island's stakeholders' towards the different scenarios are diverse. Further it can been seen that the Offshore scenario ranks favourably (in the first or second position) for all but the local resident. The remaining scenarios don't perform consistently across the weightings with the exception of the Current Trajectory which, for all but the local resident, ranks the lowest.

4.6.2. TOPSIS results

Using the same weights as used above, four different sets of rankings were found using the TOPSIS method. Again, an additional two rankings using the average of the stakeholders' weights for each criteria as well as with equal weights are also provided.

As with the PROMETHEE II assessment, there is no general agreement between the stakeholders as to which scenarios are the most preferred. The FNU stakeholder's preferences result in the Tidal scenario ranking highest while the SEV representative's place Savings and Hydro as nearly equal. The resident's weights give Hydro an edge over the Savings scenario and that edge is made even more pronounced using the EA representative's weights.

What can be seen from the overall results is that the Hydro scenario is considered a strong scenario and that the Savings scenario is worth further consideration. The Current Trajectory and Tidal scenarios perform relatively closely to each other in most of the weightings and normally only slightly worse than the Savings scenario.

4.7. MCDA results comparison

When comparing Figs. 2 and 3, it is apparent that the rankings provided by the two MCDA methods are not in full agreement. This disagreement in rankings is most apparent for the Offshore scenario. At the weightings applied, the PROMETHEE II method ranks the Offshore scenario favourably, often in the top or second position, while the TOPSIS method ranked the Offshore scenario as a middling scenario or in the bottom two rankings.

These differences in ranking are due to how the two methods evaluate scenarios. The usage of the distance from the best and worst solutions for each criterion by TOPSIS in the current assessment causes an overemphasis of the CEEP criterion. This overemphasis is a result of the relatively large distance between the best and worst solutions for the CEEP criterion and provides unfavourable results for the Offshore and Current Trajectory scenarios and more favourable results to the Tidal and Hydro scenarios.

An additional MCDA analysis was conducting using the simple additive weighting (SAW) method with the min-max criteria normalization and with the same weights as used above. The results of that analysis closely mirrored those of the PROMETHEE II analysis for the stakeholder weights.

4.8. Sensitivity analysis impact on MCDA results

An analysis was conducted for all scenarios to determine the impacts that changes in key economic parameters had on the MCDA rankings. Specifically, the production values and investment costs for each technology in each of the scenarios were adjusted incrementally ±20%.

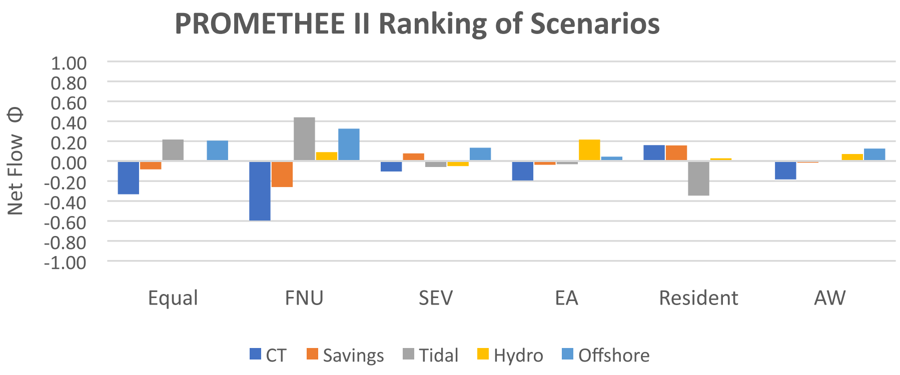

Fig. 2. Stakeholders' scenario rankings, PROMETHEE II.

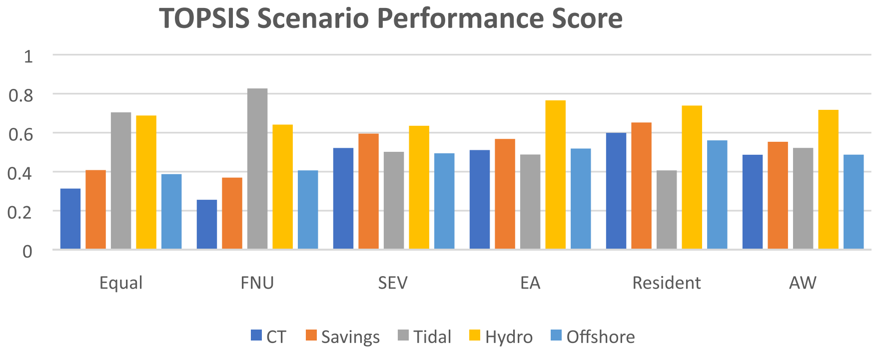

Fig. 3. Stakeholders' scenario rankings, TOPSIS.

While some changes in the PROMETHEE II rankings did occur they tended to be minor and they were generally at the extremes of the sensitivity analyses where production was increased or decreased 20% and investment costs increased or decreased 20%, or both.

No large changes in the TOPSIS rankings occurred, though some rank changes occurred at the extremes of the sensitivity study's limits.

That these ranking changes, for both PROMETHEE II and TOPSIS, largely only occurred with relatively extreme adjustments to the noted key inputs could indicate the general stability of the rankings obtained.

5. Discussion

The inclusions of the social perspectives through the usage of the jobs and consideration of visual, noise and land use change impacts caused a clear shift towards scenarios that emphasised offshore energy production. When these criteria are not included, the offshore energy scenarios performed poorly while the Hydro and Current Trajectory scenarios, in particular, perform better. Given Faroe Islanders' connection to their local environment and concern for how changes impact it, both with regard to tourism as well as energy transition, provides an additional clarification for the islands' delays in implementing its current transition plans which presently rely entirely on onshore RES. These results can be interpreted to mean that local planners should begin to include offshore technologies in their energy transition plans to account for the islands' social typology. More widely, it shows the value that inclusion of local perspectives can play for effective energy transition planning.

Of these offshore scenarios, the offshore wind ranks particularly well, albeit with significant overproduction issues. Overproduction is problematic if it must be curtailed, however it also can entail a great potential for a future energy system. In this future, electrolysis technologies and the production of green hydrogen and eventually hydrogen-based fuels can increase the flexibility of the energy system while also contributing to the decarbonisation of the water navigation sector, an important area for islands in general. Future research should study the potentials for utilising such technologies to address these overproduction concerns. Tidal technologies could also be included in these plans given they reach sufficient maturity to be deployed at the needed scale and at lower costs than assumed by this study.

6. Conclusions

In this paper a methodology for the decarbonisation of energy systems on geographic islands has been employed. A series of potential energy systems for the Faroe Islands have been generated which accomplish this decarbonisation through different potential technology pathways. These systems are assessed using a number of relevant criteria, in particular a social criterion specifically associated with the islanders' perceptions of different technologies. Two different MCDA methods using real weights provided by local stakeholders used the assessments to determine the preferred energy systems. The two methods were in partial agreement on which system was preferred, the TOPSIS method slightly favouring systems using more onshore technologies while the PROMETHEE II method slightly favouring systems with offshore technologies. It was found that the inclusion of a social criterion which considered the local perceptions of the different RES technologies caused a clear shift towards systems which included offshore technologies. These same offshore technologies were identified as having issues which would need to be considered and potentially mitigated.

The lesson taken from these findings imply that the local resident perceptions of the involved technologies and their environmental changes should be more directly considered. Doing so may avoid some of the acceptance issues currently being faced by transition planners around the world, not just on islands. The results from this study, and the methodology applied, can serve as a useful guide for energy planners on the Faroe Islands and beyond.

Future research could include applying the methodology in this study to other islands seeking to develop transition planning strategies as well to specific transition projects. Additionally the specific criteria included under each of the selection categories could be varied and expanded on to evaluate the impacts on strategy and project selection as well as to establish the most suitable grouping of criteria for the selection of island energy transition strategies and projects.

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CRediT authorship contribution statement

Andrew Barney: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization, Project administration. **Uni Reinert Petersen:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing. **Heracles Polatidis:** Methodology, Validation, Formal analysis, Writing – review & editing, Project administration.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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