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RENEWABLE ENERGY TECHNOLOGY SELECTION FOR COMMUNITY ENERGY SYSTEMS: A CASE STUDY FOR BRITISH COLUMBIA

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Abstract: Energy system planning is a complex problem, where a number of conflicting priorities need to be considered with regards to energy use, environment and socio-economic impacts, and stakeholder requirements. When selecting the supply sources for a net-zero community energy system, renewable energy (RE) technologies need to be evaluated and compared based on their performance under the above aspects. Multi-attribute decision making (MADM) techniques can be used to compare and select RE alternatives, based on the decision makers' requirements and priorities. In this study, selection of RE technologies for a net-zero community energy system is explored within the context of British Columbia, Canada. Indicators were developed to represent performance criteria for assessing technologies in community energy systems under technical, economic, environmental, and social categories. Life cycle impact assessment and life cycle cost data were used to estimate the environmental and economic performance indicator values, respectively. Benchmarks defined through critical literature review were used to screen and select the most suitable technologies, filtering out the ones with unsatisfactory performance levels. The performance scores for the RE technologies under the defined indicators on technical, environmental, economic, and social criteria were analysed through fuzzy TOPSIS method. The RE alternatives were thus ranked based on their overall performance under three decision scenarios which reflect different priorities in community-level infrastructure planning. The findings of the study can assist community developers and decision makers in selecting the most suitable energy technologies for net-zero energy systems at community level.

1 INTRODUCTION

The global drive for integrating renewable energy sources (RES) with energy supply systems has grown in the recent past. The surge in energy needs with the ever-growing population and increasing awareness on the adverse environmental impacts of conventional fossil fuel use have contributed to this phenomenon (Baños et al. 2011). The use of renewables in grid-integrated and stand-alone energy systems has been explored in many studies (Baños et al. 2011).RE delivers multiple advantages to communities, including reduction in the release of greenhouse gases (GHG) and other pollutants, and long term energy security (Baños et al. 2011). The net-zero energy (NZE) community concept has also become popular in recent times where the energy needs of the community can be met through locally available renewable energy (Carlisle, Van Geet, and Pless 2009). For optimal benefits, renewable energy planning needs to be matched with the local conditions and the stakeholder requirements (Denis and Parker 2009), resulting in a multi-criteria decision making (MCDM) problem.

Life cycle assessment (LCA) technique can be used to obtain an understanding of the environmental costs associated with the use of RES. LCA can study the impacts of a product of a system throughout its life cycle, from raw material extraction (cradle) to the eventual demolition and disposal (grave) (Varun, Bhat, and Prakash

2009). Taking this holistic approach to account for the life cycle impacts of energy and material use delivers a clearer perspective when comparing energy sources and making selections, thus improving decision making (Varun, Bhat, and Prakash 2009). While renewables are in general expected to be low or zero-emission in comparison to the conventional energy sources such as fossil fuel, GHG emissions are caused due to the upstream and downstream processes associated with RE facilities (Raadal et al. 2011). As per ISO 14040, the phases in a LCA study include goal & scope definition, inventory analysis, impact assessment and interpretation. When comparing different technologies through LCA, it is necessary to maintain the comparability of results on a common basis (The International Standards Organisation 2006). Life cycle costing (LCC) is conducted to assess the economic impacts of renewable energy systems. Minimising life cycle costs of energy systems is another key objective associated with energy system planning. In addition, other resulting factors of RE use such as human health risks, social equity and public safety have to be taken into consideration when making decisions regarding energy systems (Amponsah et al. 2014).

Energy system planning is a complex problem, where a number of conflicting priorities come into play in terms of energy use, economics, environment, and stakeholder requirements. RE alternatives available for a community's electric and thermal applications are depicted in Figure 1. In MCDM techniques, decisions are made with consideration to different criteria representing multiple conflicting objectives. The solution to any MCDM problem can vary based on the technique used, and it is necessary to select the most suitable method for the selection (Polatidis et al. 2006). The common characteristics between MCDM methods have been identified as conflict between the criteria, units without a common standard of measurement, and difficulty in selecting alternatives (San Cristóbal 2011). Multi-attribute decision making (MADM) is a subdivision within MCDM field. Under this, a finite number of alternatives can be considered for selection, ranking and prioritisation. This is done under a number of different criteria, otherwise known as “multi-attributes” (San Cristóbal 2011). MADM problems can be represented as decision matrices (Yoon and Hwang 1995). The objective of this study is to rank and select RE technologies for a net-zero community energy system, within the context of British Columbia, Canada. The findings can assist community developers and decision makers in selecting the most suitable energy technologies for net-zero energy systems at community level, based on locally available resources.

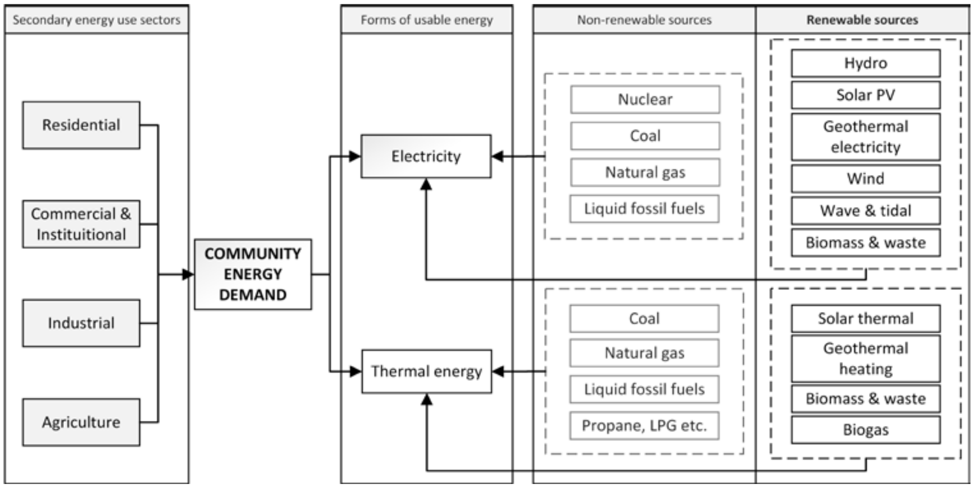

Figure 1: Energy alternatives for supplying community energy demand

2 METHODOLOGY

In this study, methodology is demonstrated on ranking and selecting RE technologies (RET) for community energy system based on a multi-criteria approach. As energy planning is generally a problem tackled through human expertise based on the decision maker's preferences, Figure 2 illustrates the steps in selecting RET for an energy system through a MADM approach. Normalisation is done to bring the criteria into a comparable scale, usually with dimensionless units (Yoon and Hwang 1995). Fuzzy TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution), which can identify the optimal alternatives from the closeness to the ideal solution (which is the reference point of the most desirable solution for the decision maker), is used as the MADM method. This technique was selected due to its relative simplicity and straightforward calculations, and the capacity to represent the logical rationale behind human choices (Shih, Shyur, and Lee 2007). The process applied in TOPSIS makes it evident which alternative has the best performance under each assessment criterion (García-Cascales and Lamata 2012). A fuzzy logic approach was used to account for the data uncertainties and imprecise information inherent in energy system problems, particularly due to the variability of information due to factors such as geography and climatic conditions, as well as the lack of information in certain instances (Sadiq and Rodriguez 2004).

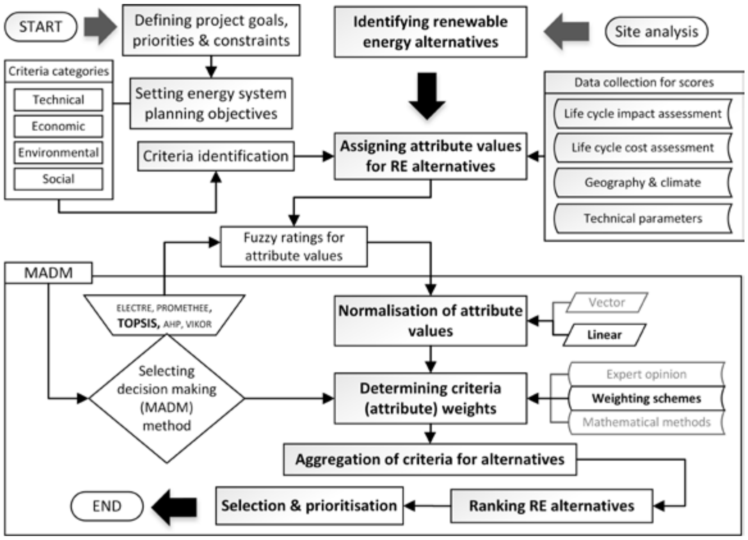

Figure 2: Application of MADM to RE selection

2.1 Indicator development and weighting

The performance criteria and the corresponding indicators indicated in Table 1 were defined through a comprehensive literature review. The values for each indicator under the different alternatives were defined based on literature, and through life cycle analysis (LCA) and life cycle costing (LCC). Decision making in energy planning and similar community level infrastructure projects rely heavily on the priorities of the decision makers', who may be community developers and planners, or local authorities. Different scenarios were defined to represent possible prioritisations by energy planners, and weighting schemes were accordingly developed as in Table 2. Within a given indicator category, indicators carry similar weights.

Table 1: Renewable energy assessment criteria and indicators

Category	*Criteria*	*Indicators*	*Reference*
Technical	Maturity	T1 – Service life of technology	(Wimmler et al. 2015)
	Theoretical potential	T2 - Estimated energy generation potential	(Ellabban, Abu-Rub, and Blaabjerg 2014)
	Reliability	T3 - Reliability of supply	(Mardani et al. 2015)
Environmental	Emissions	EN1 - Carbon/GHG emissions	(Wimmler et al. 2015)
		EN2 - Ozone depletion potential	(Environment Canada 2012)
	Water footprint	EN3 - Water depletion	(Hung 2010)
	Effect on eco-system	EN4 - Particulate matter emissions	(Wang et al. 2009)
		EN5 - Eco-toxicity	(Hung 2010)
		EN6 - Acidification	(Environment Canada 2012)
Economic	Financial feasibility	EC1 - Capital investment	(Wang et al. 2009)
		EC2 - Operational and maintenance cost	(Wang et al. 2009)
	Economic feasibility	EC3 - Payback period	(Demirtas 2013)
		EC4 - Levelised cost of energy (LCOE)	(Mardani et al. 2015)(Brown et al. 2016)
Social	Community benefits	S1 - Number of jobs created	(Wimmler et al. 2015)
	Human health	S2 - Human health non-cancer effects	(Amponsah et al. 2014)
		S3 – Human health - Carcinogens	(Passarini et al. 2014)

Table 2: Weighting schemes for decision scenarios

Criteria	*Weighting*		
Scenarios	**Neutral**	**Eco-centric**	**Economic**
Technical	0.25	0.2	0.2
Economic	0.25	0.2	0.5
Environmental	0.25	0.5	0.2
Social	0.25	0.1	0.1

2.2 Fuzzification and normalisation

In the TOPSIS method, the best alternative should be as close as possible to the positive ideal solution (PIS), and as far as possible from the negative ideal solution (NIS). For the analysis, the crisp values in the indicator scores were converted to triangular fuzzy numbers by assigning a rating on the linguistic scale, while the weights remained as crisp values. Based on previous studies, A 9-point scale was used for five fuzzy rating levels; Very Low (VL), Low (L), Medium (M), High (H), and Very High (VL), as depicted in Figure 3 (Sodhi and Prabhakar 2012). The data ranges pertaining to indicator scores under each criterion were divided into five sub ranges to assign the linguistic ratings.

Figure 3: Fuzzy ratings for linguistic variables

In a fuzzy decision matrix, the triangular fuzzy number for ith alternative under jth criterion x_{ij} is defined as $\mathrm{x_{ij}} = (\mathrm{a_{ij}}, \mathrm{b_{ij}}, \mathrm{c_{ij}})$. The attributes are categorised as cost and benefit in normalising, where cost attributes need to be minimised and benefit attributes maximised. The normalised fuzzy value r_{ij} is defined in eq. 1 and 2 (Saghafian and Hejazi 2005).

[1] $\mathrm{r_{ij}} = (\frac{\mathrm{a_{ij}}}{\mathrm{c^*_j}}, \frac{\mathrm{b_{ij}}}{\mathrm{c^*_j}}, \frac{\mathrm{c_{ij}}}{\mathrm{c^*_j}})$; for benefit criteria; where $\mathrm{c^*_j} = \max_\mathrm{i}(\mathrm{c_{ij}})$

[2] $\mathrm{r_{ij}} = (\frac{\mathrm{a^-_j}}{\mathrm{c_{ij}}}, \frac{\mathrm{a^-_j}}{\mathrm{b_{ij}}}, \frac{\mathrm{a^-_j}}{\mathrm{a_{ij}}})$; for cost criteria; where $\mathrm{a^-_j} = \min_\mathrm{i}(\mathrm{a_{ij}})$

In the weighted normalised fuzzy decision matrix, $\mathrm{v_{ij}} = \mathrm{r_{ij}}(.)\mathrm{w_j}$.

2.3 Aggregation of results and ranking

Aggregation is necessary in both determining the category scores, and assigning the final score for each alternative. Fuzzy positive ideal solution (FPIS: $A^* = (v_1^*, v_2^*, \ldots v_j^*)$) is the maximum v_{ijc} under each attribute. Fuzzy negative ideal solution (FNIS: $A^- = (v_1^-, v_2^-, \ldots v_j^-)$) is the minimum v_{ija} value under each attribute. The distance between two fuzzy numbers x_1 and x_2 was calculated based on equation 3. The distances from the fuzzy PIS and NIS are denoted by $d^*_i = \sum_{j=1}^{n} d(v_{ij}, v^*_j)$ and $d^-_i = \sum_{j=1}^{n} d(v_{ij}, v^-_j)$ respectively for each of the *i* alternatives (Saghafian and Hejazi 2005).

[3] $\mathrm{d}(\mathrm{x_1}, \mathrm{x_2}) = \sqrt{\frac{1}{3}[(\mathrm{a_1} - \mathrm{a_2})^2 + (\mathrm{b_1} - \mathrm{b_2})^2 + (\mathrm{c_1} - \mathrm{c_2})^2]}$

Once the distances from fuzzy PIS and fuzzy NIS have been calculated, closeness coefficients (CC_i) are determined for each alternative. The rankings was based on closeness coefficients (Saghafian and Hejazi 2005).

[4] $\mathrm{CC_i} = \frac{\mathrm{d^-_i}}{\mathrm{d^*_i} + \mathrm{d^-_i}}$

2.4 Life cycle assessment

Figure 4 depicts the LCA system considered in the data collection. The RET life cycle has been considered from the raw material extraction to the eventual demolition and disposal of facilities at the end of useful life. Technologically viable and commercially proven technologies which can be used at community level energy systems were selected for the analysis, based on their feasibility in British Columbia.

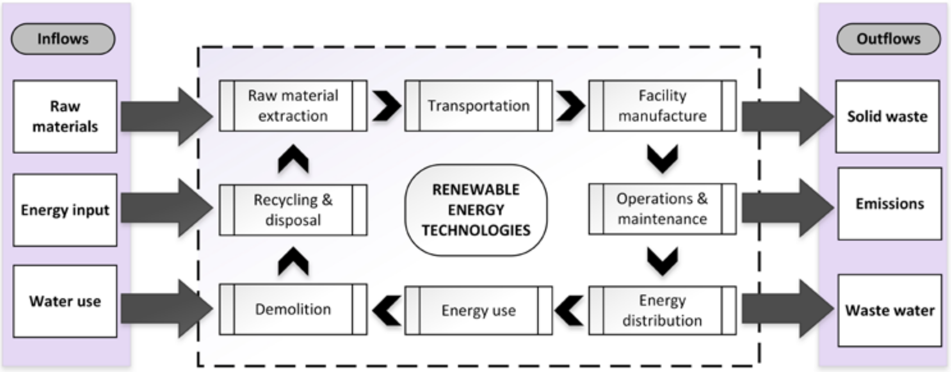

Figure 4: LCA scope for RE technologies

Geothermal heating and rooftop solar PV were assumed to be installed at residential level. For biomass and biogas energy generation, direct incineration and anaerobic digestion (AD) technologies were considered respectively. The LCA data was used in analysing the life cycle environmental and human health impacts of the identified RET. The impacts associated with generating 1 MWh of energy through a renewable source were quantified using the software SimaPro, using data from Ecoinvent 3 database. Canadian data has been used in the analysis, except in geothermal electricity generation where US data was substituted. ILCD 2011 Midpoint assessment method was used in the life cycle assessment. By selecting a mid-point analysis method, it is possible to obtain quantitative measures of the emissions and other environmental impacts (Hischier et al. 2010). Midpoint indicators are also generally more accurate than endpoint ones, which are used to represent the “damage” or the overall impact in terms relatable to the public (United Nations Environmental Program (UNEP) 2011).

3 RESULTS

Table 3 details environmental impact indicators (IM) associated with RES used in electricity generation.

Table 3: Life cycle impacts of renewable energy sources

IM	***Solar PV - centralised***	***Solar PV- rooftop***	***Solar thermal***	***Wind***	***Small hydro***	***Waste-to-energy***	***Biomass electricity***	***Biogas heating***	***Geothermal electricity***	***Geothermal heating***
a	7.75E+01	8.73E+01	2.55E+01	1.94E+01	4.20E+00	4.93E+02	5.65E+01	1.81E+02	6.27E+01	2.43E+02
b	1.40E-05	1.50E-05	4.57E-06	1.68E-06	3.19E-07	4.49E-04	1.06E-04	2.07E-06	3.70E-05	1.57E-04
c	5.61E-05	9.02E-05	7.74E-05	1.00E-05	2.03E-06	9.85E-05	4.36E-06	4.70E-05	1.33E-05	5.03E-05
d	1.16E-05	1.07E-05	1.17E-05	2.35E-05	1.29E-06	2.54E-04	8.99E-05	9.96E-06	2.12E-05	1.07E-05
e	8.41E-02	1.01E-01	3.83E-02	2.03E-02	4.99E-03	4.90E-01	3.20E-01	2.54E-02	5.25E-02	2.78E-01
f	7.84E+00	9.28E+00	2.44E+00	1.74E+00	2.62E-01	1.98E+02	3.90E+00	1.77E+00	5.20E+00	2.32E+01
g	2.42E-05	2.95E-05	8.22E-06	8.22E-02	1.14E-06	2.01E+00	1.66E+00	6.64E-06	5.63E-01	8.96E-05
h	2.84E-01	3.19E-01	1.07E-01	1.36E-01	1.86E-02	4.37E+00	2.10E+00	1.58E-01	5.55E-01	6.04E-01
i	5.61E-01	6.87E-01	3.44E-01	2.49E-01	2.24E-02	6.88E+00	1.01E+01	3.04E-01	2.00E+00	1.45E+00
j	8.43E-01	9.45E-01	3.74E-01	1.20E-02	6.52E-02	1.52E-01	5.71E-03	8.24E-01	1.93E-02	2.16E+00
k	4.99E-02	7.37E-02	4.47E-02	4.94E-02	1.51E-03	1.24E+00	1.15E+00	1.08E-01	2.04E-01	1.18E-01
l	8.96E-02	1.06E-01	3.83E-02	5.08E+03	6.00E-03	7.50E+03	1.65E+03	8.60E-02	8.79E+02	2.19E-01
m	2.40E+03	6.26E+03	1.77E+03	1.92E+02	6.55E+01	2.22E+03	5.09E+03	2.67E+03	2.46E+02	1.51E+03
n	7.88E+03	1.05E+02	-1.60E+01	2.31E-03	9.12E+00	7.97E-01	3.23E-02	1.18E+02	4.88E+00	1.67E+02
o	7.61E-01	5.51E-01	-5.50E-02	6.97E-03	2.35E-03	3.55E-02	1.87E-03	-5.10E-02	2.85E-03	-8.67E-01
p	3.85E-02	3.61E-02	6.46E-03	6.97E-03	1.26E-04	3.55E-02	1.87E-03	1.36E-03	2.85E-03	2.32E-03

a) Climate change (kgCO2 eq); b) Ozone depletion (kgCFC-11 eq); c) Human toxicity, cancer effects (CTUh); d) Human toxicity, non-cancer effects (CTUh); e) Particulate matter (kgPM2.5 eq); f) Ionizing radiation HH (kBq U235 eq); g) Photochemical ozone formation (kgNMVOC eq); h) Acidification (mol H+ eq); i) Terrestrial eutrophication (mol N eq); j) Freshwater eutrophication (kg P eq), k) Marine eutrophication (kg N eq), l) Freshwater ecotoxicity (CTUe), m) Land use (kg C deficit), n) Water resource depletion (m^3 water eq), o) Water resource depletion (m^3 water eq), p) Mineral, fossil & ren resource depletion (kg Sb eq).

The cost and technology data for the various energy technologies were determined based on information collected through literature. The average values were used in demonstrating the MCDM method, based on the range of performance values for a given indicator. The supply reliability rating was assigned through expert opinion formed based on previously published data on RES. Where information was uncertain, direct jobs were defined as construction, and O&M related jobs, which directly impact the local community.

EC1 - capital investment (CA$/kW); EC2 – O&M cost (CA$/kW/a); EC3 - payback period (years); EC4 - levelised (unit) cost of energy (CA$/MWh); T1 - Service life before replacement (years); T2 - Estimated energy potential (kWh/person/day); T3 - Reliability of supply (linguistic); S1 - direct jobs created (jobs/MW).

Table 4: Indicator scores for the alternatives

	Solar PV - centralised	***Solar PV-rooftop***	***Solar thermal***	***Wind***	***Small hydro***	***Waste-to-energy***	***Biomass electricity***	***Biogas heating***	***Geothermal electricity***	***Geothermal heating***
EC1	5066[1]	2633[1]	6175[2]	3050[1]	5500[4]	5500[5]	7530[1]	5500[4]	4550[2]	3250[9]
EC2	27.3[1]	20.8[1]	63.4[2]	42.9[1]	275[6]	525[10]	127.4[1]	250 [14]	226.8[2]	9.2[9]
EC3	30	25[11]	37 [12]	25[5]	4.5[5]	10[5]	10 [13]	10[15]	40 [16]	22.5[5]
EC4	506[3]	300	150[18]	199.5[3]	296.5[3]	134.5[3]	199[3]	106.5[3]	332[3]	221 [20]
T1	33[1]	33[1]	31[1]	20[1]	25[4]	25	28[1]	25	40 [16]	20[1]
T2	7.36[17]	1.00*	2.60*	0.98[8]	6.56[8]	1.00 [19]	12.20*	1.83[7]	5.52[8]	5.52[8]
T3	L	L	L	VL	M	H	H	H	VH	VH
S1	7.1[21]	7.1 [22]	6.3 [23]	1.08 [24]	1.3 [24]	6.6*	2.95[24]	1 [21]	4.27 [25]	4 [26]

Based on data published by [1,2] National Renewable Energy Laboratory (NREL) of the U.S. Department of Energy (USD converted to CAD at a factor of 1.3) (National Renewable Energy Laboratory 2016)(Tidball et al. 2010); [3] (BC Hydro 2013); [4] (Government of Ontario 2016); [5] (Sunshine Coast Regional District 2012); [6] O&M cost considered to be 5% of the installation cost based on BC government guidelines (Government of British Columbia 2006); [7] Estimated based on the data published on Canadian waste resources (Methane production potential through AD at 316,000 t/year for BC) (Abboud et al. 2010), considering a 40 MJ/kg calorific values for Methane, and an 85% conversion efficiency in heat generation (Barrington-Leigh and Ouliaris 2016)(Davis 2014); [8] Based on BC Hydro estimate of provincial energy potential and capacity factors (BC Hydro 2002); [9] (Crawley 2013); [10](U.S. Energy Information Administration 2016); 11 (BC Hydro 2016); [12] (Medina and Harvey 2016); [13] (Ministry Of Community & Rural Development - Government of British Columbia 2017); [14] (Lako 2010); [15] (Baldwin, Lau, and Wang 2009); [16] (Angevine, Murillo, and Pencheva 2012); [17] (British Columbia Sustainable Energy Association 2005); [18] (Helston 2012); [19] (Karunathilake et al. 2016); [20] (Jensen 2015); [21] (Dalton and Lewis 2011); [22] (Dalton and Lewis 2011); [23] (Sooriyaarachchi et al. 2015); [24] (The Pembina Institute 2006); [25] (Environmental and Energy Study Institute 2015); [26] (Geothermal Energy Association and Geothermal Resources Council 2016).

* Derived based on direct jobs for 1500 tons per day plant, using standard energy conversion rates for waste-to-energy (Environmental and Energy Study Institute 2015) (Karunathilake et al. 2016)

The fuzzy PIS and fuzzy NIS were obtained for each indicator, and d^* and d^- was calculated for each RET. This information was used to define the closeness coefficients depicted in Figure 5. Table 5 lists the ranking assigned to each RE technology under the different decision scenarios. It can be noted that under all the scenarios, geothermal electricity has the top rank, therefore indicating that it has the best overall performance of all the considered technologies. In general, solar PV and biomass appear to be the next best options.

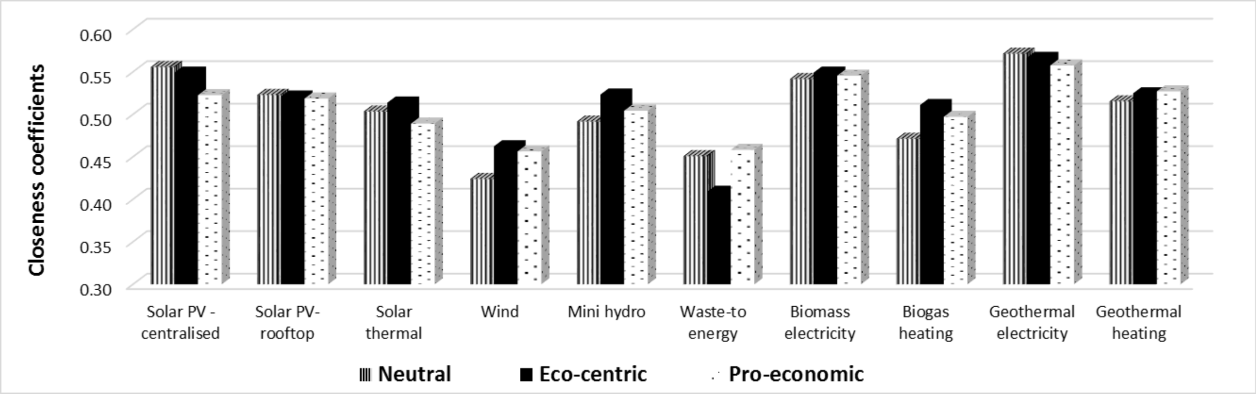

Figure 5: Closeness coefficients of the RET under different decision scenarios

Table 5: Technology rankings under different decision scenarios

Alternatives	***Ranks*** **Neutral**	**Eco-centric**	**Pro-economic**
Solar PV -centralised	2	3	4
Solar PV- rooftop	4	6	5
Solar thermal	6	7	8
Wind	10	9	10
Mini hydro	7	5	6
MSW	9	10	9
Biomass electricity	3	2	2
Biogas heating	8	8	7
Geothermal electricity	1	1	1
Geothermal heating	5	4	3

4 DISCUSSION AND CONCLUSION

The high suitability of geothermal electricity for powering communities in BC is due to the relatively high supply reliability and resource availability in the region, as well as the longer plant life. In contrast, the relatively poor performance of wind energy is mainly due to the lack of resource availability and low reliability of supply within the region. While waste-to-energy (WtE) has a supply reliability, the overall resource availability in terms of energy generation potential and the higher health and eco-impacts reduce the overall performance of the technology in the assessment. However, it can be noted that in the terms of the closeness coefficients, there is not a high variability between the different energy technologies. In terms of feasibility, all the considered are reasonably suitable candidates for community level energy systems. BC has a high availability of natural RE sources, which the province plans to exploit for fulfilling its energy demand in the future. In alignment with the study results, geothermal and biomass are key sources which are focused on by BC as both reliable and relatively low cost energy options (Government of British Columbia 2011). The different decision scenarios explored in the study were defined to investigate the effect of changing priorities in the decision-making process on the suitability of energy technologies. It can be noted that the performance value of some energy sources (expressed via the closeness coefficient to the ideal solution) such as WtE and wind change significantly with the different decision scenarios. The closeness coefficient of wind increases under the eco-centric scenario, where the reduction of environmental impacts was the most important criteria. This is due to the much lower environmental impacts associated with wind energy. In direct contrast, the closeness coefficient of WtE decreased under the eco-centric scenario. WtE technologies result in a high level of emissions and other negative environmental impacts, due to the nature of the materials being processed. The fact that the overall performance of wind is affected by its low technical viability and WtE by its low environmental performance is further evidenced by the closeness coefficient patterns in Figure 5. Geothermal electricity fares best under the neutral scenarios, with the performance somewhat decreasing under the pro-economic scenario where the economic costs and benefits are given the highest priority. The high investment and levelised costs contribute to this reduced performance under the pro-economic scenario. In contrast, the performance of geothermal heating increases with the pro-economic scenario, possibly due to the very low maintenance costs associated with geothermal heating systems.

Generally, renewable energy is less competitive than conventional fossil fuels in energy markets. In many cases complete grid parity has not yet been achieved due to the higher capital and operational costs, and the relatively low market penetration (Ellabban, Abu-Rub, and Blaabjerg 2014). As per BC Hydro information, more than 90% of BC's grid electricity mix is accounted for through hydroelectric power, from major hydro resources. This in turn contributes to the relatively low cost of energy in the province, as well as the lower environmental impacts due to energy generation. The energy price by BC Hydro in 2015 for domestic supply averaged at $ 94.29 per MWh (BC Hydro 2015). In order to reach grid parity, RE sources have to become more cost-competitive in the BC market. It is important to consider the avoided impacts in assessing the environmental impacts of RET. As a WtE seems to have higher environmental impacts in comparison to other technologies such as solar or geothermal, the effect of avoided landfilling needs to be considered to estimate the total benefits of the technology. Eliminating the need for land filling frees up valuable space in urban areas, and reduces the additional environmental problems due to the generation of leachate. In order to make the best choices regarding community infrastructure and energy investments, it is necessary for the decision makers to be provided with suitable tools. The ultimate goal of this work is to define such decision support systems which will help community developers to select the best technologies at the planning stage of a community energy system.

The key challenge faced in this study was the lack of availability and uncertainty in data. While this is accounted for to a certain degree by the use of fuzzy techniques, further data is necessary to refine the results of the evaluation. In line with this, a life cycle cost model needs to be developed as the next phase of the study. Furthermore, only selected life cycle impact indicators were used in this study to represent the most critical environmental effects. While this study analyses a number of different RE technologies, it is difficult to go a detailed level in terms of the technology and component selection (e.g. type of plant) via this method. For example, the effects of solar PV or WtE technologies can change with technological variations. Solar PV can further be divided into mono-crystalline, poly crystalline, or thin film technologies in the market, and the performance will be further affected with options such as the use of solar trackers. Similarly, there are a variety of WtE technologies which can be used in addition to incineration, such as refuse-derived fuel (RDF). Biomass energy conversion can be done via gasification and pyrolysis in addition to incineration in boilers. For a more comprehensive evaluation of technologies and decision support tools, these options need to be weighed at different levels. One possibility of developing a detailed decision tool which can evaluate at the specific technology level is through analytical hierarchy process (AHP), where a complex problem can be formed to a hierarchy with the ultimate objective at the top. Finally, in order to achieve the goal of providing decision making assistance to community developers and authorities, the findings and developed methods need to be compiled in the form of user-friendly and widely accessible tools.

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