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ANALYSIS OF MICROGENERATION OPTIONS FOR THE CITY OF EDMONTON

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Abstract—In this work we identified several microgeneration options suitable for Edmonton conditions. The microgeneration systems were evaluated on technical, economic, environmental, and social criteria, and based on this assessment and by means of an Analytical Hierarchy Process, a priority score was assigned to each option. In this way, the City of Edmonton can make informed decisions on the order of execution of future projects on microgeneration in the City.

Keywords-microgeneration; renewable energy; sustainability; urban environment

I. INTRODUCTION

The City of Edmonton is developing a program to guide the installation of solar photovoltaic systems on city facilities. In addition, the City is actively pursuing Combined Heat and Power (CHP) opportunities. On top of the efforts in progress, the City is interested in all opportunities that could exist for sustainable and/or renewable generation including a critical evaluation and relative comparison of potential technologies for microgeneration. Under Alberta Regulations, there are defined limits to the sizing of renewable, sustainable generation systems, and the City is working to define the limitations associated with the various technologies and potential for application across the City asset base. Under the Alberta Electric Utilities Act [1], a microgeneration unit is a generating unit that: i- exclusively uses sources of renewable or alternative energy; ii- has a total nameplate capacity that does not exceed 5 MW; and iii-supplies electric energy only to a site that is located on property that the custom owns or leases. In this context, renewable or alternative energy means electric energy generated from solar, wind, hydro, fuel cell, geothermal, biomass or other generation sources if the greenhouse gas (GHG) intensity of the total energy produced is less than or equal to 418 kg/MWh, the equivalent to the GHG intensity of typical combined cycle natural gas power plant.

A number of municipalities across Canada and around the world have implemented microgeneration systems such as urban wind turbines (Toronto, Portland, Detroit), in-pipe hydropower (Halifax, Portland, City of Barre), run-of-river (Quebec, Manitoba, British Columbia), wastewater hydropower (As Samra, Emmerich, Nyon), and wellhead or small geothermal power plant (Guadeloupe, Neuquen, Fang), to mention some of them. This shows the feasibility of microgeneration in urban environments, however, the site conditions and lifestyle in those cities are different from Edmonton's, above all because the extreme weather during winter in Alberta. For this reason, an evaluation of the suitability of microgeneration options in the City is required.

Aligned with the City program, the aim of this work was to compile information regarding microgeneration technologies suitable for implementation in urban environments. Based on that information and on Edmonton conditions, the availability of the energy resource for each option was assessed. The shortlisted microgeneration options were evaluated on thirteen criteria covering technical, economic, environmental, and social aspects, and a priority score, based on pairwise comparison between options and the relative importance of the criteria, was calculated for each option. In this way, the City can make informed decisions on the priority of future projects to implement microgeneration systems for buildings and facilities in Edmonton.

II. METHOD

The first step in the study was identifying microgeneration options that potentially could be implemented in Edmonton, based on literature review and interview with experts and vendors. The next step was the assessment of the availability to the City of the energy resource required for each microgeneration option. This assessment enabled to discard those options not suitable for Edmonton conditions. Then, the shortlisted options were prioritized using a method based on the Analytical Hierarchy Process (AHP). This includes the selection of the assessment criteria, definition of weights, pairwise comparison of the options on each criterion, and calculation of a priority score. Fig.1 presents a schematic of the method used in this study.

III. MICROGENERATION OPTIONS FOR EDMONTON

After performing a literature review [2-4], consulting academic experts in the field of energy and sustainability, and

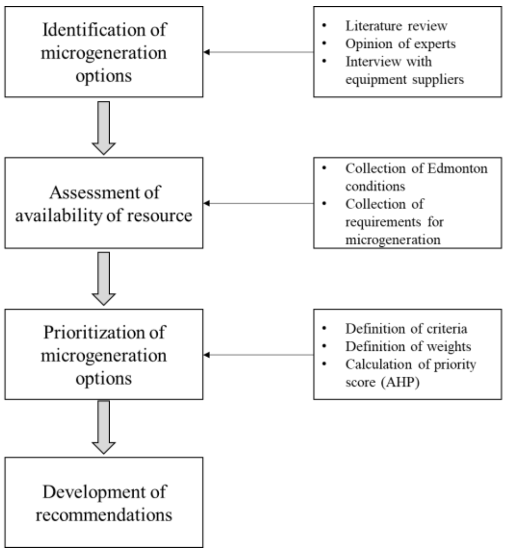

Figure 1. Schematic of the method followed in this study

interviewing equipment suppliers and vendors, the set of microgeneration options considered for this study was selected from the pool of renewable energy technologies existing in the market and already implemented in other municipalities. The list of considered microgeneration technologies is the following:

- Urban wind turbine (UWT): rooftop, vertical axis wind turbine (VAWT).
- In-pipe hydropower: turbines installed in the water distribution network of the City.
- River hydrokinetic turbine (HT): installed in North Saskatchewan River across the City.
- Run-of-river hydropower: diverting part of the flow of the North Saskatchewan River to run a hydropower plant.
- Wastewater Treatment Plant (WWTP) hydropower: turbines installed at the intake or discharge of WWTP.
- Wellhead powerplant: using the underground heat to produce steam that is expanded in a turbine to produce power.
- Micro combined heat and power (micro CHP): cogeneration of heat and power from natural gas. Three options were considered: internal combustion engines (ICE), microturbines (MT), and fuel cells (FC).
- Wood biomass: similar to micro CHP but using wood pellets made of the pruning trees of the City.
- Solar Photovoltaic (PV): rooftop PV solar panels.
- Biogas power plant: biogas generated at landfills can be used as fuel for heat production but also for electricity generation.

Besides renewable energy sources, micro CHP was also included as a microgeneration option because, as an alternative energy source, it is aligned with the definition provided by the Province of Alberta [1].

IV. Assessment of Availability of the Resource

The implementation in Edmonton of the microgeneration options listed in the previous section relies on the resources available to the City for power production. The technical requirement for each technology was collected from literature review and interviews with vendors and suppliers and compared with the existing conditions in Edmonton. Those options for which the resource is available in the City were shortlisted for the next evaluation in this study. The following microgeneration options were discarded prior to the assessment of resource availability:

- In-pipe hydropower: because the water distribution network is privately owned.
- WWTP hydropower: because the WWTP in Edmonton are privately owned.
- Biogas power plant: because this option is already implemented at the Edmonton Waste Management Center.

The results of the assessment of the remaining options are summarized in Table I. The energy resource for five out of the seven evaluated options are available to the City. The energy resource for run-of-river and wellhead power plant are not sufficient for the development of these options. A summary of the analysis are presented below. More details are found in [5].

A. *Urban wind turbine*

The energy resource for this option is the wind speed, which must be higher than the cut-in speed of the UWT to produce power. According to wind roses found in the Canada Wind Atlas, the preferred wind direction oven Edmonton is from west and north-west, but with high variability [6]. Because VAWTs are effective dealing with highly fluctuating winds [7], this type of turbine was selected for this study over

TABLE I RESULTS OF THE ASSESSMENT OF AVAILABILITY OF THE RESOURCE

Option	Energy resource	Resource requirement	Edmonton condition	Availability of resource
UWT	Wind speed	>2.5 m/s	4-6 m/s average	Sufficient
HT	Water speed	>1.2 m/s	2 m/s[a]	Sufficient
Run-of-river	Water flow and head	Flow: no limit Head: > 2 m	Flow: 147 m^3/s Head: 14.6 m in 50 km	Not sufficient
Wellhead powerplant	Geothermal heat	>100ºC	20 – 79ºC	Not sufficient
Micro CHP	Natural Gas	7,000 – 10,500 GJ/y[b]	1.7 M GJ/y	Sufficient
Biomass	Wood residues	333 t/y[c]	500 t/y	Sufficient
Solar PV	Solar	-	1,246 kWh/1 kWp	Sufficient

a. For Gross estimation
b. For 100 kW installed capacity
c. For 50 kW installed capacity

horizontal axis wind turbines. According to data from the same reference, the most frequent wind speed is around 4.0 to 6.0 m/s, depending on the height [6]. Wind speeds in this range are higher than the cut-in speed of UWTs (between 2.0 and 4.0 m/s for VAWTs [7]).

B. *Hydrokinetic turbines*

The power generation of hydrokinetic turbines depends on the water speed, which varies with time and from site to site depending on the cross-sectional area of the river., therefore a measurement campaign is required for an accurate hydrokinetic potential estimation. For this study, a water speed of 2.0 m/s [8] is assumed as a gross approximation for estimation of potential for energy production.

Water level is another critical variable for installation of hydrokinetic turbines. According to data from the 05DF001 Station (North Saskatchewan River in Edmonton) [9], the average water level for the period 2017-2019 was 3.82 m. This dept is suitable for some commercial turbines. For example, the 5 kW-Smart Hydro Power (2.7 m/s rated speed) requires a minimum depth of 1.6-2.0 m; the 3.5 kW-P66 Guinard (3.0 m/s rated speed) requires a minimum depth of 1.5 m; and the 20 kW-P154 Guinard (3.0 m/s rated speed) requires a minimum depth of 3.0 m.

C. *Run-of-river*

The potential of a run-of-river hydropower development depends on the river discharge and the available head. Discharge data for the period 2017-2019 were retrieved from the 05DF001 Station (North Saskatchewan River in Edmonton) [9]. These data were used for estimation of the Flow Duration Curve (FDC) of the river. It was observed that a flow of 249 m^3/s was equaled or exceeded in 50% of the measurements, while 147 m^3/s was equaled or exceeded in 90% of the measurements.

The software Google Earth Pro was used for estimation of the North Saskatchewan River elevation through Edmonton. It was observed that in 50 km, the elevation lost is only 14.6 m. This flat topography represents a small available head for hydropower development. Indeed, an available net head below 2.0 m is considered infeasible for development of hydropower [10]. Net head is calculated as the head minus the head lost due friction in the penstock. In this case, the penstock length required to get a head of 2.0 m is expected to be long due the flat topology, therefore the available net head is likely to be below the 2.0 m threshold.

D. *Wellhead powerplant*

The Canadian Geothermal Energy Association provides resource estimate maps in Alberta [11]. According to this reference, Edmonton does not have geothermal resource at a temperature beyond 80ºC in the range 1,000 m – 2,000 m depth. In fact, the same database shows that the geothermal resource in the City is between 20ºC and 79ºC, which is not suitable for power generation. There are nearby sites where geothermal power could be feasible. At 19 km to the west, 14 km to the north-west, 6 km to the north and 26 km to the south-east of Edmonton, geothermal resource between 80ºC and 119ºC is found within 1,000 and 2,000 m; while at 47 km to the north-east, geothermal resource at 120ºC or higher is found within the same depth. However, in this study only energy sources within the corporate boundaries of the City are considered, therefore it is concluded that the availability of the resource for wellhead power is not enough in Edmonton.

E. *Micro CHP*

The energy resource for this micro-generation is Natural Gas (NG), which is adequately supplied to Edmonton. Currently, the City Civic operations consumes approximately 1.7 M GJ NG per year[1] and the availability of this resource does not seem to be an issue in the future, thanks to the production in Alberta oil sands.

F. *Biomass*

On average, 2,000 tonnes of wood waste are generated per year in Edmonton, mainly poplar and spruce trees[2]. The City prunes and manages half of the city tree inventory each year to allow the trees time to grow. Removed trees and logs up to 40 cm in diameter are then chipped. Afterward, the chips are stored for potential redistribution to eco stations (areas where residents can access mulch for free) or disposed of in landfills. The microgeneration option consists of producing wood pellets from the wastes and using them as fuel for micro CHP based on pyrolysis and an ICE. We estimated that running a 165-kW system (30% electrical efficiency), would require about 867 tpa of wood pellet to produce 1.0 MWh. Therefore, with the current inventory of wood waste, this microgeneration option is feasible.

G. *Solar PV*

According to photovoltaic and solar resource maps in Canada, the annual potential electricity production in Edmonton is 1,247 kWh/kWp (south-facing, latitude minus 15º tilt) [12]. This means that a single 250 W panel would produce 311.8 kWh per year, therefore about 24 panels are enough to produce the 7,200 kWh a typical Albertan household consume per year [13].

V. PRIORITIZING THE OPTIONS

The shortlisted options were evaluated, and their priority was ranked according to their score on 13 criteria. The method employed for calculating the priority score was based on the Analytical Hierarchy Process (AHP), which has been used for the assessment of renewable energy technologies [14]. The method consisted in the following steps: definition of assessment criteria and weights, evaluation of each option on the assessment criteria, and prioritizing the options based on a weighted score. Fig. 2 shows a schematic of the AHP used in this study. For simplicity, only two criteria and two

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[1] Gary Cook, Energy Transition & Utility Supply; City of Edmonton. Personal communication.

[2] Kareem Abdelghany, Sustainability Scholar; City of Edmonton. Personal communication.

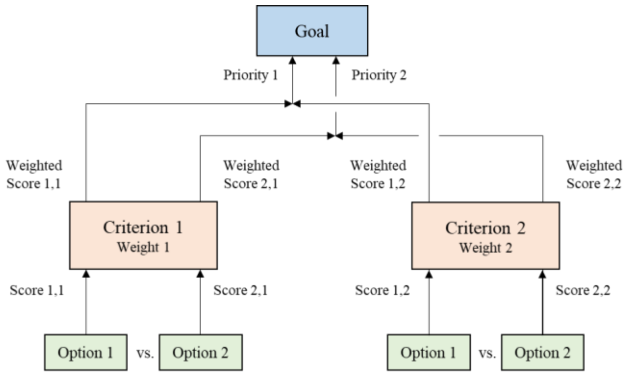

Figure 2. Schematic of the AHP used in this work

options are used in the example. First, the options are pairwise compared on their performance on each criterion, generating a score. Each criterion is assigned a weight, which is applied to the score of each option. Finally, the weighted scores of each option are combined to generate the priority score of the respective option. The following subsections describe the details of the prioritization step.

A. *Definition of criteria and weights*

The definition of criteria was performed after a literature review [14-18] and included technical, economic, environmental and social aspects. Because these aspects are considered to have the same influence on the goal, the criteria were not grouped and listed as sub-criteria. Table II presents the criteria used in this study and the units for their quantification.

The criterion Saved Carbon Emissions require a detailed explanation because the presence of cogeneration systems among the considered options. For UWT, HT and PV solar, the saved carbon emissions corresponds to the electricity displaced from the grid, which for Alberta energy mix are about 570 gCO_2/kWh [19], because the operating emissions of these systems are near to zero. In the case of micro CHP and biomass, the emission saving corresponds to the electricity displaced from the grid plus the NG displaced of the on-site heat production thanks to the additional production of heat. However, the emission saving is taxed due the CO_2 emissions

TABLE II. CRITERIA FOR THE ASSESSMENT OF MICROGENERATION OPTIONS IN URBAN ENVIRONMENTS

Aspects	Criteria	Units
Technical	Technological maturity	Qualitative
	Lifetime	Years
	Season/weather dependence	Qualitative
	Land/space used	m^2/kW
Economic	Initial investment	C$/kW
	Operating and maintenance (O&M) cost	C$/kW
	Cost of energy	C$/kWh
Environmental	Saved carbon emissions[a]	CO_2/kWh
	Impact on ecosystems	Qualitative
Social	Impact on architecture	Qualitative
	Social acceptance	Qualitative
	Disturbance on life in the city	Qualitative
	Jobs generation[b]	Jobs/MW

a. Saved emissions by implementing microgeneration
b. For maintenance and operation only

by burning NG, or wood pellets, during the operation of the system.

The criterion Cost of Energy corresponds to the levelized cost of the energy (LCOE) over the Lifetime of the system. This means, it is a combination of the Initial Investment and the O&M cost but considering the time value of the money. The calculation require the estimation of the annual energy production (AEP) by each option, which was estimated from data provided by manufacturers and site conditions in Edmonton. Details of the AEP, LCOE and saved carbon emissions are found in [5].

The importance of each criterion was defined by twenty academic experts from universities across Canada. The experts answered a survey for judging the relative importance of the criteria for the assessment of microgeneration options for urban environments in a Likert scale (from 1: less important to 5: most important). The answers were averaged and normalized to find the importance weight of each criterium. Results are shown in Fig. 3. The dotted line represents the value 0.077, which corresponds to the weight if each criterion would have had the same importance. It is observed that the criteria with the higher weights include environmental, social, and economic aspects. In general, it is not observed a clear preference on any particular aspect, which means that the experts considered all the sustainability dimensions are important for the assessment of the microgeneration options.

B. *Pairwise comparation*

The options were pairwise compared on each criterion. For any specific criterion a score of 1 was assigned to the option considered performing the worst. The other option is assigned a score according to its performance relative to the worst option and following a scale from 1 (equal performance) to 9 (extremely better). The pairwise comparison of quantitative criteria was performed for an AEP of 1,000,000 kWh, for all the microgeneration options considered in the study. For this type of criterion, the score is computed as the best option to the worst option ratio. For positive criteria, i.e., saved carbon emissions, lifetime and job generation, the worst option was that with the lower value of the respective indicator, while for

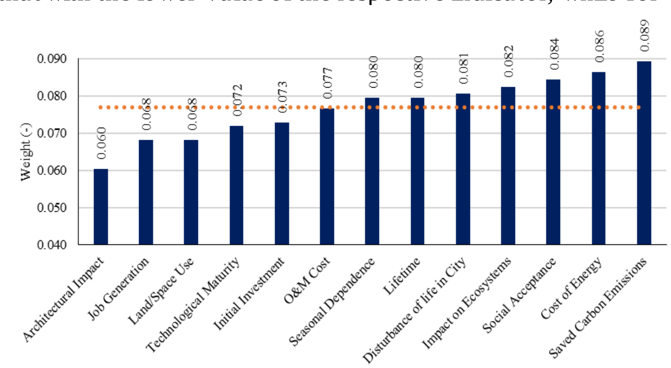

Figure 3. Criterium weights as per consultation to academic experts. The dotted line represent the hypothetical case of all criteria having the same weight

negative ones, i.e., land/space use, initial investment, O&M cost, and cost of the energy, the worst option was that with the higher value of the indicator.

The pairwise comparison of qualitative criteria was performed based on literature review and interview with vendors and suppliers. Details of the pairwise comparison of both quantitative and qualitative criteria are presented on [5].

C. Calculation of priority score

After pairwise comparison, a performance matrix for each criterion is defined. The element a_{ij} represents the ratio of the score of option i to the score of the option j obtained in the corresponding pairwise comparison. The eigenvectors of this matrix correspond to the priority of the options relative to the specific criterion. Finally, the priority score of the option is calculated as the average of the priorities for all the criteria, weighted according to the weight defined by the academic experts previously consulted.

Fig. 4 shows the score of each option on each criterion. This figure is useful for qualitative comparison between microgeneration options for a specific criterion, and for a quick examination of the performance of a specific microgeneration option on each criterion. For example, it is observed that micro CHP based on ICE and based on MT perform the best on Cost of Energy, mainly because the additional credit for generating heat. CHP based on FC does not take that much advantage of the heat credit because the principal output of this system is electricity (electric efficiency over 50%, versus 10-30% for CHP-ICE and CHP-MT [20]). Biomass is other cogeneration system that does not perform as good as CHP-ICE and CHP-MT on Energy Cost, in this case because the high initial investment and O&M cost. Besides the cost of the system for CHP, it is included the cost of the plant for producing the wood pellets used as fuel, which increases the initial investment. Regarding the O&M cost, this system generates solid wastes (ashes) that need to be landfilled. This cost component is not present in the other cogeneration options.

Let's take Season/weather Dependence as other example. It is observed that the options that rely on NG perform much better than the other options, because the production of NG is totally independent on the season or weather. However, micro CHP based on FC performs the best. This because the economy of this system is less depend on the demand of heat (its main product is electricity as mentioned before), contrary to CHP-ICE and CHP MT, whose economy is reduced during summer as near to zero heat is required. The reader is encouraged to consult [5] for details of the pairwise comparison and interpretation of the scores.

Table III presents the priority score for each option. Micro CHP options are those with the higher priority. There is not difference between ICE and MT, while micro CHP based on

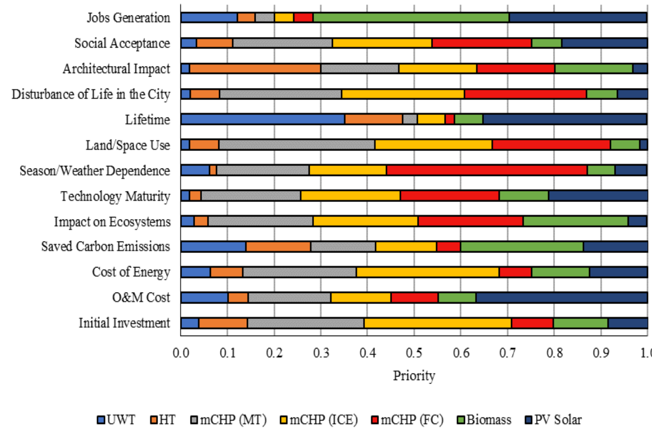

Figure 4. Score of each option on each criterion

TABLE III. CALCULATED PRIORITY SCORE OF EACH OPTION

Position	Option	Priority score
1	Micro CHP (ICE)	0.192
1	Micro CHP (MT)	0.192
3	Micro CHP (FC)	0.164
4	PV Solar	0.154
5	Biomass	0.138
6	Urban wind turbines	0.080
6	Hydrokinetic turbines	0.080

fuel cells is third, mainly because its poor performance on Initial Investment, Lifetime and Saved Carbon Emissions, as observed in Fig. 4.

VI. CONCLUSIONS

An assessment of suitable microgeneration options for the City of Edmonton has been performed. Among twelve systems that have been already implemented in different municipalities around the world, seven count with the energy resource available for implementation in Edmonton. Also, the importance of criteria for installation of such systems in an urban environment was examined by surveying academic experts. According to their opinions it is concluded that, despite the criteria have different importance weights, all aspects of sustainability, i.e., economy, environment, and society, should be considered for the selection of a microgeneration system for a city. Finally, the suitable microgeneration options were evaluated on each criterion by pairwise comparison, and a priority score was assigned after applying the weights defined by the experts. According to this score, future projects on microgeneration opportunities for the City of Edmonton should have the following priority order: micro CHP based on internal combustion engines or micro CHP based on microturbines, CHP based on fuel cells, Solar PV, biomass (wood pellets), and hydrokinetic turbines or urban wind turbines.

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REFERENCES

[1] Province of Alberta, "Electric Utilities Act. Micro-generation Regulation," ed, 2018.

[2] A. Barragan and J. Terrados, "Sustainable cities: an analysis of the contribution made by renewable energy under the umbrella of urban metabolism," International Journal of Sustainable Development and Planning, vol. 12, pp. 416-424, 2016.

[3] I. Delponte and C. Schenone, "RES implementation in urban areas: an updated overview," Sustainability, vol. 12, 2020.

[4] S. Allen, M. Mcmanus, and G. Hammond, "Prospect for and barriers to domestic micro-generation: a United Kingdom perspective," Applied Energy, vol. 85, pp. 528-544, 2008.

[5] M. Baritto, "Analysis of microgeneration options for the City of Edmonton. Intership report," City of Edmonton2020.

[6] Government of Canada. (2020, June 4). Wind Atlas. Available: http://www.windatlas.ca/nav-en.php?no=47&field=EU&height=50&season=ANU

[7] M. A. Hyams, "Wind energy in the built environment," in Metropolitan Sustainability, ed Cambridge, UK: Woodhead Publishing Limited, 2012, pp. 457-499.

[8] S. Thomson and D. L. Townsend, "River erosion and bank stabilization - North Saskatchewan River, Edmonton, Alberta," Canadian Geotechnical Journal, vol. 16, pp. 567-576, 1979.

[9] City of Edmonton. (2020, June 5). Water Levels and Flows. Available: https://data.edmonton.ca/dataset/Water-Levels-and-Flows/cnsu-iagr

[10] D. K. Okot, "Review of small hydropower technology," Renewable and Sustainable Energy Reviews, vol. 26, pp. 515-520, 2013.

[11] Canadian Geothermal Energy Association. (2020). Canadian National Geothermal Database and Territorial Resource Estimate Maps: Alberta. Available: https://www.cangea.ca/albertageothermal.html

[12] Government of Canada. (2020). Photovoltaic and solar resource maps. Available: https://www.nrcan.gc.ca/energy-efficiency/data-research-insights-energy-ef/buildings-innovation/solar-photovoltaic-energy-buildi/resources/photovoltaic-and-solar-resource-maps/18366

[13] energyrates.ca. (2020, July 15). Residential electricity and natural gas. Available: https://energyrates.ca/residential-electricity-natural-gas/

[14] I. Siksnelyte-Butkiene, E. K. Zavadskas, and D. Streimikiene, "Multi-Criteria Decision-Making (MCDM) for the Assessment of Renewable Energy Technologies in a Household: A Review," Energies, vol. 13, p. 1164, 2020.

[15] A. Barragan-Escandon, J. Terrados-Cepeda, E. Zalamea-Leon, and P. Arias-Reyes, "Electricity production using renewable resources in urban centres," Proceedings of the Institution of Civil Engineers, vol. 171, pp. 12-25, 2018.

[16] v. d. B. J. Shmelev Stanislav, "Optimal diversity of renewable energy alternatives under multiple criteria: an application to the UK," Renewable and Sustainable Energy Reviews, vol. 60, pp. 679-691, 2016.

[17] C. Zhang, Q. Wang, S. Zeng, T. Baležentis, D. Štreimikienė, I. Ališauskaitė-Šeškienė, *et al.*, "Probabilistic multi-criteria assessment of renewable micro-generation technologies in households," Journal of Cleaner Production, vol. 212, pp. 582-592, 2019.

[18] J.-J. Wang, Y.-Y. Jing, C.-F. Zhang, and J.-H. Zhao, "Review on multi-criteria decision analysis aid in sustainable energy decision-making," Renewable and Sustainable Energy Reviews, vol. 13, pp. 2263-2278, 2009.

[19] Alberta Government, "Carbon Offset Emission Factors Handbook," 2 ed, 2019.

[20] I. Stafell, D. J. L. Brett, and A. D. Hawkes, Domestic Microgeneration: Renewable and Distributed Energy Technologies, Policies and Economics: Routledge, 2015.