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COSTS OF GREEN RESIDENCES IN CANADA: AN ECONOMIC AND ENVIRONMENTAL ANALYSIS OF DEVELOPING RENEWABLE POWERED BUILDING CLUSTERS

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Abstract: The interest in renewable energy as an alternative to conventional fossil fuels has grown in recently, in response to the environmental and economic concerns of energy use. Energy Step Codes are now mandating net-zero energy buildings, to facilitate the emissions reduction targets of Canada at provincial and federal levels. While net-zero energy buildings can deliver emissions benefits, the additional costs of implementing energy efficiency measures and on-site renewable generation is a major problem to the construction industry and community developers. While studies indicate that buyers are willing to pay a premium for "green" buildings, it is difficult to establish the economic viability of net-zero buildings without conducting a comprehensive economic assessment. This research proposes to quantify the economic and environmental impacts of on-site RE integration for residential building clusters. Building level-and cluster centralised RE facilities will be considered in the assessment, and the incremental costs of converting building clusters to net-zero status will be investigated. Based on the assessment, the increase in housing prices for different housing types (i.e. single-family detached, single-family attached, multi-unit residential buildings) due to net-zero or near-zero conversion will be identified using a scenario-based approach. Moreover, the residential emissions benefits that can be achieved by different RE investments will be quantified using life cycle assessment. Based on the economic and environmental impact analysis, the effect of clean energy transformation of housing affordability will be discussed. The findings will be useful to the construction industry in making their investment decisions for net-zero ready construction.

1 INTRODUCTION

Introducing clean energy initiatives to mitigate the environmental concerns associated with the global energy use has caught public attention at many levels in the recent times (Karunathilake, Hewage, Mérida, & Sadiq, 2019). The conventional fossil fuel usage has been linked with anthropogenic climate change and many other forms of environmental damage (Ellabban, Abu-Rub, & Blaabjerg, 2014)(Moriarty & Honnery, 2012). In addition to the environmental concerns of climate change, resource depletion, and damage to eco-systems, energy use is also associated with economic and social impacts (Shafiee & Topal, 2009)(Hernández & Bird, 2010). In Canada, around 8% of the households are affected by energy poverty (Natural Resources Canada, 2017b). Further, many communities are affected by the lack of energy security and energy independence, due to the reliance on external fossil fuel resources to fulfill their basic energy services. The building sector, which comprises a significant fraction of the urban built environment, accounts for 40% of the global energy consumption (Karunathilake, Hewage, & Sadiq, 2018). In Canada buildings are responsible for one third of the country's GHG emissions (Frappé-Sénéclauze & Kniewasser, 2015). Therefore, focusing on the building sector is important in curbing the environmental and economic issues related to energy use.

The Canadian residential building sector accounts for 17% of Canada's secondary energy use 14% of the GHG emissions (Natural Resources Canada, 2016). Due to the significance of this sector in energy use and related emissions control, much attention has been shed on introducing clean energy initiatives to residential buildings. Residential buildings are classified into three main categories, as single family detached housing (SFD), single family attached housing (SFA), and multi-unit residential buildings (MURB) (Karunathilake, Perera, Ruparathna, Hewage, & Sadiq, 2018). At neighbourhood level, these buildings form clusters with similar characteristics. While clean technology initiatives can deliver great benefits for communities, the economic impacts of such initiatives have to be analysed before establishing their viability. Due to the high investment cost associated with clean energy technologies, they to an inevitable increase in the housing development costs. Past studies have identified that users are prepared to pay a higher "green" premium on green-rated housing, and that such a certification can add up to 9% to the average housing selling price (Harney, 2012). However, the exact price impact of clean energy residential development needs to be quantified to ensure whether the cost increase matches what the homeowners are willing to pay, so that the construction industry can make informed decisions.

This study focuses on quantifying the economic and environmental impacts of on-site RE integration for residential building clusters, using a community in British Columbia (BC), Canada, as a case study. The development of net-zero energy ready buildings has been mandated by the BC Energy Step Code (The Government of British Columbia, 2018). Building level-and cluster centralised RE facilities are considered in the assessment, and the incremental costs of converting building clusters to net-zero status are investigated. Based on the assessment, the increase in housing prices for different housing types due to net-zero or near-zero conversion are identified using a scenario-based approach. Moreover, the residential emissions benefits that can be achieved by different RE investments are quantified using life cycle assessment. Based on the economic and environmental impact analysis, the effect of clean energy transformation on housing affordability is discussed. The findings will be useful to the construction industry in making their investment decisions for net-zero ready construction.

1 METHODOLOY

The study location was selected as a municipality (coordinates 49.7711° N latitude, 119.7275° W longitude) in the Okanagan Valley, BC, Canada. The energy end use fractions in BC were identified based on the data published by Natural Resources Canada (Natural Resources Canada, 2018). The end uses are expected to be supplied via building level and cluster level renewable energy resources.

Table 1: Energy end uses in British Columbia residential sector

Residence type	*Single family detached*	*Single family attached*	*Apartments (multi-unit)*
Space heating	57.53%	42.90%	34.13%
Water heating	24.75%	35.89%	40.41%
Space cooling	0.89%	1.06%	0.64%
Lighting	4.77%	4.41%	3.26%
Appliances	12.06%	15.75%	21.56%

The assessment is conducted for a proposed neighbourhood in the above municipality, with a total expected population of 6500. The proposed residential development plan for the community was obtained through consultation with the community developers, and the average floor areas for the residences were estimated based on the information provided by FortisBC, the regional utility provider. The average energy use intensities for households in BC were obtained from the Statistics Canada (Statistics Canada, 2011).

Table 2: Household type characteristics

Dwelling type	*Annual energy consumption*	*Floor area*	*Units*
	kWh/household	*(sq. ft.)*	#
Single-family detached (SFD)	34722	2259	40
Single-family attached (SFA)	21111	1988	2115
Multi-unit residential buildings (MURB)	12778	1094	725

At building level, rooftop solar PV and ground source heat pumps (GSHP) were identified as viable RE technologies for the community, and at cluster level, a centralised solar PV plant, a biomass combustion facility, and a waste-to-energy (WtE) incineration facility (Karunathilake et al., 2019). Wind energy generation is not generally conducted at building level due to structural, noise, and wind pattern related issues (Torcellini, Pless, Deru, & Crawley, 2006). Solar thermal collector option was abandoned due to the low Further, the cluster-level central wind energy option was neglected in the assessment due to the low resource potential in the area (Morrison Hershfield Ltd, 2013).

1.1 Scenario development for RE integration

Energy supply scenarios were defined based on different combinations of the available supply options. Rooftop PV facilities were assumed to be only installed on SFA and SFD units. The rooftop installation capacities for SFD and SFA units were defined as 4kWp and 2kWp respectively based on rooftop area limitations. The MURBs were clustered together, to be serviced by the centralised solar PV plant. The PV plant capacity was defined under the basis of 2 kWp per MURB unit. Geothermal heating systems are recommended to be sized at 60-70% of the heating load of a residence by Natural Resources Canada, for maximum cost effectiveness (Natural Resources Canada, 2017a). Thus, the GSHP capacity for the housing units to be set at 70% of the space heating load. The maximum capacity of the WtE plant was planned to process the entire municipal solid waste mass generated in the community, and the biomass plant was sized with the assumption that at least 50% of the available biomass in proximity to the site location will be available for energy generation at the plant. Under the conventional supply side, grid electricity was assumed to accommodate both heating and electricity demand (the remainder that is not supplied through RE), as this is the recommended practice for new construction in BC (Heerema, 2017). The current grid electricity price was set at 0.0936 $/kWh (Karunathilake et al., 2019). The scenario details are provided under Table 3. For the purpose of this study, the neighbourhood and the RE facilities are assumed to undergo overnight construction. In cost allocation, the rooftop PV facilities were allocated to the individual SFD and SFA residences based on their installed capacity, and the costs of the central PV facility was allocated to the MURB units equally. Similarly, GSHP system costs were allocated to their respective housing units. The other centralised RE generation facility costs were allocated to all housing units on the basis of floor area. The above energy supply options were analysed under different implementation scenarios for the neighbourhood, thus gradually incrementing the RE fraction in the community energy mix.

Table 3: Clean energy implementation scenarios

Scenario	***Energy supply***	***Electricity***	***Heat***
1	Grid electricity	100% Grid electricity	100% Grid electricity
3	Grid electricity	Remaining electricity demand supplied by grid	Remaining heat demand supplied by grid
	Solar PV	SFD – 4 kW; SFA – 2 kW	-
4	Grid electricity	Remaining electricity demand supplied by grid	Remaining heat demand supplied by grid
	Solar PV	SFD – 4 kW; SFA – 2 kW; MURB - central PV 1450 kW	-
5	Grid electricity	Remaining electricity demand supplied by grid	Remaining heat demand supplied by grid
	Solar PV	SFD – 4 kW; SFA – 2 kW; MURB - central PV 1450 kW	-
	GSHP	-	GSHP system designed to provide 70% of the space heating load
7	Grid electricity	Remaining electricity demand supplied by grid	Remaining heat demand supplied by grid
	Solar PV	SFD – 4 kW; SFA – 2 kW; MURB - central PV 1450 kW	-
	GSHP	-	GSHP system designed to provide 70% of the space heating load
	Biomass	Biomass plant 530 kW capacity	-
	WtE	MSW incineration plant 4225-ton capacity	-

1.2 Energy generation assessment for RE facilities

For the purpose of this analysis, grid-tied and net-metered residential solar PV installations were assumed. In BC, the net metering rate is 9.99 cents per kWh (BC Hydro, 2016). The applicable solar regional factor for a PV plant was taken as 1133 kWh/kWp/a for the site location (BC Hydro & FortisBC, 2015). The average

PV system inverter efficiency was taken as 90% (Fletcher, 2014). The equation given below was used in assessing the annual solar energy generation output for the PV systems (Vanek & Albright, 2008).

[1] $E = C \times RF \times \eta_{inv}$

E = Annual energy output
C = System capacity
RF = Annual solar regional factor (solar potential)
η_{inv} = Inverter efficiency

To generate 1 MWh of electricity in a biomass plant, 0.72 oven dry tons (ODT) of wood fibre is necessary (Industrial Forestry Service Ltd., 2015). The following equation defines the total energy generation for a given amount of biomass supply. Wood-based biomass was assumed have a moisture content of 23% based on previous literature (Hallbar Consulting & Research Institute of Sweden, 2017).

[2] $EP_{Bio}(kWh) = m_{bio} \times (1 - m_w) \times \frac{1000}{0.72}$

The plant capacity factor (CF) for biomass electricity plant was defined as 91% to represent operational inefficiencies. The following equation represents the saleable energy of a biomass plant, assuming 24-hour operation throughout the year (Industrial Forestry Service Ltd., 2015).

[3] $ES_{Bio}(kWh) = C_{p,bio} \times CF \times 24 \times 365$

Considering the median biomass resource availability and cost of acquisition and delivery listed in Table 4, the cost per ton of biomass supplied to the plant was estimated as 19.91 $/ton.

Table 4: Annual biomass resource availability at selected site

Type of biomass	*Availability (ton)*	*Supply mix*	*Acquisition & delivery cost ($/ton)*
Yard and agricultural residue	500 - 800	8.18%	50
White wood	800	10.06%	15 (median)
Green wood	1500 - 2000	22.01%	17.5 (median)
Chipped wood, preserved wood, timber waste	4500 - 5000	59.75%	17.5 (median)

The following equation can be used to estimate the energy generation potential of MSW incineration. The per capita MSW production per annum for the Central Okanagan Regional District (community location) was identified as 0.650 tons, and the per ton energy generation potential (EPt) of MSW was established as 800 kWh/ton based on literature (Government of British Columbia - Canada, 2018)(Stantec, 2010).

[4] $E_{WTE} = m_{MSW,p} \times EPt_{MSW} \times P_{com}$

$P_{com} = Population\ of\ the\ community$
$EPt_{MSW} = Per\ ton\ energy\ generation\ potential\ of\ MSW$
$m_{MSW,p} = Per\ capita\ MSW\ generation$

1.3 Life impact and cost assessment

The life cycle emissions of different renewable energy facilities were evaluated through a life cycle assessment (LCA) conducted using SimaPro software. The ReCiPe midpoint impact assessment method was used for the LCA. The performance characteristics of the selected technologies are listed below under Table 5. The average cost factors for different RE generation technologies listed below were obtained primarily from the data published by the National Renewable Energy Laboratory of the U.S. Department of Energy (National Renewable Energy Laboratory, 2016)(Stantec, 2010)(Morrison Hershfield Ltd, 2013).

Table 5: Renewable energy generation facility characteristics

Technology	**Factor**	**Unit**	***Value***
Solar PV – building level	Installed cost	$/kW	3897
	Fixed O&M cost	$/kW-yr	21
	Fuel and/or water cost	$/kWh	0
	Emissions	$kgCO_2$ eq/MWh	7.82E+01
	Lifetime	Year	33
GSHP	Installed cost	$/ton	7765

	Fixed O&M cost	\$/ton-yr	109
	Fuel and/or water cost	\$/ton	397
	Emissions	kgCO$_2$ eq/MWh	2.44E+02
	Lifetime	Year	38
Solar PV (large-scale)	Installed cost	\$/kW	2493
	Fixed O&M cost	\$/kW-yr	19
	Fuel and/or water cost	\$/kWh	0
	Emissions	kgCO$_2$ eq/MWh	7.78E+01
	Lifetime	Year	33
Biomass combustion	Installed cost	\$/kW	5792
	Fixed O&M cost	\$/kW-yr	98
	Acquisition & transport	\$/ton	20
	Emissions	kgCO$_2$ eq/MWh	5.45E+01
	Lifetime	Year	28
Waste-to-energy	Installed cost	\$/annual ton	596
	O&M cost	\$/ton	50
	Emissions	kgCO$_2$ eq/MWh	4.13E+02
	Lifetime	Year	25

1.3.1 Economic impact assessment

The increase in investment per household and the annual operational energy cost savings were selected as parameters in the economic impact assessment, to reflect the effect on property developers and residents respectively.

[5] $$AOS = \left(\sum_t [OE_B + WH_B + SH_B] \times GEP\right) - \left(\sum_t CSC + \sum_t RFC\right)$$

$SH_B = Annual\ space\ heating\ load\ of\ the\ building\ (kWh)$
$WH_B = Annual\ water\ heating\ load\ of\ the\ building\ (kWh)$
$OE_B = Annual\ electric\ load\ of\ the\ building\ (kWh)$
$AOS = Annual\ operational\ energy\ cost\ savings$
$GEP = Grid\ electricity\ price$
$CSC = Conventional\ supply\ costs$
$RFC = Renewable\ fuel\ costs$

The effect on the price of energy supply was estimated based on the levelized cost of energy (LCOE), using the following equation (International Renewable Energy Agency, 2012). LCOE provides a measure of the affordability of the energy supply, and whether grid parity has been achieved (Gu Choi, Yong Park, Park, & Chul Hong, 2015). The project evaluation period was assumed to be 25 years, and the interest rate and inflation was assumed to be 5% and 2% respectively.

[6] $$LCOE = \sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t} \Big/ \sum_{t=1}^{n} \frac{E_t}{(1+r)^t}$$

I_t = Investment expenditure for year t;
M_t = O&M expenditure for year t;
F_t = Fuel expenditure for year t;
E_t = Electricity generated in year t;
r = Discount rate;
n = Facility lifetime (service life)

The increase in housing development costs due to the RE implementation in each scenario was quantified. The average housing prices published by the Okanagan Mainline Real Estate Board for Central Okanagan by were used in the assessment (Okanagan Mainline Real Estate Board, 2016).The housing prices of the region was identified from up-to-date local sources, and the increased development cost was analysed on the basis of floor area and percentage price increase per housing unit. The emissions reduction potential was estimated with reference to the grid electricity, which was estimated to have a life cycle emissions impact of 2.74E+02 kgCO$_2$eq per MWh based on the LCA results.

2 Results

Figure 1 depicts the overall energy share of renewables and conventional grid supply at community level. It can be seen that in scenario 5, almost 80% of the community's energy supply can be provided through RE, thus bringing the community close to near-zero status. As the heating demand dominates the community energy consumption, the integration of geothermal heat greatly increases the RE fraction in the energy supply.

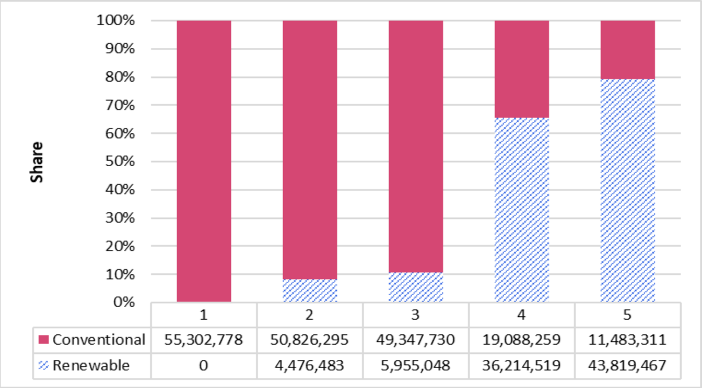

Figure 1: Share of renewables at community level

Figure 2 depicts the residential energy supply mix under different scenarios at household level. With the increasing RE integration across the scenarios, the grid supply for all types of housing gradually decreases. GSHP account for the largest share of energy at residential level.

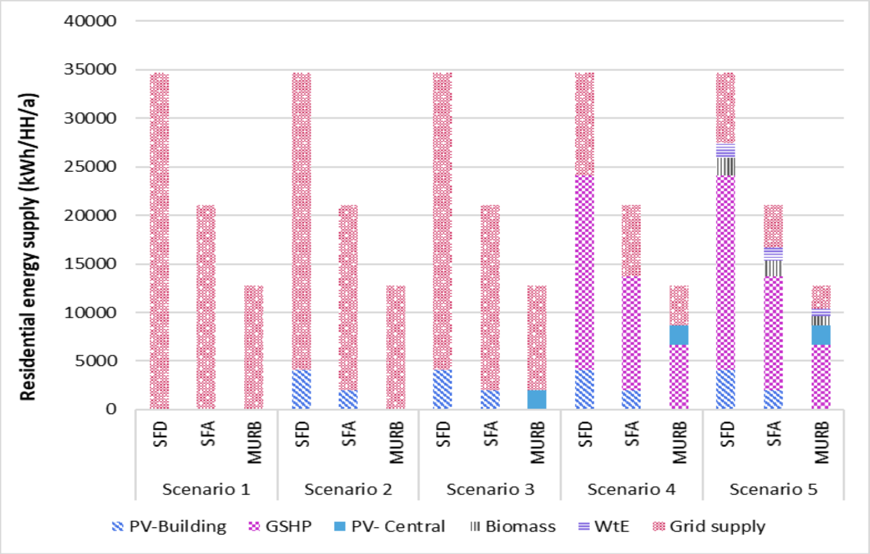

Figure 2: Residential energy supply mix for different scenarios

Table 6 lists the overall energy supply costs for each scenario at household level. The investment costs are allocated to individual housing types. The costs and energy generation of central RE facilities were allocated on the basis of floor area for different housing types. The conventional grid supply cost gradually decreases from scenario 1 to 5, with the increasing share of RE in the supply. The cost saving potential under each scenario for the housing types are displayed under Table 7. Scenarios 4 and 5 have levelized costs of energy comparable with the current grid electricity price. Moreover, those scenarios have a net return ratio above 100% when the cost saving potential over 25 years is compared with the initial investment cost (IC). Thus, the investment cost is paid back by the end of 25 years through the cost savings. Under all four RE scenarios, the households gain net energy cost savings annually.

Table 6: Energy system costs

Scenario	***Housing type***	***Grid supply***	***Investment for RET***	***Annual O&M cost***	***LCC of RET***	***Annual grid supply cost***
	Units	kWh/HH	$/HH	$/HH/a	$/HH	$/HH/a
Scenario 1	SFD	34722	0	0	0	3250
	SFA	21111	0	0	0	1976
	MURB	12778	0	0	0	1196
Scenario 2	SFD	30643	12964	106	22166	2868
	SFA	19072	6482	53	11083	1785
	MURB	12778	0	0	0	1196
Scenario 3	SFD	30643	12964	106	22166	2868
	SFA	19072	6482	53	11083	1785
	MURB	10738	6482	48	7342	1005
Scenario 4	SFD	10645	20966	612	39249	996
	SFA	7428	11347	361	21469	695
	MURB	4071	9427	234	13628	381
Scenario 5	SFD	7268	23447	846	48281	680
	SFA	4457	13530	567	29418	417
	MURB	2436	10628	348	18003	228

Table 7: Energy costs savings for households

Scenario	***Housing type***	***Annual cost savings***	***PV of cost savings***	***Ratio of cost saving to IC***	***LCOE***
	Units	$/HH/a	$/HH/a		$/kWh
Scenario 1	SFD	0	0	-	0.0936
	SFA	0	0	-	
	MURB	0	0	-	
Scenario 2	SFD	276	4802	37.04%	0.3121
	SFA	138	2401	37.04%	
	MURB	0	0	-	
Scenario 3	SFD	276	4802	37.04%	0.2859
	SFA	138	2401	37.04%	
	MURB	143	2489	38.40%	
Scenario 4	SFD	1641	28581	136.32%	0.0902
	SFA	920	16018	141.16%	
	MURB	581	10111	107.26%	
Scenario 5	SFD	1723	30006	127.97%	0.1012
	SFA	992	17272	127.65%	
	MURB	620	10801	101.63%	

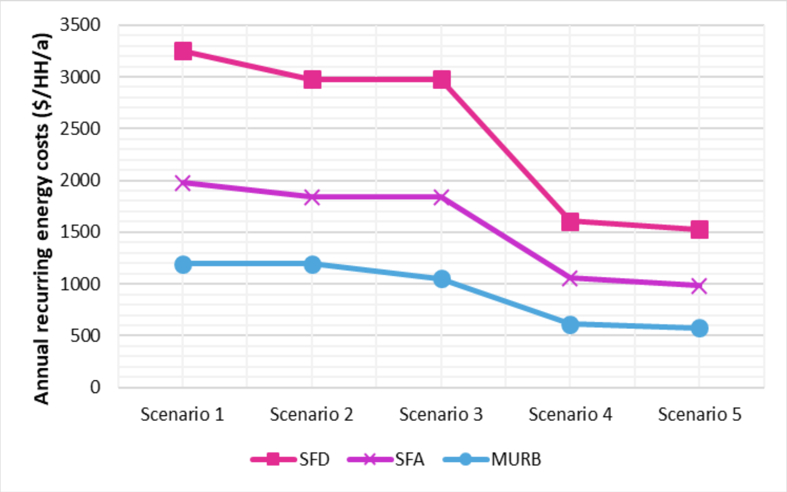

Figure 3: Variation of recurring energy costs for different types of housing

Error! Not a valid bookmark self-reference. lists the emissions and the emissions reduction potential associated with each scenario at community level.

Table 8: Emissions reduction potential at community level

Scenario	*Total RE emissions*	*Grid emissions*	*Total emissions*	*Emissions reduction*	*Percentage*	*LCC over 25 years*	*Emissions reduction per $ invested*
Units	*$kgCO_2$ eq/a*	*$kgCO_2$ eq/a*	*$kgCO_2$ eq/a*	*$kgCO_2$ eq/a*	*%*	*$*	*$kgCO_2$ eq/$*
Scenario 1	0	15152961	15152961	0	0.00%	0	0
Scenario 2	350061	13926405	14276466	876495	5.78%	24327093	0.90
Scenario 3	465093	13521278	13986371	1166590	7.70%	29650049	0.98
Scenario 4	7848404	5230183	13078587	2074374	13.69%	56858093	0.91
Scenario 5	9474604	3146427	12621031	2531930	16.71%	77201957	0.82

The percentage of emissions reduction from the base-case scenario increases with the share of RE, and a 16.7% reduction is achievable under scenario 5. The greatest emissions reduction per dollar invested can be seen under scenario 3, with the central and building level solar PV facilities. The housing prices and overall costs increase due to the added investment on RE and the facility operations, as seen under Table 9 and Table 10. However, the percentage increase in the overall housing prices and costs is below 10%, making the added economic burden fall within the acceptable range of green premiums.

Table 9: Expected housing price increase

Housing type	*Price*	*Expected increase in housing price (%)*				
	$/HH	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**
SFD	572260	0.00%	2.27%	2.27%	3.66%	4.10%
SFA	389030	0.00%	1.67%	1.67%	2.92%	3.48%
MURB	292050	0.00%	0.00%	2.22%	3.23%	3.64%

Table 10: Expected housing cost increase during lifetime

Housing type	*Expected increase in housing costs over lifetime (%)*				
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**
SFD	0.00%	3.87%	3.87%	6.86%	8.44%
SFA	0.00%	2.85%	2.85%	5.52%	7.56%
MURB	0.00%	0.00%	2.51%	4.67%	6.16%

3 Discussion and conclusions

The study results indicate that operational energy costs and emissions can be reduced at community and building level via the integration of RE. Locally available RE resources can take many communities to net-zero or near-zero status in Canada. Geothermal energy is indicated to be the most attractive technology option at building level, leading to highest comparative benefits, due to the dominance of heating energy requirement in Canadian residences. Taking a cluster approach to RE integration can deliver higher benefits in terms of overall cost and emissions reduction compared to only limiting the clean energy efforts to building level. Investing in central RE facilities for building clusters can also reduce the LCOE of the RE supply, as the economies of scale are achieved for power generation facilities. While the housing prices increase initially with the added RE, the return from annual energy cost saving over the years can make this a worthwhile investment for the residents, especially under cluster scenarios.

The community developers incur the additional investment costs for clean energy initiatives, and the residents bear the increase or decrease in operational energy costs due to the implementation. This leads to a principal agent problem since the developers gain no added benefit from the increased investment (International Energy Agency, 2008) (Karunathilake, Perera, et al., 2018). The developers can be incentivised to make this effort if their investment can be recovered through higher green premiums attached to housing price tags. Further economic incentives can be provided to such clean energy initiatvies through carbon credit mechanisms, where a financial value is assigned to the emissions reduction potential. Such programs are currently becoming popular in North America, with the increased attention on climate change and the need for emissions mitigation. The support of financial institutions to fund RE efforts in the construction industry in the form of rebates and loan schemes, and policy level support via mechanisms such as tax credits can also go a long way in promoting RE in residential construction.

While life cycle carbon emissions reductions can be achieved with increasing level of RE integration, the emissions reduction per dollar invested can decrease with the integration of GSHP, biomass, and WtE. The input energy requirement and the operational emissions of biomass incineration and WtE technologies leads to this disadvantage, with comparison to solar PV which is a zero-emissions technology. Taking a life cycle perspective on the emissions reduction aspect ensures that RE sources are not given a simple pass as “good” technologies, and instead takes a critical holistic view of their impacts.

Green energy initiatives still have a long way to go in becoming mainstream in residential construction. In the Okanagan Valley, especially in the urban centres, housing prices show an increasing trend over the years with the growth of communities. Correspondingly, RE costs have decreased during the last decade. For example, solar PV module costs were predicted to reduce by 35% in 2018 (Bloomberg LP, 2018). These factors could further increase the affordability and acceptability of RE integration in the housing market. One major challenge to further RE penetration in residential construction is the involvement of multiple stakeholders at different levels, who have conflicting objectives. Policy support and frameworks that consolidate stakeholder efforts and address the concerns of all parties are necessary to further improve building level clean energy efforts.

When applying the evaluation framework to other geographic locations, the energy generation potential of the RET and housing prices can change depending on the locational parameters, even though the cost factors of installation and O&M remain roughly the same for most parts of North America. For instance, in the northern part of Canada, the solar energy generation potential will be far below what is observed for BC. However, by using the same evaluation model, the housing price impact of clean energy for regions other than Okanagan can also be quantified.

Even though this study took a scenario-based approach in evaluating the effects of RE integration at building and cluster level, further optimisation can be conducted to identify the best approach to integrate RE in a residential neighbourhood. The same evaluation model can be used for integrating other RET options and scenarios that are not discussed in this paper in residential construction, to analyse their costs and benefits through an economic lens. Moreover, various uncertainties and variations affect the decision parameters such as the resource availability, cost factors, and prices used in the study, due to the events in the macro-environment and weather. These uncertainties can be incorporated into the decision making for further accuracy and improved information by probabilistic and possibilistic methods such as Monte Carlo analysis and fuzzy logic. Further, a sensitivity analysis approach can be used to identify how the variations in different factors affect the final economic outcomes. Future stages of this study need to address the above issues for improved decision support.

Further work needs to be conducted on identifying the best investment prioritisation strategies for building clusters and communities for RE integration. While the study was conducted for BC, this province has a much lower grid emissions factor compared to other provinces such as Alberta with higher reliance on fossil fuels. Such places as well as Canada’s North can benefit from further exploration into the integration of RE at residential level. The developed approach can be extended to other provinces in Canada to identify the development of net-zero buildings.

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