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Research Article

When the Sun Sets on Net Metering: How the Cancellation of Net Metering Impacted the Potential Adoption of Residential Rooftop Solar Photovoltaics in Regina, Saskatchewan

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Abstract: Rooftop solar photovoltaics will play a role in decarbonizing electricity generation and meeting global climate goals. Policymakers can benefit from understanding how their policy choices impact rooftop solar PV adoption. We conduct a case study of Regina, Saskatchewan to determine the extent to which solar policy changes in that Canadian province have impacted the relative desirability of rooftop solar PV. We assess financial returns that can be achieved in Regina under three policy scenarios: net metering, net billing, and net billing with a capital incentive. We use GIS analysis to identify suitable roofs in Regina and assess any shading that may occur. We calculate hourly capacity factors for these roofs using solar irradiation data, temperature data, and shading factors. We match the simulated solar output results with hourly load data to simulate over 4 million potential roof-load combinations and calculate NPV and net monthly return for each combination. We conduct a telephone survey of 451 Regina residents to assess willingness to install solar at different levels of financial return and compare these results to our solar simulations. Our results indicate that a move from net metering to net billing reduced financial returns from rooftop solar and lowered solar potential from 129 Gigawatt-hours (GWh) per year to 99 GWh/yr in Regina. The introduction of a capital incentive grant by the federal government has helped increase solar potential upwards to 120 GWh/yr. The capital incentive grant may also help overcome high discount rates by providing a larger upfront benefit to households that install solar.

Keywords: climate change; net billing; net metering; photovoltaics; Regina; Saskatchewan; solar energy; utility policy

1. Introduction

1.1. Purpose of this Study

Solar energy will play an important role in decarbonizing electricity generation and meeting global climate goals [1–4]. While utility-scale solar offers zero-emissions electricity at a lower cost [5], rooftop solar photovoltaics (PV) will also contribute to achieving decarbonization goals. In their *Net Zero by 2050* roadmap, the International Energy Agency (IEA) sets a milestone of 240 million households with rooftop solar PV installations by 2050 [2]. Jacobson *et al* [6] outline a 100% renewable energy scenario with over 1 billion residential rooftop solar PV units by 2050. The National Renewable Energy Laboratory (NREL) models rooftop solar PV scenarios ranging from 60 Gigawatts (GW) of capacity to 160 GW in the US by 2050 [7] and 8 to 23 GW in Canada by the same year [3,8]. Policymakers hoping to achieve these targets will benefit from understanding how policy can encourage rooftop solar PV adoption.

Previous research has identified factors that influence rooftop solar PV adoption. In general, these factors fall into three categories: values, information, and financial returns.

With respect to values, households may adopt rooftop solar PV because they value self-sufficiency and want to reduce dependence on the electricity grid [9] or distrust their electricity utility [10]. Other households value innovation and technology and are eager to be early adopters of rooftop solar PV [11,12]. Some may be motivated by environmental values, though this appears to be neither necessary nor sufficient for solar PV adoption [11]. Rather pro-environmental values may be related to a higher perception of personal benefits from solar [12]. The relative influence of values can vary at different levels of adoption. In a meta-analysis of literature on residential solar photovoltaic adoption, Schulte *et al.* find that pro-environmental motivations are important for early adopters of solar, while financial incentives become more important as solar PV adoption spreads beyond the early adopters [13].

Information about solar energy can encourage solar PV adoption. This information can be the result of peer effects, where a household speaks with a friend or neighbour who installed solar [14,15] or sees solar PV installations in their neighbourhood [12,16,17]. Confirming the importance of peer effects, Rode and Weber found that households in Germany were more likely to adopt rooftop solar if they saw solar installed in proximity to their homes [16]. Similarly, in a survey of 2065 Canadians, Parkins *et al.* find that respondents who regularly see solar panels are more likely to want to install panels on their own home [17]. Information can also be provided to households directly by a solar installation company [9] or a trusted third-party such as a non-profit organization or government agency [12]. In a study of solar adoption intentions in Ontario, Canada, Islam found that "Technology awareness and energy cost saving have a significant effect on the adoption probability, reinforcing the need for effective education" about solar and its benefits ([18], p. 348). Learning about solar from a trusted source can provide reassurance that the technology works as intended [14] and can reduce informational barriers to solar PV adoption [19].

The most important factor influencing rooftop solar PV adoption appears to be financial return [19,20]. Alipour *et al.* find that financial incentives that reduce solar purchase costs have a significant, positive impact on solar adoption [21]. Claudy *et al.* find that perceived cost savings from solar encourage adoption of rooftop solar PV [22]. Conversely, several papers note that high upfront installation costs serve as a barrier to solar adoption [22–24]. Karakaya & Sriwannawit review barriers to solar PV adoption and find that households evaluate the financial return provided by solar relative to alternatives; access to low-cost, non-solar energy alternatives discourage solar adoption [9]. In general, Kastner & Stern find that the financial consequences of an investment such as installing residential solar is relatively more important than factors such as the "disposition" or environmental values of a household [25]. They also find that government funding for investments increases the likelihood of investment, and grants may be more effective than low-interest loans [25]. Williams *et al.* [20] create a parsimonious model of solar PV adoption and find that the net present value (NPV) of the solar installation to the owner explains variations in solar PV adoption across countries. We adopt the parsimonious Williams *et al.* [20] approach in this study and focus on NPV and the financial returns generated by rooftop solar.

Government policy can impact NPV by influencing the capital cost of solar PV installations, the financing cost of the project, the value of avoided electricity purchases during times of self-consumption, and the value of excess power sold to the grid in times of surplus. Physical variables like the quality of the solar resource also influence NPV [26]. Multi-story buildings in high-density neighbourhoods may have limited roof space for solar relative to electricity demand [26]. Shading lowers the potential output of solar and reduces NPV. We consider government policy, the solar resource, roof space, and shading in this study.

In this paper we contribute to the literature in three ways. First, we assess how the net present value of rooftop solar PV is impacted by government policy decisions using real-world data on solar irradiation, rooftop space and orientation, and electricity usage patterns. Second, we use survey data to understand the level of financial return that households require to adopt rooftop solar PV. Third, we combine our analysis of the financial returns made possible by rooftop solar with our survey data to estimate upper bounds for solar adoption. We can then assess the degree to which policy can influence the installation of solar in our case study community of Regina, Saskatchewan. Our mixed methods approach is novel in the solar adoption literature. While papers such as Dargouth *et al.* [27] have analyzed the financial returns to solar under different policy scenarios, they did not link these to survey data of potential adopters. The bulk of the solar adoption literature focuses on either post-hoc solar installation data or surveys asking whether households intend to install solar. We offer a real-world analysis of the implications of moving away from a net metering policy.

1.2. Case Study Community of Regina, SK

We focus on Regina because there is an opportunity for solar to reduce GHG emissions in the city, and because policymakers in Regina are seeking to encourage renewable energy supply. There have also been recent changes to solar policy design in Saskatchewan that impact the financial returns of solar PV.

Regina is the capital city of the province of Saskatchewan and boasts some of the highest solar irradiation values in Canada [28]. Regina's electricity is supplied by provincially owned Crown utility SaskPower, which relies on natural gas (42%) and coal (37%) power generation for most of its electricity supply [29]. The greenhouse gas (GHG) emissions intensity of SaskPower's electricity was 637 tonnes carbon dioxide equivalent (CO_{2e}) per Gigawatt-hour (GWh) in 2021 [29]. Installing solar in Regina offsets this relatively high-emissions electricity.

The municipal government in Regina has committed to achieving a 100% renewable energy future by 2050 [30]. Our analysis seeks to inform the City of Regina's efforts as they create a strategy for achieving this goal. Programs to encourage rooftop solar PV adoption can be part of an integrated approach to municipal emissions reductions, that also involves electrification of vehicles and buildings [31].

There have been a series of changes to solar policy in Saskatchewan in recent years. SaskPower formerly offered a per-kilowatt (kW) capital subsidy for solar PV installations and allowed customers to enroll in a net metering program. Like other net metering programs, SaskPower's program compensated solar electricity exported to the grid at the retail electricity rate. After conducting a public engagement process in 2017 [32,33], SaskPower refined its residential net metering program to offer longer term contracts to customers who installed solar PV. The program changes encouraged more solar adoption in the province and led to an increase in business for the Saskatchewan solar industry. In September of 2019, SaskPower stopped accepting applicants into the net metering program, stating that they had met the 16-Megawatt (MW) quota for the program. SaskPower eliminated the per-kw subsidy and switched new solar customers to a 'net billing' program that compensated electricity sold back to the grid at 7.5 cents (Canadian dollars, CAD) per kilowatt-hour (kWh) rather than the residential retail rate, which was 14.2 cents (CAD)/kWh at the time. This was met with criticism from the solar industry and led to a 90% decline in solar installations in the province within a year of the program change [34,35]. In May 2021 the Canadian federal government introduced a program to encourage energy efficiency and rooftop solar PV. The Greener Homes Grant provides rebates of $1000 per kilowatt (kW) of installed solar, up to a maximum of 5 kilowatts per household [36,37]. In this paper we assess the impacts of this policy change and offer recommendations on program design to increase solar adoption.

2. Methods

2.1. Methods Summary

We assess the impact of the changes to Saskatchewan solar policy by simulating the solar output and financial returns that can be achieved in Regina under three policy scenarios: net metering, net billing, and net billing with the Greener Homes Grant. We use GIS analysis to identify suitable roofs in Regina and assess any shading that may occur. We use solar irradiation and temperature data to calculate hourly capacity factors for simulated solar installations in Regina [28]. We obtain anonymized smart meter data from Saskatoon, SK to understand the potential shape of electricity demand in Regina homes [38,39]. We match Saskatoon and Regina neighbourhoods to ensure load shapes reflect differences in the age of housing and demographic characteristics. We then combine roof and load data to simulate over 4 million potential roof-load combinations and calculate NPV and net monthly return for each combination.

We are interested in how changes to the financial return of rooftop solar impact solar adoption in Saskatchewan. To assess willingness to install solar at different levels of financial return we conduct a telephone survey of 451 Regina residents. We ask solar-eligible households what financial return they would require in order to install rooftop solar PV in their homes. We combine these responses with our solar generation simulations to conduct a bootstrap analysis that identifies the upper limit for solar adoption under our three policy scenarios.

2.2. Solar Potential

We assess residential rooftops in Regina, Saskatchewan for the physical potential to install solar. Hourly solar irradiation and temperature data for 2017 is sourced from Environment Canada's *Canadian Weather Energy and Engineering (CWEEDS)* dataset [28]. We use the approach outlined in Masters [40] to calculate hourly solar capacity factors. We pay particular attention to the heterogeneity of rooftops when it comes to south-facing roof area, angle of the roof relative to due south (i.e. collector azimuth), and shading.

2.2.1. Shading analysis

Hourly rooftop shading factors for Regina are found using open data geographic information system (GIS) files and a free, open-source GIS software (QGIS). We use these data sources and software for ease of access and replicability of results. Required GIS input files are a digital surface model (DSM) in raster format [41] and building footprints in vector format [42]. An additional data file containing hourly solar azimuth and elevation is also needed [43].

To find hourly shading factors, we filter the rooftops by slope and aspect (orientation). Both slope and aspect rasters are created from the DSM raster using built-in QGIS functions of 'Slope' and 'Aspect'. From this, suitable rooftop areas are filtered based on the following criteria:

- Raster files overlapping with building vectors;
- South facing and/or flat (orientation [44] between 90° and -90° and/or slope less than 5°); and
- Not a vertical or near vertical wall (slope less than 70°).

We create shading rasters for each hour of daylight over the entire city using the DSM raster, the solar azimuth and elevation, and the 'Hillshade' function, with the z-factor (exaggeration factor) set to 1 to mimic real shading conditions.

These hourly rasters are then clipped to only the suitable rooftop areas found. Using the 'Zonal statistics' function, the average hourly shading function is found for each suitable rooftop area, as well as the size of the horizontal projection (footprint) of the suitable rooftop area. Finally, the actual size of the suitable rooftop area is calculated based on the size of the horizontal projection of the suitable rooftop area and the associated slope.

Within this process, we make two key assumptions due to data availability and computational processing capabilities, respectively. First, within the DSM raster, most vegetation (tree) coverage that overlapped building footprints is assumed to be filtered out based on the suitable rooftop criteria, as surface coverage from vegetation would not fit the criteria of being flat, nor primarily south facing. This is confirmed through visual inspection of the resulting raster files. Secondly, we calculated the shading factors for only the solstices and equinoxes daylight hours. Based on the historical trends in azimuth and elevation changes, as well as sunset and sunrise times, the rest of the year is linearly interpolated from the solstice and equinox shading data.

2.2.2. Rooftop selection

Our database contains 101,128 residential, commercial and industrial buildings in Regina. We focus on residential rooftops and so select only those properties in areas zoned for medium and light density residential. Zoning data is collected from the City of Regina [42]. We also filter out 1832 multi-unit properties and focus on single-detached and duplexes to match our survey design. This leaves us with 88,876 unique residential buildings. After filtering out buildings with missing information we are left with 78,630 residential buildings in Regina, meaning we have complete information for 88.5% of the unique residential buildings we identify. For each of these buildings we know the south-facing area of the roof, the angle of the south-facing roof relative to due south and have hourly shading factors for each daylight hour of the year (4501 hours in all) using the approach outlined above.

2.2.3. Hourly capacity factors

We calculate hourly capacity factors (CF_{it}) for one year (8760 hours) for each of the 78,630 rooftops based on 2017 solar irradiation and temperature data (see Equation 1) [28]. Temperature data is relevant because temperature impacts the efficiency of solar photovoltaic production; panels produce electricity more efficiently at lower temperatures. We correct for the temperature of the solar cells using the approach outlined in Masters [40]. We assume a nominal operating cell temperature (NOCT) of 46°C based on a review of available solar panels.

We account for the angle of the roof relative to due south in our calculations (the collector azimuth angle ϕ_C in Masters, 2004). We then apply shading factors that proportionately reduce the capacity factors in each hour. The shading factors (S_{it}) represent the proportion of each roof (*i*) that is shaded in any given hour (*t*). We assume that solar panels will take up a maximum of 80% of the roof area, leaving room for maintenance access. We also assume that solar panels will be placed strategically on each roof to mitigate shading and reduce our shading factors by 30% (0.3) to account for this shade mitigation [45].

The shading correction is then applied using Equation 1:

$$CF_{it} = CF_{itu} * (1 - (S_{it} - 0.3)) \qquad (1)$$

Where CF_{itu} is the unshaded capacity factor, and CF_{it} is the capacity factor that results after accounting for shading [46].

2.3. Load Profiles

Some of the policies to encourage solar PV adoption differentiate between electricity that is exported to the grid and electricity that is consumed 'behind the meter' within the property on which the solar is installed. To account for these differences, we calculate measures of "self-consumption". This is the proportion of electricity consumed by the residential homeowner. Hourly load data is not available for Regina, Saskatchewan because smart meters are not yet widely deployed. Instead, analog electricity meters are read occasionally and consumption between meter readings is estimated. The situation is different in Saskatoon, Saskatchewan where the local utility Saskatoon Light & Power has deployed smart meters throughout their service area. We use hourly load data from Saskatoon smart meters as a substitute for the unavailable Regina load data [38,47]. We believe the substitution is valid since Saskatoon and Regina are located 250 kilometers apart, face very similar climates, and are home to people with similar lifestyles. To ensure the load shapes from Saskatoon closely approximate expected load shapes in Regina we match neighbourhoods in each city based on socio-demographics and housing characteristics. We then calculate self-consumption factors for each roof and load pair within each matched neighbourhood set.

We compare the distribution of capacity factors using the 'ggridges' package in R [48]. This visualization approach indicates the relative frequency of capacity factors within our simulations. Capacity factors are listed along the x-axis and the height of the curve indicates the relative frequency of each capacity factor score. The highest points on the distribution curves indicate the most frequent capacity factor scores. Similar visualizations are used for self-consumption scores, net present value (NPV), and monthly net returns (see figs. 1 to 9 below).

2.3.1. Neighbourhood matching

The shape of electricity load will vary by household and is determined by the lifestyles of the occupants, the nature of the appliances in the home, and building characteristics such as energy efficiency, heating system, and water heating energy source. To match Regina and Saskatoon neighbourhoods we compare six neighbourhood statistics from the 2016 Census [49–51]:

- Median after-tax income of households in 2015 (Y_l);
- Proportion of population with postsecondary certificate, diploma or degree (E_l);
- Proportion of owner-occupied dwellings (O_l);
- Proportion of dwellings built pre-1960 (A_l);
- Proportion of single-detached homes (S_l); and
- Average monthly shelter costs for owned dwellings ($) ($C_l$).

We pool the neighbourhood statistics from Regina and Saskatoon and normalize all the variables using Equation 2:

$$Norm_{kl} = \frac{(Value_{kl} - Mean_k)}{SD_k} \tag{2}$$

Where l is the neighbourhood, and k represents each of the six statistics mentioned above. We then calculate the Euclidean distance between each of the Regina and Saskatoon neighbourhood pairs using Equation 3:

$$\begin{aligned} Euclid_{lm} &= (Y_l - Y_m)^2 + (E_l - E_m)^2 + (O_l - O_m)^2 \\ &+ (A_l - A_m)^2 + (S_l - S_m)^2 + (C_l - C_m)^2 \end{aligned} \tag{3}$$

Where l represents Regina neighbourhoods and m represents Saskatoon neighbourhoods. We then sequentially select Regina-Saskatoon neighbourhood pairs with the lowest Euclidean distance scores. In all we match twenty-eight Regina neighbourhoods with Saskatoon neighbourhoods that possess similar characteristics.

2.3.2. Self-consumption calculations

We use solar capacity factor data for the 78,630 Regina rooftops, and 1648 unique load profiles from Saskatoon homes to calculate solar self-consumption. We calculate self-consumption for each roof-load combination by joining the annual capacity factor data for each Regina roof with each of the load profiles in the matched Saskatoon neighbourhood file. This means for a given Regina neighbourhood with i roofs, and v matched Saskatoon load profiles we have $i * v$ solar-load combinations.

We scale the size of the simulated solar installation to equal the size that would produce annual electricity equal to annual household load, or the maximum size possible on the available roof area, whichever is greater. We assume that 6m^2 of roof area is required for each kilowatt of solar capacity.

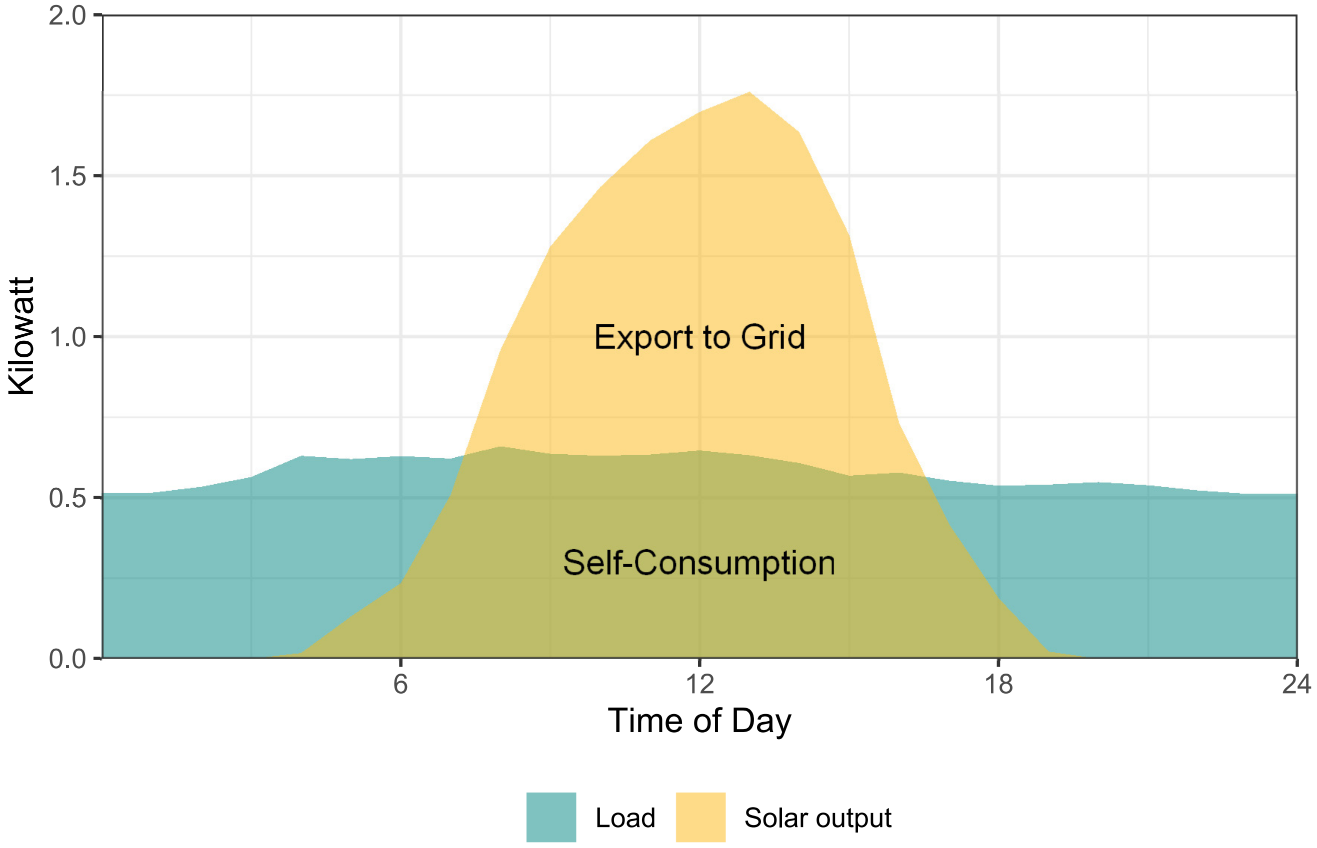

Figure 1. Representative Residential Load and Solar Output Over the Course of One Day.

We then compare hourly solar output in the simulated solar installation to hourly household load. When solar output is greater than load in a given hour, we calculate the amount of electricity exported to the grid (e.g. see Figure 1 where solar output is greater than load during peak solar production hours). We then calculate annual solar output ($output_{iv}$), load ($load_v$), and electricity exported to the grid ($export_{iv}$). Self-consumption (SC_{iv}) for each roof-load combination is calculated using Equation 4:

$$SC_{iv} = 1 - \frac{export_{iv}}{output_{iv}} \tag{4}$$

Where i refers to Regina roofs, and v refers to Saskatoon Light & Power load profiles. In total we calculate self-consumption statistics for 4,481,346 unique roof-load pairs. We summarize the distribution of self-consumption proportions using the 'ggridges package in R [48]

2.4. Policy Simulations

We simulate three solar policies modelled on past and present policies in Saskatchewan:

- Net metering policy that allows customers to receive credit for excess electricity sold to the grid at the 2022 retail rate of 14.705 cents/kWh (plus sales tax);
- Net billing policy that provides customers with a credit for excess electricity sold to the grid at a discounted rate of 7.5 cents/kWh;
- Net billing combined with a capital grant modelled after the existing Greener Homes Grant offered by the Canadian federal government that offers $1000 per kilowatt of installed solar, up to a maximum of $5000 [36].

We model the outcomes of each policy with respect to the net present value (NPV) of the solar installation, and the monthly financial outlook for a household installing solar. Williams et al. [20] suggest that NPV provides a parsimonious model of solar adoption. They find empirical support relating NPV to solar adoption rate. We calculate NPV using the formula outlined Williams et al. [20] and presented in Equation 5:

$$NPV_{iv}(\$) = (-C_{total} + S) + \sum_{t=1}^{T} \frac{output_{iv} \times SC_{iv} \times RP \times (1+\mu)^t}{(1+r)^t} + \sum_{t=1}^{T} \frac{output_{iv} \times (1 - SC_{iv}) \times \text{Solar Price}}{(1+r)^t} \tag{5}$$

Where:
C_{total}: capital cost of the PV system ($)
S: subsidy for PV purchase ($)
$output_{iv}$: total electricity produced in one year by the solar installation (kWh)
SC_{iv}: self-consumption share (%)
RP: retail price of electricity ($/kWh)
$Solar\ Price$: price paid for solar energy exported to the grid ($/kWh)
μ inflation rate (%)
r: social discount rate (%)
T: terminal year of the solar installation which is 25 assuming a 25-year life for the solar panels.

The cost of residential solar PV in Regina, Saskatchewan was $2300/kW installed in 2019 [52]. This per-kW cost is multiplied by the size of the solar installation for each roof-load combination to calculate installed capital cost. Residential solar installations are also charged flat fees of $315 for an interconnection study, $498.75 for a bidirectional meter, and must pay $150 to obtain an electrical permit. These start-up costs are added to the capital costs for each installation we simulate.

The retail price of electricity for residential customers in Saskatchewan was 14.705 cents/kWh in 2022 for energy plus a carbon pricing charge of 0.6393 cents/kWh [53]. On top of these volumetric charges, a sales tax of 5% is levied, along with a municipal surcharge of 10%. In total the retail electric charge in 2022 was 17.0974 cents/kWh. The price paid for solar energy exported to the grid is 7.5 cents/kWh in the current residential solar program [54].

We set the inflation rate equal to 0% and deal in real values, assuming that electricity prices will rise at the rate of economy-wide inflation. We use 3% for our social discount rate in our main results, and then explore sensitivity to higher discount rates in other simulations. For each policy we provide a graphical summary of the distribution of net present values (NPV) using the 'ggridges' package in R [48].

We also calculate the monthly net cost of installing solar in each roof-load combination. This monthly format is created to simulate the financial picture that a household would face when deciding whether to take out a loan to finance a solar installation. Calculating the monthly net cost also allows us to compare our findings against the results of our telephone survey of Regina residents. To calculate monthly cost we amortize the cost of the solar installation over the 25-year life expectancy of the panels. We calculate a monthly interest rate (i_m) using Equation 6:

$$i_m = (1 + i_a)^{1/12} - 1 \tag{6}$$

Where i_a is the annual interest rate, which we set at 3% to represent the cost of borrowing. We amortize the cost of the solar installation, including the start-up cost, using the standard amortization formula outlined in Equation 7:

$$Cost_m = \frac{(-C_{total} + S) * i_m \times (1 + i_m)^n}{(1 + i_m)^n - 1} \tag{7}$$

Where n represents the term of the loan in months, which we set at 300 (25 years $\times$ 12 months in a year).

2.5. Willingness to Install Solar Survey

We designed a survey instrument to ask Regina residents about their household eligibility and willingness to install solar (see Appendix A). The survey was carried out between August and September 2019. Regina residents were contacted via landline and cellular phone numbers. We surveyed 451 Regina residents, and ensured that thresholds were met for demographic representation. In particular, we did not want to weigh any one demographic group by more than two times. For example, if Regina residents between twenty and thirty years of age represented 10% of the population, we wanted to ensure they represented at least 5% of our sample.

Participants were asked a series of questions related to their support for City of Regina policies such as the goal of becoming 100% renewable by 2050 [55]Participants were then asked specifically about solar energy. To establish their eligibility to install solar we asked participants what type of home they lived in and whether they owned their home. Those who answered that they live in a single detached house or an attached house (townhouse, duplex, triplex), and who own their homes were asked follow-up questions. Our reasoning is that apartment dwellers are not individually able to install solar panels, and instead need to work through a structure like a condominium board. Renters likewise do not have the agency to install solar panels on their residence. These are the same eligibility criteria used to model distributed generation in the North American Renewable Integration Study (NARIS) [3].

Follow-up questions focused on suitability of roofs for installing solar panels and willingness to install solar panels (see questions 20-25 in the survey instrument in Appendix A). Relevant for this analysis is our use of a payment ladder to assess how willingness to install solar was influenced by the monthly net return or net cost (Q24). We first described the following scenario to participants:

"Imagine you borrow money from a bank to purchase and install solar panels. You make monthly payments to repay the loan, but installing solar panels also reduces your electricity bill. What best describes your desire to install solar panels:

- I would install solar panels even if my total monthly costs increase;
- I would install solar panels if I broke even;
- I would install solar panels only if my total monthly costs decreased."

Participants who answered that they would install solar if they broke even were assigned an adoption threshold of $0/month in total cost change. For those who responded that they would be willing to adopt solar even if total monthly costs increased, or only if total monthly costs decreased, we asked a payment ladder question (see Figure 2). Participants were assigned a random starting value on the payment ladder and asked whether they would install solar panels if they received that value in monthly net financial costs or savings. An answer of 'Yes', indicating a willingness to install solar at the stated amount, led to a follow-up question 'up' the payment ladder. An answer of 'No', indicating that they would not install solar at the stated amount, led to a follow-up question 'down' the payment ladder. These questions continued until the answer switched from Yes to No, or No to Yes. A solar adoption threshold was then assigned based on where the participant landed on the payment ladder.

We use these responses to construct a demand curve representing willingness to adopt solar at various levels of net monthly return.

2.6. Estimating Solar Adoption

We estimate the adoption of solar panels that would result from each solar policy by comparing the distribution of net monthly returns that could result from each policy with the required financial return thresholds gathered from the survey of Regina residents. For each policy we create a bootstrapped sample by selecting a random observation from the net return vector (the roof-load simulations), and matching it with a random sample from the survey results. Since we do not know the conditional probability distribution that would tell us how the required return on solar (solar threshold) varies by the solar potential of a given home, we assume an equal probability that a given simulated roof-load combination could be home to a given survey respondent. We repeat this randomized matching procedure 100,000 times for each policy, and then calculate the number of households where the financial return that could be generated by the simulated roof-load combination exceeds the required solar return threshold. We then assume that these households would adopt solar given complete information about the solar potential on their roof, the financial implications of a given solar policy, and their own required financial return from solar. This is an upper bound for solar adoption since complete information would be unlikely for most households.

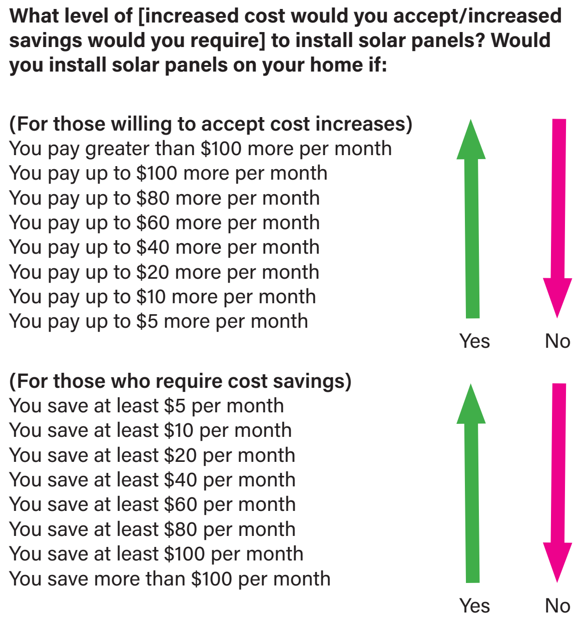

Figure 2. Payment Ladder.

Figure 3. Regina Rooftops and Solar Potential [56].

3. Results

3.1. Capacity Factor Distribution

Figure 3 shows an overhead view of a sample of the Regina rooftops included in our analysis. South-facing roofs appear in bright yellow and register the greatest potential for solar electricity production. Smaller shapes on a given lot represent garages or sheds. Accounting for the heterogeneity of rooftops in Regina allows us to estimate a distribution of solar PV capacity factors. In clear sky conditions, without any shading, a solar PV installation could be expected to perform with an annual capacity factor (CF) of around 18% in Regina, SK ("CF unshaded" in Figure 4). Variations in these unshaded capacity factors results from variations in the collector azimuth angle for each simulated rooftop.

Shading on a rooftop reduces photovoltaic production. Shading could be created by trees or neighbouring buildings. Once we account for shading, the performance of rooftop solar in Regina is reduced. Accounting for shading, the most frequent annual capacity factor simulated in our 78,530 rooftops is just under 15% ("CF shaded" in Figure 4).

3.2. Self-consumption Results

The financial return generated by rooftop solar depends on policy design, geographic factors such as solar irradiation, roof orientation, and shading, and technical factors such as photovoltaic efficiency. The temporal relationship between solar output and household electricity load is also important for policies like net billing. Under a net billing program, when solar is consumed within the home it offsets the residential price of electricity. When solar is exported to the grid, a lower value credit is offered to the solar producer. Households that match their electricity use to solar energy production earn greater returns under a net billing program by reducing their purchases of electricity from the grid.

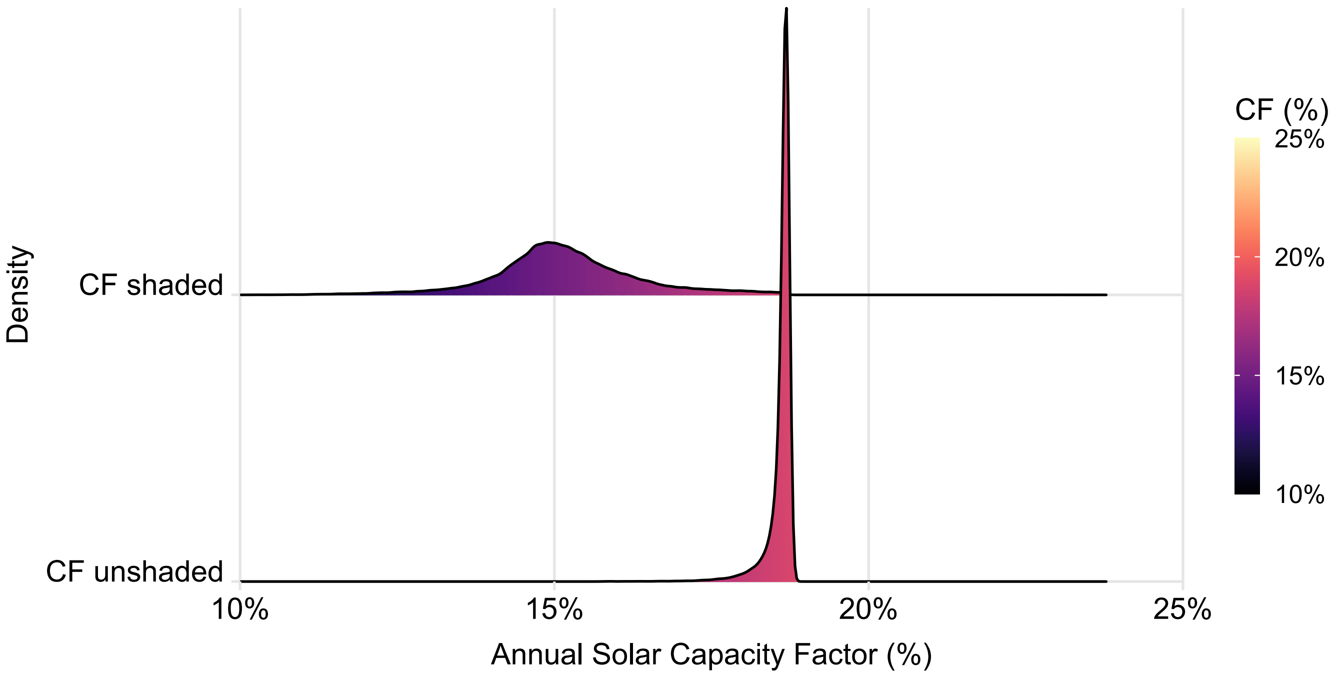

Figure 4. Annual Solar Capacity Factors.

In our simulations, we find a range of self-consumption factors centered on a median value of 44% and a mean of 53% (see panel A in Figure 5). We treat the shape of home electricity load as exogenous, meaning that it doesn't shift in response to policy. In practice, net billing would provide an incentive for homeowners to shift electricity use to the sunniest parts of the day when they are producing the most solar energy. This will become increasingly important as the vehicle fleet is electrified; vehicle charging may occur during times of peak PV output to maximize self-consumption. Our assumption that households don't shift electricity usage means the self-consumption numbers are a lower bound on what would be achievable.

Figure 5 Panel A also displays a high frequency of roof-load pairs with self-consumption proportions closer to 100%. This typically occurs when roof size constrains the size of solar installations. Panel B in Figure 5 presents a scatterplot of self-consumption proportions compared to roof size. We add a smoothed conditional mean to show the relationship between roof size and self-consumption. This line trends downwards showing higher self-consumption on smaller roofs. In cases where self-consumption shares are close to 100%, roof size is around $10m^2$. This would represent the roof of a small garage or large shed. In these cases, solar panels generate only a small share of household electricity consumption, and nearly all of this solar electricity is consumed at the time it is generated. This would mean that these small installations largely offset the purchase of electricity from the grid. So, while smaller roofs lead to less solar production in total, they can achieve higher value per kilowatt-hour under a net billing program by offsetting high-cost grid electricity.

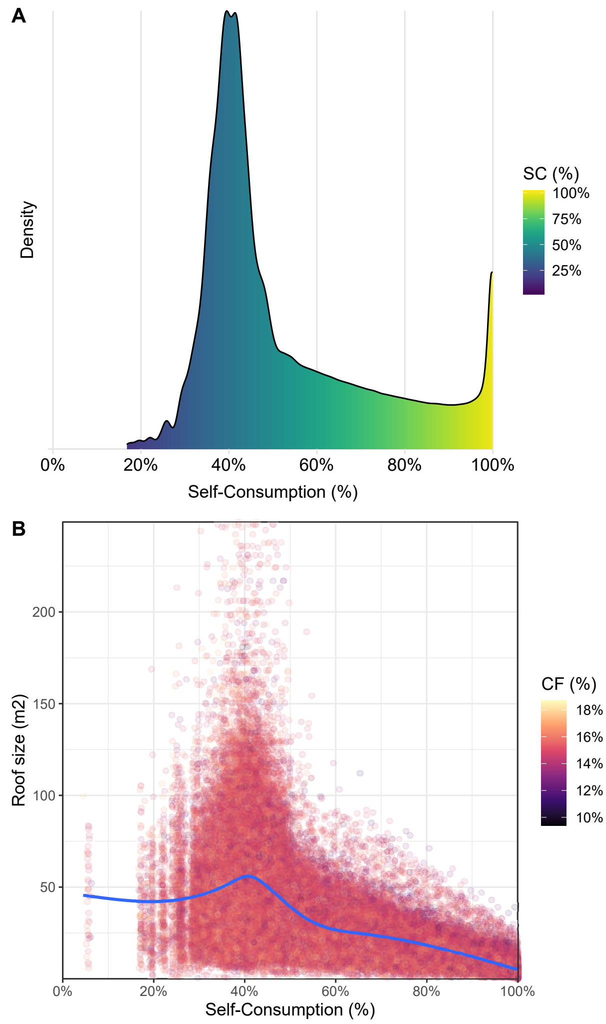

Figure 5. Annual Solar Capacity Factors.

3.3. Net Present Value Analysis

Using the parsimonious equation introduced in Williams et al. [20], we calculate net present value (NPV) for solar installations under three policy scenarios: net metering; net billing; and net billing with the Canadian federal government's Greener Homes Grant [36]. Figure 6 presents the distribution of NPV values under each policy. Table 1 summarizes the NPV results.

SaskPower's former net metering program offered the most generous payment for solar energy in Saskatchewan. Under that program, over 95% of our simulated roof-load combinations would have earned a positive NPV over the 25-year life of the solar installation. The mean value of the NPV under net metering is $5062 and the median is $4440. Calculated using the mean NPV, this program offered an equivalent annual net benefit of $292 on average [57,58].

When the net billing program was introduced in September of 2019, the potential NPV of solar projects dropped. Net billing meant that 70% of projects would achieve a positive NPV over the 25-year life of a solar installation. Financial returns fell to a mean NPV of $984 and median of $659. The equivalent annual net benefit was reduced to $56/year. This drop in financial return explains why solar installations fell by 90% after the program change [35].

The Canada Greener Homes Grant helps to restore the financial return of residential solar in Regina. The combination of net billing and the Greener Homes Grant can provide a positive NPV for 92% of our simulated roof-load combinations. The mean NPV is $3,990, and the median NPV is $3,837, which approaches the value of the former net metering program. Equivalent annual net benefit calculated for the mean NPV is $229 per year, which is about $19/month. The Greener Homes Grant program does introduce some additional logistical barriers for homeowners. To receive the incentive homeowners must first participate in an energy efficiency audit. Eligible homes can then receive an incentive of $1000 per kilowatt of installed solar, up to a maximum of $5000 in cash incentives. The Greener Homes Grant can also only be applied to solar PV systems equal to or greater than 1 kW [36], which explains why a relatively larger subset of solar installations remain in the negative NPV territory in Figure 6.

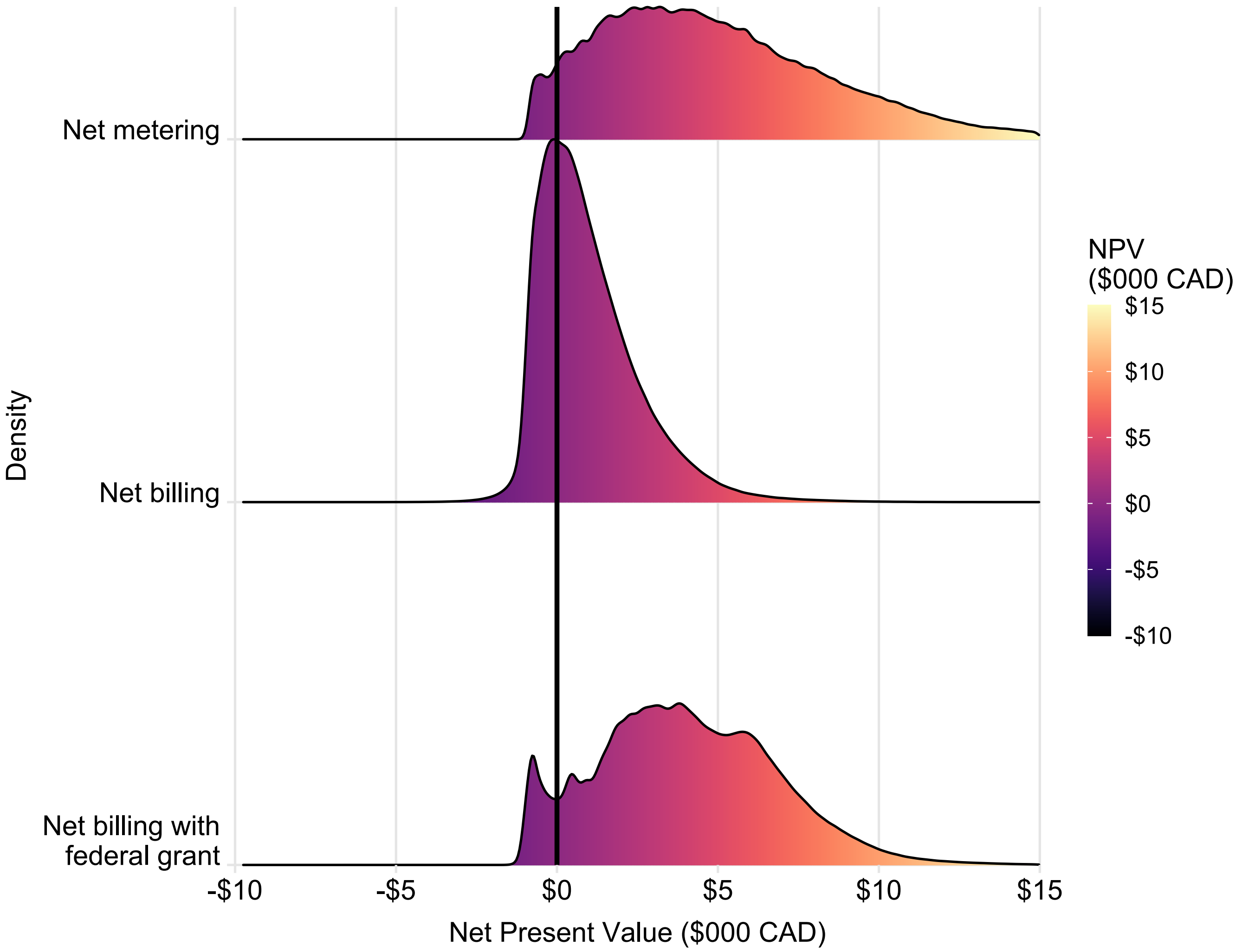

Figure 6. Net Present Value of Residential Solar in Regina Under Three Policy Scenarios.

Table 1. Net Present Value of Residential Solar in Regina Under Three Policy Scenarios.

Policy	Mean NPV	Median NPV	Proportion with NPV>0	Annual benefit (3%, n=25)
Net metering	$5,062	$4,441	95%	$291
Net billing	$984	$659	70%	$56
Net billing with federal grant	$3,990	$3,837	92%	$229

Table 2. Net Present Value of Residential Solar in Regina Under Three Policy Scenarios.

Policy	Mean NPV	Median NPV	Proportion with NPV>0	Annual benefit (10%, n=25)
Net metering	-$1,564	-$1,420	1%	-$172
Net billing	-$3,691	-$3,359	0%	-$407
Net billing with federal grant	-$685	-$654	21%	-$75

3.3.1. NPV Sensitivity to Discount Rate

The NPV analysis outlined above assumes a discount rate of 3%. This relatively low discount rate could be understood as either a social discount rate, or the cost of capital for those who install solar. In practice, many households have higher discount rates when it comes to evaluating the desirability of rooftop solar. Talevi [59] and De Groote and Verboven [60] estimate that discount rates may be as high as 15% when evaluating rooftop solar opportunities. This indicates that households heavily discount the stream of future electricity savings that will arise from installing solar panels. Using a discount rate of 10%, Figure 7 summarizes the NPV of solar under each program. Table 2 presents summary statistics at a 10% discount rate (Under a discount rate of 15%, almost no roof-load combinations would achieve a positive NPV).

The net metering program offers a positive NPV for only 1% of our roof-load combinations at a discount rate of 10%. This is close to the proportion of households that had installed solar panels at the time of our survey (see Section 3.5 below). No homes in Regina would earn a positive NPV with the net billing program at this high discount rate, which helps to explain why residential rooftop solar installations have fallen sharply since SaskPower switched from net metering to net billing. Interestingly, the Greener Homes Grant would lead to a positive NPV for 21% of our simulated homes. This is because the grant is received upon installation of the panels. This upfront value is not discounted and so has a greater impact on NPV than a stream of future revenue receipts.

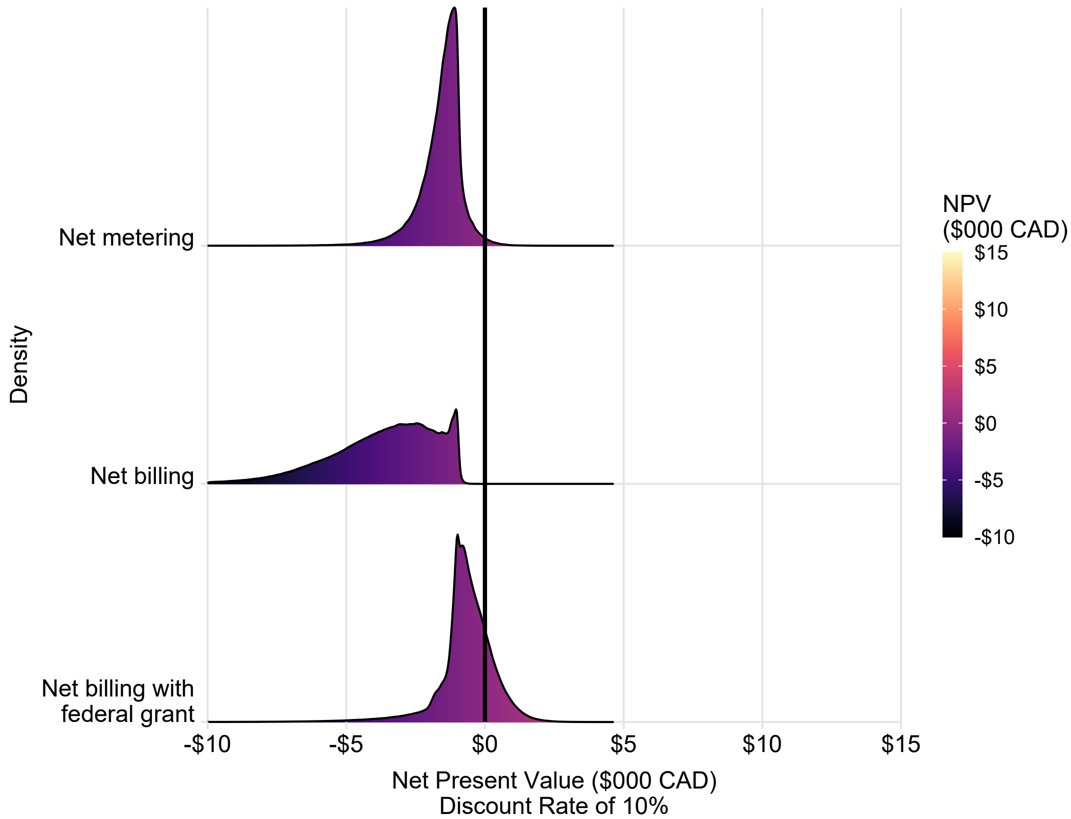

Figure 7. Net Present Value of Residential Solar in Regina Under Three Policy Scenarios With a 10% Discount Rate.

3.4. Monthly Net Return

Homeowners may not think about solar investments in terms of the lifetime NPV of the installation. On a more immediate timescale, homeowners will want to know how the benefits of solar compare to the cost of financing the solar installation. We calculate the monthly cost of financing a solar installation under each of the three policy scenarios. We then subtract this amortized monthly cost from the monthly electricity bill savings achieved by installing solar to calculate monthly net financial return. Figure 8 presents the distribution of monthly net returns. The shape mirrors that of Figure 6 above. Mean monthly net returns are $25 for net metering, $5 for net billing, and $19 for net billing with the Greener Homes Grant (see Table 3). Median net returns are $22 for net metering, $4 for net billing, and $19 for net billing with the Greener Homes Grant (Table 3).

In Section 3.6 we compare these monthly net returns to the net return thresholds identified in our survey of Regina residents to estimate solar adoption in Regina.

3.5. Survey Results

Of our 451 survey respondents, 75.9% live in a single-detached or attached house that they own. We treat this group as the population who have the agency to install solar on their own properties. A smaller percentage of survey respondents (53.5%) meet this agency criteria and have a south-facing roof where solar could be installed. We treat those who own their own single-detached or attached house, and have a suitable south-facing roof, as the population that is eligible to install solar on their homes (the solar-eligible population).

Only eight households in our survey, or 1.8%, already have solar installed on their homes. Of the survey respondents, 13% stated that they would likely or very likely install solar in the next 24 months. Note that our survey was carried out in August and September of 2019, just before the change to SaskPower's net metering program was announced.

Table 3. Monthly Net Returns of Residential Solar in Regina Under Three Policy Scenarios.

Policy	Median Monthly Net Return	Proportion with NPV>0	Proportion with Net Return > 0
Net metering	$25	$22	95%
Net billing	$5	$4	73%
Net billing with federal grant	$19	$19	92%

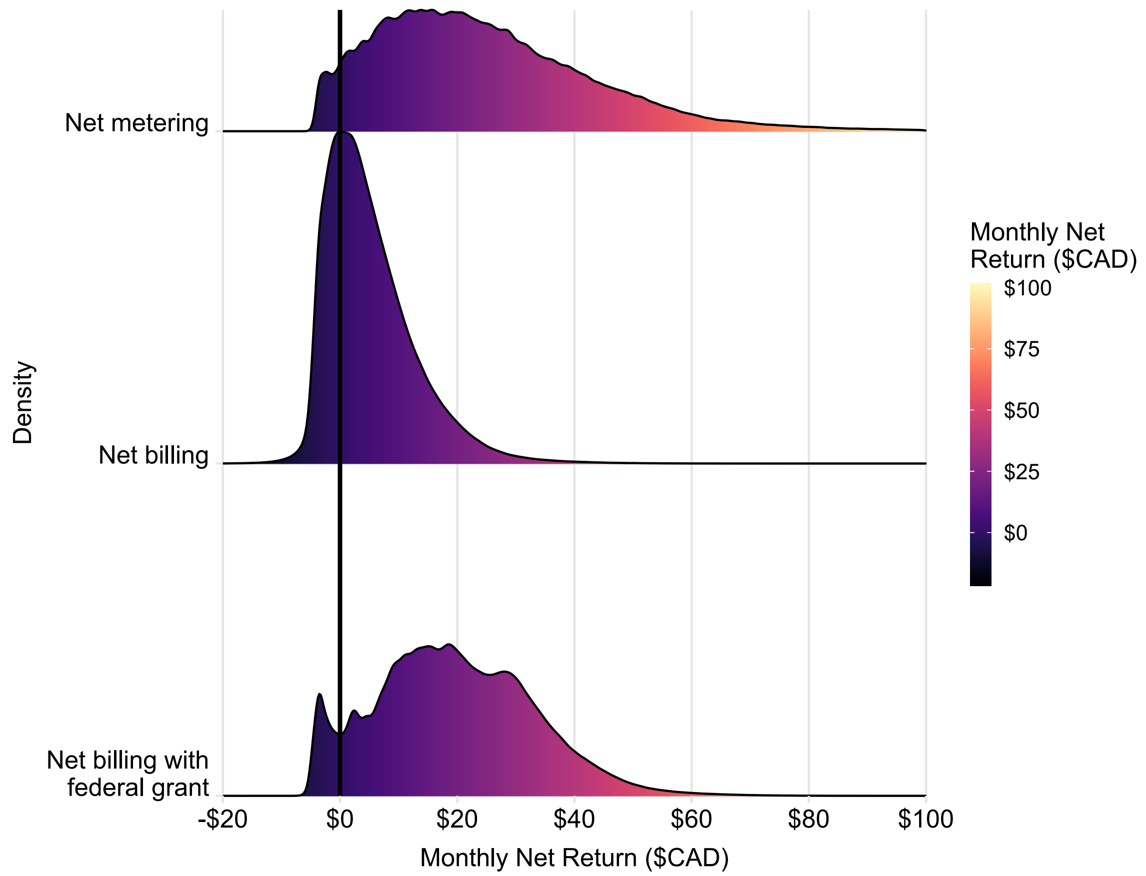

Figure 8. Monthly Net Returns from Residential Solar in Regina Under Three Policy Scenarios.

We asked survey respondents who met our eligibility criteria follow-up questions about the financial return that would incentivize them to install solar. As a proportion of solar-eligible households, 40.6% stated that they required their total monthly cost to decrease; i.e. they required a positive monthly net return (see Table 4). Another 33.1% of solar-eligible households would be willing to install panels if they broke even; i.e. net monthly costs would be equal to net monthly electricity bill savings. A smaller proportion of solar eligible households (12.3%) were willing to install solar even if their monthly costs increased. Still others stated that they would not install solar in any circumstances (11.7% of solar-eligible households) and a small portion (2.3%) declined to answer the question. If a participant stated that they would install solar only if their total monthly costs decreased, we followed up by asking about willingness to install solar if a specific financial return was achieved. We did the same for those who said they would install solar even if their costs increased. These participants moved up and down the payment ladder illustrated in Figure 2 until settling upon a net monthly return (positive or negative) that would lead them to install solar. Participants who would be willing to install solar if they broke even were coded as requiring a net monthly return of $0 in order to install solar.

Figure 9 displays the proportion of Regina households that would install solar at various levels of net return. The x-axis is cumulative since we assume, for example, that if a household would install solar when a net return of $20 was achieved, they would also be willing to install solar if a net return of $40 is achieved. The biggest jump occurs between a monthly net return of -$5 per month and $0 per month. Those who answered that they would be willing to install solar if they broke even were added to the curve at that point.

Table 4. Desire to Install Solar Panels [61].

Imagine you borrow money from a bank to purchase and install solar panels. You make monthly payments to repay the loan, but installing solar panels also reduces your electricity bill. What best describes your desire to install solar panels?	**Proportion of total sample**	**Proportion of solar-eligible households**
I would install solar panels even if my total monthly costs increase	7.0%	12.3%
I would install solar panels if I broke even	18.9%	33.1%
I would install solar panels only if my total monthly cost decreased	23.2%	40.6%
Would not install solar panels	1.3%	2.3%
Ineligible	42.8%	—

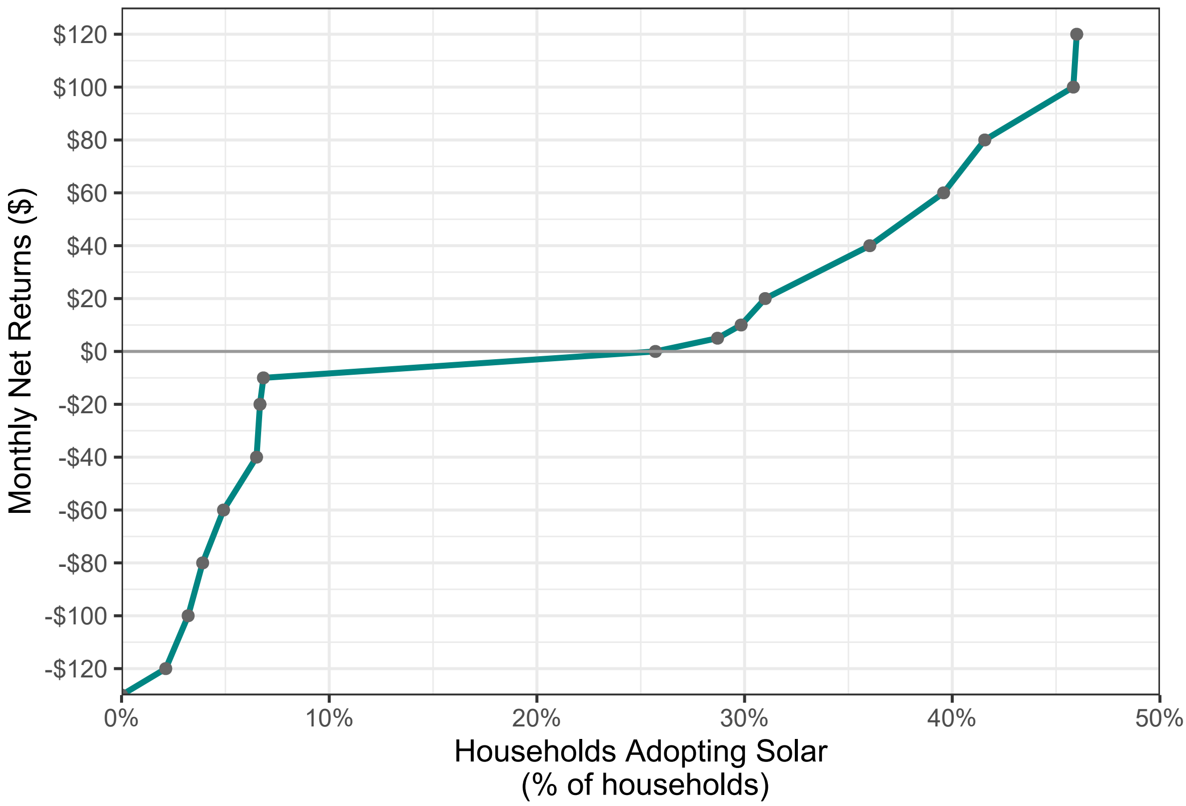

Figure 9. Regina Household Willingness to Adopt Solar Relative to Monthly Net Return.

Table 5. Solar Adoption Potential in Regina, SK.

Policy	Net return > Threshold	Solar-eligible and willing	Potential adopters	Regina homes	Avg. solar size (kW)	Solar capacity potential (MW)	Avg. solar capacity factor (%)	Electricity potential (GWh/yr)
Net metering	65%	46%	30%	87410	3.7	96	15%	129
Net billing	48%	46%	22%	87410	3.8	73	15%	99
Net billing plus grant	61%	46%	28%	87410	3.7	90	15%	120

3.6. Estimating Potential Solar Adoption

We use our survey responses, and the net monthly return data from our rooftop analysis to estimate potential solar adoption by solar policy. Because we do not have a dataset where rooftop solar potential is matched to survey responses, we create 100,000 randomly matched roof-top and survey responses for each policy. Our bootstrap analysis results are summarized in Table 5. The second column indicates the proportion of our bootstrapped sample for which net return according to the characteristics of the matched rooftop would exceed the required financial return from the matched survey response. With higher monthly net returns, the net metering program achieves the highest proportion of solar-eligible households with net monthly returns greater than required thresholds at 65%. Net billing achieves 48% of matches where net monthly return exceeds the threshold, while net billing plus the Greener Homes Grant achieves 61%. These proportions represent the proportion of solar-eligible households who would consider installing solar, and solar-eligible respondents made up 46% of the participants surveyed. When we scale by 46%, we see potential solar adoption levels of 30% for net metering, 22% for net billing, and 28% for net billing plus the Greener Homes Grant. These lower percentages represent the proportion of all Regina households who would potentially adopt solar.

Interpreting these proportions requires a note of caution. We can think of the percentage of 'potential adopters' as the upper limit for households that would install solar. We assume that the potential adopters would still require enabling conditions before they install solar. These conditions include:

- complete information about the cost of solar and the value of electricity savings benefits [19]
- confidence electricity savings benefits would be received over the lifetime of the solar installation;
- access to financing at a 3% interest rate.

If these conditions are missing, households may not install solar. Access to financing could be a problem particularly for low-income households.

Based on the upper limit proportions in the 'Potential adopters' column, we calculate the amount of solar capacity that could be installed on residential homes in Regina, and the amount of electricity that would be generated each year. Average solar size and average solar capacity factor are based on the characteristics of the bootstrapped sample. We take the mean of installation size (kW) and capacity factor (%) for those households where net return exceeds the required threshold. The amount of solar energy that could be generated from rooftop solar ranges from 99 GWh/yr to 129 GWh/yr.

4. Discussion

4.1. Residential Rooftop Solar Can Play a (Small) Role in Regina's Energy Future

As the City of Regina works towards a goal of using 100% renewable energy by 2050, residential rooftop solar can play a role. Regina, Saskatchewan boasts a strong solar resource, and our analysis finds that residential rooftops can generate electricity with a capacity factor of around 15% given existing technology and after accounting for shading. On the high end of potential adoption, residential rooftops in Regina could be home to nearly 100 MW of rooftop solar capacity and generate 129 GWh of electricity per year. The City of Regina estimates that city operations use 230 GWh of energy per year in all of its forms (i.e. electricity, heating, vehicles) [62].

To generate half of that energy with residential rooftop solar electricity, Regina would need approximately one-third of Regina households to install solar photovoltaics on their roofs.

To meet a city-wide goal of 100% renewable energy by 2050, Regina will need to develop a broader mix of electricity generation options. Looking only at electricity, Regina homes, businesses and industry use approximately 2500 GWh of electricity per year. Much more electricity will be required as Regina shifts to electric vehicles, electric heat, and electric industry to reduce greenhouse gas emissions. This means that while residential rooftop solar can contribute to achieving Regina's 100% renewable goals, other energy sources will be necessary to meet energy demand. Additional solar photovoltaic development could include more rooftop solar on commercial buildings within Regina, as well as large, utility-scale (i.e. >10 MW) solar farms outside of the city. South-central Saskatchewan is also an ideal location for wind energy developments [63].

The City of Regina could look to regional partnerships to boost production of wind and solar energy. For example, the Cowessess First Nation has developed a wind-solar-battery energy production site to the east of Regina [64]. Further partnerships with First Nations and rural municipalities can allow Regina to secure the renewable energy needed to achieve the 100% renewable goal.

4.2. Program and Policy Design a Key Driver of Household Financial Returns from Rooftop Solar

Policy design impacts the desirability of installing solar in Regina. Of the policies we evaluate, net metering offers the highest net present value and net monthly financial return to homeowners in Regina, SK. SaskPower had a net metering program in place until 2019 and it was popular. That popularity led to the program's cancellation once SaskPower hit a cap of 16 Megawatts (MW) of solar installed under the net metering program [34]. Our results confirm that the net billing program that replaced net metering offers lower financial returns. The move to net billing decreased the mean NPV of rooftop solar from $5062 to $984, while the mean monthly net financial return fell from $25 to $5 at a discount rate of 3%. This drop makes rooftop solar only marginally desirable for most households. Any unplanned maintenance or excess shading could put a net financial return into jeopardy. This drop in the financial benefit of rooftop solar helps to explain why solar installations in Saskatchewan decreased by 90% after the program change [35].

The federal government's Greener Homes Grant, when combined with SaskPower's net billing program, restores the NPV and monthly net financial return of solar to levels nearly equal with net metering. The federal government will provide households with an incentive payment of $1000 per kilowatt of solar photovoltaic capacity installed, up to a maximum of $5000 [36]. The combination of net billing with the Greener Homes Grant increases the mean NPV of solar to $3,990 and the monthly net financial gain to $19 at a discount rate of 3%. If the City of Regina would like to increase adoption of rooftop solar it could consider topping up this capital incentive with an additional payment from the municipality.

4.3. High Discount Rates Reduce the Desirability of Rooftop Solar, While Front-Loaded Grants Can Increase Desirability

Residential rooftop solar in Regina may not approach the upper limit of its potential if homeowners have high discount rates and policies do not account for this. Without declines to the cost of installing solar, households with discount rates of 10% or 15% will likely not install solar, even with Regina's relatively good solar irradiation conditions. We find that the mean NPV for solar is negative for solar under all three policy designs when discount rates are set to 10%. When discount rates are high, the upfront capital grant provided by the federal Greener Homes Grant program does improve the NPV of solar relative to programs that do not have a capital grant. With a combination of net billing and the Greener Homes Grant, 21% of households would have a positive NPV even when discount rates are set at 10%. This is an improvement over the net metering program which provided a positive NPV to only 1% of households at a discount rate of 10%. This finding speaks to the advantage of grant-based programs in countering the myopia of homeowners. As Talevi [59] notes, policymakers who wish to encourage solar installations can design incentive structures that frontload payments for solar. These upfront payments can encourage solar at a lower cost than programs that focus on paying higher electricity rates in the future.

Low-interest loan programs may also be of value to remove barriers to rooftop solar and reframe benefits in terms of monthly net financial returns. As reported in several other papers, lack of financing and high upfront costs can be a barrier to the installation of rooftop solar [22–25]. A capital grant plus access to a lower-interest loan can enable investments without high, upfront expenses. Just as households discount the stream of future benefits of an investment in rooftop solar, they may discount the stream of future costs of loan repayments. This would turn attention to the monthly net financial return from solar, which is generally positive under all three policy scenarios (see Table 3). The City of Regina could explore provision of 'Property Assessed Clean Energy' (PACE) loans for rooftop solar to provide low-interest loans. These loans are attached to properties, rather than individuals, which can also alleviate household concerns that they may move before recouping the value of their investment in rooftop solar. In general, solar adoption will be higher when efforts are made to spread costs over a longer period of time, and shift benefits to the present.

5. Conclusion

5.1. Summary of Findings

With high irradiation values, and cold, clear winter days that allow for high photovoltaic efficiency, Regina, Saskatchewan is ideally situated for solar energy. We find that residential rooftop solar can achieve capacity factors of 15% on average in Regina once shading is considered. Assuming that the size and shape of residential electricity load is comparable to Saskatoon, the average household in Regina uses close to 7000 kilowatt-hours (kWh) of electricity per year. A solar installation of about 5.3 kilowatts (kW) would generate electricity equivalent to this electricity load.

We find that the switch from net metering to net billing led to a sharp decline in the NPV of rooftop solar in Regina. This policy change reduced the potential rooftop solar adoption rate from 30% of Regina households to 22%. We find that the Greener Homes Grant restored the NPV of rooftop solar in Regina to levels nearly equal to the net metering program. The Greener Homes Grant also has the advantage of providing an upfront incentive, which may be more effective at encouraging solar PV adoption due to the high discount rates of households [59,60]. The City of Regina can look to build on the Greener Homes Grant as a method of further encouraging rooftop solar PV adoption in Regina. The City of Regina can also consider providing low-interest loans for rooftop solar installations to remove the barrier of high upfront capital costs.

5.2. Limitations and Future Work

In our analysis, we focus on the perspective of the homeowner considering the adoption of solar. We do this to estimate upper limits on what solar could contribute to the City of Regina's 100% renewable energy goals. We do not forecast solar adoption into the future. Follow-up work could calibrate solar adoption using historic solar installation data and use that to produce a forecast of solar adoption [65,66]. This modelling could also incorporate the peer impacts of solar adoption; households are more likely to adopt solar if they see that their neighbours have done so [12,14–17,65].

Future analysis could also consider the broader social value of residential rooftop solar. Electric utilities throughout North America are grappling with the design of rooftop solar compensation policies. From the perspective of the electric utility SaskPower, solar energy is worth only the avoided cost of reducing natural gas usage. When the sun is shining, SaskPower can run its natural gas power plants at a lower capacity and save on fuel costs. Viewed this way, SaskPower values solar electricity at only $0.04 per kWh, plus any associated carbon pricing savings [32]. Even the net billing program could be perceived as overly generous from the utility's perspective [67]. SaskPower has shown a preference for large, "utility-scale" solar installations that can achieve generation costs closer to SaskPower's avoided cost [68]. The utility also plans to build much more wind capacity in coming years since the levelized cost of wind is now equal or less than SaskPower's avoided cost of generation [5,69–71]. Future analysis could consider the broader social impacts of rooftop solar on electricity system costs and benefits. Additional costs include the rate impacts felt by households that do not generate solar energy, and any increase in the cost of electricity distribution system infrastructure to enable solar self-generation. Additional benefits include household energy security, which may be possible if households can self-generate, store electricity, and "island" at times when power is lost on the grid.

We do not forecast declines in the cost of residential rooftop solar. Solar modules have dropped in price over the period of 2009-2021 [5] and future price drops would improve the financial returns from residential rooftop solar. Future work could evaluate the degree to which rooftop solar installed costs will decline as module prices fall and innovations are made to reduce the "soft costs" of residential solar installations such as permitting and customer recruitment [72].

In previous research, Dolter and Boucher [33] outlined how the changes to SaskPower's net metering program made in 2017 and 2018 emerged from a process of engagement with Saskatchewan residents and the solar industry. This process was an example of procedural energy justice, enabling a diversity of voices to contribute to program design. The program changes SaskPower made in 2019 were carried out without consultation and resulted in anger. The rationale for the program changes was that net metering leads to cross-subsidization as non-solar customers pay higher electricity rates due to load defection by customers who install solar. Equity issues arise when high-income households receive generous payments for installing solar, and higher rates pose a burden for low-income households. Those who we deem as solar-eligible were more likely to have incomes greater than $60,000 compared to the sample as a whole. Future work can address the distributional equity of solar energy program design, and issues of procedural energy justice.

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Appendix

Appendix A - Regina Energy Futures Survey Instrument

INTRODUCTION

Hello, I'm ____________ from Prairie Research Associates. We are conducting an important study on behalf of the University of Regina on the City of Regina's Energy future. We are collecting community feedback on what policies and actions the City should take related to Regina energy sources and energy use.

The survey will take approximately 12 minutes. Your phone number has been randomly selected to participate in the study.

This survey has received ethics approval from the University of Regina Research Ethics Board. All information collected will be kept completely anonymous. You may refuse to answer any specific questions or withdraw your consent at any time.

The result of this study will be made public, and if you are interested, we will send you a summary of the research report.

Do you have time now?

YES CONTINUE

NO SKIP TO INTR2

(ONLY IF NEEDED)
If you would like more information on the study, please contact Dr. Brett Dolter at 306-337-2923. If you have any concerns or questions about the survey, you may contact the Research Ethics Office at the University of Regina at 306-585-4775.

INTR2 If you do not have time now, I could send you a link to complete the survey online. Would you prefer this option? (Just to confirm you are a Regina resident?)

NO – PREFER PHONE – SET AS CB

YES – GO TO INTR3

NQ – Not a Regina Resident - TERMINATE

INTR3 Could you provide me with an email address and I'll send you the link immediately.

EMAIL: ______________________

First of all, can I confirm you live in the City of Regina?

Yes –> GO TO QUESTION 11
No –> THANK AND TERMINATE AT T.1
T.1 Thank you, that's all the questions I have. Have a great day.

And you 18 years of age or older?
Yes –> GO TO QUESTION 11
No –> THANK AND TERMINATE AT T.1
T.1 Thank you, that's all the questions I have. Have a great day.

Section 1 – City of Regina (13)

Questions 1 to 10 dropped

1. Dropped after pretest
2. Dropped after pretest
3. Dropped after pretest
4. Dropped after pretest
5. Dropped after pretest
6. Dropped after pretest
7. Dropped after pretest
8. Dropped after pretest
9. Dropped after pretest
10. Dropped after pretest

To start, I'm going to read some statements. As I read each, please rate your support or opposition using a scale of 1 to 5 where 1 means strongly oppose and 5 means strongly support.

The City of Regina has committed to the goal of using 100% renewable energy by 2050. Renewable energy sources include hydroelectricity, solar panels, wind turbines, and geothermal.

11. To what extent do you support or oppose the City of Regina working to power all of its buildings and vehicles using 100% renewable energy by 2050? (PROMPT: Again, use the scale of 1 to 5, where 1 means you strongly oppose and 5 mean you strongly support. PROMPT IF ASKED ABOUT COST: City staff are currently working on a plan looking at how to meet this target, but have not completed the plan or calculated the cost yet. We would like to know whether you support the goal in principle.)

Strongly oppose	1
	2
	3
	4
Strongly support	5
(DO NOT READ) Don't Know/Undecided	8

12. To what extent do you support or oppose the City of Regina working to ensure that the entire city, including private buildings and vehicles, is powered by 100% renewable energy by 2050? (PROMPT: Again, use the scale of 1 to 5, where 1 means you strongly oppose and 5 mean you strongly support. PROMPT IF ASKED ABOUT COST: City staff are currently working on a plan looking at how to meet this target, but have not completed the plan or calculated the cost yet. We would like to know whether you support the goal in principle.))

Strongly oppose	1
	2
	3
	4
Strongly support	5

(DO NOT READ) Don't Know/Undecided 8

13. To what extent do you support or oppose construction of a wind power farm outside of Regina's city limits to supply electricity to Regina homes and businesses? [PROMPT: One wind turbine is currently operating just east of Regina. PROMPT: Again, use the scale of 1 to 5, where 1 means you strongly oppose and 5 mean you strongly support.)

Strongly oppose	1
	2
	3
	4
Strongly support	5
(DO NOT READ) Don't Know/Undecided	8

Section 2 - Residential Property Taxes (4)

14. Do you rent or own your dwelling?

Rent	1 (GO TO 17)
Own	2 (GO TO 15)

15. Approximately, how much do you pay in property taxes each month or each year? ($0-$24000)

____________ per month ($0-$2000)

____________ per year ($0-24000)

Don't know 88888

Currently about **20%** of the electricity SaskPower generates comes from renewable energy sources like wind and hydroelectricity, while about 80% comes from natural gas or coal plants. For 100% of electricity used by Regina homes and businesses to come from renewable energy sources, Regina would need to generate or purchase electricity from wind, solar, hydroelectricity, biomass or geothermal sources.

16. Would you support an added charge on your property taxes that would be dedicated to encouraging renewable energy in Regina? [If you own a home your property taxes would go up. If you rent your dwelling imagine that your rent would increase by this amount.]

Yes	1
No - $0 MORE PER MONTH	0 (GO TO 18)
Depends on the amount	2
Don't know	8

17. To ensure that 100% of electricity come from these renewable energy sources, each month on your [property taxes/ rent] would you be willing to pay...? (RANDOMIZE AND READ - FROM STARTING POINT IF YES GO UP TILL NO, IF NO GO DOWN IF YES)

More than $100 per month more	8
Up to $100 per month more	7
Up to $80 more per month	6
Up to $60 more per month	5
Up to $40 more per month	4
Up to $20 more per month	3
Up to $10 more per month	2
Up to $5 more per month	1
(DO NOT READ) Don't know	8

Section 3 – Residential Solar Energy Systems (8)

18. How would you describe the type of home you live in? Is it a... (READ)

Single detached house	1
Attached house (townhouse, duplex, triplex, etc.)	2
Apartment	3 (GO TO 20 and then Section 4)
Mobile home	4 (GO TO 20 and then Section 4)
Other: ________	66 (GO TO 20 and then Section 4)
(DO NOT READ) No response	99

(IF Q14 = 1 'OWN' CONTINUE, ELSE GO TO SECTION 4)

19. Approximately how much does your household typically spend on electricity per month? [If you do not have equalized payments, how much is your electricity bill in a typical May or October?] ($0-$1000)

____

Don't Know 8888

20. Do you currently have solar panels installed on your residential property?

Yes	1 (GO TO Section 4)
No	0
No response	9

21. Do you live in a home where it is possible to install solar panels? For example, do you have a south-facing roof that is not shaded by trees?

Yes	1
No	0 (GO TO Section 4)
Uncertain	8 (GO TO Q22)

A solar panel system that can generate enough electricity to equal the amount used in a typical home can cost between $20,000 and $25,000. Electricity bill savings might pay for the solar panels over a period of 10-15 years and most systems now come with a 25 year warranty.

22. Using a scale of 1 to 5, where 5 means very likely and 1 means very unlikely, how likely would you be to seriously consider installing solar panels on your home in the next 24 months?

Very Likely	5
	4
	3
	2
Very unlikely	1
(DO NOT READ) Undecided	8
(DO NOT READ) Decline to Answer	9

Imagine you borrow money from a bank to purchase and install solar panels. You make monthly payments to repay the loan, but installing solar panels also reduces your electricity bill.

23. What best describes your desire to install solar panels:

I would install solar panels even if my total monthly costs increase	1 [GO TO 24A]
I would install solar panels if I broke even	2 [GO TO Q25]
I would install solar panels only if my total monthly costs decreased	3 [GO TO 24B]
(DO NOT READ) Would not install Solar Panels	8 [GO TO NEXT SECTION]
(DO NOT READ) Undecided / Decline to Answer	9 [GO TO NEXT SECTION]

24. What level of [increased cost would you accept/increased savings would you require] to install solar panels? Would you install solar panels on your home if: (RANDOMIZE AND READ - FROM STARTING POINT IF YES GO UP TILL NO, IF NO GO DOWN IT YES))

[24A: For those willing to accept cost increases]	Y/N
You pay greater than $100 more per month	1/0
You pay up to $100 more per month	1/0
You pay up to $80 more per month	1/0
You pay up to $60 more per month	1/0
You pay up to $40 more per month	1/0
You pay up to $20 more per month	1/0
You pay up to $10 more per month	1/0
You pay up to $5 more per month	1/0
(DO NOT READ) Don't know	8

[24B: For those who require cost savings]	
You pay greater than $100 more per month	1/0
You pay up to $100 more per month	1/0
You pay up to $80 more per month	1/0
You pay up to $60 more per month	1/0
You pay up to $40 more per month	1/0
You pay up to $20 more per month	1/0
You pay up to $10 more per month	1/0
You pay up to $5 more per month	1/0
(DO NOT READ) Don't know	8

One way that cities can encourage people to install solar panels is to provide low-interest loans.

25. If you could access a low-interest loan that you repay over time on your property taxes, how likely would you be to purchase and install solar panels? Would you be...

Much more likely	5
Somewhat more likely	4
Neither more or less likely	3
Somewhat less unlikely	2
Much less unlikely	1
(DO NOT READ) Would not install Solar Panels	8
(DO NOT READ) Undecided / Decline to Answer	9

Section 4 – Transportation

Now I'd like to ask you some questions about travelling within Regina.

4.1 Travel within Regina (5)

26. What is your primary method of transportation when travelling around Regina?

Drive by myself	1
Drive in a vehicle with other people (carpool)	2
Public transit (city buses)	3
Bicycle	4
Walk	5
Taxi	6
Other (SPECIFY)	66

(DO NOT READ) Decline to answer 99

27. Do you commute outside of your home to get to work or school?

Yes	1 (GO TO 28)
No	0 (GO TO NEXT SECTION)
(DO NOT READ) Decline to answer	9 (GO TO NEXT SECTION)

28. How many times a week do you commute to get to work or school (1-20)

____

Prefer not to answer 9

29. What is the six character postal code of the location to which you commute?

___ ___ ___ ___ ___ ___

Don't know	888888 (ASK Q29A)
Decline to answer	999999 (ASK Q29A)

29a. (If unsure of the postal code) What is the address you commute to or the intersection nearest to the location to which you commute?

____

Don't know	88
Decline to answer	99

30. How long does it usually take to commute to [work/school] using your usual method of transportation? (1-180)

__________ minutes

Prefer not to answer 888

4.2 Sustainable Transportation Options (4) – section dropped after pretest

31. Dropped after pretest
32. Dropped after pretest
33. Dropped after pretest
34. Dropped after pretest

4.3 Transportation (3)

I'm going to read a series of statements. Please rate each on a scale of 1 to 5, where 1 means you strongly disagree and 5 means you strongly agree.

35. How long does it usually take to commute to [work/school] using your usual method of transportation? (1-180)

Strongly Disagree	1
	2
	3
	4
Strongly Agree	5
(DO NOT READ) I am unable to walk, cycle or use public transit	7
(DO NOT READ) Undecided / Don't Know	8

36. I worry about the environmental impact of my normal method of travel.

Strongly Disagree	1
	2
	3
	4
Strongly Agree	5
(DO NOT READ) Undecided / Don't Know	8

37. When I choose where to live, the walkability of the neighbourhood is important to me (for example, restaurants and stores that I could walk to, nearby walking and cycling paths)

Strongly Disagree	1
	2
	3
	4
Strongly Agree	5
(DO NOT READ) Undecided / Don't Know	8

Section 5 – Climate Change and Energy (4)

38. You may have heard that the world's temperature has been going up slowly over the past 100 years. This temperature increase is usually referred to as climate change or global warming. Do you believe climate change is happening?

Yes	1
No	0
(DO NOT READ) Unsure	8
(DO NOT READ) I prefer not to answer	9

39. Using that scale of 1 to 5, where 1 means strongly disagree and 5 means strongly agree, do you agree or disagree that climate change is caused mostly by human activities?

Strongly Disagree	1
	2
	3
	4
Strongly Agree	5
(DO NOT READ) I am unable to walk, cycle or use public transit	8
(DO NOT READ) Undecided / Don't Know	9

40. Which of the following statements is closest to your opinion on climate change? (READ)

It is a serious problem, and immediate action is necessary	1
It could be a serious problem, and we should take some action now	2
More research is needed before deciding if action should be taken	3
It is not a problem and does not require any action	4
(DO NOT READ) I don't know enough about this issue	8
(DO NOT READ) I prefer not to answer	9

41. In Canada, there are discussions about building new oil pipelines. For example, there are discussions about building an expanded pipeline to transport Alberta oil to an export facility in British Columbia. Using that scale of 1 to 5, where 1 means strongly disagree and 5 means strongly agree, do you agree or disagree that NEW oil pipelines should be built to transport oil to export markets? (READ)

Strongly Disagree	1
	2
	3
	4
Strongly Agree	5
(DO NOT READ) I am unable to walk, cycle or use public transit	8
(DO NOT READ) Undecided / Don't Know	9

Section 6 – News Source (2)

42. Where do you most often look for news about current events? (RECORD ALL MENTIONS)

Television news	1
News radio	2
Newspaper	3
News apps	4
Social media	5
Friends and family	6
Other (Specify)	66
(DO NOT READ) I don't follow current events	00
(DO NOT READ) I prefer not to answer	99

43. What is the name of the news source you most trust? (DO NOT READ – RECORD JUST ONE)

Newspaper	
Regina Leader Post	1
National Post	2
Globe and Mail	3
News App	
CBC	10
National Post	11
Globe and Mail	12
Huffington Post	13
The Guardian	14
Radio	
CBC Radio One	20
91.3 CJTR	21
MBC Radio	22
News/Talk 980	23
TV	
CBC	30
CTV	31
Global	32
CNN	33
Fox	34
MSNBC	35
Internet	
Facebook	40
Google	41
Twitter	42

Other (SPECIFY) ________________________ 66

(DO NOT READ) Don't Know 88
(DO NOT READ) Decline to answer 99

Section 7 - Demographics (16)

And finally I have some background questions. These are asked to ensure we get a good mix of Regina Residents.

44. What year were you born?

Year: _______________
No response 8888

45. Including yourself, how many people live in your household? (1-20)

RECORD: _____
(IF 1 GO TO Q72)
Prefer not to answer 88

46. Do you have children under the age of 18 in the household?

Yes	1 (GO TO 50)
No	0 (GO TO 51)
Prefer not to answer	8 (GO TO 51)

47. How many people under the age of 18 live in your household? (1-10)

RECORD: _____
Prefer not to answer 88

48. What is the highest level of education you have completed?

High school or less	1
An apprenticeship or trades certificate or diploma	2
A college diploma (e.g. Sask Polytechnic)	3
Bachelor's degree (e.g. University of Regina or University of Saskatchewan)	4
Graduate degree or higher (e.g. Master's degree or PhD)	5
Prefer not to answer	8

49. What is your current employment status?

Unemployed	1
Employed part time	2
Employed full time	3
Self-employed	4
Full-time student	5
Retired	6
Homemaker	7
Prefer not to answer	8

50. What is your six character Postal Code?

___ ___ ___ ___ ___ ___

51. Thinking of 12 months ago, did you live at the same address you do now?

Yes	1 (GO TO 56)
No	0 (GO TO 55)
Prefer not to answer	8 (GO TO 55)

52. 12 months ago, did you live... (READ)

In Regina, but at a different address	1
In Saskatchewan, but in a different city, town, village, township, municipality or Indian reserve	2
In Canada, but a different province or territory	3
Outside of Canada	4
Prefer not to answer	9

53. Do you identify as an Aboriginal or Indigenous person, that is, First Nations, Metis, or Inuk (Inuit)?

Yes	1 (GO TO Q58)
No	0 (GO TO Q57)
Prefer not to answer	8 (GO TO Q57)

54. Would you describe yourself as a visible minority?

Yes	1
No	0
Prefer not to answer	8

55. What is your gender identity?

Male	1
Female	2
Non-binary	3
Prefer not to answer	8

56. What is the combined annual income for all individuals living in your household before taxes?

Less than $20,000	1
$20,000 to $39,999	2
$40,000 to $59,999	3
$60,000 to $79,999	4
$80,000 to $99,999	5
$100,000 to $119,999	6
$120,000 and above	7
Prefer not to answer	8

57. Did you vote in the last Regina Municipal Election held in October 2016?

Yes	1
No	0
I was not eligible to vote	8

58. Again, just to ensure we get a good mix of Regina Residents, generally ... Which Canadian federal political party do you most support?

Conservative Party	1
Green Party	2
Liberal Party	3
New Democratic Party (NDP)	4
People’s Party	5

Other: ___________________________	66
Non-partisan	55
Prefer not to answer	88

59. Which Saskatchewan provincial political party do you most support?

Green Party	1
New Democratic Party (NDP)	2
Progressive Conservative Party	3
Saskatchewan Party	4
Other: ___________________________	66
Non-partisan	55
Prefer not to answer	88

60. **DROPPED AFTER PRETEST**

Section 7 -Workshop Participation (5)

This fall, the University of Regina is organizing some workshops to discuss Regina's energy future. The workshop will be held in Regina and might be held on a weekday evening or a weekend day. It would involve other people like you and would take about 4-hours. For participating you will be given $75.

61. Is this something you might be interested in participating in? (If you are, the University of Regina will follow-up with you directly once the time and day has been finalized. You would then be able to decide whether you are able to attend.)

Yes	1
No	0 (GO TO Q67)

The University of Regina will be in touch this fall when the final date and location is set.

62. Could you provide me your first name and email address so the University can contact you with further details?

First name: ___________
Email address: ___________________

63. Can you confirm that this phone number is the best to reach you at?

Recall phone number: ________________

64. Would you be interested in receiving an electronic copy of the research report where we will summarize the results of this survey?

Yes	1
No	0 (END WITH THANKS)

65. (IF NOT RECORDED IN Q85) Please provide me with your email address so we can send you a copy of the report?

Email address: _______________________________

Appendix B – Neighbourhood Matching Results

Table B1 presents the Regina-Saskatoon matches based on our Euclidean distance analysis. The roof-load combinations are calculated by multiplying each roof count with the matching load count. In total we simulate 4,491,428 roof-load combinations.

Table B1. Neighbourhood Matching Using Euclidean Distance Analysis.

Regina neighbourhood	Roof count	Saskatoon neighbourhood	Load count	Roof-Load Combinations	Euclidean Distance
Al Ritchie	4,441	Hudson Bay Park	61	270,901	0.65
Albert Park	2,798	College Park	61	170,678	0.73
Arcola East	7,673	Erindale	32	245,536	0.83
Argyle Park Englewood	1,805	Forest Grove	61	110,105	0.84
Boothill	1,699	Caswell Hill	61	103,639	1.29
Cathedral	3,381	Haultain	61	206,241	0.38
Coronation Park	2,923	Holiday Park	61	178,303	1.50
Dewdney East	6,237	Meadowgreen	61	380,457	2.98
Dieppe	927	Queen Elizabeth	61	56,547	2.94
Eastview	1,005	Mayfair	61	61,305	0.90
Gladmer Park	290	Sutherland	61	17,690	1.41
Harbour Landing	2,422	Arbor Creek	31	75,082	2.59
Heritage	1,763	Riversdale	61	107,543	1.32
Hillsdale	1,553	Brevoort Park	61	94,733	1.07
Lakeview	4,428	Avalon	61	270,108	1.02
Mcnab	527	Exhibition	61	32,147	1.18
Normanview West	1,300	Pleasant Hill	60	78,000	4.45
Normanview	1,578	Eastview	61	96,258	0.34
North Central	5,346	Westmount	60	320,760	1.65
Northeast	3,549	Mount Royal	61	216,489	0.97
Prairie View	2,921	Silverspring	62	181,102	0.96
Regent Park	1,578	King George	61	96,258	2.66
Rosemont Mount Royal	4,793	North Park	61	292,373	0.90
Sherwood Mccarthy	2,262	College Park East	61	137,982	1.42
Twin Lakes	1,993	Adelaide-Churchill	61	121,573	3.15
Uplands	2,258	Nutana Park	61	137,738	0.93
Walsh Acres Lakeridge Garden Ridge	4,254	Richmond Heights	61	259,494	1.94
Whitmore Park	2,826	Montgomery Place	61	172,386	0.93
Total	78,530		1648	4,491,428	