Renewable Energy Support Through Feed-in Tariffs: A Retrospective Stakeholder Analysis

Majid Hashemi
Department of Economics, Queens University, Kingston, Ontario, Canada
E-mail: hashemi.s@queensu.ca

Glenn P. Jenkins
Department of Economics Queen's University Canada
Cyprus International University, North Cyprus
Email: jenkinsg@queensu.ca

Frank Milne
Department of Economics, Queens University, Kingston, Ontario, Canada
milnef@econ.queensu.ca

Development Discussion Paper: 2023-08

ABSTRACT

This study develops a generalized evaluation framework that can be used to quantify the financial, economic, stakeholder, and environmental impacts of renewable energy support programs. The application of this framework is demonstrated by evaluating the Feed-In Tariff (FIT) program for solar distributed energy resources (DER) in Ontario, Canada. Our analysis reveals that although Ontario's FIT program has successfully promoted the adoption of solar DER across communities, considering all the criteria of cost-benefit analysis, including optimal timing, economic resource efficiency, environmental cost-effectiveness, and distributional impacts, this policy has been a complete failure. The program has led to a significant cross-subsidization from program non-participants to participants and losses to the Canadian economy in return for insignificant environmental benefits. The losses would have been reduced by approximately 50 percent if the program had been delayed and implemented in 2016 instead of 2010. The lessons from this analysis provide insights for designing future policies to reduce greenhouse gas emissions.

Keywords: renewable energy subsidy; distributed energy resources; feed-in tariff; stakeholder analysis; benefit-cost analysis; Ontario; Canada.

JEL Classification: O2, D61, Q42, Q48

1. Introduction

With national and subnational governments increasingly designing programs to promote investments in renewable energy resources, an important policy question is how the benefits and costs of these programs are allocated among the stakeholders after the program implementation. The answer to this question will provide key insights to enable decision-makers to reform existing programs to the extent possible and improve the design of similar programs in the future. This study aims to formalize an ex-post evaluation framework for estimating the magnitude of the impacts created by a renewable energy support program. As a case study, we apply the framework to assess the Feed-In Tariff (FIT) program for distribution-connected solar photovoltaic (PV) systems in Ontario, Canada, over the decade following its implementation in 2010.

The FIT program is one of the most widely adopted programs worldwide. As of 2022, more than 90 national and subnational governments had implemented some form of FIT program (REN21, 2022). In Canada, the Ontario Green Energy and Green Economy Act (herein the Green Act) was introduced in 2009 to accelerate the addition of renewable energy resources into Ontario's electricity generation mix. Ontario's FIT program was established in the Green Act, providing long-term fixed-price power purchase agreements (PPA) for renewable energy generators, including on-shore wind, solar PV, renewable biomass, hydropower, biogas, and landfill gas.

We start our analysis by identifying all stakeholders involved in the FIT program: (1) FIT participants, (2) other electricity consumers in Ontario (non-participants), (3) provincial and federal governments, and (4) the global environment. We then develop a series of equations describing how the benefits and costs to each of these stakeholders are measured throughout the program's life. The evaluation period is set from 2010 to 2038, but all the estimates are from the perspective of the year 2023 and are therefore expressed in 2023 prices.

Our results indicate that the program successfully attracted participants because the expected financial rates of return were above the participants' opportunity cost of capital. The financial return for FIT participants has an average of 15 percent (net of inflation), which is above the opportunity cost of capital of 7 percent used in our analysis. We also observe that rooftop systems were financially more attractive than ground-mount systems in the earlier years, mainly because of more generous PPA prices for rooftop systems. However, this pattern is reversed in the later years due to the adjustments to the PPA prices for rooftop systems.

Despite the financial profitability of such investments for the participants, we estimate a significant cross-subsidization from the current and future residents of Ontario to the FIT participants: the present value of the financial burden imposed by the FIT participants between 2010 and 2038 (when the last contract expires) adds up to 9.50 CAD billion in 2023 prices. In the earlier years of the program, the shifted cost was recovered from the electricity consumer base through adjustments in electricity bills, but after the introduction of the Renewable Cost Shift program in 2021, the cost recovery was switched from the consumer base to the taxpayer base in Ontario. In other words, during the time that the costs were being recovered by increases in electricity bills, a total of 3,073 Ontario electricity consumers who were able to join the program between 2010 and 2019 benefited from the FIT program, while the remaining 5 million non-participating electricity consumers were required to compensate them.

We also quantify to what extent the output from solar PV systems displaces the electricity generation by the peaking power plants (natural gas-fired plants in the case of Ontario) and hence has reduced the amount of carbon dioxide (CO_2) emissions in the province.[2] We see that for every dollar of global benefit from reducing CO_2 emissions, the economic cost to Canada is 8.29 CAD. Moreover, the levelized cost of carbon abatement (LCCA) by solar PV systems under the FIT program is 484 CAD per CO_2 tonne, which is above the current (2023) and future (2030 and after) Federal Government's suggested carbon prices of 65 and 170 CAD per CO_2 tonne. Therefore, although the Ontario FIT program has contributed to the emission reduction in the electricity sector, it has not been an economically efficient and cost-effective carbon abatement program.

In the final part of our analysis, we ask how the estimated impacts would have changed if the program had been implemented a few years later than its original implementation. The rationale behind this "what-if" analysis is that there was a consensus among industry experts around the time this program was implemented that the cost of solar PV systems was experiencing a rapidly declining trend. In such an environment, postponing the program implementation until the investment costs had become stable could potentially have result in substantial cost savings. Our analysis documents that if the program had been implemented in 2016 instead of 2010, the magnitude of the economic loss to the Canadian economy, the financial burden to Ontario residents, and the LCCA would have been 49, 52, and 61 percent lower than the original estimated impacts, respectively.

Our findings contribute to the literature on the role of benefit-cost analysis in the design of climate policies. As Bureau et al. (2021) argue, benefit-cost analysis has played a minor role in the design of climate policies. With heterogenous abatement costs across and within sectors and across and within countries, an integrated benefit-cost analysis that deals with the efficiency and

[2] Solar-generated electricity is considered a peak load generation resource because almost all its energy is supplied during the peak demand period.

distributive impacts of climate policies is essential for achieving net-zero emissions at a reasonable cost. The framework we develop in this paper provides a practical tool for policymakers to evaluate climate policies from the efficiency and equity perspectives.

The rest of the paper is structured as follows. Section 2 describes the design of Ontario's FIT program and reviews the concerns raised by the studies that analyzed this program in its early years. In Section 3 we provide a step-by-step description of the methodology and data sources we employ in this paper. Lastly, we present our empirical results in Section 4 and conclude the paper by listing the conclusion and policy implications in Section 5.

2. Ontario's Feed-in Tariff (FIT) program

The solar FIT program was designed with two streams: (1) micro-FIT stream for projects under 10 kW; and (2) FIT stream for projects over 10 kW. As of 2023, a total of 1,756 MW is procured under the micro-FIT (259 MW) and FIT (1,497 MW) streams, accounting for 55 percent of total solar installations across Ontario (see Table 1). Out of the 3,081 installed systems under the FIT stream, only eight are transmission-connected (80 MW), while the rest are distribution-connected (1,417 MW). This study focuses on the distribution-connected systems under the FIT stream.[3]

It took only a few years for Ontario to become the leading jurisdiction for wind and solar energy in Canada. This dramatic increase in the share of total capacity installed was mainly due to relatively high rates of return and preferred access to transmission and distribution under the FIT program (Yatchew and Baziliauskas, 2011). However, the program's pricing model generated

[3] The electricity generated by the FIT solar PV systems is injected into the electricity grid at either the transmission level or the distribution level. Transmission-connected generators are large-scale facilities connected to the high-voltage Independent Electricity System Operator (IESO)-controlled grid, whereas distributed-connected generators (also known as embedded generators) are small-scale generators located within local distribution companies' territories.

many controversies from the beginning because it offered renewable electricity producers a guaranteed rate far above the average electricity price, leading to substantial real increases in electricity bills for households and businesses (Auditor General of Ontario, 2011).

Table 1: Ontario's installed solar capacity by contract type

Contract type	Number of contracts	Contracted capacity (MW)	% of total solar capacity
Feed-In-Tariff (FIT)			
FIT (> 10 kW)	3,081	1,497	55%
Distribution-connected	3,073	1,417	52%
Transmission-connected	8	80	3%
Micro-FIT (≤ 10 kW)	30,067	259	9%
Net-metering (as of 2022)	3,124	66	2%
Other programs (GEIA, LRP, and RESOP*)	83	894	33%
All contracts	36,355	2,716	100%

Source: Independent Electricity System Operator's report on contracted electricity supply, October 2022.

* GEIA: Green Energy Investment Agreement Power Purchase; LRP: Large Renewable Procurement Program; RESOP: Renewable Energy Standard Offer Program.

Proponents of the FIT program have argued that although the program has been costly, it has resulted in a "learning-by-doing" benefit, reducing the future costs of adoption due to technological and supply chain improvements. Nonetheless, Beck et al. (2018) show that even after assuming moderately high learning effects, the support rates offered by Ontario's FIT program cannot be justified. Some studies in the early years of program implementation raised concerns about the costs of supporting renewable electricity over the course of the FIT program (Pirnia et al., 2011; Dachis and Carr, 2011), as well as the potential for a net increase in air emissions due to the backup requirements for solar and wind resources (McKitrick, 2013).

Eventually, the program limited the acceptance of new applications. On February 24, 2017, in his speech at the Economic Club of Canada in Ottawa, Ontario's Energy Minister, Glenn

Thibeault, admitted that the FIT program had led to "sub-optimal outcomes" for consumers and increased prices in electricity for families and businesses in Ontario.[4]

3. Methodology and data

3.1 Methodology

Our analysis is conducted in three parts. First, we develop an integrated investment appraisal (IIA) framework that enables us to estimate the FIT program's impacts on each stakeholder affected by this program. Second, we evaluate the cost-effectiveness of abating greenhouse gas (GHG) emissions by the FIT program by estimating the LCCA. Third, we ask how the findings from the first and second parts of the analysis would have changed if the implementation of the FIT program had been postponed by six years. In the following subsections, we describe each of the components.

3.1.1 Integrated Investment Appraisal (IIA) framework

The IIA method evaluates benefits and costs in terms of domestic prices from both financial and economic points of view, rather than carrying out these analyses separately. Based on this method, the difference between the net present value of net financial cash flows ($NPV_t^{financial}$) and economic resource flows ($NPV_t^{economic}$) must reconcile with the summation of the present value of stakeholders' impacts ($PV_{i,t}^{stakeholder}$) created by the program over its life. This relationship is expressed in Equation 1.

$$NPV_t^{economic} = NPV_t^{financial} + \sum_i PV_{i,t}^{stakeholder} \quad (1)$$

[4] Global News, February 24, 2017. https://globalnews.ca/news/3272095/ontario-energy-minister-admits-mistake-with-green-energy-program.

The rate at which financial, economic, and stakeholder impacts are discounted should be the economic opportunity cost of capital (EOCK). The EOCK is the measure of the real opportunity cost of funds used to finance investments that are drawn out of the country's pool of capital (both private and public). For Canada, the EOCK is estimated to be 7 percent (Jenkins and Kuo, 2007; TBCS, 2022).

We now describe how we adopt this framework to evaluate Ontario's FIT program for solar PV systems. Those electricity consumers who joined the FIT program by installing solar PV systems are the financial beneficiaries. From their perspective, the decision to join solely depended on the net financial impact of the investment over the PPA contract term (i.e., 20 years). However, there will also be some economy-wide benefits and costs that do not flow to the FIT participants, such as cost savings from avoided fossil-fuel-based electricity generation or the costs of integrating solar PV systems into the electricity network. While these items do not show up in the financial cash flow statements, the economic resource flow statement captures these impacts, eventually reflected in the net present value of economic impact ($NPV_t^{economic}$).

If the economic and financial analyses are done correctly, the difference between the two will be a series of distributional impacts that can be identified and measured. In addition to the private investors, four other stakeholders within the Canadian economy are affected by the FIT program: (1) Ontarian electricity consumers who did not join the FIT program; (2) the Government of Ontario; (3) the Government of Alberta; and (4) the Federal Government of Canada. Given that the FIT program's objective is to reduce the emission of GHGs in the electricity sector, we also consider the global environment as another stakeholder from the global perspective (i.e., the Canadian economy plus other economies).

We arrive at Equation 2 after re-writing Equation 1 to include all the stakeholders.

$$NPV^{Canadian\ Economy} = NPV^{FIT\ Participants} + \underbrace{PV^{ON\ electricty\ consumers} + PV^{FG} + PV^{ON} + PV^{AL}}_{\text{Stakeholder impacts}} \quad (2)$$

where FG, ON, and AL represent the Federal, Ontario, and Alberta governments, respectively.

The present value of the net impact from a global perspective ($PV^{Global\ economy}$) is derived by adding the environmental benefit from the reduction in GHG emissions to the present value of net economic impact from Canada's perspective to arrive at Equation 3.

$$NPV^{Global\ economy} = \underbrace{NPV^{FIT\ Participants} + PV^{ON\ electricty\ consumers} + PV^{FG} + PV^{ON} + PV^{AL}}_{\text{Canadian Economy}} + \underbrace{PV^{GHG\ emission\ reduction}}_{\text{Global Environment}} \quad (3)$$

It should be mentioned here that our analysis is retrospective, given that the FIT program has been in place since 2010, that is, for 13 years at the time of this study. Therefore, when we estimate the present values, we make a series of adjustments to ensure that the values represent the current year's perspective ($t = t_n$). In other words, the opportunity cost of net cash or resource flows realized in the earlier years of the program (between t_0 and t_n) must be compounded to the current year (i.e., the year 2023 in this analysis). On the other hand, the flows that will be realized in future periods must be discounted back to the current year. Equation 4 formalizes the framework employed in our methodology to estimate the present value of cash and resource flows.

$$PV_{t_n} = \sum_{t=t_0}^{t=t_n} NCF_t(1 + EOCK)^{t_n - t} + \sum_{t=t_{n+1}}^{t=t_e} \frac{NCF_t}{(1 + EOCK)^{t_e - t}} \quad (4)$$

Table 2: Description of variables used in the methodology section

Parameters	Description
Indices	
t_0	Program start year
t_n	Current year
t_e	Program end year
Prices	
p_{FIT_t}	Guaranteed price for the power purchase agreement starting in year *t* (CAD/kWh)
p_t^{gas}	Dawn Hub natural gas price (CAD/million BTU)
p_t^{carbon}	Carbon pollution price in year *t* (CAD/tonne CO_2e)
Quantities	
$q_{i,t}$	Electricity generated by a representative FIT participant *i* in year *t*
$Q_{i,t}$	Total electricity generated by all FIT participants in year *t*
Solar PV system	
k_i	Capacity of solar PV system installed by participant *i* (kW)
θ_i	Solar PV's potential yield (kWh per kW)
α_t	Annual degradation rate of the installed solar PV system (%)
$C_{i,capex}$	Capital expenditures of installing a solar PV system
$C_{i,t,opex}$	Operating and maintenance expenditures for a solar PV system at year *t*
Electricity network	
TL_t	Electricity transmission losses as a percentage of generation output (%)
$HR_{j,t}$	Heat rate of gas-fueled generation plant *j* at year *t* (BTU/MWh)
$l_{j,t}$	Technical efficiency loss of gas-fueled generation plant *j* at year *t* (%)
Emission	
NG_t^d	Quantity of natural gas displaced by solar-generated electricity at year *t* (million BTU)
F_t^{CO2}	Natural gas CO_2 emission coefficient at year *t* (kg CO_2 /million BTU)

In the following subsections, we explain how we measure the net impact of the FIT program on each of the stakeholders listed in Equation 3. The description of the variables used to develop the equations is listed in Table 2.

3.1.1.1 FIT participants

From each participant's perspective, the decision to invest in a FIT solar system depends on whether the present value of the payments under the PPA outweighs the present value of the solar PV system's investment cost, maintenance cost, and income taxes. The annual inflow of a FIT project is the gross-of-tax revenues for the total MWhs of electricity generated in that year. Consequently, the first step in evaluating the participation decision is to estimate the annual solar-generated electricity by participant *i* in year *t* ($q_{i,t}$), which is the product of installed capacity (k_i) and solar potential yield (i.e., kWhs of solar electricity per kW of installed capacity) at the participant's location (θ_i). The output must be adjusted for efficiency losses over the system's economic life at an annual rate of α_t.

$$q_{i,t} = k_i \times \theta_i \times (1 - \alpha_t) \tag{5}$$

Next, the local electricity distribution company purchases the solar system's output from the participant at the pre-determined PPA price (p_{FIT_t}). Equation 6 demonstrates how the yearly nominal revenues ($r_{i,t}$) for a representative participant are projected.

$$r_{i,t} = q_{i,t} \times p_{FIT_t} \tag{6}$$

As shown in Equation 7, the cash outflows have three components: (1) the upfront capital expenditures at year 0; (2) the operating and maintenance expenditures of the installed system, that is, mainly the cost of replacing the inverter after 12 years of operation[5]; and (3) the income tax payable on the income from FIT payments after deductions.

$$c_{i,t}^{FIT\ participant} = \underbrace{c_{i,capex}}_{\text{capital expenditures}} + \underbrace{c_{i,t,opex}}_{\text{operating expenditures}} + \underbrace{TI_{i,t} \times CIT}_{\text{income tax expense}} \tag{7}$$

[5] The inverter must be replaced after 12 years, unlike all other system components, which have an expected life of 20 years. Hence, we estimate the present value of purchasing a new inverter in 12 years and add it to the upfront investment in the cash flow statement.

While the capital and operating expenditures can be estimated by the system size, the taxable income varies over the 20-year evaluation period. Thus, to calculate the taxable income, the following items must be deducted from the revenues: operating and maintenance costs, capital cost allowance, and the interest paid on debt. The only operating and maintenance cost over the system's economic life is the cost of replacing the inverter after 12 years of operation ($OM_{i,t}$). Under the Income Tax Regulations, the capital costs of solar PV systems are eligible for a 50 percent accelerated capital cost allowance on a declining balance basis. Lastly, the investment is often financed by a mix of debt and equity, so the annual interest paid on the debt (denoted by $IE_{i,t}$) is deductible from gross revenues. Thus, the taxable income ($TI_{i,t}$) is calculated by subtracting all the deductibles from the gross revenues, as expressed in Equation 8. For the years in which taxable income is negative, the losses are not carried forward but are used to offset taxable income from other business activities.

$$TI_{i,t} = r_{i,t} - c_{i,t,opex} - CCA_{i,t} - IE_{i,t} \tag{8}$$

We use equations 6–8 to project the benefits and costs to a representative FIT participant over the 20 years of the FIT contract.

3.1.1.2 Canadian economy

The Canadian economy benefits in the form of avoided purchases of natural gas by the mid-day peaking gas-fueled electricity generation plants in Ontario. To quantify the economic benefits from savings in natural gas purchases in year *t* (B_t^{econ}), we measure the annual quantity of natural gas purchases avoided by displaced natural gas plants (NG_t^d) and multiply those quantities by the average price of natural gas in that year (p_t^g).

The equation for estimating the quantity of avoided natural gas has two components (Equation 9): (1) the total quantity of solar-generated electricity by all FIT participants in any given year ($Q_t = \sum q_{i,t}$); and (2) the weighted average of heat rates ($w_{j,t}HR_{j,t}$), i.e., the rate at which gas-fueled plants would turn one unit of natural gas into one unit of electricity. The first component must be adjusted for the avoided transmission losses (TL_t) that no longer occur because of the proximity of the electricity supply source to end-use consumers. Also, the second component needs to be adjusted for the annual reduction in the heat rates ($l_{j,t}$) to reflect the loss in technical efficiency of Ontario's gas-fueled fleet over their operating lives.

$$NG_t^d = \underbrace{\sum_{i,t} \frac{Q_t}{(1 - TL_t)}}_{\text{Solar-generated electricity}} \times \underbrace{\sum_{j,t} w_{j,t} HR_{j,t}(1 - l_{j,t})}_{\text{Weighted average of heat rates}} \quad (9)$$

It should be noted here that most of the natural gas used in Ontario comes from Alberta. For each unit of avoided natural gas in Ontario's electricity generation, the Government of Alberta loses the royalty revenue (R_t^{AL}) that it would have collected from selling that unit to Ontario. Therefore, we consider the forgone value of royalty revenues to Alberta by adjusting the natural gas price when estimating the net economic benefits in Equation 10.

$$B_t^{econ} = p_t^{gas}(1 - R_t^{AL}) \times NG_t^d \quad (10)$$

On the economic cost side, three categories of costs must be accounted for: (1) the capital expenditures of the installed solar PV systems under the FIT program ($C_{t,capex} = \sum_i \; c_{i,capex}$); (2) the resources spent on the operating expenditures of those systems ($C_{t,opex} = \sum_i \; c_{i,opex}$); and (3) the additional costs to the Canadian economy of integrating these systems into the grid ($C_{t,int}$). Thus, the economic resource outflows and the present value of the net impact can be expressed as

$$C_t^{econ} = C_{t,capex} + C_{t,opex} + C_{t,int} \tag{11}$$

$$NPV^{econ} = \sum_{t}^{T} \frac{B_t^{econ} - C_t^{econ}}{(1 + EOCK)^t} \tag{12}$$

In addition to evaluating the economic impacts that directly affect Canada, we must evaluate the incremental global environmental impacts of the FIT program, because there is certainly a reduction in global GHG emissions. This benefit is allocated as a global economic benefit in the stakeholder analysis, rather than as a direct benefit to Canadian residents.

3.1.1.3 Electricity consumers in Ontario

One of the main challenges associated with FIT programs is that the compensation offered to the FIT system owners can lead to cost shifting onto non-participants. Ontario's Independent Electricity System Operator (IESO) is a revenue-neutral electricity system operator, and therefore it shifts the incremental benefits and costs of the FIT PPA to its remaining consumer base. On the benefit side, the solar electricity generated by the FIT systems during the daytime will reduce the generation by natural gas plants, as they are generally the marginal generation source when solar panels produce electricity. This results in savings in natural gas purchases to generate electricity. On the cost side, the present value of the FIT contract payments (i.e., summation of all participants' revenues, $\sum_{i,t} r_{i,t}$) will be passed on to all electricity consumers in Ontario.

Additionally, solar energy production under the FIT program is mostly located within the electrical distribution systems, and the electricity distribution companies will incur incremental integration costs to host the FIT capacity in their distribution network.[6] The integration costs include various required investments ranging from upgrading transformers to the procurement of additional ancillary services such as reserves and fast-ramping resources due to the intermittency of solar output.[7]

Consequently, the net incremental impact on Ontario electricity consumers is the present value of the difference between the benefits from savings in natural gas purchases for electricity generation ($B_t^{ON\ electricity\ consumers}$) and the costs that will be passed on to all electricity consumers across Ontario ($C_t^{ON\ electricity\ consumers}$).

$$B_t^{ON\ electricity\ consumers} = p_t^{gas} NG_t^d \tag{13}$$

$$C_t^{ON\ electricity\ consumers} = \sum_{i,t} r_{i,t} + C_{t,int} \tag{14}$$

$$PV^{ON\ electricity\ consumers} = \sum_{t}^{T} \frac{B_t^{ON\ electricity\ consumers} - C_t^{ON\ electricity\ consumers}}{(1 + EOCK)^t} \tag{15}$$

3.1.1.4 Government (Federal and Provincial levels)

---

[6] This is in contrast to what distributed-generation advocates claim about the avoided investments in the distribution network because of solar DERs. There are two reasons why we believe their impact on the distribution network is an incremental cost. First, the empirical evidence suggests that solar DERs have an insignificant to no impact on reducing the required investments in distribution networks (Astier et al., 2023). Second, a review of Ontario Energy Board reports on the issues related to connection of embedded generation facilities demonstrates that distribution companies have raised concerns about the cost responsibility of upstream upgrades in their distribution networks as the penetration rate of solar DER increases (OEB, 2012).

[7] The natural gas-fired generation in Ontario has played the main role in providing backup reliability services to the grid. As of December 2022, natural gas generation provides 28 percent of the electricity system's installed capacity, whereas the actual amount of energy produced by natural gas plants accounts for only 8.6 percent of the total amount of energy produced.

The introduction of the FIT program has also created fiscal impacts on both the Federal and Provincial Governments in the form of changes in the expected tax revenues. Business income tax regulation had considered an accelerated capital cost allowance (CCA) for investments in clean energy generation equipment such as solar PV systems. Therefore, both government levels have experienced some level of forgone corporate income tax revenues as a result of having accelerated rather than regular capital cost deduction rates (50 percent versus 30 percent annual deduction allowance). In other words, the CCA creates a tax shelter for businesses by shifting investments toward clean energy generation equipment, but those benefits for businesses translate into forgone tax revenues for the government. Equation 16 shows that the cost to the government at year *t* (C_t^{Gov}) is estimated by multiplying the change in taxable income at that year ($\Delta TI_{i,t}$) by the corporate income tax rate (CIT^{Gov}).

$$C_t^{Gov} = \Delta TI_{i,t} \times CIT^{Gov} \tag{16}$$

The present value of the net impact on government levels is estimated as shown in Equation 17.

$$PV^{Gov} = \sum_{t}^{T} \frac{B_t^{Gov} - C_t^{Gov}}{(1 + EOCK)^t} \tag{17}$$

We must also adjust the gains from the natural gas purchases avoided by the amount the Alberta Government loses in royalty revenues. The present value of forgone royalty revenues, a transfer from taxpayers in Alberta to those in Ontario, is estimated as follows.

$$PV^{AL} = \sum_{t}^{T} \frac{p_t^{gas} \times NG_t^d \times r_t^{AL}}{(1 + EOCK)^t} \tag{18}$$

3.1.1.5 Global environment

Reduced emissions of GHGs are another quantifiable benefit of solar net-metered systems. A key policy objective of the governments of Ontario and Canada is to reduce CO_2 emissions by displacing fossil-fuel electricity generation (i.e., natural gas in Ontario). The benefits realized are a function of the type of generation being displaced, its carbon emission rates, and the carbon pollution price.

To calculate the value of environmental benefits, we first need to project the quantity of natural gas displaced by net-metered systems (NG_t^d) and then use the weighted average emission factor of the natural gas fleet in Ontario (F_t^{CO2}) to estimate how many megatons of CO_2-equivalent emissions will be avoided.[8] After estimating the associated levels of emissions, we assign a price to the CO_2 emitted to quantify the global environmental benefits. The present value of avoided CO_2 emissions that is attributable to the installed solar FIT capacity is estimated as follows.

$$PV^{environment} = \sum_{t}^{T} \frac{p_t^{carbon}(NG_t^d \times F_t^{CO2})}{(1+EOCK)^t} \quad (19)$$

3.1.2 The levelized cost of carbon abatement (LCCA)

The LCCA for a given technology is the carbon price (in real terms) that would equate the present value of economic benefits from the avoided GHG emissions by the solar-generated electricity ($\frac{Q_t}{(1-TD_t)}$ from Eq. 8) with the present value of net economic costs of that technology over its economic life ($\frac{C_t^{econ}}{(1+EOCK)^t}$ from Eq. 11).

---

[8] CO_2 is not the only GHG; others include methane, nitrous oxide, and hydrofluorocarbons. However, the conventional approach is to convert the non-CO_2 GHG emissions into CO_2-equivalent units.

$$\sum_{t}^{T}[\frac{Q_t}{(1-TD_t)}\times\frac{LCCA}{(1+EOCK)^t}]=\sum_{t}^{T}\frac{B_t^{econ}-C_t^{econ}}{(1+EOCK)^t} \quad (20)$$

After re-arranging Equation 20, the LCCA for FIT systems can be estimated by dividing the present value of FIT systems' costs by the present value of total electricity generated by those systems, as expressed in Equation 21.

$$LCCA=\frac{\sum_t^T\frac{B_t^{econ}-C_t^{econ}}{(1+EOCK)^t}}{\sum_t^T\frac{\frac{Q_t}{(1-TD_t)}}{(1+EOCK)^t}} \quad (21)$$

3.1.3 Timing of investments

One of the most important steps in the process of project preparation and implementation is to decide on the appropriate time at which the project should start. The determination of the correct timing of investment projects will be a function of how it is anticipated that future benefits and costs will move in relation to their present values. In the case of solar PV systems, the expectations were that technological breakthroughs would reduce the investment costs for solar PVs. Hence, the question that arises here is how the financial, economic, and stakeholder impacts would have differed had the FIT program been implemented later than its original start. If investment costs are expected to fall in the future, the optimal option would be for the program to be implemented later than if investment costs remained constant or rose over time. We will test this prediction for Ontario's solar FIT program. Given that this analysis is retrospective, the lessons learned from this analysis will be critical input for decision-makers when evaluating similar investments in the future.

3.2 Data

3.2.1 Solar PV costs and PPA prices

Panels A and B of Figure 1 show the trends in the average (nominal) prices of solar PV systems in Canada by technology type (rooftop or ground-mount) next to the PPA prices offered to the FIT program's participants based on the year they joined the program. Over the time that the program accepted new applications, the PPA prices were frequently adjusted to reflect the reductions in the cost of solar PV systems. The cost of a grid-connected rooftop system ranged from 5.27 CAD per watt in 2010 to 1.80 CAD per watt in 2019. Meanwhile, ground-mount installations tend to have larger system sizes and, therefore, reduced per-watt cost through economies of scale. Over 2010–2019, ground-mount systems had lower relative prices than rooftop systems. Additionally, with the declining trend in system costs over the period 2010–2019, those FIT participants who joined the program in the earlier years had investment costs of multiple times those of systems installed in later years.

Figure 2 shows the number of FIT contracts by the year of installation and the technology type on the left vertical axis, and the cumulative capacity on the right vertical axis. Although rooftop systems make up most FIT contracts, the cumulative capacity of ground-mount installations is almost twice the capacity of rooftop systems. In fact, the maximum rooftop system has a size of 0.5 MW, whereas the ground-mount systems have up to 10 MW of capacity.

[Insert Figure 1 here]

[Insert Figure 2 here]

The IESO contracted a total of 3,081 solar FIT contracts between 2010 and 2019, aggregating to 1,497 MW. In this study, we focus on distribution-connected systems with a total capacity of 1,407 MW. As shown in Figure 3, the first group of FIT contracts started feeding the distribution grids in 2010 with a 1.45 MW capacity. The generation capacity accumulated as new systems were connected to the distribution systems over the period 2010–2019. Starting in 2030, there will be annual reductions in the total capacity as the contract end-dates approach. The last year with an active PPA under the FIT program will be 2038, when the contracted FIT capacity of 2019 will reach its 20-year operation year (see Figure 3).

[Insert Figure 3 here]

3.2.2 Solar photovoltaic yield by location

The FIT systems are installed across the municipalities of Ontario. Because we observe the municipality in which each system is installed in the dataset, we match the annual yields provided by Natural Resources Canada with each system's municipality. Annual yields have a mean value of 1,165 MWh/MW and a standard deviation of 21 MWh/MW, with a minimum and maximum of 1,131 MWh/MW and 1,268 MWh/MW. The low standard deviation in the annual yield values allows us to assume an average annual yield of 1,165 MWh/MW for all the systems under the FIT program.

3.2.3 The Carbon Pollution Price

To quantify the impact of reductions in CO_2 emissions from natural gas-fired power plants displaced by the solar FIT systems, we follow the federal carbon pricing benchmark in Canada. Starting with 20 CAD/tonne CO_2e in 2019, the carbon price increased by 10 CAD per year until 2022 and is scheduled to increase by 15 CAD per year from 2023 to 2030. Eventually, the carbon price will reach 170 CAD/tonne CO_2e in 2030 and stay at 170 CAD thereafter (Government of Canada, 2021). The federal carbon pricing schedule was enacted in 2019. Given that our evaluation period for the FIT program is spread over the period 2010–2038, we need a carbon price for the years before 2019. We assume a price of 20 CAD/tonne CO_2e for the years between 2010 and 2019.

4. Results

4.1 Financial impact

The PPAs have starting years between 2010 and 2019, and they expire after 20 years of operation. With changes in solar PV investment costs and the offered rate under the FIT program over the years, the financial feasibility of a representative system would depend on the year the PPA contract started. Therefore, we start by building financial cash flow statements for 1 MW of installed capacity under the FIT program from the perspective of successive years, with all the cash flows indexed to 2023 prices. This approach is important for evaluating the FIT program because the FIT contract prices and the solar PV systems' costs have changed significantly over the period in which the program accepted applications. Table 3 lists the inputs used for constructing the financial cash flow statement from the FIT participant's perspective.

Table 3: Summary of inputs for the financial analysis

Parameter	Input	Source
Solar PV technical features		
Annual yield	1,165 MWh per MW	Natural Resources Canada
Annual output degradation	0.50% per year	National Renewable Energy Laboratory (NREL)
Inverter replacement cost after 12 years of operation	15% of the system cost	National Renewable Energy Laboratory (NREL)
Investment cost	Investment cost changes based on the start year of the FIT contract (see Figure 2)	National Survey Report of PV Power Applications in Canada
Financing	60% debt, 40% equity	
	Interest rate: 5% fixed	
	Loan tenure: 10 years	

Depreciation		
Accelerated capital cost allowance	50% per year on a declining balance, with only half of the deduction allowed in the year of acquisition	Class 43.2 of the Tax Regulations, Government of Canada
Taxation		
Corporate income tax	26.50%	Government of Canada
Federal	15.00%	
Ontario	11.50%	

Panels A and B in Figure 4 show the outcome of financial analysis by technology type and the year in which participants joined the program. It appears that both technology types were expected to yield a positive NPV and higher-than-discount-rate internal rate of return for participants. Therefore, it is not surprising that the FIT program could successfully promote the adoption of solar PV systems in Ontario. Nonetheless, it should be mentioned that the gains on investments in the earlier years are relatively greater than those in later years due to more generous PPA rates in those years.

[Insert Figure 4 here]

4.2 Economic impact

The benefits from the Canadian economy's perspective are the reduction in the dispatch of gas-fired generators during the operating hours of the solar PV systems and the avoided transmission losses due to the proximity of these distribution-connected systems to final consumers. With a one-to-one displacement rate of the natural gas power plants with the FIT systems' output and a 3 percent avoided transmission loss, the projected reduction in the purchase of gas-fueled electricity by local distribution companies would be 31 terawatt-hours (TWhs) over the FIT program's life. To put this number into perspective, the solar FIT output in our projection would result in avoided electricity generation of 1.62 TWhs in 2022, the year in which the total output of natural gas plants in Ontario was 12 TWhs.

The electricity generation avoided due to the installed capacity under the FIT program translates into economic resource savings in the form of avoided natural gas use by electricity generation plants. Our model estimates a present value of 1.11 CAD billion over the life of the FIT program. From the perspective of Ontario electricity consumers, the financial benefit of the avoided natural gas purchases is the delivered price of the natural gas from Alberta, which includes the commodity price plus an 8 percent royalty collected by the Alberta Government. The forgone royalty revenues are a transfer within the economy, not an economic benefit. Therefore, we only consider 1.03 CAD billion of net economic benefits and will assign the value of forgone royalty revenues, 0.08 CAD billion, as a transfer from Alberta residents to Ontario electricity consumers later in the stakeholder impact analysis.

The economic benefits from the FIT program come at a substantial economic cost. The incremental economic resource outflows due to investment and maintenance costs of solar PV systems have a present value of 6.80 CAD billion. Moreover, with a conservative assumption of 2.65 CAD per MWh of installed solar capacity for integration costs, the present value of integration costs is 0.08 CAD billion. The net economic impact is a loss of 5.86 CAD billion to the Canadian economy (see Table 4), with the economic benefits offsetting only 15 percent of the economic costs.

Table 4: The impact of Ontario's solar FIT program on the Canadian economy

Resource flows statement	Present value @EOCK = 7% (CAD billion, 2023 prices)
1. Economic resource inflows	1.03

• Savings in natural gas for electricity generation		1.03
2. Economic resource outflows	6.89	
• Investment cost		6.48
• Operating and maintenance (O&M)		0.32
• Solar-to-grid integration cost		0.08
3. Net economic resource flows	**− 5.86**	

4.3 Stakeholder impact

In this subsection, we discuss the sign and magnitude of impacts on each stakeholder. The difference between the financial gain by FIT participants and the economic loss is the aggregate impact on all stakeholders (see Equation 2). To aggregate the financial impact on all the FIT participants, we multiply our per-MW estimates from Subsection 4.1 by the total MW of installed capacity each year and then add them up throughout the evaluation period. Our results indicate that the owners of solar FIT systems are made better off by 3.86 CAD billion (2023 prices) through implementing Ontario's FIT program, which is the difference between the present value of PPA payments received by them (10.52 CAD billion) and the present value of their costs (6.66 CAD billion).[9] Given our estimate of the economic impact in Subsection 4.2, the aggregate impact on stakeholders of Ontario's solar FIT program is a loss of 9.72 CAD billion (in present value terms) distributed among the stakeholders within the Canadian economy (see Table 5).

The present value of the net impact on the electricity consumer base in Ontario of procuring solar FIT contracts amounts to 9.49 CAD billion. This burden fell initially on electricity ratepayers in the form of higher electricity bills until the Ontario Government introduced the Renewable Cost

[9] The FIT contracts have different start and end dates, and therefore the benefits and costs of the FIT systems have been and will be realized across different years. To make the numbers comparable, all items on the cash flow statements are indexed to 2023 prices.

Shift program in 2021. The objective of this subsidy program is to shift most of the cost of electricity generation from renewable energy contracts (approximately 85 percent) from Ontario's electricity consumers to taxpayers. According to the estimates of Ontario's Financial Accountability Office (FAO), the Renewable Cost Shift will cost the province a total of 38.6 CAD billion (FAO, 2022) over the 20 years from 2021 to 2040. With 34 percent of the contracted renewable capacity in Ontario being the solar FIT contracts evaluated in this analysis, the Ontario Government will have to allocate 13 CAD billion (in nominal prices) toward these contracts.

The Ontario Government and the Federal Government of Canada also experience losses of 0.06 and 0.08 CAD billion, respectively, in the form of forgone corporate income tax due to accelerated CCA for solar PV systems. Additionally, the Government of Alberta loses the projected royalty revenues from the expected natural gas purchases by the gas-fired power plants in Ontario. The present value of forgone royalty revenues is estimated at 0.09 CAD billion.

Table 5: Allocation of stakeholder impacts for Ontario's solar FIT program

Stakeholder	Present values @EOCK=7% (CAD billion, 2023 prices)	
1. Ontario electricity consumers	− 9.49	
Savings in natural gas purchases for gas-fired power plants		1.11
Payments to FIT participants		− 10.52
Solar-to-grid integration cost by FIT program		− 0.08
2. Federal Government	− 0.08	
Incremental corporate income tax revenues from the FIT participants		− 0.08
3. Ontario Government	− 0.06	

Incremental corporate income tax revenues from the FIT participants		− 0.08
4. Alberta Government	− 0.09	
Forgone royalty revenues from natural gas production		− 0.09
5. Total impacts on the stakeholders within the Canadian economy	− 9.72	

4.4 Environmental impact

From the global environmental perspective, our estimates indicate that the solar FIT program reduces CO_2 emissions by 11.43 megatons (Mt).[10] The product of reduced CO_2 emissions each year and the determined carbon price for that year project the yearly social value of the reduction in carbon emissions. The present value of savings in emissions from the program start year up to the year that the last contract expires adds up to 0.71 CAD billion. Table 6 shows the reconciliation of financial, economic, stakeholder, and environmental appraisals. Moreover, with a net economic cost of 5.86 CAD billion, the levelized cost of abating 1 tonne of CO_2 by the FIT program is 484 CAD, almost three times the projected carbon price of 170 CAD per CO_2 tonne in Canada.

Table 6: Reconciliation of impacts for Ontario's solar FIT program

Point of view	Present value of impacts (CAD billion, 2023 prices)			
	Economic	Financial	Stakeholders	Environmental
Canadian economy	−5.86	3.86	−9.72	-
Canadian economy + Global environment	−5.15	3.86	−9.01	0.71

4.5 Sensitivity analysis

[10] To put this number into perspective, Ontario's electricity sector emitted 5.4 Mt of CO_2 in 2020 (IESO, 2021).

We re-evaluate the FIT program by switching the program start year in our model from 2010 to 2016. The idea here is to see how the program impacts would change if the implementation had been postponed to later years when the trend in solar PV costs flattened (see Figure 1). As in the original analysis, we evaluate the program from the perspective of the year 2023, and all prices are indexed to 2023 prices. As shown in Table 7, the net economic costs would have been lower by almost 50 percent (changing from −5.90 to −2.97 CAD billion). This significant reduction in economic costs is mainly due to the reduction in the PPA payments to FIT participants due to lower system costs.

Table 7: Timing of Ontario's solar FIT program implementation

Analysis outcome	Original start in 2010	If started in 2016	% change in impacts
1. Present value of impacts from the perspective of 2023			
a. Economic	−5.90	−2.98	−49%
b. Stakeholders	−8.49	−4.73	−44%
2. Levelized cost of abatement (CAD per ton of CO_2e)	487	304	−61%

Therefore, postponing the implementation of the FIT program would have yielded a net gain of 2.88 CAD billion to the Canadian economy. This gain is the difference between the forgone economic benefits from natural gas savings and the corresponding emissions avoided (0.19 CAD billion), and the economic resource savings because of the reductions in solar PV investment costs (3.07 CAD billion). It is also worth mentioning that the LCCA due to the FIT program would have been lower by almost 61 percent if its implementation had been postponed from 2010 to 2016. This finding highlights the importance of the decision on the appropriate time at which a program should start.

The discount rate we used in our analysis is the real rate of 7 percent recommended by the Treasury Board of Canada Secretariat for the cost-benefit analysis of regulatory proposals. However, some departments and governments consider a real rate of 3 percent when certain human health and environmental concerns are associated with a program (Government of Canada, 2023). Therefore, we test the sensitivity of our findings to the discount rate choice. The results indicate that while a lower discount rate improves the FIT program's economic efficiency and effectiveness criteria, the negative impacts on the Canadian economy and stakeholders are still significant (see Table 8).

Table 8: The choice of discount rate

Impact	Impacts with different discount rates (CAD billion, 2023 prices)	
	7%	3%
1. Financial	3.86	4.81
2. Economic	−5.86	−4.04
3. Stakeholder	−9.72	−8.85
4. Global environment	0.71	0.78
5. Levelized cost of abatement	484	351

5. Conclusion and policy implications

This paper develops a framework for integrating all the criteria of cost-benefit analysis, including optimal timing, economic resource efficiency, environmental cost-effectiveness, and distributional impacts, when evaluating renewable energy support programs. We apply this framework to analyze the financial, economic, and stakeholder impacts of Ontario's FIT program for solar DERs over the decade following its implementation in 2010. The program has successfully stimulated the installation of solar DER across Ontario, and those electricity consumers who joined the program derived a substantial net benefit from their investments. However, these benefits that accrued to a few well-off institutions have come at a tremendous cost to the lower-income electricity consumers of Ontario.

Our findings show that the economic waste imposed on the Canadian economy ranges from 4.04 to 5.86 CAD billion, depending on the discount rate applied. Moreover, the program has caused inequitable societal outcomes through a cross-subsidization with a present value of approximately 10 CAD billion, paid for by the electricity consumer base, for the benefit of only the 0.06 percent of electricity consumers who were able to install solar PVs between 2010 and 2019. Furthermore, the displacement of gas-powered electricity generators has yielded fuel savings of a value that is less than 10 percent of the costs imposed by the FIT systems on Ontario electricity consumers. Moreover, the monetized benefits of reductions in CO_2 emissions because of this displacement (mainly a gain to the global environment) do not exceed 12 percent of the net loss to the Canadian economy.

The sensitivity analysis confirms that the loss to the Canadian economy and stakeholders could have been reduced substantially if the Government of Ontario had delayed the implementation by a few years. This finding has policy implications for jurisdictions such as Ontario, with a relatively low-emission electricity sector. Instead of rushing to administratively set high compensation rates for solar output to increase private investment in renewable energy projects, decision-makers can prioritize cost-effective alternatives and postpone those with expected real cost reductions in the near future. Otherwise, scarce public funds with high opportunity costs will maximize returns to a small group of beneficiaries at the expense of millions of residents.

Our findings highlight the importance of conducting a detailed appraisal of renewable energy programs and advising the stakeholder involved of the expected cost impacts before the implementation. According to the report of the Auditor General of Ontario (2011), several consumer surveys conducted by the government in 2010 indicated that although consumers generally supported renewable energy, they were unaware of its impact on prices. Therefore, a transparent reporting of the results of an ex-ante IIA that quantifies the financial and economic outcomes and the likely impacts on all the stakeholders is essential for designing sustainable programs to address GHG emissions.

References

Astier, Nicolas, Ram Rajagopal, and Frank A. Wolak. 2023. "Can distributed intermittent renewable generation reduce future grid investments? Evidence from France," *Journal of the European Economic Association*, 21(1): 367-412.

Auditor General of Ontario. 2011. "Electricity Sector-Renewable Energy Initiatives." In *Annual Report of the Auditor General of Ontario*, Chapter 3. Available at https://www.auditor.on.ca/en/content/annualreports/arreports/en11/303en11.pdf (accessed April 25, 2023).

Beck, Marisa, Nicholas Rivers, and Randall Wigle. 2018. "How do learning externalities influence the evaluation of Ontario's renewables support policies?" *Energy Policy*, 117: 86-99.

Bureau, Dominique, Alain Quinet, and Katheline Schubert. 2021. "Benefit-Cost Analysis for Climate Action," *Journal of Benefit-Cost Analysis*, 12(3): 494-517.

Dachis, Benjamin and Jan Carr. 2011. "Zapped: the High Cost of Ontario's Renewable Electricity Subsidies." No. 117. CD Howe Institute.

Financial Accountability Office of Ontario (FAO). 2022. "Ontario's Energy and Electricity Subsidy Programs." Available at https://www.fao-on.org/en/Blog/publications/energy-and-electricity-2022 (accessed March 17, 2023).

Government of Canada. 2021. https://www.canada.ca/en/environment-climate-change/services/climate-change/pricing-pollution-how-it-will-work/carbon-pollution-pricing-federal-benchmark-information/federal-benchmark-2023-2030.html (accessed April 20, 2023).

Government of Canada. 2023. Canada's Cost-Benefit Analysis Guide for Regulatory Proposals. Available at: https://www.canada.ca/en/government/system/laws/developing-improving-federal-regulations/requirements-developing-managing-reviewing-regulations/guidelines-tools/cost-benefit-analysis-guide-regulatory-proposals.html#toc-10 (accessed April 25, 2023).

Independent Electricity System Operator (IESO). 2021. Decarbonization and Ontario's Electricity System. Available at https://www.ieso.ca/en/Learn/The-Evolving-Grid/Decarbonizing-the-Electricity-Sector (accessed March 17, 2023).

Jenkins, Glenn, and Kuo, Chun-Yan. 2007. "The Economic Opportunity Cost of Capital for Canada—An Empirical Update." QED Working Paper Number 1133, Department of Economics, Queen's University, Kingston, Canada, 2007. Available at https://www.econ.queensu.ca/sites/econ.queensu.ca/files/qed_wp_1133.pdf. (accessed June 19, 2023).

McKitrick, Ross. 2013. “Environmental and economic consequences of Ontario’s green energy act.” Fraser Institute Ontario Prosperity Initiative. Available at https://www.fraserinstitute.org/sites/default/files/environmental-and-economic-consequences-ontarios-green-energy-act.pdf (accessed June 8, 2023).

Ontario Energy Board (OEB). 2012. Policy Review of Micro-embedded Generation Connection Issues. Available at https://www.oeb.ca/industry/policy-initiatives-and-consultations/policy-review-micro-embedded-generation-connection (accessed April 25, 2023).

Pirnia, Mehrdad, Jatin Nathwani, and David Fuller. 2011. “Ontario feed-in-tariffs: System planning implications and impacts on social welfare,” *The Electricity Journal*, 24(8): 18-28.

Renewable Energy Policy Network for the 21st Century (REN21). 2022. *Renewables 2022 Global Status Report*. Available at https://www.ren21.net/wp-content/uploads/2019/05/GSR2022_Full_Report.pdf (accessed April 18, 2023).

Treasury Board of Canada Secretariat (TBCS). 2022. Canada’s Cost-Benefit Analysis Guide for Regulatory Proposals. Available at https://publications.gc.ca/collections/collection_2022/sct-tbs/BT58-5-2022-eng.pdf (accessed April 18, 2023).

Yatchew, Adonis and Andy Baziliauskas. 2011. “Ontario feed-in-tariff programs,” *Energy Policy*, 39(7): 3885-3893.