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Challenges in energy policies for the economic integration of prosumers in electric energy systems: A critical survey with a focus on Ontario (Canada)

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Abstract: The accessibility and reducing cost of distributed renewable energy sources are stimulating the emergence of small-scale residential prosumers who can produce and consume electricity. This may lead to various scenarios. Such prosumers may increase the uncertainty of consumption behavior, reduce consumption from the grid, and eventually disconnect from the grid. However, they may remain connected, and their energy potential can provide flexibility for the overall system. Current policy in some jurisdictions promotes disconnection through tax increases, grid charges, and other non-commodity costs. In particular, in Ontario (Canada) only 8.7% of the typical electricity bill covers the cost of energy and power; the remainder subsidizes governmental energy-procurement contracts, compensates the grid, pays for environmental initiatives, and covers other taxes. The situation is aggravated by a lack of a global vision for the energy system and of coordinated actions to achieve this vision. We support the preferred scenario in which prosumers remain connected to the grid. As an alternative to Ontario's current attempts to artificially slow the increase in electricity prices, we present an extended critical survey of energy policies to motivate a thoughtful reconsideration of current schemes for the economic integration of prosumers in the energy system.

Keywords: Energy system, small-scale prosumer, renewable energy source, energy policy, electricity bill, energy and power charges, grid fees, feed-in-tariff

Acronyms

DG distributed generation

DR demand response

EV electric vehicle

FIT feed-in-tariff

GA global adjustment

HOEP hourly Ontario electricity price

OEB Ontario Energy Board

PV photovoltaic

RES renewable energy sources

TLOU time-and-level-of-use

TOU time-of-use

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1 Introduction

In recent decades there have been several major shifts in the reality of power systems. There has been a rapid deployment of renewable energy sources (RES) worldwide. The global RES capacity (including hydropower, wind, and solar technologies) doubled between 2008 and 2017 [1]. Specifically, bioenergies and wind power increased by factors of 2 and 4.5 respectively, while solar power had a phenomenal 26-fold rise [1]. This was a result of various government policies and initiatives, including the feed-in-tariff (FIT), that stimulated RES deployment. The FIT combines long-term, fixed-price purchase agreements and guaranteed grid access. Used in just two countries in 1990, FIT had been adopted to various extent in 66 countries by 2012 [2]. By 2015, RES-related policies were in place in 146 countries [3]. These policies require important subsidies, e.g., it is estimated that from 2009 to 2012 Spain paid around EUR 2.5 Bn annually in FITs for photovoltaic (PV) generators [4].

This shift in the power generation portfolio has been concurrent with an increase in the number and severity of power utilities' operational problems. The aging electricity grid is susceptible to weather events (storms, floods, etc.), human errors, malicious attacks, and equipment failures. Their undesired effects can propagate in the system and lead to massive blackouts [5]. Furthermore, aging problem is also relevant for centralized power plants supporting base generation (e.g., nuclear) or peaking generation (e.g., natural gas, hydropower). For example, the age of the US grid components in some cases exceeds 50 years [6], and 26% of its nuclear capacity will be retired between 2017 and 2050 if current economic and demographic trends continue [7]. All this requires an impressive annual expenditure: USD 122.8 Bn in 2017 with 29% devoted to power generation, 29% to distribution, 17% to transmission, and the remaining 25% to other infrastructure and initiatives [8].

Much of these expenditures are covered by electricity consumers whose electricity bills appear to be larger each year. First, the adoption of new environmental initiatives, such as FITs for distributed generation (DG), requires increased environmental levies. Second, integrating intermittent DG into aging grid networks requires investment in infrastructure upgrades. However, the cost of generation has been decreasing because of stagnation (or reduction) in the raw-material prices, capacity increases arising from RES deployment, and modest economic growth. As a result, a household with constant or decreasing consumption may see its electricity bill increase despite the decrease of electricity generation cost. In the province of Ontario in Canada, it has become impossible for some consumers to pay their bills, and 4.4% of consumers experienced short- or long-term disconnections (sometimes in the winter) by their suppliers between 2013 and 2016 [9, 10]. This became a political issue and had an important impact on the election results in June 2018 [11]. While political measures that artificially control price increases have proved ineffective in other countries, such as Spain [12], the Ontario government continues to undertake such measures [13].

Increasing electricity bills have accelerated the emergence of small-scale prosumers (who both produce and consume electricity). Other contributing factors have been the massive deployment of PV panels, which cost continues to fall, and advances in storage technologies, including electric vehicle (EV)-to-grid storage. The rapid growth of solar technologies is not confined to equatorial countries: in Canada, the solar capacity increased from 0.033 GW in 2008 to 2.9 GW in 2017 [1] and is expected to more than double by 2040 [14]. 98% of Canada's solar power capacity is installed in Ontario and is integrated mainly into low- and medium-voltage grids [15]. Therefore, Ontario will likely follow the path taken by some Western European countries, such as the Netherlands, where the percentage of solar PV prosumers is expected to reach 9.5% of households by 2030 [16].

The emergence of these prosumers is expected to follow one of two possible scenarios. In the first scenario, high grid costs and taxes will lead prosumers to increase the uncertainty of consumption behavior, reduce their consumption from the grid, and eventually disconnect from the grid. The current situation in Ontario promotes disconnection: the consumer does not benefit from decreasing energy prices since grid fees and taxes form the largest component of the electricity bill. At the same time, the end of the FIT program has led the tariff for distributed RES to converge toward the regular tariff, removing the economic incentive to remain connected. Disconnection is particularly attractive

for prosumers in low-density regions. They usually have the space for RES and storage technologies, and their grid fees are the highest in Ontario. The voluntary disconnection of RES households will increase the pressure on the remaining connected households, which will be faced with increased fees to maintain the network, amplifying the energy poverty effect (see Sections 2 and 3 for details).

The second scenario, which we support, is that prosumers will remain connected. They may provide flexibility by participating in demand response (DR) programs and become valuable stakeholders of the energy system. With careful consideration of these new stakeholders, their potential could be used for the benefit of the entire system (see Section 4). We propose to work on i) a new economic scheme to involve prosumers in the global energy management strategy and ii) a computational decision-making framework to help test and adjust this scheme (Section 5). The paper contributions are as follows:

- We give a thorough state-of-the-art analysis of the adoption of environmental initiatives (especially FIT) in various countries, with a specific focus on Ontario;
- We present a vision for the Ontario electricity system based on affordability and optimal energy mix with the contribution of small-scale prosumers;
- We propose a vision for new economic scheme and a decision-making framework to ensure that the involvement of small-scale prosumers benefits the entire system.

2 Energy system organization

2.1 System stakeholders and commercial relationships

This section discusses the major stakeholders and their relationships within a generalized energy system that is representative of most jurisdictions (Figure 1).

Each stakeholder willing to establish a connection with the *transmission and distribution networks* pays the connection cost. This cost is composed of the grid connection charges related to the physical connection and the transmission and distribution fees associated with the energy exchange.

The grid connection cost is a one-time installation cost shared between the utility company and the new stakeholder (consumer or generator). This cost typically includes service connection expenses from the distribution system to the stakeholder's main circuit breaker, i.e., connection charges, and the cost of developing the grid to serve an area [17]. While the cost of grid expansion and upgrade is typically borne by the utility [18], the connection charges are paid by the stakeholder. They usually cover the estimated costs of materials, labour, and transport for the connection from the nearest pole of the distribution system; the costs of an inspection of the consumer premises; and perhaps a relatively small one-time application fee [17]. Similarly to the consumer connection, the connection charges for DGs, such as PV installations, include permission, engineering, and inspection costs paid to the utility company to ensure that the new installation meets engineering and safety standards [19].

The transmission and distribution fees are shared between consumers and generators; they are collected by the grid operator. They include transmission fees for sending the electricity from the generators to where it is needed. The generation companies may pay the transmission and distribution fees to the grid operators and partially pass these costs on to consumers [20], or the supplier may collect the consumers' contribution through their electricity bills [21]. For small consumers these costs are included in the rate, but for large users they may be shown separately.

The electricity bill includes the following components that may or may not be itemized separately [22], [23]:

- generation cost;
- transmission and distribution fees (transport, balancing, and reliability);
- retail services cost;
- other costs including taxes and environmental incentives (or levies).

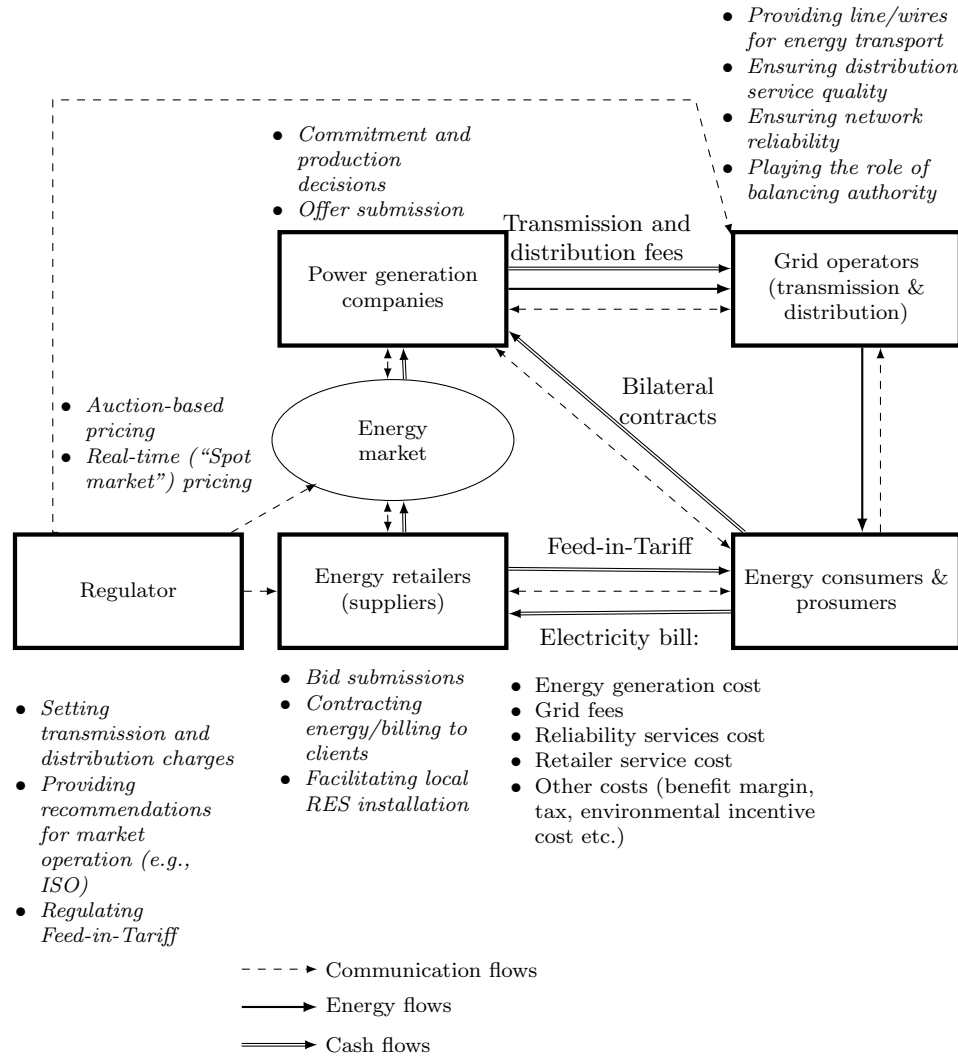


Figure 1: Grid stakeholders and signals.

Before the introduction of environmental incentives, the bill mostly represented the wholesale energy cost, which reflects the generation cost. The wholesale cost fluctuates depending on the daily system conditions, the time of year, and the geographical location. This is due to the fluctuations in the price of fuel (such as natural gas or oil) and the energy demand [21]. In some countries, the cost of transmission services is embedded in the wholesale price. In addition, it may include the cost of losses, which represent the cost of the additional energy required to operate the transmission and distribution system. In some schemes, the loss costs are volume-adjusted at the time of billing [22]. However, in this paper the term “wholesale energy cost” will refer exclusively to electricity generation, while the transmission cost will be considered a grid fee.

Several other wholesale electricity products transacted through a wholesale market must be purchased by retailers along with energy and are embedded in the electricity bill. These products are part of the transmission and distribution fees and are related to the reliability services provided by the grid [21]. They include the capacity market service, also known as the peak-load contribution, which is based on consumption (\$/MW). It is established annually based on the consumer portion of the total peak demand of the grid. Also, identify the capacity rate upon which the proposal is based. Ancillary services ensure grid reliability through frequency regulation, non-spinning and responsive reserves, emergency response, reliability unit commitment, etc. [22].

An example of an environmental levy embedded in the bill is a FIT. FITs were introduced to support renewable energy development via a long-term financial incentive offered through a standardized and streamlined process [24]. A utility, supplier, or grid operator is legally required to pay for a unit of RES electricity [25]. FIT is controlled by a federal (or regional) government (that may be represented by a Regulator), and reflects the levelized costs of electrical energy of RES plus a reasonable profit rate [26]. The budget for FIT comes from i) a domestic FIT budget and ii) an international support mechanism [2]. The domestic (national) FIT budget is funded by taxes and charges (including environmental levy in the bill), which are reviewed periodically and phased out as the share of RES increases [27]. The annual subsidy paid by the international support mechanism is typically proportional to the RES share, annual investment in additional capacity, and the RES unit cost per kilowatt-hour [28]. It also depends on factors such as the current consumption, the target threshold for per-capita consumption, and the subsidy duration and schedule [28].

2.2 Current reality for consumers

Almost all the commodity costs (energy and power cost) and non-commodity costs (transmission and distribution fees, environmental levies, other taxes) are charged to the end-consumers through their electricity bills. Figure 2b shows the average cost per kWh (or typical¹ monthly electricity bill) normalized by typical household monthly consumption for households of selected countries between 2000 and 2017². Note that consumption remained almost constant (and decreased in some countries) during this period (Figure 2a).

The rate of increase of the electricity bill is greater than that of total household consumption expenditure³ taken as a proxy of national economic growth [43]. Figure 3 shows the trends of total monthly expenditure and electricity bills. In the US, the UK and Australia, the increase in electricity bills follows a similar trend in total expenditures. In Spain, Germany, and Ontario the electricity bills increase has recently outpaced the increase in total expenditures (Figure 3).

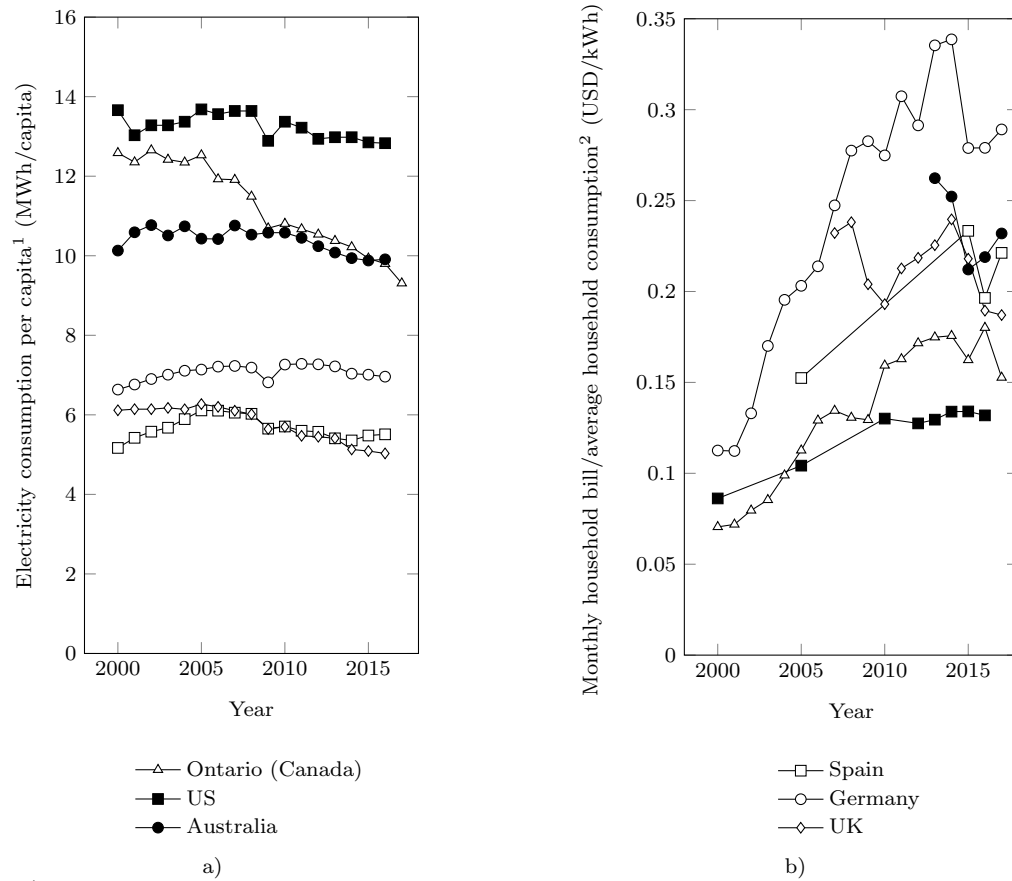
Figure 4 shows how the average electricity bill breaks down into its main components (in USD for 2016): energy and power cost, grid fees, and levies and taxes. The breakdown percentages are similar for Spain, Germany, and the UK. The energy and power cost ranges from 24% to 38.8%, and the delivery cost ranges from 17% to 26%. The levies and taxes are important, with the highest fees in Spain and Germany: 59% and 54%, respectively. In Australia, the US, and Ontario show a marked difference in commodity and non-commodity cost: the levies and taxes are lower while the commodity and delivery costs are much higher than in Europe.

In Ontario the average household consumption is not the highest, but it has the highest electricity bills. It reaches 144 USD/month, of which the commodity costs are 89 USD/month and the delivery costs are 43 USD/month. Note that in Ontario the commodity cost is composed of the hourly Ontario electricity price (HOEP), i.e., the wholesale costs, and the global adjustment (GA) scheme (which includes the RES levies). The actual variable cost share from a competitive market is only 8.6% of the bill while GA, responsible for more than 50% of the bill, can be classified into taxes and levies (as in other countries). Environmental and other levies as well as the grid fees are particularly significant in Ontario. In part because of the Green Energy Act adopted in 2009 [46], the bill almost doubled between 2010 and 2016 [51]. We focus on Ontario as a case study to discuss the bill components in comparison with international trends.

¹Here and in the following analysis we consider monthly electricity bills for typical households as specified in Figure 2, unless stated otherwise.

²Here and in the following analysis all costs are converted from national currencies (i.e., EUR for Germany and Spain, GBP for the UK, CAD for Ontario, and AUD for Australia) to USD using the average annual historical rates from [29].

³The total household expenditure represents the expenditure made by households to meet their daily needs: food, clothing, housing (rent), energy, transport, durable goods (notably cars), health costs, leisure, and miscellaneous services.



¹ Data sources of electricity consumption per capita: [30] for Spain, Germany, UK, US, and Australia and [31] for Ontario.

² Average household bills were established using the following typical consumptions: 366 kWh/month for Spain [32], 333 kWh/month for Germany [33–35], 316 kWh/month for the UK [36], 750 kWh/month for Ontario [37, 38], 850 kWh/month for the US [39], and 383 kWh/month for Australia [40].

Figure 2: Evolution of a) electricity consumption per capita and b) normalized monthly household bills.

3 Bill analysis and discussion for Ontario

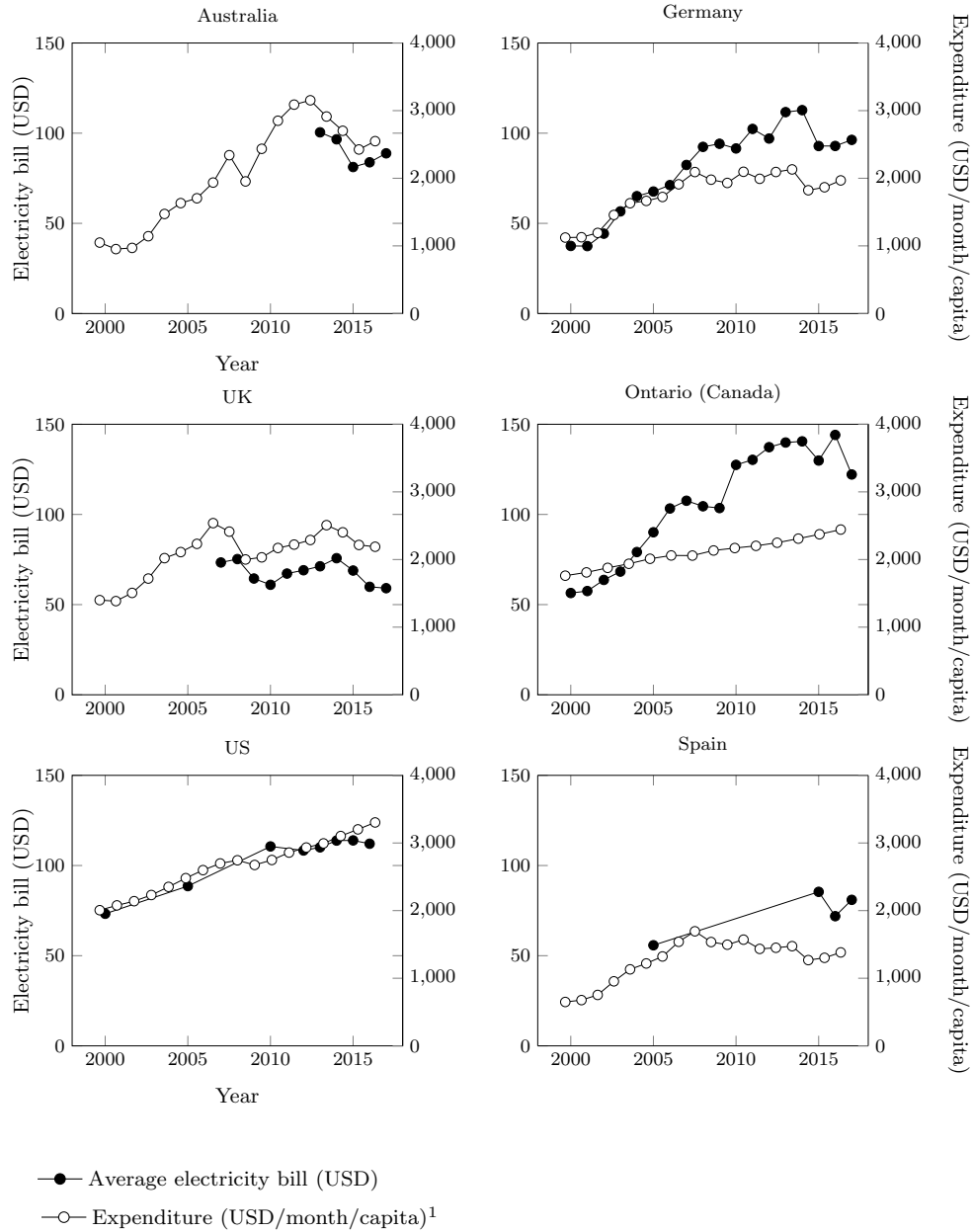
In Ontario, a typical household pays USD 144 per month. The main components of the bill are:

- the energy and power cost (HOEP plus GA) is USD 89 (59.4%);
- the grid fees are USD 43 (30%);
- the FIT levy is USD 20.52 (14%).

3.1 Energy and power charges

3.1.1 Cost formation

The variable cost depends on the actual user consumption (kWh) and is determined by the wholesale price (USD/kWh). The demand or peak-load contribution (kW), related to the fixed cost, represents the electric power (or the speed of consumer energy use) that the utility must deliver at any time. However, the actual demand and the billed demand are different. The consumer will pay the maximum of the demand identified for periods of high consumption (air-conditioning in summer or heating in winter) and the actual power. The consumer may pay the highest average demand in one month for a number of subsequent months independently of actual demand (which may even decrease).

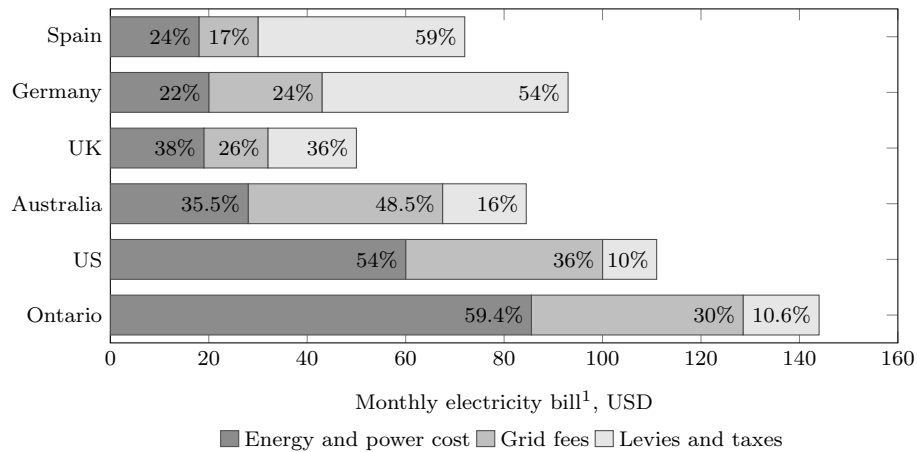


¹ Data for expenditure was extracted from [41] for Spain, Germany, the UK, Australia, and the US and [42] for Ontario.

Figure 3: Average monthly electricity bill and total monthly expenditure per capita.

The commodity price for Ontario households is the HOEP plus the GA taxes and levies. The sum is denoted time-of-use (TOU). Because of factors such as efficiency gains in appliances, increased power production capacities (including RES), and decreases in fuel costs, the HOEP tends to stagnate or decrease [52]: it decreased by 60% between 2010 and 2018, leading to a considerable decrease in the generation cost component (Figure 5). In 2016, the average HOEP paid monthly was USD 12.45 (8.7% of the average bill).

However, the commodity cost includes also a GA surcharge designed to guarantee steady revenue for generators such as large nuclear and hydroelectric plants [53]. The GA increases annually as the HOEP decreases to guarantee the revenues of conventional generators (according to contracts with the



¹ Percentage of monthly bill was established for 2016 via: [44] for Spain (2015), [34] for Germany, [45] for UK, [46–48] for Ontario, [49] for US, and [50] for Australia. The totals may not be 100% due to rounding.

Figure 4: Breakdown of average electricity bills.

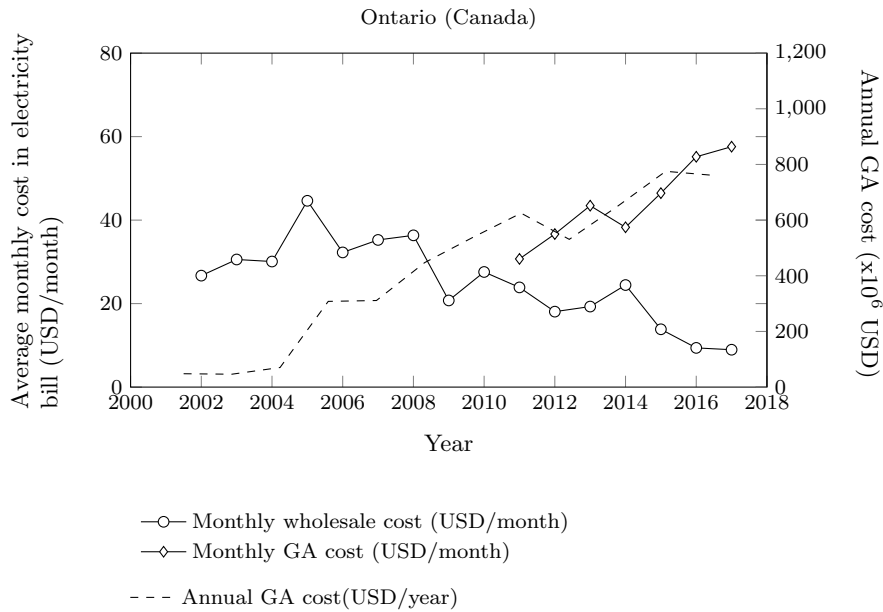


Figure 5: Average costs of wholesale energy and GA in monthly electricity bill.

provincial government agreed in 2004) and to finance new environmental initiatives, such as FITs [53]. The typical monthly cost of these in 2016 was USD 73.10 (50.7% of the bill). Figure 6 shows HOEP and the decomposition of the GA monthly cost into its main components.

3.1.2 Discussion and international perspectives

The factors influencing supply and demand have an immediate impact on the market electricity price. In jurisdictions with a wholesale market, generators find ways to be more competitive [55], and thus prices stagnate or decrease slightly. This is the case for Ontario (Figure 5), and recent investigation shows that this decreasing tendency will likely continue worldwide [56]. The real reason for the commodity cost increase in Ontario is the GA component.

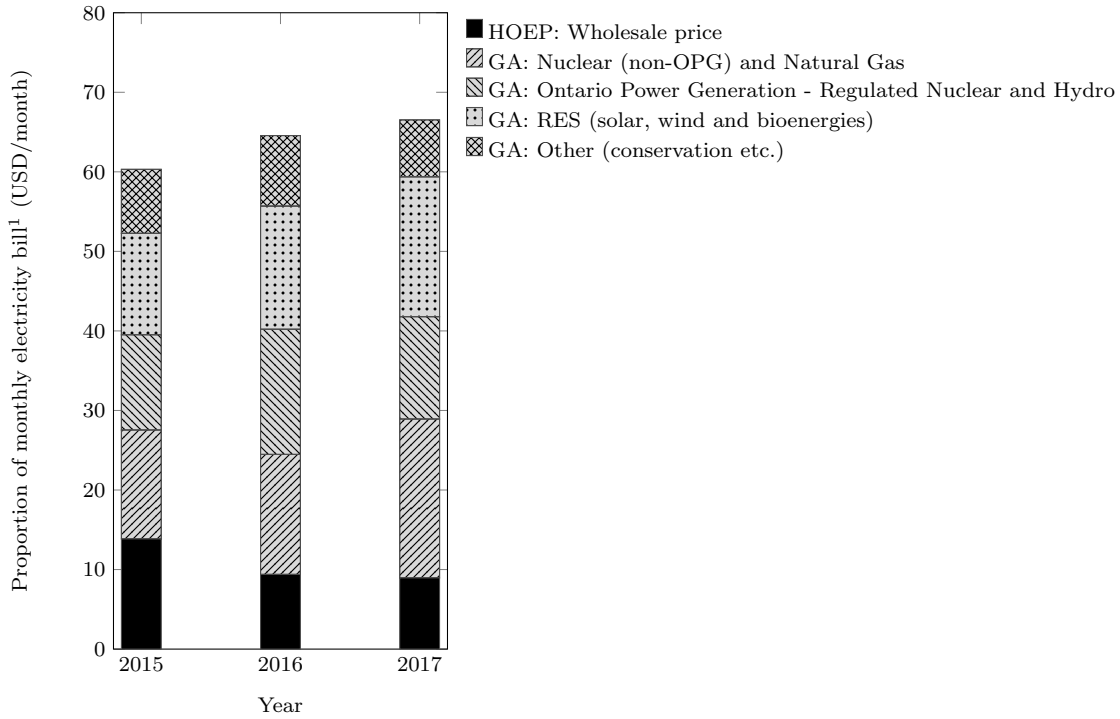


Figure 6: Breakdown of the consumption-related portion of the bill of a typical household in Ontario.

3.2 Grid fees

3.2.1 Cost formation

Delivery or connection fees play an essential role in deregulated power markets. They recover grid investment and maintenance costs from users and send economic signals to influence the users' behavior [57]. These fees increase with the following factors:

- increased distance between the load and the generator;
- fewer consumers connected to the network (in remote low-density areas).

The transmission rates (USD/kW) are regulated by the independent authority (the *Regulator* in Figure 1) and are multiplied by the consumer peak-load contribution (kW). In the current paradigm, regulators set network prices according to their assessment of the cost of delivering network services [55]. The distribution rates (USD/kW) must also be approved by an independent authority and are usually higher than the transmission rates. Their values depend on the distribution-grid density and the number of consumers. A low-density system tends to be more expensive because the operator must build, operate, and maintain more poles, wires, and facilities per consumer.

Ontario has the highest delivery fees of the six countries in Figure 4: its average is USD 43 (30% of the typical bill). In addition, the province is characterized by a large disparity in grid fees, i.e., consumers in low-density locations may pay twice as much as consumers in high-density locations [60]. Figure 7 illustrates the distribution of the estimated monthly delivery fees for 2016 for a typical household [58] superimposed on the population density. The total delivery fees ranges from USD 22 for dense regions to USD 71 for remote regions. The total delivery fees in the low-density areas represent 42% of the total bill (Figure 8). Note that independent delivery companies offer more advantageous tariffs than large providers for regions with similar densities. The share of the transmission cost is between 14% and 20% of the total delivery fees. Figure 8 shows a breakdown of the electricity bills

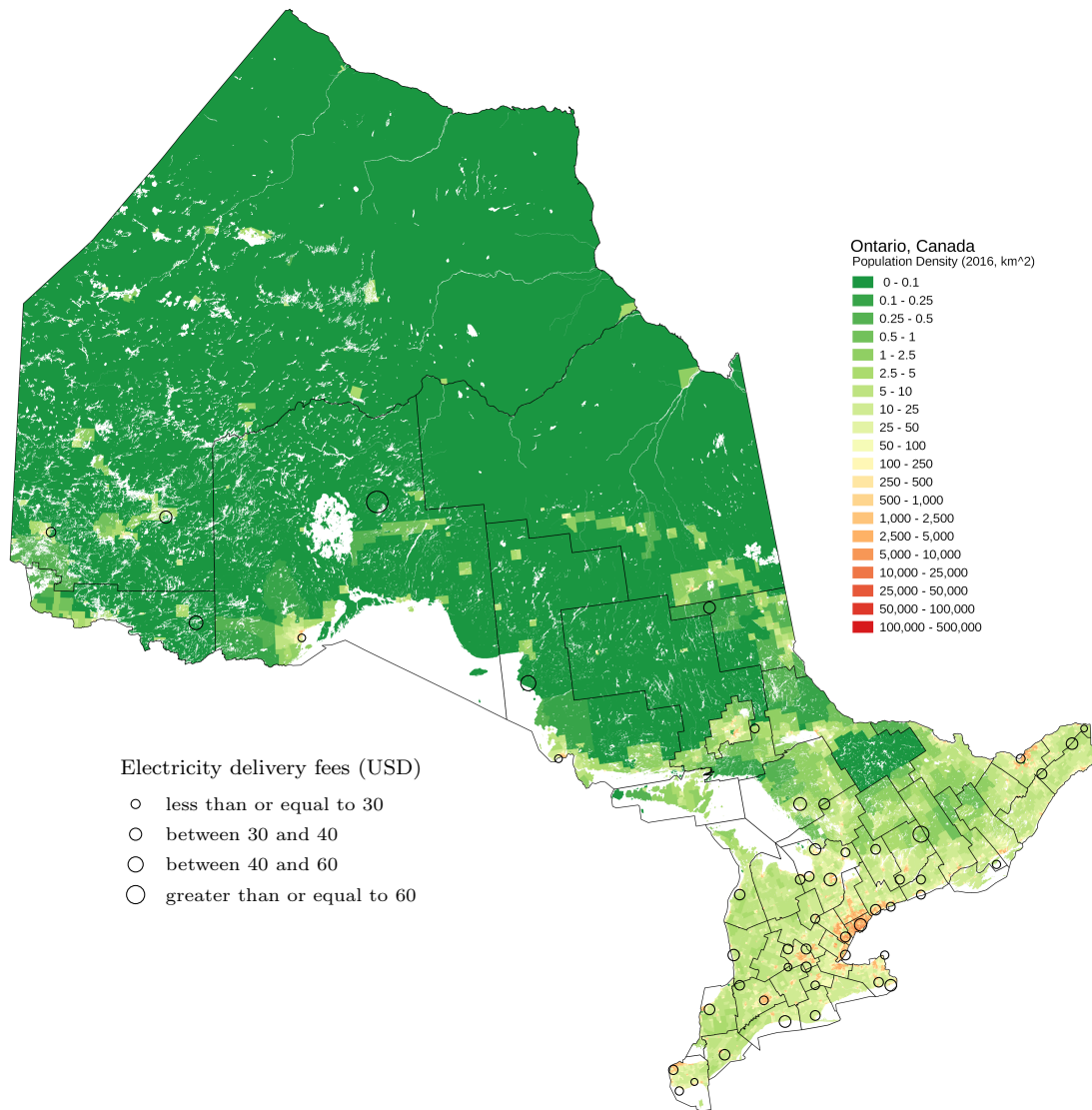


Figure 7: Estimated electricity delivery fees [58] in typical household bill along with population density (2016) [59].

for typical monthly consumption for high-density and low-density areas, demonstrating the connection between delivery fees and taxes, and geographical location.

3.2.2 Discussion and international perspectives

Discussions of how to determine connection fees are taking place in various countries. For example, UK power generators pay connection fees based on the above factors, and this implies high connection costs for Scottish plants that use the grid to power the densely populated south. To avoid the risk of plant closures, the Office of Gas and Electricity Markets (OFGEM) has declared its intention to update the calculation to reduce the north-south differential [61].

In Australia, to anticipate both standalone (temporarily disconnected) and disconnected (physically disconnected) operation, the network is pushing for compulsory connection fees for all homes and businesses—even if they are not connected—and penalties for those who choose to disconnect [62]. Under current tariff and incentive arrangements for standalone systems, up to 10% of grid-connected consumers could choose to go off-grid by 2050 [63], accepting the implications for their energy reliability.

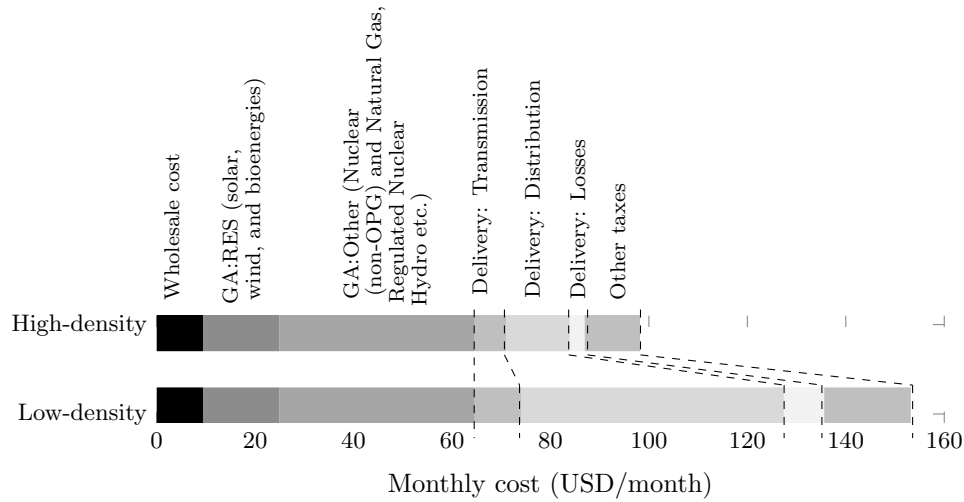


Figure 8: Breakdown of Ontario electricity bill for typical households for high- and low-density areas in 2016.

The additional measures are supposed to avoid inequitable outcomes where some users exit the grid, placing an increased burden on those remaining connected [62].

Technological progress in microgrid energy management and DG technology is also a threat to utilities in the USA and has led to discussions on the development of new grid standards and regulations [64]. It has been suggested that microgrid operators who remain tied to power lines should shoulder some of the costs of keeping the grid stable, perhaps through connection fees. The adjustment of these fees is also seen as a way to escape a “death spiral” scenario in which increased DG penetration reduces the energy purchased from the grid and leads to a revenue decrease for centralized utilities [65]. Utilities could increase retail prices, but this would encourage more consumers to rely on DG to avoid consumption from the grid. In principle, fixed connection fees are supported by the major US states [65].

3.3 Environmental levies: Feed-in-tariffs

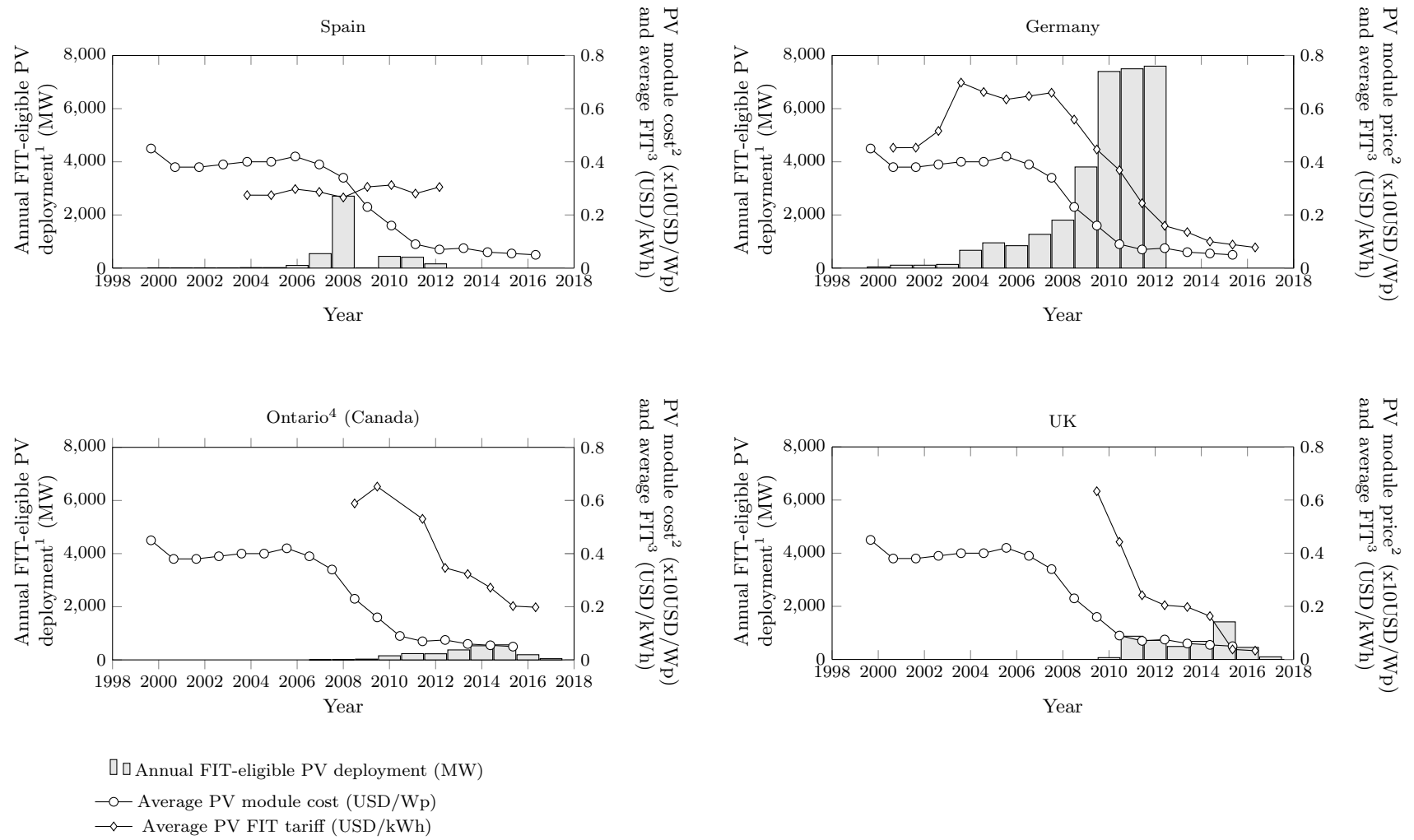
3.3.1 Cost formation

FIT was designed several decades ago to support RES development and implementation [28] and adopted by 23 EU countries in 2013/14 [66].

The value of FIT depends on the approach adopted in the specific jurisdiction [67]. They can be:

- based on the actual levelized cost of renewable energy generation (commonly used in the EU);
- based on the value of renewable energy generation, generally expressed in terms of avoided costs (used in California and British Columbia);
- fixed-price incentives without regard to levelized RES generation costs or avoided costs (used by certain utilities in the USA);
- based on the results of an auction or bidding process (this is a variant of the cost-based approach), which informs price discovery by appealing to the market directly.

Figure 9 shows the evolution of FITs in Spain, Germany, the UK, and Ontario with respect to the annual PV capacity deployment and average PV module price. Due to the rapid expansion of PV, average module price tends to halve every 10 years. In Spain, FIT were almost constant (around 0.3 USD/kWh), but Spanish environmental conditions highly favourable for PV and affordable PV prices led to over-deployment and a budget deficit. The astonishingly fast deployment of nearly 500 MW of PV each month from April 2007 to August 2008 forced the Spanish authorities to stop FIT-eligible PV deployment in 2009 and to reconsider the FIT policy [4]).



¹ Annual FIT-eligible deployment was extracted via: Spain and Germany [4], the UK [69], and Ontario [70]. Because of the progressive exit from FIT schemes, the authors were unable to find data for FIT-eligible deployment in Spain and Germany after 2012.

² Average selling price for c-Si wafer-based modules from [71, 72].

³ Average FIT was calculated for eligible standard PV installations with 4kW to 5000kW capacities: Spain [4], Germany [73], the UK [74], and Ontario [70].

⁴ In Ontario FIT was set to zero for new installations in 2011 before the official review program in 2012 and 2013 [70].

Figure 9: Evolution of annual FIT-eligible PV capacity deployment, average PV module price, local FIT values, and retail electricity prices for Spain, Germany, the UK, and Ontario.

In Germany, the UK, and Ontario, FITs started just above 0.6 USD/kWh. Following the continuous decrease of PV prices, they decreased every year. However, in Ontario the decrease was relatively slow: in 2012 the province was still offering an average of 0.53 USD/kWh while Germany and the UK had decreased to 0.24 USD/kWh. In 2016, Ontario proposed an average FIT twice as high as that in Germany and five times higher than in the UK. Each year Ontario installed one-third of the PV capacity deployed in the UK but had five times fewer consumers. As a consequence, FITs contribute significantly to the GA surcharge in the monthly bill: USD 20.52 (14% of the total average bill) was paid for FIT program support in 2016. This observation is in line with various analyses, e.g., [68] shows that only high learning rates (connecting RES adoption with technology cost decreases) and the pollution avoided by replacing conventional generation with RES can justify these FIT values in Ontario.

3.3.2 Discussion and international perspectives

FIT has met many of its original objectives, as shown by the earliest adopters, such as Germany and Spain [75]. Germany (where a policy was adopted in 1990) saw RES share in electricity generation increase from 4% in 1990 to more than 30% in 2017, and Spain (where a policy was adopted in 1997) experienced an increase its renewable coverage of electricity demand from 18.4% in 2006 to 37.4% in 2015 [76]. However, some FIT issues first discussed almost a decade ago are a reality now. Several are relevant to our analysis. First, FIT can lead to a short-term upward pressure on electricity rates, particularly if they lead to rapid growth in emerging RE technologies [67]. Indeed, a rapid expansion of RES share and the associated decrease in generation cost together with an unchanged FIT level will lead to a domestic FIT budget deficit. To overcome this issue and to ensure FIT payments at the guaranteed level, the electricity bill must be increased. Following this reasoning, already in 2013 55% of a consumer bill in Spain reflected regulated costs, on-going subsidies, and part of the accumulated deficit resulting from the spectacular rise of FIT-eligible PV installations [77]. This installation peak is visible in Figure 9a. With the continuous deployment of FIT-eligible PV, the cost of this FIT initiative continues to increase, and the consumer bill increases accordingly.

In the UK (FIT implemented in 2000), green levies on energy bills are more modest: 5% in 2015. This is expected to increase to 15% by 2020 [78]. FIT can be more expensive than anticipated. For example, to achieve a 0.84% RES share in the UK consumption in 2014, the total annual cost of the FIT scheme was over a billion USD [79].

Another indirect yet important impact of FIT policy on electricity prices occurs in the medium- and long-term. The Australian example of fast-growing penetration of rooftop PV (around 5% of total monthly generation [80]) shows that while in the short-term solar generation can place downward pressure on electricity prices, in the longer term, it contributes to higher and more volatile prices [81]. This is because the reduction in wholesale prices as a result of additional supply from solar exports during the day means that expensive generators, such as coal or natural gas technologies [82], may not recover their operating and maintenance costs. This may result in their exit from the market, leading to increased prices.

Another issue is the difficulty of equitably sharing costs across consumer classes and geographic areas [67]. Similarly to connection fees, the distribution of the environmental incentive cost among all consumers could penalize low-usage and low-income households, if the cost of the FIT scheme is passed to all consumers regardless of whether or not they have RES. Moreover, FIT eligibility is often defined through criteria that exclude some RES installations. Both Australia and the UK have been concerned about small RES receiving more than market price awarded to large RES for their generation [81], [79].

In recent years, some countries have begun a shift away from FIT and toward more market-driven RES promotion mechanisms [76]. In the UK, several measures have been introduced, from the withdrawal of FIT-accredited installation from the beneficial list in 2014 to the closure of the FIT scheme to new applicants from 1 April 2019 [74]. Spain chooses premium constant, or sliding FITs based on

the spot electricity price. This leads to higher total payments and greater investor risk related to the uncertain policy cost for the country [67]. The Australian government set the FIT rates close to the wholesale rate, so that retailers are not required to pay extra for electricity bought from consumers [83].

In Ontario, producer coalitions tend to press for high, stable levels of support, while both cost-effectiveness and political sustainability imply that subsidy levels should come down over time, but not so rapidly that investment is choked off [84]. Because this balance is hard to get right, support programmes for some technologies and in some countries have been characterised by boom-and-bust cycles [85], leading to the conclusion that the policy must be adaptive [84].

3.4 Implications for Ontario

Our analysis reveals the following implications for Ontario:

- **The average FIT for renewable generators is not in adequacy with the technology cost and the number of consumers.** This problem is especially severe for PV technology set up at the beginning of the program in 2009 with FIT of almost 0.60 USD/kWh (the PV module cost was 2.3 USD/Wp) and kept the same⁴ until 2013 (Figure 9). In countries with similar values (0.63 USD/kWh in the UK and 0.56 USD/kWh in Germany), the FITs lost up to half of their value every year from 2011 to 2013. In addition, the number of consumers is considerably lower than in European countries, i.e., in Ontario electricity consumers pay higher FIT fees than in UK with similar deployment rate.
- **High delivery costs play a major role in making electricity unaffordable.** In 2017, the Ontario Energy Board (OEB) ordered local utilities to transition to a flat delivery charge per household over the next eight years. The OEB requires fixed delivery rates independent of the household's peak-load contribution [86]. The delivery fees for rural regions will be capped and remote consumers will benefit from a distribution credit rate. The consequences for Ontario in terms of energy efficiency and load management could be significant. The change could eliminate the incentive to refurbish households, to improve appliance efficiency, and to participate in load management programs [87]. Moreover, it could penalize households with low consumption and efficient installations, which would no longer be economically attractive.
- **Long-term government-directed procurement contracts with conventional generators provide the only way for the commodity cost to increase.** Figure 6 shows the importance of these payments: *Nuclear (non-OPG) and Natural Gas* and *Regulated Nuclear & Hydro* represented 27.33% and 28.51% respectively in 2016. In countries such as the UK, this expenditure is embedded in the wholesale prices defined through competitive market mechanisms, allowing power production companies to generate a profit [88]. In Ontario, this compensation is important. Note that GA charges are applied only to in-province consumers. In 2016, electricity exports represented almost 15% (21.9 TWh) of total Ontario generation, and out-of-province customers typically purchase this electricity at the wholesale price [89]. Moreover, the GA contribution for conventional generation is increasing continuously: *GA Nuclear (non-OPG) and Natural Gas* increased by 40% between 2015 and 2017. This increase kept the GA share for RES at around 30% for the last three years despite the projection that the GA portion for wind, solar, and biomass would increase its share of the total GA budget to 42% between May 2017 and April 2018 [46].
- **The breakdown of the consumer bill hides the real problem.** GA, included in the generation component [46, 48, 51], makes that component 50.7% of the total bill. In contrast, the real commodity cost of generation defined by HOEP (i.e., the wholesale price) was only 8.7% of the average bill in 2016 (Figure 6). GA represents the additional levies collected mainly to compensate all generators when their contracted rates are higher than the HOEP and to a much lesser extent to finance the building and refurbishment of generators, and to invest in conservation (e.g., the promotion of high-efficiency appliances). The payments made to generator companies

⁴In 2011 Ontario had no new FIT contracts.

are prescribed by the OEB, a governmental institution, which regulates the energy sector (it is equivalent to the *Regulatory agency* in Figure 1). They are not set based on competitive pricing behavior. Thus, GA can be viewed as the additional taxes and levies charged to Ontario consumers.

- **There is a lack of a global vision for the Ontario energy system and of coordinated actions to achieve this vision.** The rapid growth in various components of the electricity bill has led to the rapid adoption of “one-shot” measures to reduce consumer dissatisfaction. However, no careful analyses of the consequences for the overall energy system have been made public. The various measures usually remain in effect until changed and OEB does not explain how they will help to achieve its global vision. Consumers in medium- and low-density regions are undervalued, which encourages them to take the risk of leaving the grid. Some experts [90, 91] claim that going off-grid in Canada is technologically complex (requiring a mix of technologies that is not yet mature and efficient), costly (the CAPEX of off-grid installation package for a four-bedroom home costs around USD 55,000) and needs space (e.g., for the installation of a solar array or geothermal piping system). Other analysts [92, 93] believe that large-scale departures from the grid will soon be a reality, stimulated by price decreases, increased efficiency of DG and storage technologies, and higher electricity bills. Some Ontarian households are already living this off-grid reality [94].

4 Importance of small-scale prosumers

High electricity bills considerably impact household expenditure. However, artificial caps prompted by public dissatisfaction typically have negative results. In Spain, California, and Belgium, the government tried to use price caps as a long-term measure, but it did not yield the expected positive outcomes [95]. The isolation of the supply side from the demand side in a liberalized energy market may lead to losses that must eventually be paid by the government, and thus indirectly by consumers. For example, an artificial freezing of prices and the massive integration of FIT-eligible PV capacities led to a multimillion tariff deficit in the Spanish system [12]. The resulting rushed exit from the FIT program generated many international investment arbitration cases from PV investors [96].

High charges for centralized utilities and the availability of affordable DG installations encourage consumers to become small-scale prosumers. The effects of these new stakeholders will initially be difficult to perceive, hidden by the conventional consumption patterns adopted by most consumers and producers. However, when the number of prosumers reaches a critical threshold their behavior can have the following negative effects:

- **Increased uncertainty in consumption behavior.** The appearance of prosumers makes the load harder to predict. The load profile is influenced by factors such as consumer behavior, weather conditions, and seasonal changes, and prediction models using historical data have performed well. However, the appearance of prosumers with the flexibility to change their consumption (via the integration of distributed RES and storage technologies) will lead to increased uncertainty in the total load profile and the failure of conventional prediction models. There may be a need for investment in the power system to maintain always peaking, “always ready to go” power resources, and other techniques to counter these uncertainties.
- **Increased effect of personality component.** Prosumers may have a strong personal motivation that should not be neglected [97]. An interesting finding indicates that because prosumers invest time, money, and effort, they have high expectations for acknowledgement by the energy system. Moreover, prosumers may choose to deliberately withhold their energy excess, with negative consequences for the sustainable development of the energy system [97].
- **Reduction of consumption from the grid.** Prosumers will reduce the commodity component of their bills. This will lead to disconnection and temporary stand-alone operation, decreasing the consumption from the grid and the use of conventional generators during high-price periods.

As a consequence, the generators could struggle to recover their costs, leading to a generalized increase in electricity prices.

- **Radical scenario of physical disconnection.** The exhaustion of opportunity for variable (commodity) costs reduction and high charges (independent or quasi-independent of consumption) create an opening for a more radical scenario: physical disconnection from the grid. This scenario can lead to the decline of conventional utilities acting as electricity generators, transmitters, and distributors.

Alternatively, prosumers could become valuable stakeholders and benefit the entire energy system:

- **A prosumer is more flexible than a conventional consumer and can react more rapidly to economic signals, supporting increased participation in DR.**
- **A prosumer can operate in stand-alone mode during certain periods (e.g., critical consumption peak or failure periods) to reduce costs and the pressure on the utility's installations.**
- **The prosumer's involvement in DR can be adjusted by the dispatch of economic signals to a selected group of prosumers.**

However, the current economic framework does not allow the efficient integration of prosumers. This is the motivation for our proposal in the next section.

5 Proposal

We argue that there is a need for a new computational framework to validate new economic arrangements that include prosumers in an energy management strategy. This would tackle the threat of disconnection. The idea is to take advantage of the advent of small-scale prosumers, rather than to limit their development with arbitrary actions. The decision-making framework must follow a bottom-up approach that takes into account the prosumers' peculiarities, complementing existing top-down microeconomic frameworks.

We decompose the system into a three-layer optimization problem with the different levels of the grid corresponding to the typical voltage levels. The layers will be connected via bidirectional data flows to enable the cascade aggregation of energy management strategies. At the top level, the grid operator wishes to maximize the grid usage at the different levels. The intermediate level includes several aggregators who dispatch economic incentives to small prosumers (situated at the third level) and perform the aggregation of the prosumers' energy management decisions. The aggregators may have various objectives, such as increasing revenue by the efficient aggregation of decisions. At the third level, the prosumers perform their load scheduling by taking into account their available installations (e.g., RES, storage, EV) and the incentives; their goal is to minimize the bill. The model structure for an individual agent encompasses all the aspects of prosumer behavior, i.e., personal (values, beliefs, and motives), behavioral (level of commitment and flexibility), and contextual (operational conditions). Distributed intelligence techniques, based on optimization or learning approaches, will be incorporated in all the agents (prosumers, aggregators, and grid operator) and at the different voltage levels. These techniques will reflect the specific behavior of the various stakeholders and enhance the intelligence of their decisions for the benefit of the entire grid.

The new economic arrangements will likely be based on economic incentives that replace classical cost arrangements for consumption, generation, and delivery. The TOU could evolve toward time-and-level-of-use (TLOU) pricing taking into account price variations over time and at different levels [98]. The payments received by prosumers may range from the HOEP received by other producers to a higher tariff designed to encourage participation. The level of connection (or the delivery fees) may also vary depending on the prosumer's ability to operate in stand-alone mode at different time periods.

At the initial stage, this decision-making framework will be a simulation model considering the following questions:

- What is the critical threshold of active prosumers that will fundamentally alter the grid operation?
- What are the associated operational conditions (e.g., weather conditions, price variations) that amplify the prosumer effect?

In the second stage, the framework will test new economic arrangements and explore the crucial questions:

- How to assign incentives to prosumers given their operational characteristics so as to maximize their involvement in DR?
- How to aggregate the prosumer responses to accommodate their decentralized scheduling within the optimal centralized grid management?
- What are the acceptable ranges for the economic incentives?
- What economic incentives will prevent disconnection and maximize the use of the prosumers' potential?

6 Conclusions and policy implications

Motivated by ever-increasing electricity bills, we have provided an extended state-of-the-art analysis exploring the issues underlying this increase. We have discussed the evolution of typical monthly electricity costs and consumption in relation to the monthly household expenditure for several countries in the period from 2000 to 2018. The countries studied are leaders in the adoption of RES initiatives and, in particular, FIT programs. This analysis together with the bill breakdown has revealed for some jurisdictions a distortion of the commodity and non-commodity costs in consumer bills. The detailed investigation of bill components conducted for Ontario has revealed the (usually invisible) true commodity and non-commodity costs. We have discussed these costs and their future evolution using examples from other countries, pointing out the likely outcomes of Ontario's energy policy decisions.

The current economic policy promotes the disconnection of prosumers. In Europe the integration of prosumer stakeholders into the energy vision was initiated by the European Parliament in 2013 [99], but Ontario requires a thoughtful consideration of prosumer stakeholders and their importance for the system. We support the preferred scenario in which prosumers remain connected to the grid. We have proposed a layout for a decision-making framework that can be used to simulate the critical threshold of prosumers and to test new economic incentives. These incentives are an alternative to Ontario's current attempts to artificially decelerate price increases, to freeze grid fees for different areas, and to end FIT programs. The new vision makes use of the fruits of FIT (the accelerated integration of DR RES) and sheds light on the potential of prosumers.

Future work will include the development of a computational agent-based model framework and the detailed formulation of economic incentives to integrate small-scale prosumers into the energy management process.

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