Les Cahiers du GERAD ISSN: 0711–2440

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

E. Kuznetsova,
M.F. Anjos

G–2019–44

June 2019
Revised: April 2020

CITATION ORIGINALE / ORIGINAL CITATION

E. Kuznetsova, & M. F. Anjos (2020) Challenges in energy policies for the economic integration of prosumers in electric systems: A critical survey with a focus on Ontario (Canada), Energy Policy, 142. https://doi.org/10.1016/j.enpol.2020.111429.

La publication de ces rapports de recherche est rendue possible grâce au soutien de HEC Montréal, Polytechnique Montréal, Université McGill, Université du Québec à Montréal, ainsi que du Fonds de recherche du Québec – Nature et technologies.

The publication of these research reports is made possible thanks to the support of HEC Montréal, Polytechnique Montréal, McGill University, Université du Québec à Montréal, as well as the Fonds de recherche du Québec – Nature et technologies.

Dépôt légal – Bibliothèque et Archives nationales du Québec, 2020
– Bibliothèque et Archives Canada, 2020

Legal deposit – Bibliothèque et Archives nationales du Québec, 2020
– Library and Archives Canada, 2020

GERAD HEC Montréal
3000, chemin de la Côte-Sainte-Catherine
Montréal (Québec) Canada H3T 2A7

Tél. : 514 340-6053
Téléc. : 514 340-5665
info@gerad.ca
www.gerad.ca

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

Elizaveta Kuznetsova [a,b]
Miguel F. Anjos [a,c]

[a] *GERAD, Montréal (Québec), Canada, H3T 2A7*

[b] *Department of Mathematics and Industrial Engineering, Polytechnique Montréal, Montréal (Québec) Canada, H3C 3A7*

[c] *School of Mathematics, University of Edinburgh, Edinburgh EH9 3FD, United Kingdom*

elizaveta.kuznetsova@gerad.ca
anjos@stanfordalumni.org

June 2019
Revised: April 2020
Les Cahiers du GERAD
G–2019–44

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

---

Acknowledgments: This research was supported by an IVADO Postdoctoral Scholarship awarded to the first author. The authors also wish to thank anonymous referees for their thorough review of the previous version of this work and for the comments provided that helped improve the paper significantly.

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 (mostly due to hydropower, wind, and solar technologies) doubled between 2008 and 2017 [61]. Specifically, bioenergies and wind power increased by factors of 2 and 4.5 respectively, while solar power had a phenomenal 26-fold rise [61]. 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 [49]. By 2015, RES-related policies were in place in 146 countries [91]. 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 [93].

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 [105]. 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 [5], and the average age of nuclear reactors generating 20% of all US electricity is 38 years (with a planned 40-year lifespan and possibility to extend their operation for an additional 20 years) [24]. 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 [21].

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 variable 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 [83, 46]. This became a political issue and had an important impact on the election results in June 2018 [8]. While political measures that artificially control price increases have proved ineffective in other countries, such as Spain [19], the Ontario government continues to undertake such measures [35].

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 [61] and is expected to more than double by 2040 [76]. 98% of Canada's solar power capacity is installed in Ontario and is integrated mainly into low- and medium-voltage grids [75]. 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 [30].

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 (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 [38]. While the cost of grid expansion and upgrade is typically borne by the utility [10], 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 [38]. 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 [70].

The transmission and distribution fees are shared between consumers and generators; they are collected by the grid operator. They include transmission and distribution 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 [74], or the supplier may collect the consumers' contribution through their electricity bills [62]. For small consumers these costs are included in the rate, but for large users they may be shown separately.

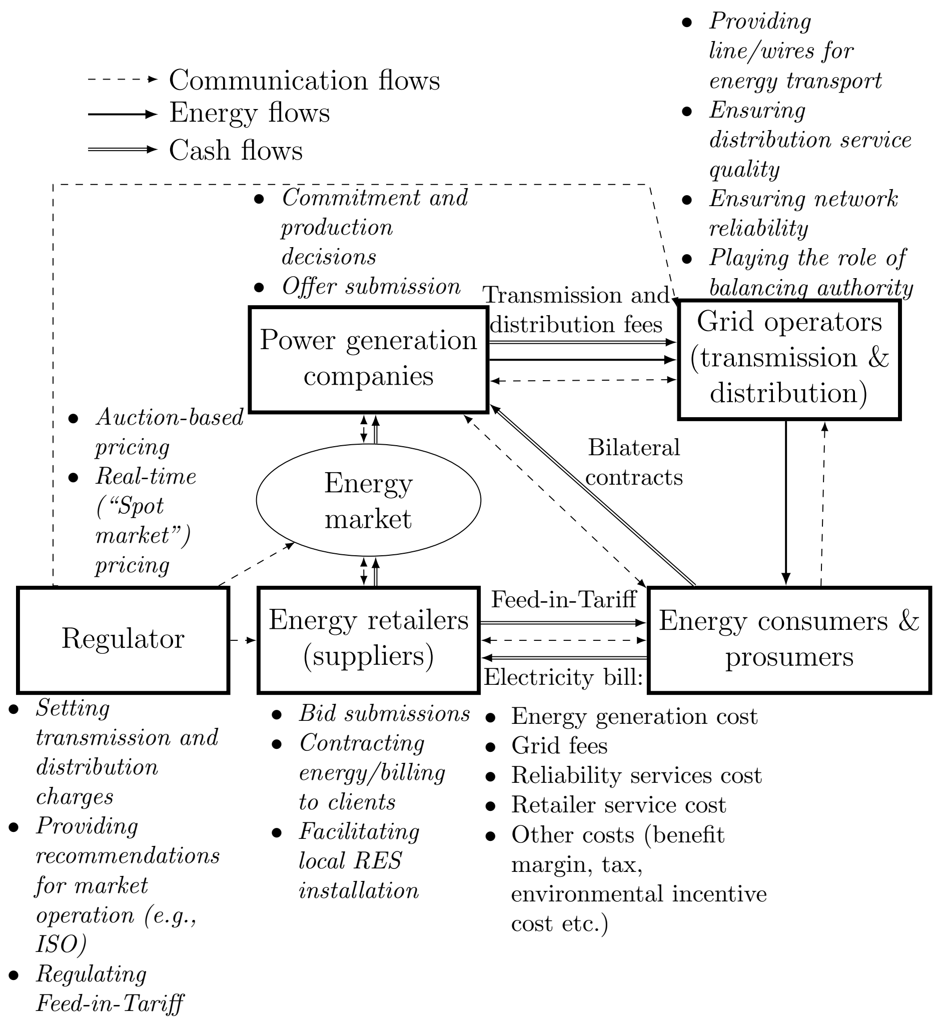


Figure 1: Grid stakeholders and signals.

The electricity bill includes the following components that may or may not be itemized separately [28, 84]:

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

The wholesale cost represents the generation cost and 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 [62]. In some countries, the cost of transmission services is embedded in the wholesale price. In addition, it may include the cost of losses, which represents 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 [28]. 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 [62]. They include the capacity market service, also known as the peak-load contribution of the consumer to the total peak demand of the grid and based on capacity rate ($/MW). Ancillary services ensure grid reliability through frequency regulation, non-spinning and responsive reserves, emergency response, reliability unit commitment, etc. [28].

Taxes and levies may represent more than half of the electricity bill [33] and the environmental levy may have the same share in the bill as the wholesale cost and grid fees [104]. 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 [103]. A utility, supplier, or grid operator is legally required to pay for a unit of RES electricity [92]. 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 [66]. The budget for FIT rests on i) a domestic FIT budget and, in some developing countries, on ii) an additional international support mechanism [108]. 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 [11].

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 typical[1] monthly electricity bill) normalized by typical household monthly consumption for households of selected countries between 2000 and 2017.[2] 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 expenditure[3] taken as a proxy of national economic growth [15]. 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).

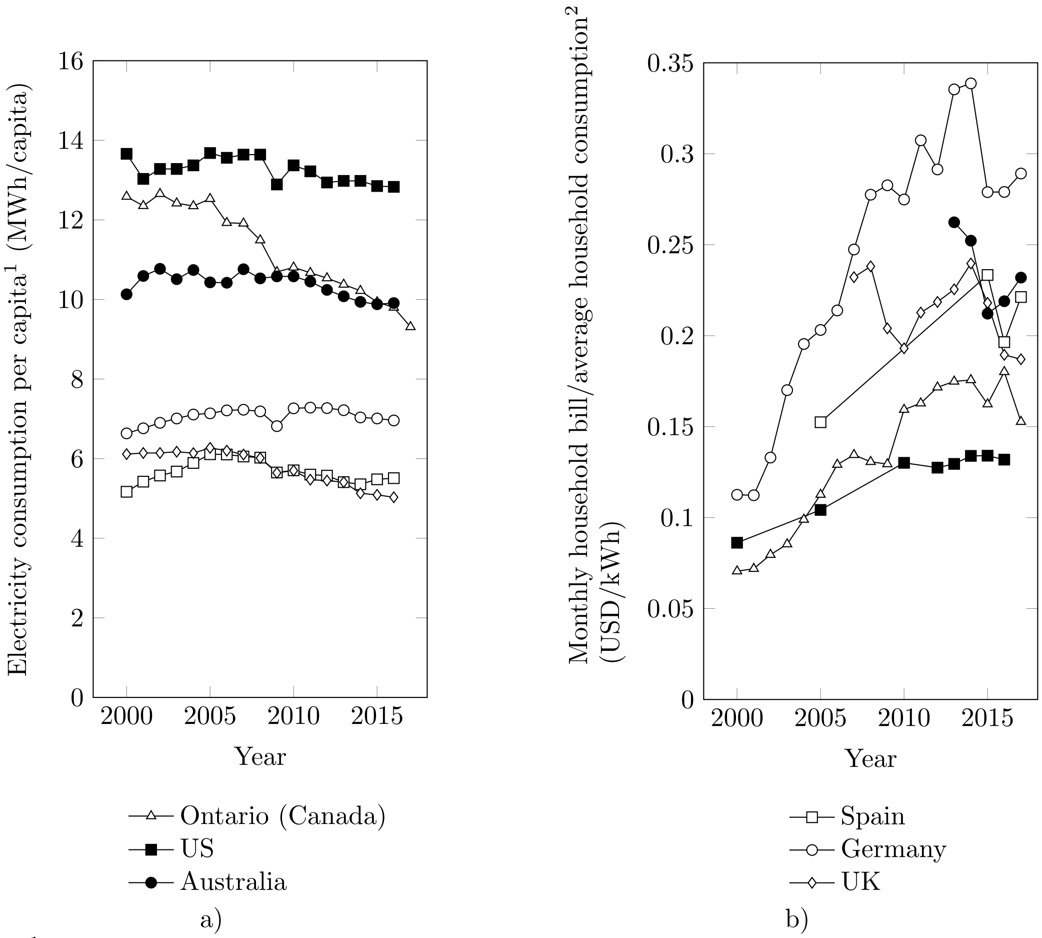
Figure 4 shows how the average electricity bill for each jurisdiction breaks down into its main components (in USD for 2016): energy and power cost, grid fees, and levies and taxes. Note that while the US is characterized by a large disparity of electricity rates per state depending on their generation mix and regulation, Figure 4 represents the overall situation for the entire country.

In Europe the costs of the two first categories are very similar. The energy and power costs are 18, 19 and 20 USD/month in Spain, UK and Germany, respectively. The grid fees range from 12 to 23 USD/month for these countries. The levies and taxes are important, with the highest fees in Spain and Germany: 59% and 54%, respectively. The levies and taxes are important for Spain and Germany, due to broad and accelerated integration of FIT-eligible RES. The cost of this category is 42 and 50 USD/month for Spain and Germany, respectively, and represents more than a half of the monthly electricity bill.

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

[2] Here 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 [78].

[3] The 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.

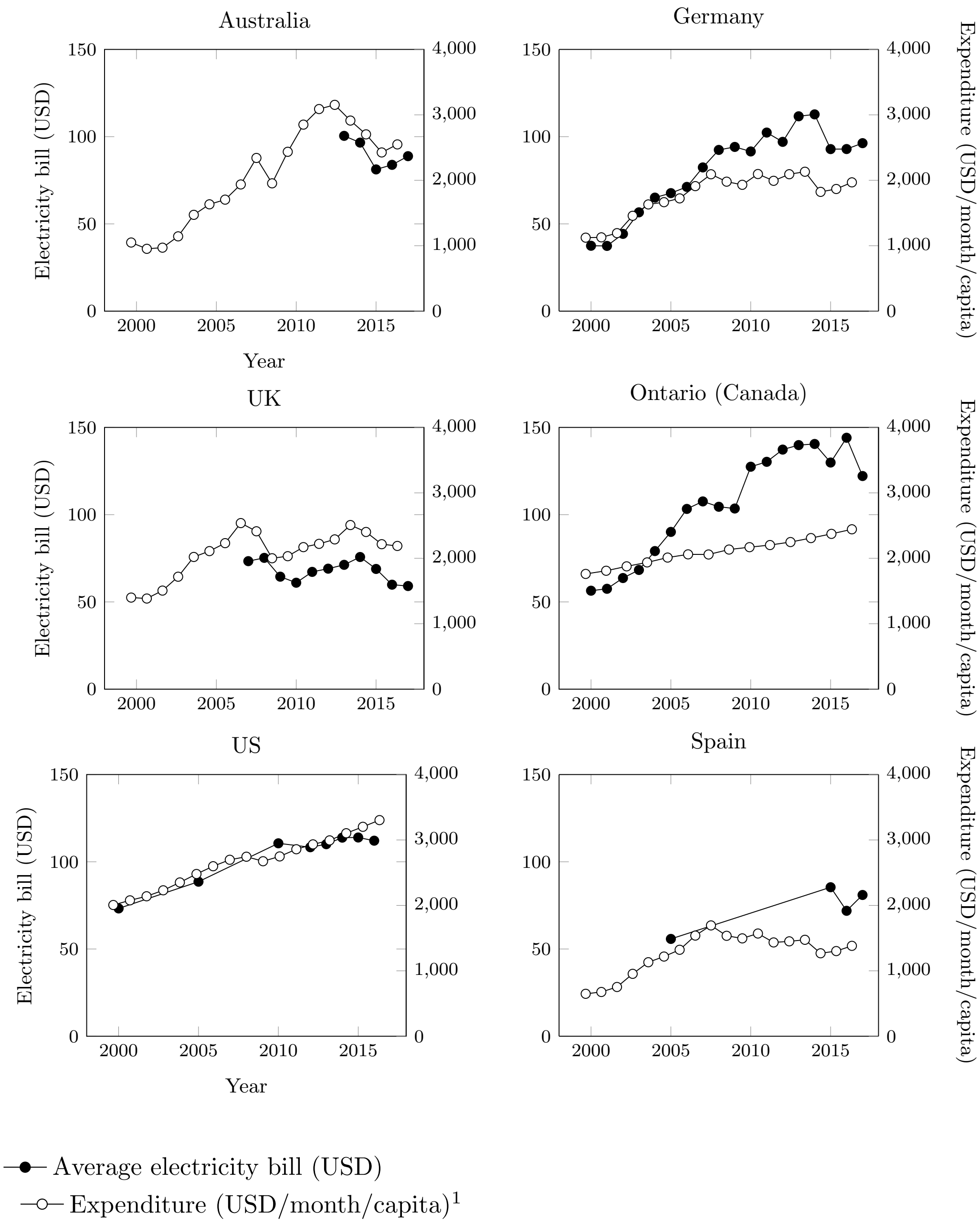


[1] Data sources of electricity consumption per capita: [52] for Spain, Germany, UK, US, and Australia and [55] for Ontario.

[2] Average household bills were established using the following typical consumptions: 366 kWh/month for Spain [96], 333 kWh/month for Germany [71, 104, 99], 316 kWh/month for the UK [98], 750 kWh/month for Ontario [82, 100], 850 kWh/month for the US [23], and 383 kWh/month for Australia [3].

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

The grid fees in Australia, the US, and Ontario are at least two times higher than in Europe and reach 39.5, 40 and 43 USD/month. This is mainly explained by the low ratio between the length of transmission and distribution lines and number of connected consumers. However, the striking difference is on the generation cost especially for Ontario where the typical total electricity bill reaches 144 USD/month, of which the commodity costs are 85.5 USD/month, representing almost 60% of the total electricity bill. The key of this extremely high cost lies in the way adopted by Ontario government and utilities to present the energy and power cost by including in it not only the hourly Ontario electricity price (HOEP), i.e., the wholesale costs, but also the global adjustment (GA) cost (which among other includes the RES levies). The actual variable cost share from a competitive market is only 8.7% of the bill while GA, responsible for more than 50% of the bill, can be classified into taxes and levies (as in other countries). The conventional breakdown of the electricity bill for Ontario shows that the category of taxes and levies is particularly significant. In part because of the Green Energy Act adopted in 2009 [63], the bill almost doubled between 2010 and 2016 [72]. We focus on Ontario as a case study to discuss the bill components and structure in comparison with international trends.



[1] Data for expenditure was extracted from [106] for Spain, Germany, the UK, Australia, and the US and [40] for Ontario.

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

3 Bill analysis and discussion for Ontario

In Ontario, a typical household pays USD 144 per month. The main components analysed here are:

- the energy and power cost (HOEP plus total GA) is USD 85.5 (59.4%);
- the grid fees are USD 43 (30%);
- the FIT levy is USD 20.52 (14%).

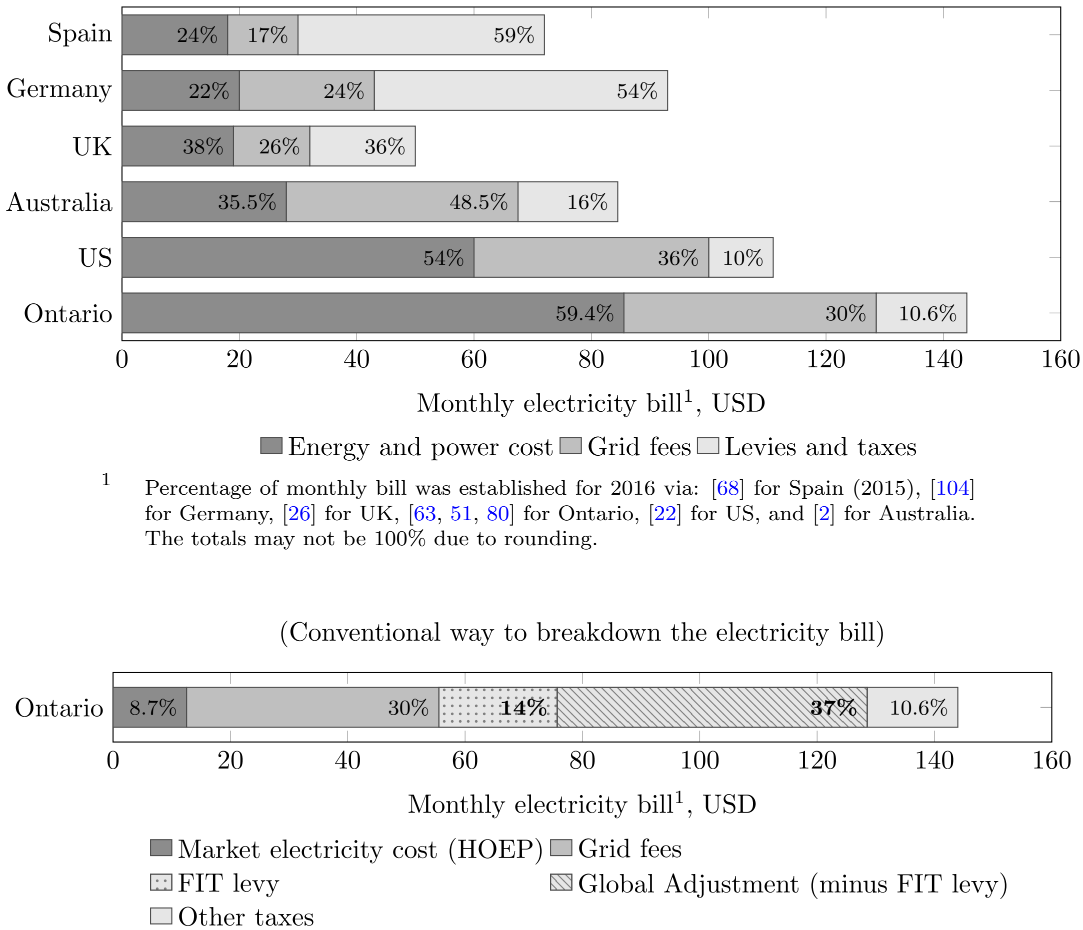


Figure 4: Breakdown of average electricity bills.

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).

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 [47]: 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 [69]. The GA increases annually as the HOEP decreases to guarantee the revenues of conventional generators (according to contracts with the provincial government agreed in 2004) and to finance new environmental initiatives, such as FITs [69].

The typical monthly cost of GA in 2016 was USD 73.14 (50.8% of the bill). Figure 6 shows HOEP and the decomposition of the GA monthly cost into its main components.

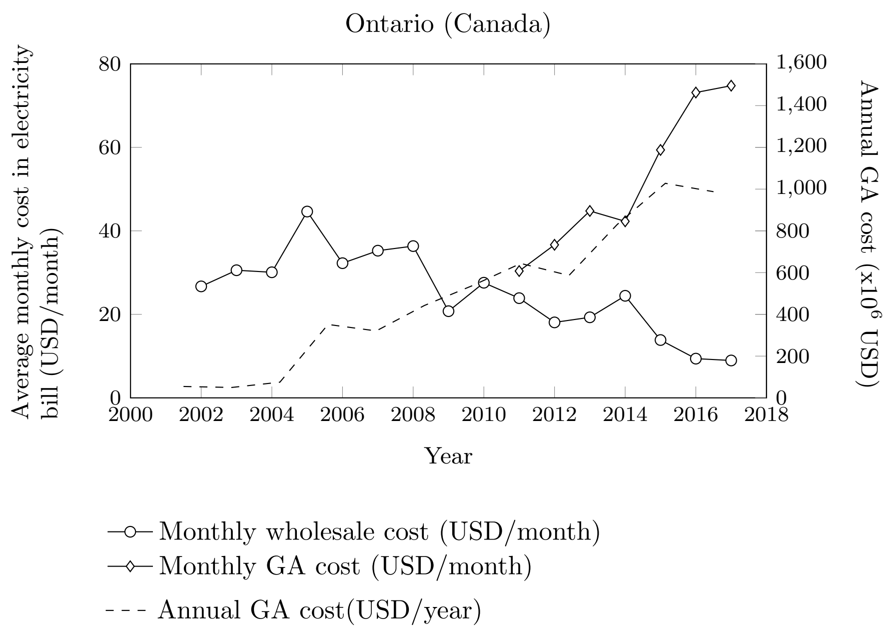
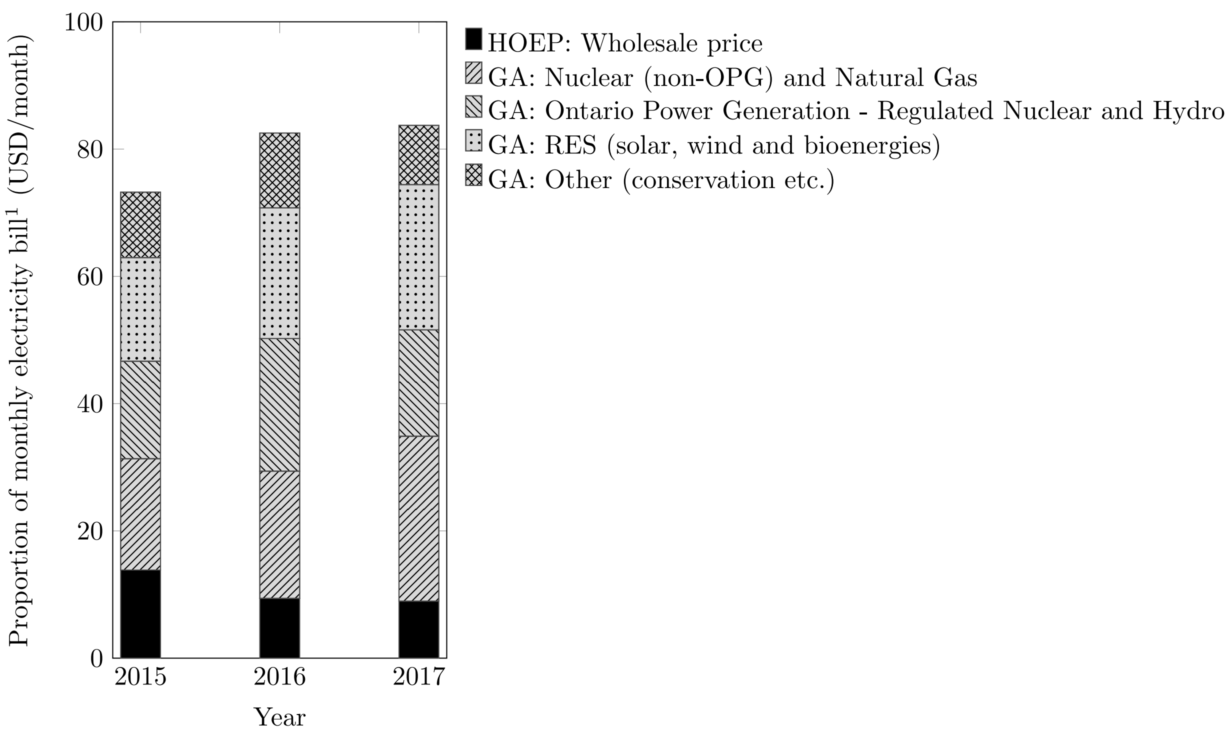


Figure 5: Average costs of wholesale energy and GA in monthly electricity bill.



[1] Cost of the average wholesale and GA components in the monthly electricity bill was calculated using average annual HOEP and GA prices [53].

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

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 [65], 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 [43]. The real reason for the commodity cost increase in Ontario is the GA component.

GA covers the cost of building new electricity infrastructure in the province, as well as delivering Ontario's conservation programs, altogether to ensure that enough electricity supply will be available in the long term [57]. The GA is set monthly and contributes to regulated and contracted rates for Ontario generating plants, payments for building or refurbishing infrastructure and the cost of delivering conservation programs [57]. To a certain extent, the GA (without its RES component) is comparable to capacity mechanisms introduced in some EU countries to tackle the increase of variable renewable share in the global mix and the consequent decrease of conventional power plant profitability because of both shorter runtimes and lower wholesale prices [29]. The remunerations within the capacity mechanisms are usually reviewed using different market-based approaches. In volume-based mechanisms used in Germany, UK and France, policy-makers decide on the required volume of capacity and let the market set the price [29]. In price-based mechanism used in Spain, policy-makers set the price and let investors decide how much they are willing to invest for a given price [29]. The capacity mechanisms were widely analysed and criticised from different perspectives. For example, it was found that such mechanisms may increase the dependence on fossil fuel power plants and, thus, undermine decarbonisation objectives, and that their introduction is based more on political motivations than on a rigorous analysis of their need [9]. The new design criteria were set to ensure a fully integrated energy market. In particular, capacity mechanisms must be entirely market-based to ensure efficient capacity investments, and market-wide (i.e., to include storage, RES and demand side management) to avoid competition distortion [31].

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 [42]. 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 [65]. The distribution rates (USD/kW) must also be approved by an independent authority and are usually higher than the transmission rates. In addition, the grid fees may include fixed service charges per month paid undependently of household electricity consumption. 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 [45]. Figure 7 illustrates the distribution of the estimated monthly delivery fees for 2016 for a typical household [81] superimposed on the population density. The total delivery fees ranges from USD 22

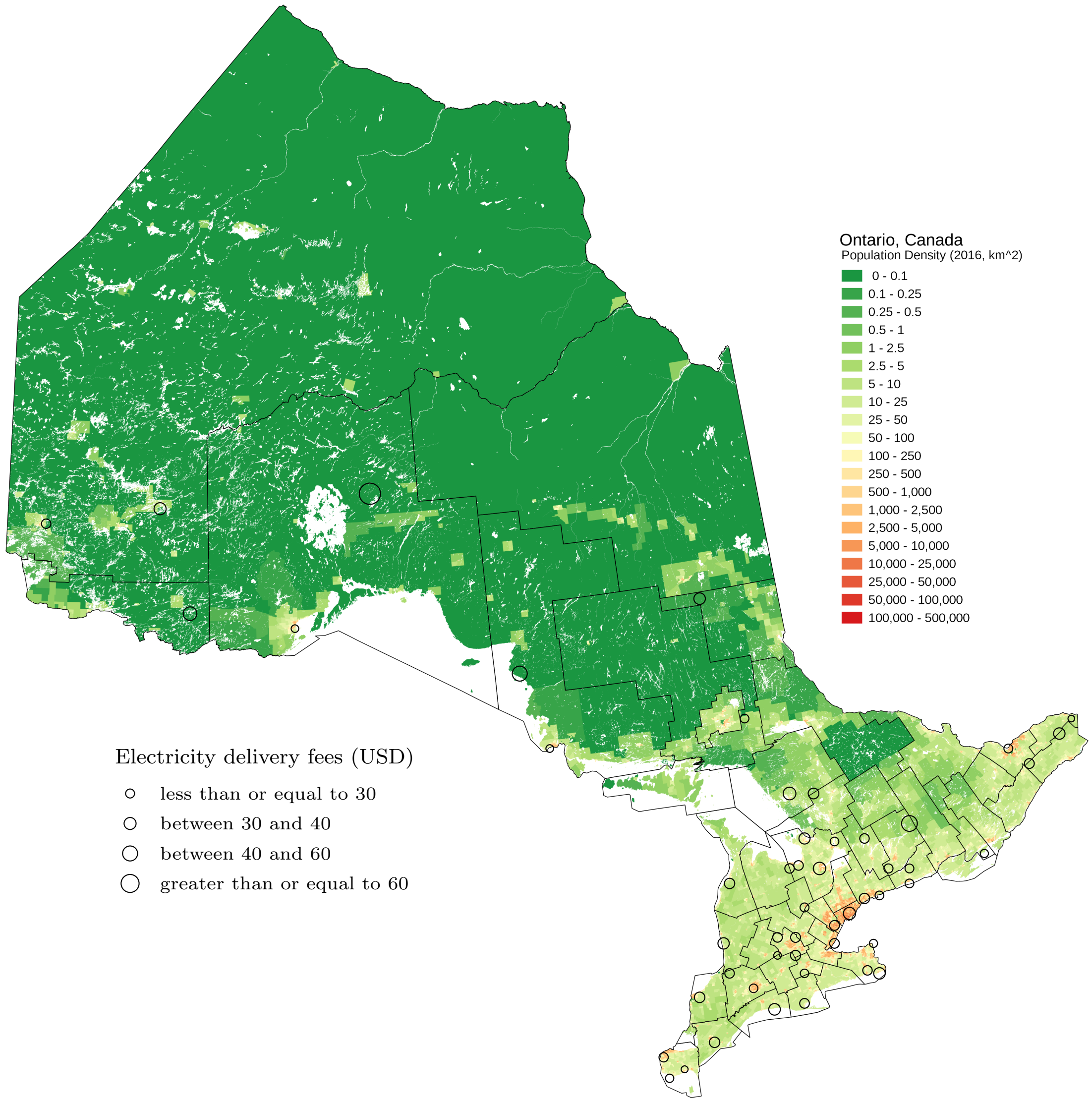


Figure 7: Estimated electricity delivery fees [81] in typical household bill along with population density (2016) [112].

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. The share of fixed service in the total delivery fees considerably varies depending on the distribution company tarification from around 40% up to 83% [81]. Figure 8 shows a breakdown of the electricity bills 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 [89].

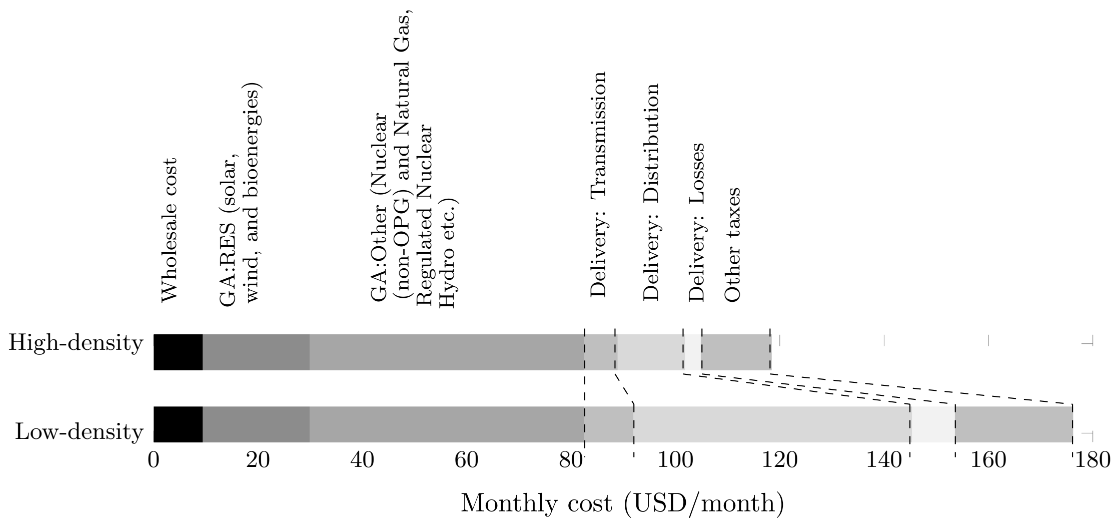


Figure 8: Breakdown of Ontario electricity bill for typical households for high- and low-density areas in 2016.

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 [88]. Under current tariff and incentive arrangements for standalone systems, up to 10% of grid-connected consumers could choose to go off-grid by 2050 [25], accepting the implications for their energy reliability. The additional measures are supposed to avoid inequitable outcomes where some users exit the grid, placing an increased burden on those remaining connected [88].

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 [79]. 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 [64]. 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 [64].

3.3 Environmental levies: Feed-in-tariffs

3.3.1 Cost formation

FIT was designed several decades ago to support RES development and implementation [17] and adopted by 23 EU countries in 2013/14 [13].

The value of FIT depends on the approach adopted in the specific jurisdiction [16]. 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 around 160 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 [93]).

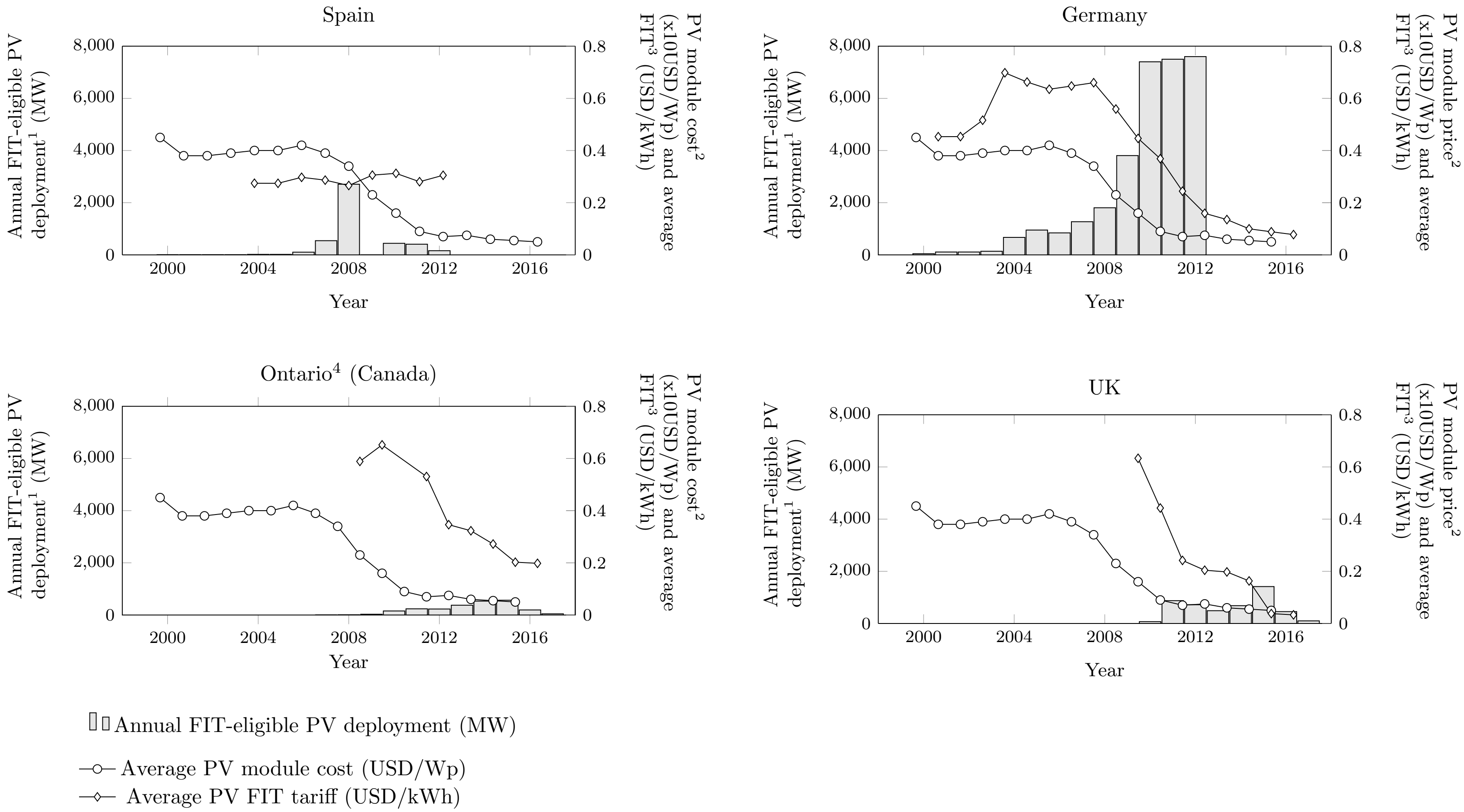
In Germany, the UK, and Ontario, FITs started just above 0.6 USD/kWh. Following the continuous decrease of PV prices, they decreased every year. However, in Ontario the decrease was relatively slow: in 2012 the province was still offering an average of 0.53 USD/kWh while Germany and the UK had decreased 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., [6] 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, where the FIT scheme was broad and available to large-scale installations [44]. 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 of its electricity demand share covered by RES from 18.4% in 2006 to 37.4% in 2015 [67]. 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 [16]. 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 [94]. 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, green levies on energy bills are more modest: 5% in 2015. This is expected to increase to 15% by 2020 [102]. The FIT program (implemented in 2000 and concluded in 2015), applied to small-scale generators of less than 5 MW capacity, allowed to deploy over 650 thousands installations [77]. By the end of the FIT program, FIT-eligible RES provided 0.84% of the electricity consumed in the UK while the total share of RES generation was almost 20% [18]. The total annual cost of the FIT scheme was over a billion USD [77].

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 [41]) 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 [58]. 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 [7], may not recover their operating and maintenance costs. This may result in their exit from the market, leading to increased prices.



1 Annual FIT-eligible deployment was extracted via: Spain and Germany [93], the UK [107], and Ontario [54]. 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 [59, 60].

3 Average FIT was calculated for eligible standard PV installations with 4 kW to 5000 kW capacities: Spain [93], Germany [111], the UK [85], and Ontario [54].

4 In Ontario FIT was set to zero for new installations in 2011 before the official review program in 2012 and 2013 [54].

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.

Another issue is the difficulty of equitably sharing costs across consumer classes and geographic areas [16]. 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 [58], [77].

In recent years, some countries have begun a shift away from FIT and toward more market-driven RES promotion mechanisms [67]. 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 [85]. As an alternative to FIT, in 2012 Germany introduced the optional sliding Feed-in-Premium tariff paid on top of the revenues from the direct sale of RES electricity on the spot market [13]. This new scheme progressively replaced FIT for all new RES plants. 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 [16]. 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 [1].

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 [101]. 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 [20], leading to the conclusion that the policy must be adaptive [101].

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 same[4] 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 [50]. 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 [110]. 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 [27]. In Ontario, this compensation is important. Note that GA charges are applied only to in-province consumers. In 2016, electricity

[4]In 2011 Ontario had no new FIT contracts.

exports represented almost 15% (21.9 TWh) of total Ontario generation, and out-of-province customers typically purchase this electricity at the wholesale price [56]. 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 [63].

- **The breakdown of the consumer bill hides the real problem.** GA, included in the generation component [72, 63, 80], 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 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 [73, 95] 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 [37, 34] 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 [97].

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 [109]. 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 [19]. The resulting rushed exit from the FIT program generated many international investment arbitration cases from PV investors [36].

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 [86]. 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 [86].
- **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.

A massive disconnection of household electricity consumers may stimulate the so-called death spiral effect already observed or predicted for several jurisdictions. The causes of this effect may lie not only in the high grid fees (e.g., Australia [25]) but also high environmental levies (e.g., Germany [48]), and continuous decrease of RES capital costs. The combination of these factors encourages consumers to leave the grid. The decrease of connected customers makes it more difficult to recover grid costs and pay incentives, and increases these costs for the remaining consumers. This incentivizes even more the remaining consumers to disconnect.
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.** Daily power demand adjustment of a conventional consumer is constrained by scheduling requirements of different home appliances. The total load cannot go below the minimum power demand of always plugged-in appliances [90]. By contrast, the total prosumer load may even be negative due to the participation of RES and battery storage in the dispatch process [4].
- **Prosumers can self-organize and operate in stand-alone mode during critical periods (e.g., power outages), and thus reduce costs, relieve the pressure on the utility's infrastructure, and increase system resilience.** In addition to the already known prosumer's ability of stand-alone operation, new mechanism of self-organized energy-sharing may become available [12]. It relies on a self-organization approach that automatically alters the physical grid topology and forms local energy groups in order to mitigate the effects of widespread outages. In other words, during an outage, prosumers first meet their own demand, and then distribute the leftover supply to other affected members of the group.
- **Prosumers hold a better understanding of challenges related to variable RES management which adds value to their involvement in addressing the various energy system challenges at utility level.** In addition to their technological capabilities for flexibility and self-organization, prosumers hold better understanding of energy system challenges which allows them to improve system efficiency in a variety of ways [87]. This may naturally stimulate the diffusion and adoption of prosumption and lead to greater integration of variable renewable energies to decarbonize the energy mix.

However, the current economic framework in major jurisdictions restricts or outright blocks the efficient integration of prosumers. This is the motivation for our proposal in the next section. We stress that we advocate for grid-connected prosumers that may bring a series of advantages to the grid. However, we acknowledge that in the future the situation when all original consumers remain connected is not necessary economically optimal. The appearance of prosumers at different voltage levels increases grid operational complexity and increases operational costs for reliability services, maintenance and upgrade. At the same time, it will decrease utilities revenues due to lower sales of electricity. The transition from the conventional business model toward new business models with the objective of keeping all original consumers connected at all costs may be tumultuous and not economically optimal for the grid. We assume that the situation where some proportion of the prosumers may disconnect from the main grid and form a stand-alone self-sufficient microgrid is possible and may be economically optimal for some jurisdictions with large territory and high variability of grid density.

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 classical DR programs focus on the shift of electricity consumption from peak to off-peak hours. This can be done not only through consumer adherence to a DR program, but also by stimulating consumer transformation into a prosumer. Such program is operational in Minnesota (USA) since 2015 where participants need to subscribe to at least one 410-watt solar panel (from the existing community solar array) to offset their monthly bill and can receive a free water-heater which may be controlled by the utility for up to sixteen continuous hours during most critical hours [14]. In addition, a different tariff structure may be proposed for more efficient management of flexibility. The TOU could evolve toward time-and-level-of-use (TLOU) pricing taking into account price variations over time and at different load levels [39]. However, as we could see from the analysis done in Section 3, the importance of electricity consumption in the total electricity bill may be limited and the bill may include high fixed charges paid independently each month. This decrease the effect of RES and their smart management for the grid-connected prosumer, and brings up an important open question about changing the structure of the electricity bill to include all categories.

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:

- What are the acceptable ranges for the economic incentives related to consumption, generation and delivery?
- 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 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 [32], 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.

References

[1] ABC. Explained: Why feed-in tariffs began so high and have fallen so low, 2016.

[2] AEMC. 2017 Residential Electricity Price Trends. Technical report, Australian Energy Market Commission (AEMC), Sydney, 2017.

[3] AEMC. Market reviews and advice, 2018.

[4] S L Arun and M P Selvan. Prosumer based Demand Response for Profitable Power Exchange between End-user and Utility. In 2018 20th National Power Systems Conference (NPSC), pages 1–6. IEEE, 2018.

[5] ASCE. A comprehensive assessment of America's Infrastructure. Technical report, American Society of Civil Engineers, 2017.

[6] Marisa Beck, Nicholas Rivers, and Randall Wigle. How do learning externalities influence the evaluation of Ontario's renewables support policies? Energy Policy, 117(September 2017):86–99, 2018.

[7] Seth Blumsack. Basic economics of power generation, transmission and distribution, 2017.

[8] Darrell Bricker. COMMENTARY: An election powered by electricity, 2018.

[9] Laurie Van Der Burg and Shelagh Whitley. Rethinking power markets : capacity mechanisms and decarbonisation. Technical Report May, Overseas Development Institute, London, 2016.

[10] Bettina Burgholzer and Hans Auer. Cost/benefit analysis of transmission grid expansion to enable further integration of renewable electricity generation in Austria. Renewable Energy, 97(1364):189–196, 2016.

[11] Carlo Carraro, Suneel Pandey, and Steven Stone. Why fiscal policy matters for a green economy transition. Third Green Growth Knowledge Platform Annual Conference, January 29, 2014.

[12] Selma Čaušević, Kritika Saxena, Martijn Warnier, Abhijit R Abhyankar, and Frances M T Brazier. Energy resilience through self-organization during widespread power outages. Sustainable and Resilient Infrastructure, 00(00):1–15, 2019.

[13] CEER. Status Review of Renewable and Energy Efficiency Support Schemes in Europe in 2012 and 2013. Technical Report January, Council of European Energy Regulators, Brussels, Belgium, 2015.

[14] CERT. Steele-Waseca Cooperative Electric offers sweet community solar and water heater bundle, 2015.

[15] Andreas Chai. Household Consumption Patterns and the Sectoral Composition of Growing Economies: A Review of the Interlinkages. Technical report, United Nations Industrial Development Organization, Vienna, Austria, 2018.

[16] Toby D. Couture, Karlynn Cory, Claire Kreycik, and Emily Williams. A Policymaker's Guide to Feed-in Tariff Policy Design. Technical Report July, National Renewable Energy Laboratory, 2010.

[17] Samantha De Martino and David Le Blanc. Estimating the amount of a global feed-in tariff for renewable electricity. Technical Report 95, United Nations, 2010.

[18] DESS. Renewable energy in 2014. Technical Report June, Department of Energy and Climate Change, 2015.

[19] Sonia Diaz. Tariff deficit: how expensive will it be?, 2017.

[20] Katherine L. Dykes and John D. Sterman. Boom and Bust Cycles in Wind Energy Diffusion Due to Inconsistency and Short-term Bias in National Energy Policies. In The 28th International Conference of the System Dynamics Society, pages 1–26, Seoul, Korea, 2010.

[21] EEI. Industry Capital Expenditures. Technical report, Edison Electric Institute, 2017.

[22] EIA. Electricity prices reflect rising delivery costs, declining power production costs, 2017.

[23] EIA. Residential Energy Consumption Survey (RECS), 2018.

[24] EIA. U.S. nuclear industry, 2019.

[25] ENA. What could customers save with standalone systems and microgrids?, 2016.

[26] Energy UK. Energy bill breakdown, 2018.

[27] Energy UK. Energy companies' profits and prices, 2018.

[28] ENGIE. Electricity Pricing Breakdown: The Energy Pyramid, 2013.

[29] Gregor Erbach. Capacity mechanisms for electricity. Technical Report May, European Parliamentary Research Service, 2017.

[30] European Commission. Study on “Residential Prosumers in the European Energy Union”. JUST/2015/CONS/FW/C006/0127. Framework Contract EAHC/2013/CP/04. Technical Report May, 2017.

[31] European Parliament. Energy Union: Key Decisions for the Realisation of a Fully Integrated Energy Market. Technical report, European Parliament, 2016.

[32] European Parliament. European Parliament resolution of 26 May 2016 on delivering a new deal for energy consumers (2015/2323(INI)). Technical report, European Parliament, Brussels, Belgium, 2016.

[33] Eurostat. Energy prices in EU in 2015. Technical Report May, Eurostat, 2016.

[34] James Gaede and Ian H. Rowlands. How ‘transformative’ is energy storage? Insights from stakeholder perceptions in Ontario. Energy Research and Social Science, 44(May):268–277, 2018.

[35] Parker Gallanti. The push is on to make Ontario’s disastrous ‘Fair Power Plan’ even worse, 2018.

[36] C. O. Garcia-Castrillon. Spain and investment arbitration: The renewable energy explosion. Investor-State Arbitration Series, (17), 2016.

[37] Justin Giovannetti. In Ontario, hydro’s future gets murkier as costs of leaving the grid decline, 2017.

[38] Raluca Golumbeanu and Douglas Barnes. Connection charges and electricity access in sub-Saharan Africa. Technical Report June, 2013.

[39] Juan A Gomez-Herrera and Miguel F Anjos. Optimal collaborative demand-response planner for smart residential buildings. Energy, 161:370–380, 2018.

[40] Government of Ontario. Economic Data Tables, 2017.

[41] Green Energy Markets. Renewable Energy Index. Technical Report March, 2018.

[42] Chenghong Gu, Chenchen Yuan, and Furong Li. Risk management in use-of-system tariffs for network users. IEEE Transactions on Power Systems, 28(4):4683–4691, 2013.

[43] Jenny A. Hayward and Paul W. Graham. Electricity generation technology cost projections: 2017-2050. Technical Report December, CSIRO, Australia, 2017.

[44] A. Held, M. Ragwitz, G. Resch, Franko Nemac, and K. Vertin. Feed-in Systems in Germany, Spain and Slovenia: A comparison, 2010.

[45] Brian Hill. How much have hydro bills in Ontario really gone up?, 2017.

[46] Brian Hill. How big is Ontario’s hydro problem? And can the Liberals, NDP or PCs fix it?, 2018.

[47] Lion Hirth. What caused the drop in european electricity prices? A factor decomposition analysis. The Energy Journal, 39(1):143–158, 2018.

[48] Jan Hromadko. German Companies Take Back the Power, 2014.

[49] Joern Huenteler. International support for feed-in tariffs in developing countries - A review and analysis of proposed mechanisms. Renewable and Sustainable Energy Reviews, 39:857–873, 2014.

[50] Hydro One. Moving to Fixed Distribution Rates, 2017.

[51] Hydro One. When you pay your bill, what are you paying for?, 2017.

[52] IEA. Statistics: Electric Power Consumption (kWh per capita), 2018.

[53] IESO. Data Directory, 2016.

[54] IESO. Progress Report on Contracted Electricity Supply. Technical report, Independent Electric System Operator, Toronto, Ontario, 2017.

[55] IESO. Demand overview. Historical demand., 2018.

[56] IESO. Imports and Exports, 2018.

[57] IESO. Price Overview, 2018.

[58] IPART. Solar feed-in tariffs. The value of electricity from small-scale solar panels in 2018-19. Technical Report June, Independent Pricing and Regulatory Tribunal (2018), New South Wales, Australia, 2018.

[59] IRENA. Renewable Energy Technologies: Cost Analysis Series. Solar Photovoltaics. Technical Report 4/5, International Renewable Energy Agency, Bonn, Germany, 2012.

[60] IRENA. IRENA Cost and Competitive Indicators: Rooftop solar PV. Technical Report December, International Renewable Energy Agency, Abu Dhabi, 2017.

[61] IRENA. Renewable capacity statistics 2018. Technical report, International Renewable Energy Agency (IRENA), Abu Dhabi, 2018.

[62] ISO NE. Wholesale vs. Retail Electricity Costs, 2018.

[63] Taylor Jackson, Ashley Stedman, Elmira Aliakbari, and Kenneth P. Green. Evaluating Electricity Price Growth in Ontario. Technical report, Fraser Institute, 2017.

[64] Celia Kuperszmid Lehrman and Shannon Baker-Branstetter. The Fees That Raise Your Electric Bill Even When You Use Less Energy, 2016.

[65] Ariel Liebman. Let's Disconnect from the Grid!, 2014.

[66] Boqiang Lin and Jianglong Li. Analyzing cost of grid-connection of renewable energy development in China. Renewable and Sustainable Energy Reviews, 50:1373–1382, 2015.

[67] Chris Lo. Renewable energy: Are feed-in tariffs going out of style?, 2017.

[68] David Marrero. ¿A dónde va el dinero que pagas en tu factura de la luz?, 2015.

[69] Ross McKitrick and Tom Adams. What goes up... Technical report, 2014.

[70] Carl Mills and Kurt Newick. Solar Electric Permit Fees in Northern California. A Comparative Study. Technical report, 2011.

[71] Craig Morris. High German power prices, low monthly bills?, 2018.

[72] Adrian Morrow and Tom Cardoso. Why does Ontario's electricity cost so much? A reality check. The Globe and Mail, pages 1–60, 2017.

[73] Nicole Mortillaro. Why living "off the grid" isn't possible for most Canadians, 2016.

[74] National Grid. Electricity Transmission network charging. Technical Report January, 2018.

[75] NEB. Canada's Renewable Power Landscape. Energy Market Analysis 2016. Technical report, National Energy Board, 2016.

[76] NEB. Canada' s Energy Future 2017. Energy Supply and Demand Projections to 2040. Technical report, National Energy Board, 2017.

[77] Colin Nolden. Performance and Impact of the Feed-in Tariff Scheme: Review of Evidence. Technical report, Department of Energy and Climate Change, London, UK, 2015.

[78] OANDA. Foreign Exchange Average Converter, 2018.

[79] Andy O'Brien. The Future of Microgrids and Cleaner Locally Managed Power regulators, 2017.

[80] OEB. Electricity Power System Planning. Technical report, Auditor General of Ontario, 2015.

[81] OEB. 2016 electricity distribution rate applications, 2016.

[82] OEB. Defining Ontario's Typical Electricity Customer. Technical report, Ontario Energy Board, 2016.

[83] OEB. 2017 Yearbook of Electricity Distributors. Technical report, Ontario Energy Board, 2018.

[84] OFGEM. Regional differences in network charges. Technical Report October, 2015.

[85] OFGEM. Feed-In-Tariff (FIT) rates, 2018.

[86] Laura Olkkonen, Kristiina Korjonen-Kuusipuro, and Liro Grönberg. Redefining a stakeholder relation: Finnish energy "prosumers" as co-producers. Environmental Innovation and Societal Transitions, 24:57–66, 2017.

[87] Yael Parag and Benjamin K Sovacool. Electricity market design for the prosumer era. Nature energy, (March), 2016.

[88] Giles Parkinson. Networks propose compulsory fees for all – to stop grid defections, 2015.

[89] Alicia Queiro. What is the National Grid and why does it cost to connect to it?, 2014.

[90] S Reka Sofana and V Ramesh. A demand response modeling for residential consumers in smart grid environment using game theory based energy scheduling algorithm. Ain Shams Engineering Journal, 7(2):835–845, 2016.

[91] REN21. Policy landscape. Technical report, 2016.

[92] Gustav Resch, Mario Ragwitz, Anne Held, Thomas Faber, and Reinhard Haas. Feed-in Tariffs and Quotas for Renewable Energy in Europe. Technical report, 2007.

[93] Pablo Río González and Pere Mir-Artigues. A cautionary tale: Spain's solar PV investment bubble. International Institute for Sustainable Development, (February), 2014.

[94] David Robinson. Pulling the Plug on Renewable Power in Spain. Technical Report December, Oxford Institute for Energy Studies, 2013.

[95] Peter A. Robson. On grid or off?, 2017.

[96] Mario Saavedra. La vertiginosa historia de la factura de la luz en España, 2017.

[97] Don Scallen. Going of the Grid, 2017.

[98] Statista. Average annual domestic electricity bill in the United Kingdom (UK) from 2007 to 2017 (In British pounds), 2018.

[99] Statista. Durchschnittliche Stromrechnung eines 3-Personen-Haushalte Jahren 1998 bis 2018 (in Euro pro Monat), 2018.

[100] Statistics Canada. Table 18-10-0005-01 Consumer Price Index, annual average, not seasonally adjusted, 2018.

[101] Leah C. Stokes. The politics of renewable energy policies: The case of feed-in tariffs in Ontario, Canada. Energy Policy, 56:490–500, 2013.

[102] Steven Swinford. Green levies on energy bills to treble by 2020 because of renewable targets, official figures suggest, 2015.

[103] Julie Taylor and Sanford Berg. If a government decides to consider feed-in tariffs (FITs) as a tool to promote distributed generation via renewable energy , what are the regulatory steps that should be taken to implement these rules ?, 2013.

[104] Ellen Thalman and Benjamin Wehrmann. What German Households Pay for Power, 2018.

[105] The National Academies of Sciences Engineering and Medicine. Chapter 3. The Many Causes of Grid Failure. In Enhancing the Resilience of the Nation's Electricity System, pages 1–40. The National Academies Press, Washington, DC, 2017.

[106] The World Bank. Households and NPISHs final consumption expenditure (current US$), 2018.

[107] UK Government. Solar photovoltaics deployment, 2018.

[108] UNDP. Transforming On-Grid Renewable Energy Markets. Technical report, United Nations Development Programme, 2012.

[109] Loes Vandenbussche. Energy price freeze: A Government measure with consequences, 2012.

[110] WEC. Electricity use per household, Electricity Consumption Efficiency, 2014.

[111] Jurgen Weiss. Solar Energy Support in Germany. A Closer Look, 2014.

[112] Wikimedia. Ontario Population Density 2016, 2017.