Expert assessment of prioritized determinants for a smarter grid through the lens of residential demand response: The case study of Ontario, Canada

Iliopoulos Nikolaos^{a*}, Onuki Motoharu^a, Nistor Ioan^b, Esteban Miguel^c

^aThe University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa City, T277-8563, Japan

^bUniversity of Ottawa, 115 Séraphin-Marion, Room HGN215, Ottawa, ON, K1N 6N5, Canada

^cWaseda University, 60-106, 3-4-1 Okubo, Shinjuku-ku, Tokyo 169-8555, Japan

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Abstract

In recent years, smart grids have attracted considerable attention. However, despite the promising potential of the technologies encompassed within such systems, their adoption has been slow, geographically varied, and in the context of residential demand response, often subject to public scrutiny. The heterogeneous evolution of the smart grid is not only the product of technological limitations but is additionally sensitive to socio-political considerations prevalent at the national or provincial level. Through expert interviews that were conducted in Ontario, Canada, this study provides insights into which smart grid factors are considered as most important for its development, and also what are the drivers, inhibitors, benefits, and drawbacks that a smart grid provides and / or entails, placing particular emphasis on residential demand response programs. The constructs scrutinized were adapted from previous studies, and the information collected was analyzed following the procedure of the Grounded Delphi Method. The findings indicate that a consensus was reached, in that smart grids pave the way for increased demand flexibility and loss reductions, though these are contingent on measures being implemented regarding the creation of investment opportunities, engagement of consumers, and ensuring the security of private data. Relevant policy implications and research recommendations are also explored.

Keywords: Smart grid; demand response; Grounded Delphi Method; residential sector; Ontario, Canada

Abbreviations:

SG(s)	: Smart grid(s)
GHG	: Greenhouse Gases
DR	: Demand response
GDM	: Grounded Delphi Method

1. Introduction

As delineated by the Pan-Canadian Framework on Clean Growth and Climate Change [1], the federal government of Canada, together with provincial governments and private organizations, is poised to modernize its electrical power network. This transformation entails the incremental implementation of smart grid (SG) initiatives that can revolutionize the backbone of electricity systems through technological and social changes spanning electricity generation, distribution, control and consumption [2]. From an environmental-sustainability perspective, the underlying elements of SGs have the collective capability of increasing the penetration of intermittent renewable energy sources [3] and reducing some of the greenhouse gas (GHG) emissions associated with building heating [4] and personal transportation [5]. From a financial point of view, SGs can also enhance grid reliability and efficiency, reduce transmission and distribution costs, balance supply and demand [6] and expand the potential of energy services, leading to the creation of new jobs [7]. In the Canadian context, such initiatives draw monetary resources from a federal budget of \$2.3 billion that was pledged in 2017 to support the implementation of sustainable energy technologies [8]. At the provincial level, other SG financial agendas also exist, such as that established by the provincial Government of Ontario (alongside its public and private partners), whom have collectively invested over \$200 million into the “Smart Grid Fund” since 2011 [8].

In recent years, the momentum of such SG projects has accelerated. However, due to the jurisdictional complexity surrounding them, there is no universal understanding of what a SG is [9]. The term SG may apply to a number of technological solutions and is influenced to a large extent by geopolitical parameters and the current situation electrical infrastructure in a given area. For instance, in upstream (e.g. electricity generation) or downstream (e.g. consumers) markets, SG is often viewed as an extension of smart meters, which record information such as the consumption of electric energy, voltage levels and current in real-time [10].

* Corresponding Author

Tel.: +81 07042332933; E-mail: nikolaos.iliopoulos@s.k.u-tokyo.ac.jp

On the other hand, SGs in the context of power system management encompass all the functions which improve the automation and optimization of bulk generation, storage, transmission and distribution [11]. Moreover, whereas the European Technology Platform views SG as a steppingstone for improving the interconnectedness of the grid [12], the United States Department of Energy depict SGs in terms of their potential to provide technically oriented solutions [13]. In this paper the authors favor the definition provided by the Canadian Electricity Association which sees the SG as *"suite of information-based applications made possible by increased automation of the electricity grid, as well as the underlying automation and communication infrastructure itself"* [14].

The lack of a clear definition of what an SG is reflects both the complexity and dynamic nature of the power network, and has resulted in many SG initiatives having competing goals [15] that ultimately hinder their implementation [16]. Coupled with variations in provincial policies, the lack of transparency in what a true SG entails may create technological lock-in mechanisms in the transition process of the grid [17], leading to a heterogeneous, decoupled energy landscape [18]. In addition to favoring particular technological configurations over others, this might intensify the "efficiency gap" that exists between the realized and theoretical potential of SG initiatives [19]. Amidst this ambiguity, stakeholder cooperation will play an important role in the development of SGs [20], particularly for technologies that are becoming increasingly visible to the public such as home energy management systems [21]; a vital component of demand response.

According to the US Department of Energy, DR refers to *"changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized"* [22]. In the Canadian context, behavioral modifications can substantially alleviate secondary energy use and the associated GHG emissions of households [23]. However, despite such promising potential, DR has been historically centered around industrial and large-scale commercial users [24] and comparatively little attention has been paid to the residential sector [25]. Residential energy demand patterns are subject to variations based on the core values of individuals [26], [27], their perspectives regarding the risks and benefits brought by DR [28]–[30] as well as the level of trust they have on project implementers and relevant operators [31], [32]. Key stakeholders can play an influential role in this decision-making process of consumers by using storylines to offer alternative interpretations of particular energy projects, thereby shaping the trajectory of energy policies [33]–[35]. For example, governmental organizations may choose to direct public opinion towards the financial advantages of certain

projects, paying less attention to discussions relating to "clean" versus "dirty" energy [36]. Evidence suggests that such approaches can stimulate public opposition, when the consumers perceives other stakeholders as not acting in the best public interest [37], [38].

It is in the context of these discourses that the authors maintain that it is important to identify, classify and delineate the factors that positively or negatively impact the trajectory of SG projects, particularly from the perspective of key SG stakeholders.

1.1. An overview of contemporary literature

Previous studies focusing on the factors that influence the development of the SG have highlighted the need to upgrade the infrastructure [39], decentralize generation [40], increase the penetration of electric vehicles [41], increase energy efficiency [42], decrease power outages [43], or engage residential consumers [44]. With respect to the role of SG experts on smart energy transition, previous studies have focused on blockchain-based P2P energy systems [45], smart meters [46] and smart city implementations through citizen-centric e-governance [47]. Others focused on the expansion of the energy mix [48], day-ahead markets [49], clean energy incentives [50] and sustainable energy system transformation [51]. In Canada, while some recent stakeholder analysis studies have focused primarily on the development of SGs in the Province of Quebec [52] or British Columbia [15], others have examined the national SGs collectively through the lens of renewable energy [2], or through the perspective of Canadian media [53]. One report focusing in the Province of Ontario highlighted peak shifting, ancillary services and renewable integration as significant benefits, and lack of knowledge sharing, immature technology and risk averse behavior, as significant barriers of the development of the regional SG [54]. Though informative, the aforementioned report looked at the SG in the Province of Ontario through the perspective of the government alone, and as such could not provide a holistic representation of the most important factors that influence the development of SG in the Province of Ontario through a multidisciplinary and multisectoral lens.

In this paper the authors aim to produce an interdisciplinary examination of the most important SG functions and parameters through an expert elicitation methodology. To the best of the authors' knowledge, this is the first study to investigate the feedback of SG experts in the Province of Ontario and the extent to which they recognize and articulate the motives and most important criteria underlying the potential deployment of SG technologies, focusing particularly on those applicable to residential DR. The constructs utilized were built upon the foundation established by previous studies that considered the socio-environmental or financial values [55], benefits [56], or other desired functions [57], [58] that a SG provides and/or entails and the data collected were analyzed through

the Grounded Delphi Method. The Province of Ontario, Canada was utilized as a case study, as the rollout of smart meters (i.e. a critical component of demand response, DR) was met with considerable resistance [59], making it an ideal place to study the challenges these initiatives are facing. Essentially, studying an area where problems have already been noted to exist can help to provide lessons to other cities elsewhere.

2. Methodology

This study employed an iterative qualitative design based on the Grounded Delphi Method (GDM), which amalgamates the theoretical principles of two commonly used exploratory research theories, namely the Delphi method and Grounded Theory [60]. The stepwise research process of GDM was selected as compared to the aforementioned theories, it yields richer data that is conducive to theory building by providing a more rigorous criteria selection, based upon the consensus and item ranking of experts [61]. An overview of the methodological framework of the GDM is provided in Figure 1 below.

Figure 1 An overview of Grounded Delphi Method, adapted from Pääväranta et al [60].

The first phase of the GDM consists of carefully selecting and inviting qualified SG experts to join the study. The selection of experts was completed through relevant networks and via search engines and literature searches. As a prerequisite, participants were required to have a deep understanding of the full array of socio-technical and financial issues pertaining to SGs and be interested in and capable of attending all the phases of this study. With respect to the first criterion, academics were required to have published work in this area (e.g., journal articles and / or book chapters, etc.), whereas government officials and industry leaders were required to have worked on SG projects in the past. As suggested by previous studies, a Knowledge Resource Nomination Worksheet (KRNW) was

prepared to minimize researcher bias and help segregate potential experts into relevant categories [62].

Initially, 60 experts working in the Province of Ontario and spanning three sectors (i.e. academia, industry, and government) were identified through a literature review. With respect to their expertise, the majority of the participants were engineers (focusing on energy systems, security architecture, etc.) while others were social scientists (economists, policy, and sustainability scientists, etc.). The list was later narrowed down to 15 participants; 6 academics, 3 government officials, 4 industrial agents and 2 individuals who worked for both academia and the government.

In the second phase, a questionnaire survey was sent to the participants on July 19th, 2019. This survey invited them to select up to three criteria directly associated with the factors that drive or inhibit Ontario's SG transition, and also the benefits and drawbacks that follow such technological implementations. In addition, the survey also drew attention to the most dominant underlying themes of eight SG functionalities, explicitly those with respect to SG's *standards, technological issues, data handling, market structure, regulations, coordination, customer engagement and investment*. The questionnaire survey presented all of the above factors and functionalities of the SG in the form of a comprehensive list of constructs (see Tables A1 to A12 in the Appendix). This list comprised a number of key issues pertaining to the technical, social and financial determinants surrounding the advancement of SGs, and was adapted from a selection of previous studies that scrutinized the development of the SG [57], [58].

The third phase involved the categorization of the answers of the participants into a series of ranked constructs. This narrowed down list was presented to the participants through in-person interviews and digital meetings that took place between August 7th and August 26th, 2019. Collectively, these aimed at eliciting further arguments in support of the constructs identified in the previous phase. In addition, the experts were invited to elaborate on the positive or negative influence that these issues can exert on residential demand response programs in Ontario.

The fourth phase was subdivided into three stages and involved the content analysis of the responses derived from the previous phase. First, each interview transcript was separated into numerous individual remarks. Secondly, the remarks from each participant were grouped together into beliefs of similar utterances. Thirdly, these grouped remarks were narrowed down into a series of idiosyncratic groups and subcategories. This process of concept discovery and prioritization was repeated six times until the newly built interlinked categories were clearly discernible. The themes underlying these categories were grouped into five classes, based on their correlation and frequency of appearance.

Lastly, this framework was enhanced by the authors through the addition of a fifth phase. This last phase used a

stopping criterion and an initial analysis sample to help the authors confidently conclude whether a theoretical saturation point had been reached, thereby determining the adequacy of the acquired sample size [63], [64]. Data saturation was achieved following a 10-point initial analysis sample with the stopping criterion set at three consecutive interviews, as suggested by previous studies [63].

3. Results

The first section presents and discusses the factors that constitute benefits, drawbacks, drivers, and inhibitors of Ontario's SGs whereas the second delineates eight functions that could potentially facilitate the transition to a smarter energy grid. These responses can be found in the Appendix (see Tables A1 to A12). The third section provides an in-depth analysis of GDM's phase 4 "theory development".

3.1 GDM phase 2: factors influencing the transition to a smarter energy grid

3.1.1. Drivers and inhibiting factors of SGs

The most frequently identified drivers of SGs in Ontario reflect approximately 65% of responses. *Government policy and regulations* as well as *the need to increase renewables* were both cited as equally important drivers. Both of these relate to Ontario's environmental sustainability policies (e.g. Ontario's Climate Change Action Plan), which aim at reducing the energy sector's GHG emissions through the increased penetration of renewables [65]. The third most frequent driver was *demand management/reduction* opportunities enabled through energy efficiency and DR measures, which can collectively offset unnecessary infrastructure expansion. *The need to increase low carbon technologies*, such as plug-in hybrid electric vehicle (PHEV) was also cited as an important driver, given its potential to reduce GHG emissions [6]. Paradoxically, although all the aforementioned drivers are in part influenced by anthropocentrically exacerbated climate change, the "*alleviation of climate change*" itself (as presented in the questionnaire) did not attract much attention as a factor driving SG development. Four factors that inhibit the development of SGs were identified, the accumulated score of which reflect over 60% of responses. *Customer disengagement/resistance* and *investment related expenditures* were cited as equally important inhibiting factors for SGs. The first one represents the (unfulfilled) expectations of DR participants (e.g. households) regarding what was actually done by utility operators, governmental officials, and/ or academic researchers. *Investment related expenditures* indicates the loss averse investment behavior of actors initiating pilot projects in the unpredictable (i.e. high-risk) domains of SGs. *Unclear policy & governance* was mentioned as the third inhibiting factor, emphasizing the

need to establish strong, long-term policy measures related to energy sustainability. *Industry inertia and resistance* was the last inhibiting factor highlighted.

3.1.2 Benefits and drawbacks of SGs

The benefits derived from Ontario's SG implementation projects are presented in this section, with the top three representing approximately 55% of responses. The most frequently cited benefit was *energy efficiency / loss reduction*, where the respondents placed a strong emphasis on maximizing the capabilities of existing grid assets and minimizing the costs incurred during electricity transmission and distribution. *Decentralized generation* was cited as the second most important benefit, as it diversifies the province's energy portfolio and enables the simultaneous and automatic operation of localized electricity generation systems (i.e. microgrids). Practices centered around the *active network management* of the grid were considered as the third most important benefits (in the context of this study active network management refers to strategies that maintain the system's parameters, such as voltage or frequency within operational limits). With respect to SG related drawbacks, the top three cited results reflect 40% of responses. The most prevalent drawback was that related to *data protection/privacy concerns*, arising from customer's apprehensive stance towards advanced metering infrastructure that could transfer private information. The second most prevalent drawback is centered around *system vulnerability/less resilient*. This was a particularly interesting finding as, according to some respondents, and in contrast with the earlier statement, SGs typically enhance and strengthen the security of the power network. Thus, the lower resiliency and higher vulnerability does not stem from the technologies implemented *per se*, but could instead take place due to parties profiteering from the bi-directional communication information between customers and utility operators. Lastly, the third drawback of SGs was *disengaged/uncooperative customers and stakeholders*. This refers to the difference in expectations with respect to balancing the potential of DR programs' amongst consumers (e.g. households who want to maximize DR's personal utility) and other SG stakeholders (e.g. utility operators who want to increase the demand flexibility of consumers).

3.2 GDM phase 2: prevalent elements of SGs

3.2.1 Standard functionalities

The top four cited standards that are necessary for the further development of Ontario's SGs account for 80% of responses. Communication protocols and appliances' data exchange and control were highlighted as equally important. The first is centered around infrastructure that enables the flawless communication between SG entities

(e.g. dedicated software, control centers), whereas the second accounts for standards that ensure the secure and reliable exchange of information, particularly with respect to data derived from demand side management practices. The third most cited standard corresponds to the design and implementation of smart meters within the residential sector. Standards pertaining to Industry collaboration were identified as the fourth most important, reflecting the need for amalgamating the scope and functionality of service-oriented technologies such as in-home displays.

3.2.2 Technical functionalities

The top four cited technical functionalities account for 78% of responses. The first two highlighted the equal and interrelated importance of active network management and ICT and data management / storage. These are interlinked, as functions of the former (e.g. monitoring and control) interoperate with the latter (e.g. through intelligent electronic devices) within electricity distribution systems. The third technical issue is associated with interoperable communication, which relates to the equilibrium operation of network segments that connect a vast number of nonhomogeneous SG equipment (e.g. end-users' devices). The last technical functionality considered was that of PHEV facilitation, particularly looking into the issue of utility maximization through scheduled PHEV charging, which is challenging considering that residential customers and utility companies have opposing interests (i.e. convenience versus peak shifting).

3.2.3 Data handling

The top three items reflect over 60% of responses. Smart meters collect and transmit in real-time a series of delicate customer information, and concerns have emerged regarding the potential exploitation of such data by third parties through non-intrusive load monitoring techniques. In the Province of Ontario, these issues have in part diluted, as they are regulated by the Municipal Freedom of Information Protection and Privacy Act [66], though some skepticism regarding information sharing still remains. Thus, *public acceptability / trust*, *data protection* and *privacy guarantees* were highlighted as important data handling issues.

3.2.4 Market structure

Three dominant market structure items were identified, corresponding to 52% of responses. These were the development of demand side management programs, as well as enhancing the relationship between distributed network operators and customers and aggregator opportunities. With respect to the first, the penetration of demand side management practices (i.e. energy efficiency, DR programs), within Ontario's households is believed to

hold substantial value, given the untapped energy shift potential of the residential sector. However, maximizing the use of energy efficient appliances and electricity shift/curtailment potential of these households is contingent to a large extent on establishing a level of trust between customers and distributed network operators (in addition to the existence of targeted government subsidies focusing on aggregator's R&D on demand side management techniques and practices).

3.2.5 Regulations

The most important items identified under regulations account for approximately 62% of responses. Effective commercial arrangements and pricing was cited as the most important item, reflecting the need to establish demand response tariffs that weigh both the real-time cost of electricity and also consumers' subjective values in shifting / curtailing their demand for electricity. Facilitating aggregator operation was highlighted as the second most important item as, according to the respondents, regulatory restrictions surrounding aggregators interaction with their electricity consumers (e.g. through in-home displays) need to be lightened. This also falls in line with the last item, which discusses the importance of incentivizing cooperation of, and alternative revenues amongst entities that deal with electricity distribution and aggregation.

3.2.6 Coordination

The coordination items selected reflect 56% of responses. Alignment of incentives with objectives was ranked first, emerging from the context of residential and small-scale commercial DR. A number of respondents noted that incentive-based DR programs (e.g. Ontario's Peak-shaver) have not been considered to be successful, as these type of electricity consumers (e.g. households) are given little to no incentives for shifting / curtailing their demand. Hence, more emphasis should be placed on coordinating strategies that aim at appraising households' load flexibility. Following the assumption that residential DR programs can indeed prevent the need to construct new peak power plants, the value of such benefits should be transferred to the households (e.g. in the form of monetary rebates) that participated in DR. In the same light, respondents mentioned that cross-sectoral coordination towards building consumer choice and trust around SG technologies and services will also play an important role for the implementation of SG projects. Lastly, clarifying funding availability for demand response R&D and pilot projects was also mentioned as an important coordination strategy.

3.2.7 Customer engagement

Overall, five items were selected, corresponding to 93% of responses. The results displayed considerable discrepancies and a lack of consensus amongst respondents. Customer and public education / awareness as well as savings / cost reduction (for consumers) were both considered equally important in the domain of customer engagement. With respect to the first, one respondent stated, “...although retail electricity prices have been incrementally increasing in Ontario, the majority of consumers do not understand why this is happening and / or how demand response reduces electricity tariffs while simultaneously alleviating GHG emissions”. With respect to the second item, most respondents agreed that the currently available financial incentives for DR have not been successful in changing electricity consumers’ electricity patterns. The provision of tailored SG solutions was highlighted as the third most important item, focusing particularly on groups with special interests, such as low-income households and the elderly. Finally, smart meter functionality and billing information clarity were mentioned last and achieved a rank of equal importance. The former relates to the emergence of concerns centered around the safety underlying smart meter installation and maintenance, while the latter reflects the need to provide interpretative electricity consumption and electricity curtailed/shifted information on consumers’ bills.

3.2.8 Investments

Three items were mentioned which accounted for 70% of responses. The emerging interest for more reliable new modes of financing / business models was noted as the most important investment issue, reflecting the uncertainty in existing SG business models, particularly in the field of demand side management. Moreover, unlike the more technical aspects of SGs (such as distributed energy storage and monitoring automation), technologies centered around demand side management depend on human elements (such as consumers bounded rationality) and are thus considered difficult to predict. Hence, the second most important investment-related issue mentioned reflects the need to further clarify the weighted benefits that such technologies/services (e.g. price-based DR) grant to SG shareholders. Lastly, long-term regulations/policy certainty/objectives were collectively mentioned as the third item, delineating the importance of consistent, long-term objectives and regulations.coordination items selected reflect 56% of responses. Alignment of incentives with objectives was ranked first, emerging from the context

3.3 GDM phase 4: theory development

The initial consolidated list included 192 summary beliefs (both shared and idiosyncratic). These were grouped by theme and were narrowed down to form 5 main groups (two

of which were divided into 5 additional subgroups): control (demand forecasting, SG installation & maintenance, SG development); internal factors (education & awareness, concerns); investment; personalization and external challenges. As evidenced through the line representing all beliefs in Figure 2, 50 beliefs had been elicited by the initial analysis sample (which was earlier positioned at 10). Thereafter, two new beliefs that were categorized as “control” were acquired at the 11th interview. Subsequent interviews 12th, 13th and 14th yielded no new idiosyncratic beliefs and as such the stopping criterion for data saturation (which was earlier set at 3) was reached, indicating that saturation had been achieved after 14 interviews. The total

number of beliefs at the 15th interview was 52.

Figure 2 Cumulative summary of the five main belief groups elicited through the GDM.

3.3.1 Control of temporal and functional parameters

Through a cross-case analysis of the respondents’ beliefs, the authors identified as important the establishment of a hierarchical sense of control over three power network functions; all three of which have a temporal element embedded in them and positively or negatively influence DR. These are *demand forecasting, SG installation & maintenance and SG development* which relate to the past, present and future activities that have been, or will be undertaken by utility operators. On a theoretical level, participants reported that tapping into the potential of the residential sector’s flexible demand through DR programs appears as a promising solution to balancing critical peaks and intermittent RE technologies. However, aside from the human-oriented risks and uncertainties that such investments entail (as will be mentioned later), residential DR has so far fallen short of its potential in Ontario.

When participants were asked to elaborate as to why DR has been ineffective in shifting/curtailing residential demand for electricity, many responded that the answer partially lies in the historically overestimated growth of the region's electricity demand. One participant summarized the importance of controlling demand forecasting as follows *"...DR programs such as "TOU" and "Peak Shaver" were first introduced when coal was still used as one of the main sources for balancing winter and summer peaks. With future predictions indicating a steep increase in demand for electricity and the need to reduce GHG emissions, Canada incrementally shifted from coal to LNG [natural gas] and other renewables. With electricity demand falling short of expectations, Ontario now has very large, dispatchable natural gas generation capacity... thus, DR programs today may have more utility in balancing intermittent RE than dealing with critical peaks and are at a far less critical stage than they were 10 years ago".* Though this issue has already been mentioned by a number of studies [67]–[69], the discussion had not been extended to the degree to which it may influence the trajectory and ultimate effectiveness of residential DR.

With respect to *installation & maintenance*, some noted that technologies pertaining to SG are generally procured to expand on the previously limited functionalities of existing utilities. This transition often translates to the replacement of installed mechanical devices with more sophisticated apparatuses that facilitate communication and control automation. Though the overarching structure of the power network is improved through the integration of such newly implemented technologies, devices such as advanced metering infrastructure are susceptible to malfunction. For instance, respondents reported the occurrence of numerous household fires linked smart meters between 2011 and 2013, which stigmatized the technology and led to the withdrawal of over 100,000 of recently installed smart meters [59], [69]. Consequently, respondents concluded that the success of SG technologies, particularly those under the home energy management system, is very much contingent on installation and maintenance procedures that are regulated by rigorous safety protocols.

The last category, *SG development*, refers to the extent to which organizational, regulatory, and behavioral structures can adapt to the ever-changing power network environment that is brought about by SG technologies and services. In the context of DR, a number of participants discussed about Ontario's residential electricity consumers perturbing attitude regarding the speed at which the existing power network is transforming into a SG. One participant added that *"...from the perspective of residential electricity consumers, SGs often entail their proactive participation in energy shifting/curtailing schemes that provide little financial benefits in return. As such, these [DR programs] are generally perceived as gratuitously meddling, and the whole concept is exacerbated by the [fast] rate of*

which these were introduced to them." On the other hand, from an organizational perspective, participants mentioned that building a cross-sectional know-how pertaining to the co-operation and outsourcing of employees or knowledge is vital for organizations that are unable or struggle to cope with the multifaceted domain of SGs.

3.3.2 Internal factors

When asked to elaborate in greater detail about the social factors that inhibit the adoption of residential DR, respondents unanimously underlined two elements, both of which pertain to the psychosocial characteristics of the potential DR participants. In brief, these relate to households' level of understanding of DR and the techno-economic concerns that they have accumulated over time, which govern their decision(s) to follow or forgo DR related actions.

Traditionally, the interaction between residential electricity consumers and energy providers has centered around energy billing or customer service, an interaction which typically lasts for a maximum of nine minutes per year [70]. With the emergence of demand side management, this relationship has slowly but surely been redefined over the years, and up until recently energy providers were striving to stimulate consumer adoption and uptake of DR programs in a timely and cost-effective manner. However, the majority of these attempts in Ontario were fruitless. A 2015 report from the Canadian Ministry of Energy highlighted that many households did not understand why their electricity pricing had been increasing, nor did they understand the structure or the socio-environmental benefits derived from DR programs [71]. As a result, many consumers were unwilling or were largely unaware as to how to regulate their electricity consumption through activities that could ultimately reduce their household's ecological footprint. Two respondents noted that this characterized "failure" to transmit DR's value propositions lied in part in the energy providers' lack of expertise in non-traditional customer-oriented tasks such as education and channel management. To this end, one participant elaborated on the importance of cognitive bias in rationality judgement, particularly indicating that *"contemporary educational approaches tend to follow expected utility theory and thus often make faulty predictions about people's decisions"*. This indicates that perhaps alternative hypotheses to utility theory (e.g. prospect theory) should be used to structure fundamental strategies that aim towards enhancing consumers' awareness and understanding of DR.

The confluence of lack of awareness and sufficient understanding of demand side management schemes, aside from directly impacting the adoption rate of DR programs, also led to the emergence of concerns and discussions pertaining to the indirect, yet multifaceted influence of these strategies on consumers' lives. Arguably the most

prominent of these are the concerns involving the protection, secure handling, and distribution of private information (e.g. households' power signatures). In 2016, the Independent Electricity System Operator in conjunction with the Office of the Information and Privacy Commissioner of Ontario collaborated on developing a set of guidelines which would ensure the privacy-preserving integrity of such information [71]. Although this ensured the safety of such information from external sources, some participants noted that private data is also subject to potential embezzlement from within the organization of local distribution companies. For instance, one respondent summarized the issue as follows *"...local distribution companies generally utilize proprietary methods to analyze and handle smart-meter related data; the majority of which cannot be categorized as "best practices" in terms of safekeeping information"*. Other notable concerns highlighted were those related to consumers' distrust of the government/local distribution companies as well as the belief that DR is intrusive, and its adoption will negatively affect their households' lifestyle and comfort levels. More specifically, a number of participants expressed the view that households in Ontario display an overall mistrust of DR and the associated energy data that accompany such programs (e.g. comparison of energy consumption patterns between households). Further, such feelings of mistrust are generally exacerbated as an increasing number of consumers believe that the monetary benefits of participating in DR do not outweigh the associated loss of comfort and reduction of energy consumption flexibility.

3.3.3 Investment

Although the readiness to adopt DR automation is typically heightened by environmental, social, or financial reasons, all of the study's participants agreed that the monetary benefits for households to increase their demand flexibility is, in most cases, negligible. According to respondents, the differential gap in the expected versus the actual monetary value of Ontario's residential DR is reflected in part by the Ministry's lack of attention in conducting a systematic cost-benefit analysis prior to mandating the installation of SG instruments (such as smart meters). This resulted in a poor understanding of the financial contributions of residential DR to the power network and consequently to each individual stakeholder taking part in DR schemes. For instance, when DR tariffs (i.e. TOU) were first introduced in 2006, peak rates were three times higher than off peak rates [72] and were as such characterized by one participant as *"...conducive to households' participation in DR programs"*. However, given concerns that the residential sector's load flexibility is sporadic and temperamental, the difference between peak and off-peak rates shrunk substantially [72], reducing peoples' interest in such programs. Further, it was noted that incentive-based programs such as "Peak Shaver",

awarded residential consumers with a free in-home display in exchange for increasing their load flexibility during strategic times, but provided no additional monetary benefits. This is clearly different from DR strategies that attract the attention of large industrial consumers. A number of participants highlighted industrial DR as *"...tremendously advantageous to the point that inspired discussions as to whether these [DR programs] were essentially government's way of providing industrial consumers with an overall financial break"*. Building on top of this discussion, two participants added that the re-introduction of a higher tariff for peak electricity consumers could act as a potential solution to enhancing energy efficiency in the residential sector. However, it is worth noting that, in line with this suggestion, others argued that such measures might not gain public's support, as there is some controversy regarding whether this is ethical or not.

3.3.4 Personalization

When the Canadian Minister of Energy directed the Ontario Power Authority to tap into Ontario's residential energy conservation potential in 2006 [73], traditional behavioral economic theories were utilized to design relevant DR programs. These were initially based upon the assumption that financial incentives alone can mobilize optimal decision-making, explaining why initially local distribution companies invested little in learning about consumers' needs and preferences. According to participants, during the initial stages of DR deployment in Ontario, many municipalities attempted to enlist predominantly high-income households as potential participants. Although this was a technically sound decision, such measures failed to take into account the high rate to which such consumers had retrofitted their households with energy saving appliances (e.g. "green" fridges, lighting, etc.). Thus, short-term electricity shifting/curtailment, delivered little benefit to utility operators, which in turn did not translate into a significant income saving for such households. Furthermore, it was later discovered that many of the aforementioned households were not interested in participating in DR for monetary gains (perhaps because there were very little financial incentives to begin with), but would decrease their energy consumption for social or environmental purposes. Instances like the ones just described refuted the assumption of "rational" consumers, and today a consensus has been reached that decision-making is restricted by bounded rationality, which influences the amount of knowledge a consumer can derive from a trusted source within a given amount of time [74]. Following this train of thought, many participants in this study agreed that consumers should be segregated into homogeneous segments based on criteria that encompass their values and inclinations with respect to energy efficiency at home. Such segment can facilitate proactive DR participation amongst

residential consumers through tailored solutions that scrutinize elements beyond just financial gains.

3.3.5 External challenges

DR has been intrinsically built around a single energy carrier and cannot exploit non-electricity loads (e.g. natural gas-powered space heating). One concern that was unanimously voiced amongst all participants was that heating of premises accounts for a disproportionately large portion of households' energy usage in Ontario [75], the majority of which is provided by natural gas [76]. When asked to describe some possible solutions to this issue, some stated that integrating natural gas into the matrix of DR could possibly help alleviate some of the rising demand for this energy form. Others maintained that although DR for natural gas has been proposed in the literature, it is still very much subject to the same socioeconomic constraints as traditional DR (if not more so), and as such has ambiguous potential. One participant summarized the issues follows *"...Winters in Canada represent tremendous DR potential when considering the possibility of integrating natural gas into the equation. However, due to the physiological nature of our bodies, it is much harder, from an ethical standpoint, to control a households' temperature during the winter than it is during the summer. For instance, in the summer, it would be marginally acceptable to change the temperature of a house from 35C to 20C, but you cannot do that in the winter when the temperature is -30C"*.

It is in the context of such challenges that the concept of integrated demand response (IDR) based on multi-energy systems appeared. Unlike contemporary DR schemes, IDR enables a synchronous interaction between numerous distributed energy resources (including for example energy storage systems and micro-turbines). This has the capacity to improve the capability of DR by optimally converting one energy input (e.g. natural gas) into an alternative output (e.g. electricity) [77]. For instance, when electricity prices spike during peak hours, natural gas will be converted into an electricity load through micro-turbines, and when natural gas is in shortage and/or electricity prices flatten, bulk electricity will be supplied to meet households' needs [77]. This form of synchronous flow between energy forms would allow consumers to increase their load flexibility without having to severely sacrifice their indoor-comfort levels and will ultimately enhance the effectiveness of DR (thus transforming it from contemporary DR to IDR) [78].

4. Conclusion

To the authors' knowledge, this is the first study conducted in the Ontario that scrutinized the perspective of academics, government officers and industrial agents on the interplay between the smartification of the power system of the province and the socio-political elements that influence its development. In addition, the latter part of this study

indicated the problems and associated causes that are considered important in the context of the effective deployment of residential demand response programs.

Following a systematic GDM procedure, the findings of this study show that the energy efficiency derived from measures such as residential demand response is a vital component of the SG and is driven predominantly by governmental policies and regulations. However, privacy concerns related to the collection, dissemination, and analysis of private information have led to customer disengagement and resistance to such programs. Further, the participants of this study were presented with eight functionalities of a given SG and were instructed to choose which of the underlying social, technical, and regulative steps need to be undertaken in order to facilitate the effectiveness of the SG. A high degree of consensus was reached amongst items underlying the following functionalities, "data handling"; "market structure"; "regulations"; "coordination"; and "investment". Overall, the highest priority underlying all of these functionalities was reported as the development of effective socio-economic arrangements linked to the engagement of households in DR activities. In brief, these pertain to the enhancement of new business models that ensure the protection of customers' information and augment the alignment of incentives with DR's techno-environmental objectives. "Standards"; "Technological issues" and "Customer engagement" covered a larger number of critical steps that need to be undertaken, thus displaying a lower degree of consensus amongst participants. The first two focused predominantly on highly technical elements of the SG, such as the enhancement of communication protocols and the active network management of the power network, respectively; whereas customer education was perceived as the most important measure for raising the willingness of consumers to use DR.

Furthermore, the participants were also asked to provide additional suggestions to overcome the barriers and hindrances identified, focusing particularly on residential demand response. The theorized set of factors identified were narrowed down to the following categories:

- *Control (demand forecasting, SG installation & maintenance, SG development)*: Collectively, these highlight the need to coordinate and enhance risk measuring techniques of decision making. Information acquisition and dissemination amongst relevant actors should be facilitated to clarify the level of uncertainty and variability that exists in forecasting demand and installation of newly developed technologies. Additionally, the rate to which such technologies are introduced should be optimized so as to take into consideration the perspective of households and electricity providers and their readiness to change their operational patterns to fit the needs of DR.

- **Internal Factors (education & awareness, concerns):** Human-centered criteria such as consumers understanding, and concerns of residential DR programs were noted by the majority of participants as prominent elements of DR. Participants agreed that consumers do not understand the full extent of the socio-economic or environmental benefits that are derived through DR, intensifying customer inertia. This is caused in part due to the lack of expertise of energy providers in communicating educational values to consumers and the complicated (technical) nature of DR. Thus, efforts to simplify the basic design of DR programs should be made in conjunction with the transparent dissemination of information to prospective end-users (who tend to overemphasize the pitfalls involved in DR schemes). Furthermore, reassurances with respect to data protection need to be devised to increase the trust of customers in DR, particularly since many households maintain that energy providers do not generally act according to their customers' best interests.
- **Investment:** Ontario's residential sector holds significant theoretical potential for load flexibility, yet local energy providers are given few incentives to encourage households to adhere to such principles. In addition, the extent to which electricity consumers adopt DR is also influenced by the lack of monetary compensations, as characterized by the small differentiation between off-peak and peak TOU pricing. Thus, one way of drawing customers into DR would be by reflecting the dynamic socio-environmental cost of electricity directly into consumer bills, thus accelerating the rate at which off-peak rates are accepted.
- **Personalization:** Compliance with DR schemes is driven by the financial, social, or environmental principles that each individual may embrace. Thus, to improve the cost-efficient and effective implementation of DR, residential DR programs need to encapsulate the heterogeneous nature of electricity consumers. In addition to providing adequate monetary compensations, DR schemes should allow customers to set their own goals and perhaps even allow them to customize the content of their DR services.
- **External Challenges:** Ontario's contemporary DR cannot exploit shiftable or curtailable non-electricity loads of energy users in the province. This limitation substantially influences the potential of residential DR, particularly since natural gas is the main energy source for space and water heating amongst the province's households. The concept of IDR is introduced and recommended as a system-supporting function, which would enable the conglomeration of multiple energy sources into a multi-energy system, thus allowing

consumers to flexibly change their consumption patterns with minimum comfort losses.

Appendix

Tables A1 to A12 present the ranked findings acquired through the questionnaire survey.

Table A1 The list of SG drivers that were identified as prevalent

Items	Rank	Votes	Per. (%)
Drivers			
Government policy and regulations	1=	8	17.8
The need to increase renewables	1=	8	17.8
Demand management / reduction	2	7	15.6
The need to increase low carbon technologies (e.g. PHEV)	3	6	13.3
The need to increase distributed generation	4	4	8.9
Alleviation of climate change and emissions reduction	4=	4	8.9
The need to enhance supply security	5	3	6.7
The need to cut costs and increase efficiency	5=	3	6.7
Infrastructure investment	6	2	4.4

Table A2 The list of SG inhibitors that were identified as prevalent

Items	Rank	Votes	Per. (%)
Inhibitors			
Customer disengagement / resistance	1=	8	18.6
Investment related expenditures	1=	8	18.6
Unclear policy, governance	2	6	13.9
Industry inertia and resistance	3	5	11.6
Market structure	4=	4	9.3
Data protection / privacy	4=	4	9.3
Complexity of solutions	5=	3	6.9
Lack of expertise / innovation capacity	5=	3	6.9
Future uncertainties	6	2	4.6

Table A3 The list of SG benefits that were identified as prevalent

Items	Rank	Votes	Per. (%)
Benefits			
Energy efficiency / loss reduction	1	9	20.5
Decentralized generation	2	8	18.2
Enablement of active network management	3	7	15.9
Facilitation of more renewables	4=	5	11.4
Demand reduction / management	4=	5	11.4
Emissions reduction	5=	4	9.1
Community /consumer engagement	5=	4	9.1
Facilitation of new technologies (e.g., EVs)	6	2	4.5

Table A4 The list of SG drawbacks that were identified as prevalent

Items	Rank	Votes	Per. (%)
Drawbacks			
Data protection / privacy concerns	1	7	15.9
System vulnerability / less resilient	2	6	13.6
Disengaged / uncooperative customers and	3	5	11.4

stakeholders			
Investment issues	4=	4	9.1
Business case unclear / not fit for purpose	4=	4	9.1
Poor definition / understanding	4=	4	9.1
Complexity of proposed solution	5=	3	6.8
Disjointed decision making / planning	5=	3	6.8
Conflict of interests	5=	3	6.8
Regulatory constraints	5=	3	6.8
Over-expectations	6	2	4.5

Table A5 Consolidated list of ranked standards that are expected to influence Ontario's SG development.

Items	Rank	Votes	Per. (%)
Standards			
Communication protocols	1=	8	22.2
Appliances' data exchange and control	1=	8	22.2
Smart metering	2	7	19.4
Utility / industry collaboration strategies	3	6	16.7
Demand management	4	4	11.1
Consistency and approaches to long-term planning	5	3	8.3

Table A6 Consolidated list of ranked technical functionalities that are expected to influence Ontario's SG development.

Items	Rank	Votes	Per. (%)
Technical functionalities			
Active network management	1=	9	21.4
ICT and data management / storage	1=	9	21.4
Interoperable communications	2	8	19
PHEV facilitation	3	7	16.7
Load balancing	4	5	11.9
Condition and voltage monitoring	5	4	9.5

Table A7 Consolidated list of ranked data handling functionalities that are expected to influence Ontario's SG development.

Items	Rank	Votes	Per. (%)
Data handling functionalities			
Public acceptability / trust	1	11	25
Data protection	2	9	20.5
Privacy guarantees	3	8	18.5
Standardization of protection protocols	4	6	13.6
ICT hardware	5=	5	11.4
Data management	5=	5	11.4

Table A8 Consolidated list of ranked market structure factors that are expected to influence Ontario's SG development.

Items	Rank	Votes	Per. (%)
Market structure factors			
Development of demand side management programs	1	9	21.4
The relationship between distributed network operators and customers	2	7	16.7
Aggregator opportunities	3	6	14.3
Pricing structures	4=	5	11.9
Regulations to encourage the participation of distributed network operators	4=	5	11.9

Government intervention to enforce changes (e.g., provision of subsidies)	5=	3	7.1
Sector fragmentation	5=	3	7.1
Lack of cooperation between distributed network operators and suppliers	6=	2	4.7
Pricing / tariff clarity	6=	2	4.7

Table A9 Consolidated list of ranked regulations that are expected to influence Ontario's SG development.

Items	Rank	Votes	Per. (%)
Regulations			
Effective commercial arrangements and pricing	1	10	23.8
Allow more aggregation	2	9	21.4
Incentivize cooperation and alternative revenues	3	7	16.7
Structure reformation of distributed network operators	4=	6	14.3
Data access / availability	4=	6	14.3
Standardization	5	4	9.5

Table A10 Consolidated list of ranked coordination strategies that are expected to influence Ontario's SG development.

Items	Rank	Votes	Per. (%)
Coordination strategies			
Align incentives with objectives	1	10	24.4
Build consumer choice and trust	2	7	17.1
Clarify funding availability	3	6	14.6
Clarify decarbonization targets	4=	5	14.6
Align goals with objectives	4=	5	14.6
Long-term vision / commitment	5	4	9.8
Broaden skill base	6	3	7.3
Consistent messages / approaches			

Table A11 Consolidated list of ranked customer engagement strategies that are expected to influence Ontario's SG development.

Items	Rank	Votes	Per. (%)
Customer engagement strategies			
Customer and public education / awareness	1=	10	23.8
Savings / cost reduction (for consumers)	1=	10	23.8
Provision of tailored solutions	2	7	16.7
Smart meter functionality	3=	6	14.3
Billing information clarity	3=	6	14.3

Table A12 Consolidated list of ranked investment strategies that are expected to influence Ontario's SG development.

Items	Rank	Votes	Per. (%)
Investment strategies			
New modes of financing / business models	1	12	28.9
Clarification of SG benefits	2	10	23.3
Long-term regulations / policy certainty / objectives	3	8	18.6
New value delivery mechanisms	4	4	9.3
The participation of many stakeholders	5	3	7
Demand side investment policies	6=	2	4.7
High investment costs	6=	2	4.7
Upgrade / maximize system performance	6=	2	4.7

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