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Canadian Residential Demand Response and Ancillary Service Market Opportunities

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Date:
April 1, 2015

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Acknowledgements

Financial support for this report was provided by Natural Resources Canada through the Program on Energy Research and Development. The author would also like to recognize Alexandre Prieur, Véronique Delisle, Jennifer Hiscock, David Beauvais, and Josef Ayoub for their valuable thoughts, ideas, and suggestions that went into this report.

Summary

BACKGROUND

The introduction of the smart grid, particularly two-way communications between operators and loads, is opening up new resources for demand response (DR) with a wide range of capabilities and applications. Among the benefits that this new DR can bring are improved power system asset utilization, optimized generator operation, and increased reliability and security. The residential sector, constituting a third of Canada's electricity consumption, is a relatively untapped resource that can contribute to this DR potential. Varying by province, this potential is contingent on the sector's load size and composition.

Of the aforementioned benefits, contributions to reliability and security by DR may be easily realized and monetized through the provision of ancillary services (ASs). ASs are resources employed to support the transmission of energy throughout the bulk electric grid. Most ASs are used to facilitate balance between supply and demand, either routinely or in emergencies, and have traditionally been acquired from conventional bulk generators. With the smart grid, DR-enabled loads may also be able to supply ASs; already, loads from the commercial and industrial sectors have been deployed on a limited basis for this purpose. DR from the residential sector is an additional resource for ASs, and conversely ASs are a source of value for its DR resources.

OBJECTIVES AND METHODS

This report first appraises the existing AS market across Canada, focusing on those that are both commonly utilized by system operators and can be served from DR resources. These include ASs that are routinely deployed (regulation and load following reserves) and those activated during contingencies (spinning, non-spinning, and replacement/supplemental reserves). Each AS is defined, their method of procurement identified, and market size and value assessed.

Second, this report looks at Canada's residential sector, which is characterized by a large number of small but simple loads that will, as the smart grid develops, become economically and technically feasible to employ as DR resources capable of complex tasks (such as contributing to the aforementioned ASs). It identifies, by end-use, which of these loads will have

the most DR potential from technical and accessibility perspectives. As part of this assessment, an evaluation of the potential available from each province is highlighted. While these two appraisals, of AS and residential DR potential, stand well on their own – ASs can be served by more than one resource (e.g., storage) and DR can serve more than one purpose – this report goes further by appraising the technical and economic potential of each residential load end-use as a purveyor of DR for AS applications.

ANCILLARY SERVICE MARKET ASSESSMENT

AS reserve requirements are set by each province to meet reliability requirements (a function of prior performance and asset mix and configuration); these are estimated, for each province, in Fig. S-1. Commensurate with total electric loads, QC and ON have the largest market for ASs followed by BC and AB.

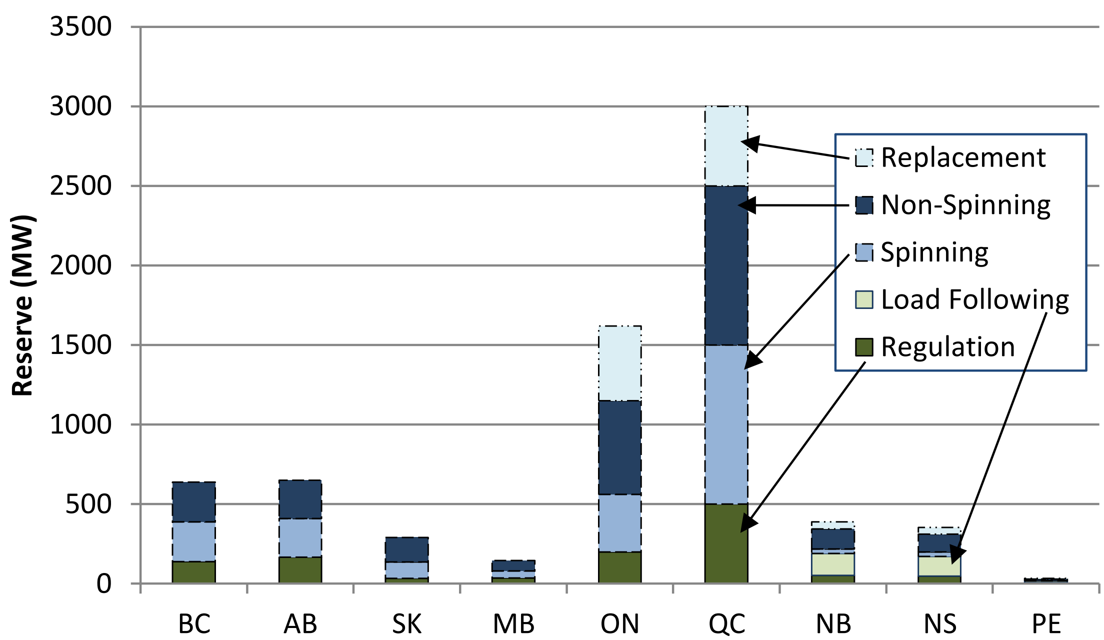

Figure S-1: Estimated AS reserve requirements

Years 2012 or 2014 estimates of AS rates are given in Table S-1. They reflect either market costs (for AB or ON) or tariffs associated with connected vertically integrated utility's transmission network. (Data on QC was unavailable.) There are significant variations by province, both by costs and rank (by most valued).

Table S-1: Procurement costs of reserves

	BC	AB	SK	MB	ON	QC	NB/PE*	NS
Regulation ($/MWh)	6.4	11	14	5.1	>24	n/a	2.0	8.5
Load following ($/MWh)	-	-	-	-	-	-	1.8	12
Spinning ($/MWh)	6.2	13	9.7	5.1	7.3	n/a	8.7	11
Non-spinning ($/MWh)	6.3	12	9.7	3.1	6.2	n/a	4.5	5.5
Replacement ($/MWh)	-	-	-	-	1.3	-	15	13

*Estimated assuming that NB/PE transmission users have the same obligations as NS users

Taking AS market size and rates, approximations can be made of the annual market value of each, by province; these are given in Fig. S-2. The two deregulated provinces (AB and ON) also have ASs with the highest market value.

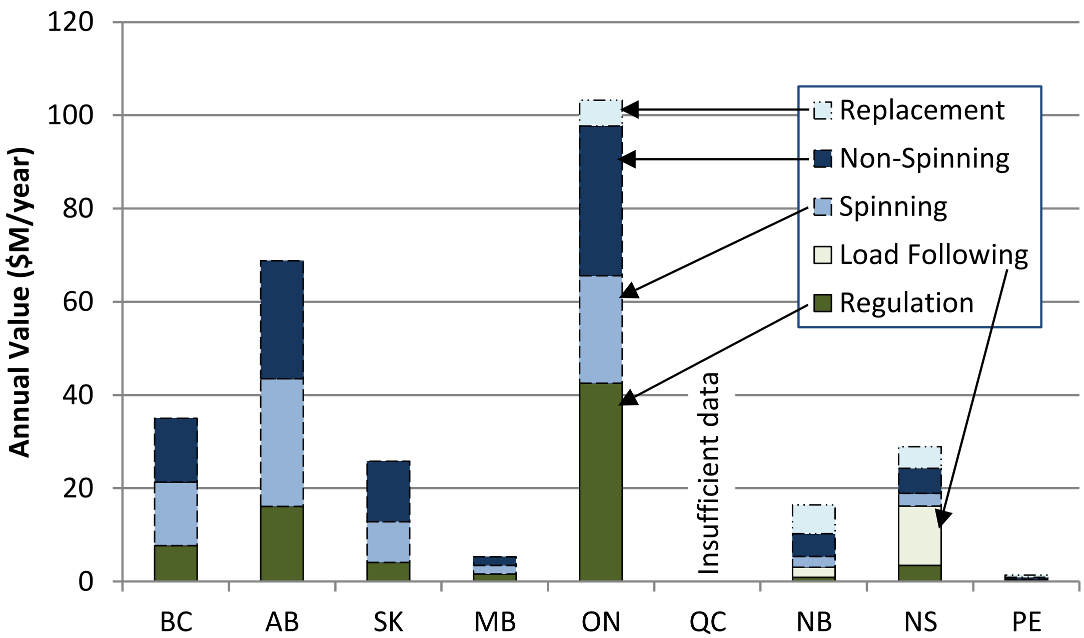

Figure S-2: Annual value of reserve services

RESIDENTIAL DEMAND RESPONSE ASSESSMENT

NRCan classifies residential electric loads into five major end-use categories: space heating, space cooling, water heating, lighting, and appliances. The technical competency of each end-use to supply DR, generally, and DR for ASs, specifically, varies. Adding the stipulation that user comfort must be maintained during DR deployment, appliance and lighting categories were found to be poor candidates for the DR. The other end-uses were found to be more amiable for general DR deployment, with each’s potential as an AS resources given in Table S-2, ranked low (–), moderate (↗), or high (↑).

Table S-2: End-use DR technical competencies to supply reserve ASs

Reserve	Space Heating	Space Cooling	Water Heating
Regulation	↗	↗	↗
Load Following	↗	↗	↗
Spinning	↑	–	↑
Non-spinning	↑	–	↑
Replacement	↑	–	↑

The DR resource potential of end-use loads, by province, can be gauged by measuring penetration by magnitude or as a function of power system demand. Table S-3 below shows peak electric space and water heating loads and thermal storage capacity. The numbers of homes with central AC units are also given. By magnitude, the highest potential resides in the largest provinces (ON and QC).

Table S-3: Electric end-use load attributes

		BC	AB	SK	MB	ON	QC	NB	NS	PE	NL	Total
Space Heating	Peak Load (GW)	3.6	0.58	0.25	1.2	6.1	13	1.1	0.68	0.02	0.93	27
	Thermal Storage Capacity (GWh)	7.2	1.2	4.9	2.4	12	25	2.2	1.4	0.05	1.9	58
Space Cooling	No. Homes with Central AC (k)	198	221	194	271	3110	524	52	18.0	0.5	4.8	4593
Water Heating	Peak Load (GW)	0.73	0.12	0.08	0.27	1.3	3.6	3.3	2.3	0.01	0.23	12
	Thermal Storage Capacity (GWh)	2.8	0.46	0.30	1.0	5.2	14	1.3	0.91	0.05	0.88	27

DR potential by province, as a function of grid demands, requires compiling other indicators such as max load as a % of system peak load, demand as a % of system demand, and storage capacity as a % of system average hourly demand. By these indicators, QC, NB, and NL appear to have the most space heating resource potential, followed by BC, MB, ON, and NS.

POTENTIAL OF RESIDENTIAL DEMAND RESPONSE TO SUPPLY ANCILLARY SERVICES

There are numerous revenue streams available to residential DR through the several benefits they offer; however, this work focuses just on those it can get through ASs. In Table S-4, their overall potential, as evaluated by weighing DR technical potential with the size and value of the AS market in each province, is ranked as low (–), moderate (↗), or high (↑). Where a dot (·) appears, not enough information was available on AS cost to make a determination.

Table S-4: Overall end-use DR potential to serve reserve ASs

	BC	AB	SK	MB	ON	QC	NB	NS	PE	NL
Space Heating										
Regulation	↗	–	–	↗	↑	·	–	↗	–	·
Load Following	–	–	–	–	–	–	–	↑	–	·
Spinning	↗	–	–	↗	↗	·	↑	↑	–	·
Non-Spinning	↗	–	–	↗	↗	·	↗	↗	–	·
Replacement	–	–	–	–	–	·	↑	↑	–	·
Space Cooling										
Regulation	–	–	–	↗	↗	–	–	–	–	–
Load Following	–	–	–	–	–	–	–	–	–	–
Spinning	–	–	–	–	–	–	–	–	–	–
Non-Spinning	–	–	–	–	–	–	–	–	–	–
Replacement	–	–	–	–	–	–	–	–	–	–
Water Heating										
Regulation	↗	–	–	↗	↑	·	–	↗	–	·
Load Following	–	–	–	–	–	–	–	↑	–	·
Spinning	↗	–	–	↗	↗	·	↑	↑	↑	·
Non-Spinning	↗	–	–	↗	↗	·	↗	↗	↗	·
Replacement	–	–	–	–	–	·	↑	↑	↑	·

Table S-5 shows the potential monetary value of utilizing a home's space heating system as a DR resource to the various contingency reserves 15% and 20% of the year. (These numbers assume a single detached or semi-detached heating requirement of 5 kW.)

Table S-5: Annual value, per home, of space heating DR contributions to contingency reserves

Load Availability	BC	AB	SK	MB	ON	QC	NB	NS	PE	NL
Spinning Reserve ($/home/year)										
15%	41	85	64	33	48	-	57	75	57	-
20%	54	114	85	45	64	-	76	100	76	-
Non-Spinning Reserve ($/home/year)										
15%	41	79	64	21	41	-	30	36	30	-
20%	55	105	85	28	54	-	39	48	39	-
Replacement Reserve ($/home/year)										
15%	-	-	-	-	9	-	101	84	101	-
20%	-	-	-	-	12	-	135	112	135	-

Similarly, Table S-6 shows the potential income per electric water heater if it was applied as a DR resource for contingency reserves. Two values are given for each reserve: the first represents baseload, i.e., that a minimum of 5% are available to be turned OFF (that would otherwise be ON) at all hours; the second represents intermediate-load, i.e., that a minimum of 15% of electric water heaters are available to be turned OFF 65% of the time. These values are considerably less than that for space heating, reflecting their lower energy consumption.

Table S-6: Annual value of electric water heater (EWH) DR contributions to contingency reserves

Sheddable Loads	Load Avail.	BC	AB	SK	MB	ON	QC	NB	NS	PE	NL
Spinning Reserve ($/EWH/year)											
5%	100%	10	20	15	8	12	-	14	18	14	-
15%	65%	19	40	30	16	23	-	27	35	27	-
Non-Spinning Reserve ($/EWH/year)											
5%	100%	10	19	15	5	10	-	7	9	7	-
15%	65%	19	37	30	10	19	-	14	17	14	-
Replacement Reserve ($/EWH/year)											
5%	100%	-	-	-	-	2	-	24	20	24	-
15%	65%	-	-	-	-	4	-	47	39	47	-

CONCLUSIONS

Embracing smart grid-enabled residential end-use loads as demand response (DR) resources enables their participation in the grid as value-added products (rather than as just uncontrollable loads). Their value as DR resources include increased asset utilization and capital investment deferment, improved system security and reliability, and increased energy optimization. Serving ancillary services (ASs, particularly reserves), as explored in this paper, are just one of many possible contributions they can make to improving system security and reliability. Together, DR opportunities can change the way utilities and operators view and interact with residential loads.

It was shown that there is substantial DR potential in residential space heating, space cooling, and electric water heating loads; this DR can be applied not just to the aforementioned ASs, but also to gain other benefits as well. The collective potential of residential DR across Canada from space and water heating end-uses alone was estimated to be 39 GW/85 GWh, the size of Québec's winter peak demand for 2 hours. All provinces but AB and SK have proportionally significant contributions to this potential.

There exists a substantial, but varying, market for ASs across the country that residential loads with the right technical capabilities could serve. Such DR loads would be able to capitalize on the value of ASs as one of many revenue streams it could participate in; in this regard, the most potential proportionally (by size) was found to lie in NB and NS with moderate opportunities in BC, MB, and ON. (The potential in QC was not evaluated.)

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Abbreviations

AC	Air conditioning
AS	Ancillary service
DA mkt	Day-ahead market
DER	Distributed energy resource
DR	Demand response
EWH	Electric water heater
FERC	US Federal Energy Regulatory Commission
ICT	Information and communications technology
NERC	North American Electric Reliability Corporation
NRCan	Natural Resources Canada
OATT	Open Access Transmission Tariff
RC	Regional council
RT mkt	Real-time market
SDAH	Single detached or attached house
SH	Space heating
TCL	Thermostatically controlled load
VIU	Vertically integrated utility

Provinces

BC	British Columbia
AB	Alberta
SK	Saskatchewan
MB	Manitoba
ON	Ontario
QC	Québec
NS	Nova Scotia
NB	New Brunswick
PE	Prince Edward Island
NL	Newfoundland and Labrador

1. Introduction

Historically, the power system has drawn mostly upon conventional bulk generators, such as hydro-electric plants, to provide the flexibility required to maintain supply-demand balance on the electric grid. In some areas, load has also played a small role in providing flexibility through rudimentary demand response (DR). While simple and not very responsive, such an arrangement has been suitable enough to provide basic peak shaving or load shifting services.

New smart grid technologies incorporating two-way communications can increase load responsiveness and flexibility, enabling them to offer more sophisticated DR services. These technologies have begun to be deployed in wholesale markets such as in the commercial and industrial sectors which feature large loads that provide good returns on required information and communications technology (ICT) investments. For example, established ICT systems such as that employed by the openADR Alliance [1] are enabling utilities to get automated load reductions dynamically from participants.

The residential sector, which constitutes about a third of all electricity consumption, represents an untapped potential for the more advanced forms of DR. Taken individually, the contributions from any single residential load is just a very small fraction of what could be gained from a large industrial or commercial customer; aggregated, they form a large resource pool. This potential has already been partially recognized, with simple devices attached to air conditioning (AC) or electric water heater (EWH) thermostats to provide rudimentary peak shaving or load shifting services to the utility (such as for Ontario's peaksaver Plus program [2]). However, up until now advanced DR with these loads has been cost prohibitive because of the complex ICT architecture required to capture flexibility from the vast number of small loads that make up the sector. The future smart grid will change that, bringing with it the backbone to facilitate residential contributions to the power system and automated management of loads.

This paper explores which residential resources and end-use applications are best suited for playing a role in future DR programs, quantifying their potential through a variety of measures by province. It assumes that the necessary ICT is in place and that while new devices or modifications to existing ones may be needed to enable their DR capabilities, the physical fundamentals of their behaviour (e.g., thermodynamics) and the needs of end-users remain unchanged.

Knowing where to apply DR to best benefit the power system and provide adequate revenue streams to cover costs is important for developing its potential. There are many benefits that can be explored, falling chiefly into the following categories: increased asset utilization and capital investment deferment, improved system security and reliability, and increased energy optimization. Aspects of improved security and reliability present a clearly defined and quantifiable 'added-value' revenue benefit via ancillary services (ASs). This report suggests existing ASs that can be supplied from DR and estimates its value to the DR loads.

Fig. 1 illustrates the scope of this work and its place in the smart grid picture, listing distributed energy resources (DER) on the left and their benefits on the right. While this work focusses on improved system security and reliability benefit (through ASs) from residential DR, other DERs may also bring similar benefits. Likewise, while this work highlights residential DR's potential value from serving AS, the DR also has value from the other benefits listed. The two subjects of this work, residential load DR and improved system security and reliability, are evaluated separately before being combined to evaluate overall market potential.

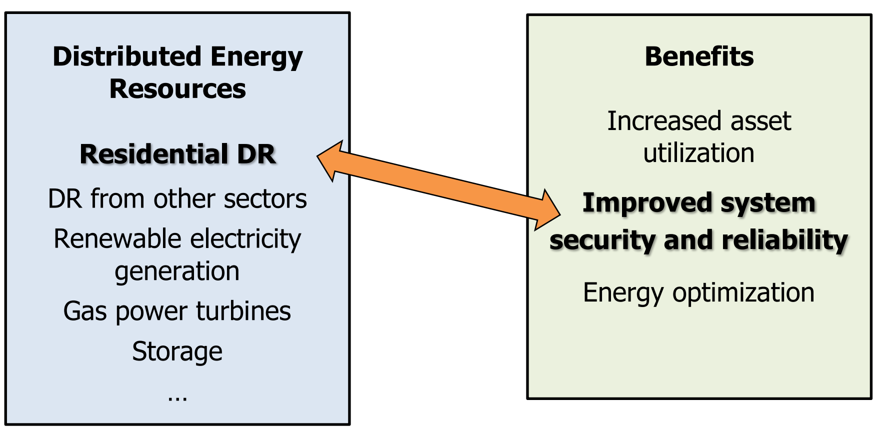

Figure 1: Scope of study

Section 2 defines the ASs and examines their potential by province, highlighting the market structure, value, and size for each. Section 3 identifies the major residential DR opportunities and evaluates their suitability in each of the AS categories. It also quantifies total DR potential by province and by end-use or appliance. The technical and economic suitability of each DR resources and their AS roles are altogether assessed by province and estimate market potential given in Section 4. Section 5 gives some final thoughts on benefits and challenges.

2. Ancillary Service Market Assessment

In Canada, electricity is individually regulated by each province, with federal oversight through the National Energy Board (NEB) limited to inter-provincial and international trading[1]. However, utilities in almost all provinces must adhere to reliability standards set out by the North American Electric Reliability Council (NERC). It is by NERC, and the regional councils (RCs), that AS and its rules are defined.

NERC (and FERC) identify ASs as those "necessary to support the transmission of capacity and energy from resources to loads while maintaining reliable operation of the Transmission Service Provider's transmission system in accordance with good utility practice [3]." They are categorized as those for balancing in normal conditions, those for balancing in contingency conditions, and others. The first two categories embrace the reserve services, loosely defined here as capacity available to be deployed towards maintaining balance between supply and demand. The other AS services, reactive power support and black-start capability, are not suitable roles for residential DR as, excepting electric vehicles, they cannot feed power into the system. In this section, these reserves will be further defined and followed by an analysis of the size and value of the market across the provinces except Newfoundland and Labrador (NL), which is not a member of NERC and for which there is limited data.

2.1. Services

NERC has identified and described five different reserves commonly used throughout Canada and the US [3], as reproduced in Table 1. As NERC notes, these are not definitive insomuch as it is a generalization of the definitions and criteria which vary by region, province or state. It may be noticed that these AS definitions are not inclusive of DR; it is expected that their role as a DR provider will evolve as utilities gain more experience and evidence of their capabilities.

[1] This is different than in the US, where its Federal Energy Regulatory Commission (FERC) has oversight of energy markets.

Table 1: Reserve ancillary service definitions [3]

Regulation Reserve	Online resources, on automatic generation control (AGC) that can respond rapidly to AGC requests for up and down movements; used to track the minute-to-minute fluctuations in system load and to correct for unintended fluctuations in generator output […].
Load Following	Similar to regulation but slower. Bridges between the regulation service and the hourly energy markets.
Spinning Reserve	Online generation, synchronized to the grid, that can begin to increase output immediately in response to a major generator or transmission outage and can reach full output within 10 minutes […].
Non-Spinning Reserve	Same as spinning reserve, but does not need to respond immediately; resources can be offline but still must be capable of reaching full output within the required 10 minutes
Replacement/ Supplemental Reserve	Supplemental reserve is used to restore spinning and non-spinning reserves to their pre-contingency status; it must have a 30-60 minutes response time.

Regulation and load following reserves are continuously in operation during normal system conditions. Regulation is a fast acting reserve that is responsive to frequency changes on the network and is used to correct second-by-second differences between generation and demand. Load following corrects for demand-supply imbalances between dispatch periods.

Spinning, non-spinning, and replacement/supplemental reserves are activated only during contingency conditions. Ten-minute spinning and non-spinning reserves are used to help the power system survive any immediate contingency. Together, these reserves are sized to be able to at minimum replace the generation lost from any foreseeable single element outage (e.g., generator or transmission circuit) and keep the system running. Spinning reserves are resources synchronized (connected) to the power system able to respond immediately and, within 10 minutes, fully. Non-spinning reserves are resources not connected to the grid but also able to respond fully within 10 minutes. The mix between spinning and non-spinning is a function of RC regulations and past performance of the utility. Thirty-minute replacement reserves are used to restore, i.e., take the place of, the ten-minute reserves following a contingency, so that the ten-minute reserves can be in place should another contingency occurs. As its name suggests, 30-minute reserves must be usable within 30 minutes.

Table 2 gives the criteria under which generation resources, and future DR providers, must meet to provision AS resources. These criteria are fairly similar across RCs, though as seen in Section 2.2 not all provinces will have a need for all of them. (This is particularly true of load following, which is more common in systems that only dispatch once every hour or so, to address intra-hour demand-supply variations not covered by regulation.)

Table 2: Reserve ancillary service criteria [3]

	Response Speed	Duration	Cycle Time
Regulation Reserve	1 min	minutes	minutes
Load Following	5 - 10 min	5 min - hours	5 min - hours
Spinning Reserve	seconds - 10 min	10 min - 2 h	hours - days
Non-Spinning Reserve	< 10 min	10 min - 2 h	hours - days
Replacement/Supplemental Reserve	< 30 min	2 h	hours - days

Response speed is a measure of how quickly the reserve must deploy once activated; in terms of DR, it's how quickly the load can react once called upon. Duration is the length of time after deployment that the reserve must be able to stay activated and 'producing.' Cycle time is the period between deployments.[2] From a thermal storage enabled DR perspective (see Section 3.1), duration can be paralleled to storage capacity and cycle time to thermal recharge period. These characteristics will become important when assessing the DR capacity of each resource; but before that, reserve market type and size will be discussed.

2.2. System Structure and Size

Power systems and their ancillary services operate in one of two regulatory atmospheres: deregulated (market) or vertically-integrated. In the deregulated markets (AB and ON) most ASs are procured via auction. In vertically-integrated utility (VIU) systems (all other provinces), ASs are self-supplied by the utilities or procured by contract from third parties. Table 3 shows the avenues by which they are currently procured in each province. (Material on ASs within

[2] It is noted once again that these are the current criteria for existing ASs. Today's standards do not preclude changes in the future that will be more amiable to new sources of ASs. This may be include, e.g., recognizing that most spinning/non-spinning reserve deployments are for far shorter periods than that required and creating new services to suit [11].

deregulated systems was gathered from readily available market documents, whereas that within VIUs was derived from open access transmission tariffs (OATTs), the rules prescribing third party access to a province's electric grid.)

Table 3: AS Reserve procurement structure

Reserve	BC	AB	SK	MB	ON	QC	NB/PE*	NS
Regulation	VIU	RT mkt	VIU	VIU	Contract	VIU	VIU	VIU
Load following	-	-	-	-	-	-	VIU	VIU
Spinning	VIU	DA mkt	VIU	VIU	RT mkt	VIU	VIU	VIU
Non-spinning	VIU	DA mkt	VIU	VIU	RT mkt	VIU	VIU	VIU
Replacement	-	-	-	-	RT mkt	-	VIU	VIU

In AB and ON, ASs may be procured in the day-ahead (DA) or real-time (RT) market (mkt). The fast-dispatch energy markets of AB (1 min.) and ON (5 min.) preclude the need for load following reserves. AB market documents make no reference to replacement reserves, and ON acquires its regulation reserve through undisclosed contract. In the other provinces, ASs were procured in a VIU environment (noting that NB and PE OATTs are structured similarly). In all but the Maritime VIUs, load following and replacement reserve does not appear in the OATTs as a tariffed service.

Drawing back to DR, the regulatory environments dictate not the potential but the path DR would need to take to serve ASs. In markets, DR would have to compete, likely through third party aggregators, with conventional generation and each other for the privilege of supplying reserves. In VIUs, DR would have to be contracted by the utility or `lines' user, either directly through a program of its own or third party aggregators.

Each provincial power system operator sets its own reserve requirements to meet its RC and NERC reliability requirements. Estimates are given in Table 4 and charted in Fig. 2; these are based on market data, RC reliability assessment reports, and calculations from OATT data. For reference and perspective, each province's average and peak loads are also given.

Table 4: Power system loads and estimated reserve requirements

	BC	AB	SK	MB	ON	QC	NB	NS	PE
Avg. Load (MW)	6900	8600	2200	2700	16100	19400	1500	1400	130
Peak Load (MW)	11000	10300	3200	4400	24600	38000	2800	2200	220
Reserve Requirements									
Regulation (MW)	140	110-225	30	40	200	500	50	50	5
Load Following (MW)	-	-	-	-	-	-	140	120	10
Spinning (MW)	250	225-257	100	40	360	1000	30	30	3
Non-Spinning (MW)	250	225-257	150	70	590	1000	120	110	10
Replacement (MW)	-	-	-	-	470	500	50	40	4

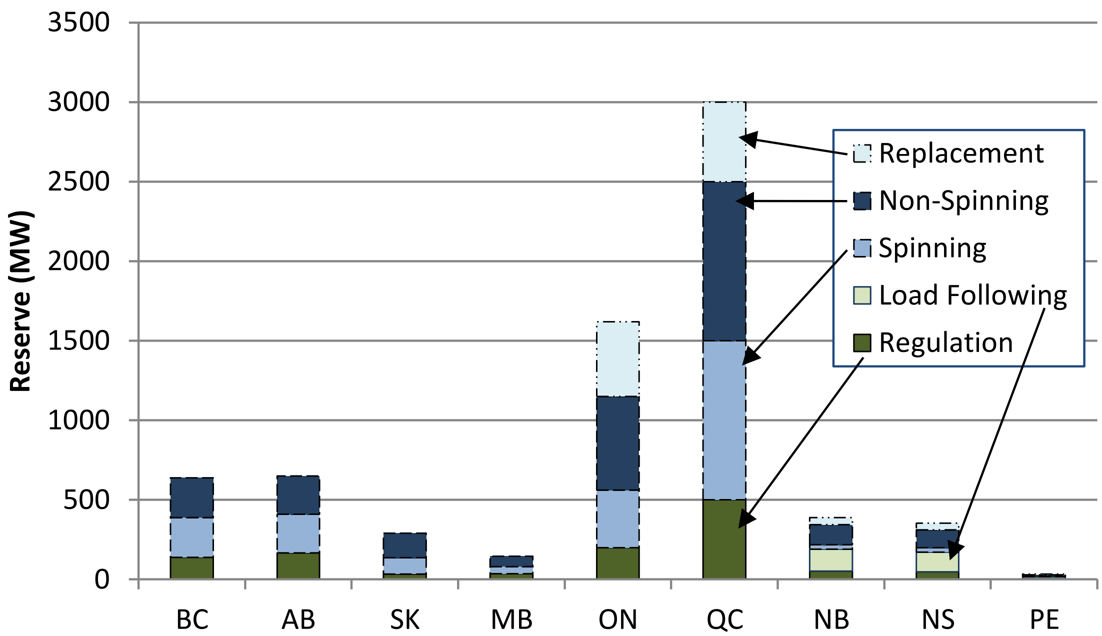

Figure 2: Estimated AS reserve requirements

While not exactly proportional (due to different generator and transmission assets), each province's reserve requirements are roughly commensurate to load. BC and AB split their 10-minute reserve requirements between spinning and non-spinning 50-50 with the other using a split closer to 35-65. By magnitude, QC and ON have the largest opportunities for AS serving DR, followed by BC and AB.

2.3. Value

Current procurement costs of providing ASs, whether from utility owned assets, contracts, or competitive market, vary by province. As done to fill in Table 5, they can be estimated/ascertained from OATTs[3], regulatory documents, or historic market prices.

Table 5: Procurement costs of reserve

	BC	AB	SK	MB	ON	QC[1]	NB/PE[2]	NS
Regulation ($/MWh)	6.4	11	14	5.1	>24	n/a	2.0	8.5
Load following ($/MWh)	-	-	-	-	-	-	1.8	12
Spinning ($/MWh)	6.2	13	9.7	5.1	7.3	n/a	8.7	11
Non-spinning ($/MWh)	6.3	12	9.7	3.1	6.2	n/a	4.5	5.5
Replacement ($/MWh)	-	-	-	-	1.3	-	15	13

[1] Insufficient information available
[2] Estimated assuming that NB/PE transmission users have the same obligations as NS users.

Estimates in ON (excluding regulation) and AB reflect their average 2012 standby prices and exclude activation/deployment costs. These costs, priced in the RT or DA markets, must cover both direct costs (e.g., fuel, O&M) of the reserve resource and opportunity costs (from not being able to use that resource in the energy markets). The other estimates were calculated from OATTs in effect at the beginning of 2014 by dividing the default monthly rates by user obligation and probably include both the stand-by and (pro-rated) activation/deployment costs.

There is a wide variation in reserve costs both amongst the provinces and between reserve services, reflecting the diversity of each province's assets. BC and MB's lower rates for all services may be attributed to the vast hydro-electric resources they can draw upon. AB, SK, and NS's costs reflect a higher reliance on more costly thermal resources. Ontario's regulation cost, markedly higher than that of other provinces, reflects the market price for electricity (the average hourly Ontario electric price), i.e., the opportunity cost from not being able to participate in energy markets. NB/PE's costs for regulation and load following are

[3] The 2012 average standby (non-activation) prices were used for AB and ON, and the 2014 OATT costs, taken by dividing the default monthly rates by user obligation, were used for the other provinces. Insufficient information was available on QC's tariffs and NB & PE rates were estimated assuming that they pass on the same obligations to their network users as NS does to theirs.)

uncharacteristically lower than that for the contingency reserves; a reason for this might be that cheaper hydro is used to service the former, while thermal generators are used for the latter.

Fig. 3 charts the annual value of each reserve service for each province excluding QC. From a monetary standpoint (negating any policy or regulatory hurdles), the largest total potential revenue markets for DR-enabled ASs are ON and AB, followed by BC, SK, NB, and NS. The most valued AS, by type, differs by province.

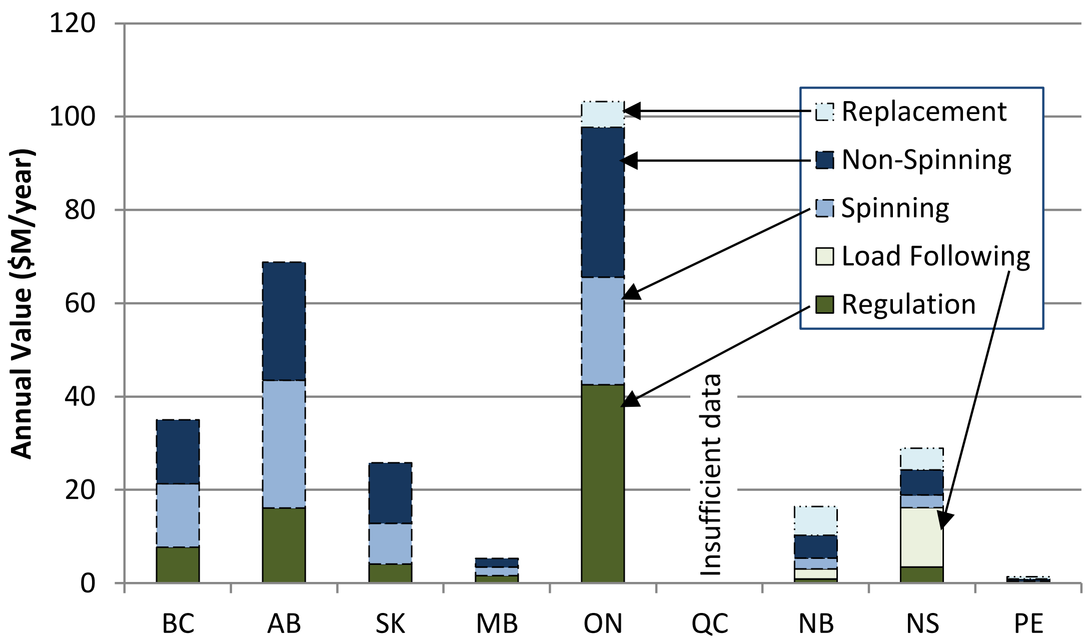

Figure 3: Annual value of reserve services

Their value driven upward by deregulation, the annual market for ancillary services is estimated to be about $70 M in AB and $100 M in ON. In those markets, DR may be in a good position to build its revenue stream via ASs because their small operational and opportunity cost puts it in a more competitive position than conventional providers. In VIUs, where the most value resides in BC, NS, and SK, DR-enabled ASs will offer utilities a way to free up resources (e.g., for export markets) otherwise tasked to ASs.

3. Demand Response Assessment

Responsible for a third of electricity consumption, Canada's residential sector is a considerable source of flexible DR potential which, beyond some rudimentary application to peak shaving and load shifting applications, has hitherto largely gone untapped. Whereas new ICT capabilities being developed alongside the smart grid will soon make it possible to capture this potential, previously the fuller exploitation of these loads had been hindered by the lack of ICT architecture required to effectively and economically manage the numerous small loads that characterize the sector.

The purpose of this section is to estimate Canada's potential residential DR capacity both in a general sense and in regards to the reserve ASs described in Section 2. It assumes that the necessary ICT to exploit loads for DR is available, and that while different loads may need to be modified for DR, their fundamental operational characteristics remain the same thus remaining invisible to the end user. The estimation will both be a factor of the fundamental physics and behaviour driving end-uses (from which the DR will draw) as well as the quantity available to be enlisted.

NRCan [4] broadly categorizes these end-uses into one of the following: appliances, lighting, space cooling, space heating, and water heating. Their makeup is shown in Fig. 4 as a percentage of total electric energy consumption nationwide; they form the basis of this report's examination into end-use supported DR.

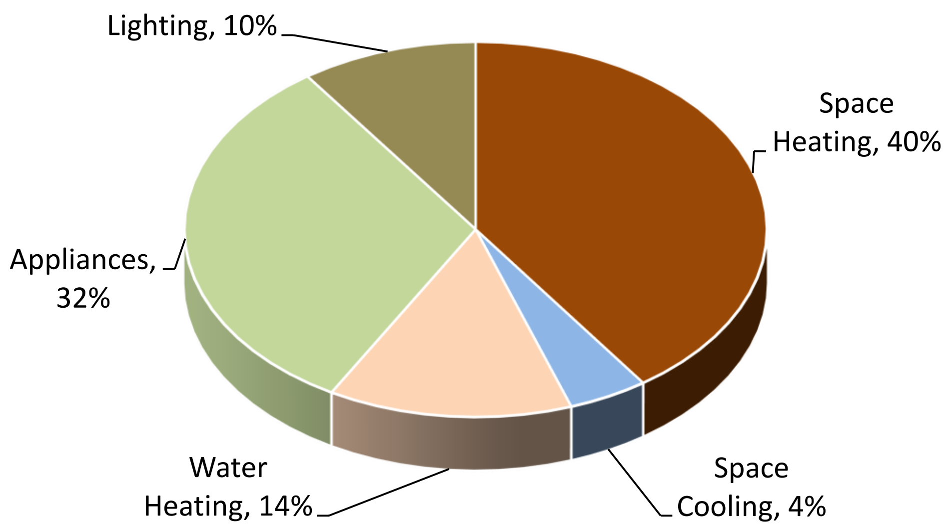

Figure 4: Electricity consumption, by end-use [4]

Unsurprisingly, the chief end-use consumer of electricity is space heating, at 40%. This is followed by appliances, at 32%, and includes large and small appliances not separately counted. Lighting, water heating, and space cooling applications round out the remaining 28% of electricity consumption. For reasons soon expounded, space heating, space cooling, and water heating are the best resources for DR and will bear most of the focus of this work.

In this section, first an overview of end-use applications is given with an eye for their suitability as sources for DR. Next, a provincial inventory is made of viable DR assets, along with an estimate of their potential. Finally, the provincial market potential of each identified DR end-use serving as a resource in any of the reserve ASs is given.

3.1. End-use DR Technical Competencies

Thermostatically controlled loads (TCLs), comprising the vast majority of all heating and cooling loads, make up the greatest portion of Canada's residential energy needs. The thermostats of these TCLs use their heating or cooling elements to maintain temperatures within a specified temperature range (deadband); this deadband gives electrically-fueled TCLs a pool of thermal storage potential from which to draw upon for DR capacity without having a noticeable effect on end-users or device applications. TCLs have been cited by Callaway et al. [5], Mathieu et al. [6], and others as having the most DR potential to deliver “short timescale” ASs such as regulation and load following. Other research [7,8] has shown that other TCLs also have potential as providers of “mid-timescale services,” i.e., peak shaving or contingency reserves.

While non-TCLs, such as washers, dryers, and lighting, can be recruited for DR, with the exception of yet to be widely adopted electric vehicles (EVs) most do not have any storage potential. Activating these non-TCLs will have an immediate impact on end-users or device applications, limiting their use for DR. Subsequently, most of these are better suited to peak reduction or load shifting efforts that are behavioural driven (e.g., by implementing time-of-use rates).

TCLs, and their viability as DR resources, will drive the identification and quantification of DR potential in each of the aforementioned end-use categories.

3.1.1. Space Heating

The claim that space heating is among the better residential DR resources can be made for two reasons. First, every home has a good quantity of thermal capacitance/mass (from its envelope and contents) that can store energy that can be drawn from for DR. The thermal capacitance allows space heating to be turned OFF for short periods while keeping temperature within an acceptable comfort range [7]. Second, substantiated by the fact that it can account for a significant portion of a power system’s demand profile, space heating represents a lot of energy and power that can be controlled and relied on for DR.

The prevalent technology behind electric space heating is the electric baseboard heater, followed by the electric furnace and the heat pump, all of which can be enrolled in a DR program. Supported by the home’s thermal mass, these can be turned ON and OFF, as necessary to supply DR, to the extent that temperature ranges remain comfortable. (E.g., depending on the home, space heating can be switched OFF for about two hours in exchange for a 3°C temperature drop.) Additional thermal capacitance, and thus DR capacity, can be gained by installing electric thermal storage devices which can store a half-day or more of heat.

The long cycle times between reserve activations (Table 2) mean that heating loads will always have sufficient thermal storage capacity to meet the requirements for servicing contingency reserves. However, it is not known how well heating loads may lend themselves to regulation or load following – the fast cycle times required of these reserves may cause storage capacity to be exhausted or filled if up and down reserve calls are unbalanced, or alternatively, to be always sufficient if up and down reserve calls balance each other out.

The caveat with using space heating for DR is that its potential varies with season: the most potential will be in the winter, when heating requirements are at their fullest; obviously, there is none in the summer when there is no heating requirement.

3.1.2. Space Cooling

Space cooling is a TCL that can also be a good DR resource. To offer the DR, it uses the same principle as space heating DR and draws upon a home's thermal capacity to maintain a comfortable temperature range while keeping AC OFF. However, compared to space heating, the period that temperature can be maintained comfortably (when AC is OFF) is shorter (about 30 to 60 minutes). This is due to thermal gains from people and equipment (which, while beneficial for space heating DR is detrimental here) and solar gains (which often coincides with the time of day that space cooling DR is needed). This shorter effective thermal DR storage capacity may make space cooling DR more suitable for regulation and load following [9], though it limits its ability to serve contingency reserves (which have longer deployment periods).

Complementing the availability of DR from heating loads, space cooling demand (and DR from it) will be mostly confined to hot summer days. This puts a limit on its period of usefulness as a DR resource and restricts the regions in which it can be applied, as reflected in its low energy consumption shown in Fig. 4.

3.1.3. Water Heating

EWHs are also TCLs, each having a hot water storage tank typically 40 or 60 UK gallons capable of storing 3 to 6 kWh of accessible thermal energy when its contents are fully charged (at the upper end of the deadband). This tank, used to give end-users have a constant supply of hot water, also allows its heating elements to be switched on or off as necessary for DR while ensuring that user needs are met. [8]

There are some characteristics of EWHs that require them to be treated differently than space heating or space cooling TCLs as a DR resource. First, EWHs are well-insulated and have limited heat losses to the environment. Second, EWH loads are not as seasonal or weather dependent to the extent that space heating and cooling loads are, but instead are subject to user behaviour with variation throughout the day. This means that the thermal capacity of EWHs, and subsequently their DR potential, varies during the day as dictated by the user demand for hot water. Fortunately, these daily profiles are predictable at the aggregated level for a large population.

A typical load profile of a large population of EWHs is given in Fig. 5. For any given minute, it shows the fraction of EWHs that would normally (i.e., without DR) be drawing power from the grid. Drawing power between 5 and 30% of the population's cumulative rated power capacity, there is one peak in the morning, another peak in the evening, and a large valley in the late-night/early morning. EWH DR would have to work within the limitations of this curve, e.g., recognizing that during valleys EWHs may need to be constrained off (since, once the upper deadband is reached, there is no energy extraction/water draw to release capacity) and likewise during peaks EWHs may need to be constrained on (to maintain minimum temperatures).

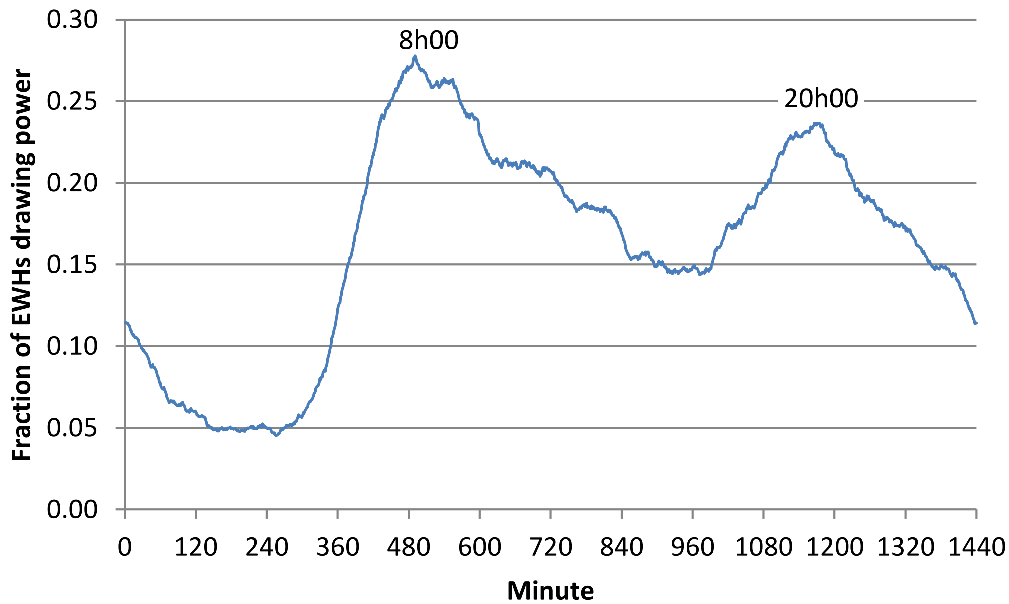

Figure 5: Daily EWH population load profile [8]

Like the other TCLs discussed, EWHs appear suitable for providing DR for contingency reserves with minimal impact on the user, although capacity will vary during the day. There may also be similar opportunities for EWH DR to supply regulation and load following services, but this requires further study.

3.1.4. Appliances and Lighting

Appliances include all those large and small not already falling into another category; the highest energy users are refrigerators, clothes dryers, and ranges. However, even though this category encompasses some TCLs, such as refrigerators and freezers [6], their power draw is not considerable. Most of the other non-TCL appliances would also make poor resources for DR, since activation would have an immediate and definitive impact on end-use. (This does not discount their suitability for other uses beyond this work's scope, such as peak reduction or load shifting).

All-electric vehicles (EVs) or plug-in hybrid electric vehicles (PHEVs) are potential game changers which may open up a vast new flexible resource pool for DR. At minimum, the emergence of EV/PHEV at more than diminutive numbers will require some charging control to avoid problems associated with peaking demands. Fully utilized, the batteries of EVs and PHEVs can be used in vehicle-to-grid-half (V2G-half), vehicle-to-grid full (V2G) and/or vehicle-to-building DR programs [10]. However, as for the moment their adoption is at infancy, possible utilizations fall out of the scope of this report.

Lighting, also a non-TCL, is not well suited for DR in the residential sector since it is uncontrolled. While there have been demonstrations of lighting supported DR in the commercial sector, it cannot be easily or economically applied to individual homes.

3.1.5. Summary

Table 6 summarizes the above discussions, indicating whether the various residential sector end-uses seem technologically well suited to supply each of the reserve ancillary services as per the criteria given in Section 2.1. A “moderate” assessment means that suitability is more limited or that further study is needed.

Table 6: End-use DR technical competencies to supply reserve ASs (low (–), moderate (↗), and high (↑))

Reserve	Space Heating	Space Cooling	Water Heating	Appliances	Lighting
Regulation	↗	↗	↗	–	–
Load Following	↗	↗	↗	–	–
Spinning	↑	–	↑	–	–
Non-spinning	↑	–	↑	–	–
Replacement	↑	–	↑	–	–

These end-use technical capabilities should be weighed alongside their abundance or scarcity in the provinces.

3.2. End-use DR Provincial Inventory

Total residential sector electricity demands, and the array of end-uses that make up each, varies widely by province and so does the potential DR from each. Table 7 illustrates these differences in total residential energy consumption, both by magnitude and as a percentage of total electrical use by all sectors.

Table 7: Electric residential energy consumption, by province [4]

	BC	AB	SK	MB	ON	QC	NB	NS	PE	NL
End-use (TWh)	19.2	11.8	3.4	8.0	33.2	63.3	5.4	4.3	0.2	3.9
End-use (% of all elec. demand)	31%	16%	10%	32%	22%	33%	44%	34%	13%	44%

The magnitude of residential electricity end-use is correlated to a province's population and/or the sector's reliance on electricity for end-use needs. By this measure, QC, ON, and BC have the largest demands. On the other hand, the percentage measure correlates just to a province's reliance on electricity for residential energy needs. By this measure, residential demands in BC, MB, QC, NB, NS, and NL all show significant dependence on electrical energy.

These differences in provincial residential demands may be attributable to historic and current policies and electric rates, geography (climate), and fuel/energy availability, etc. Also affecting end-use, and therefore DR potential, is each province's blend of housing stock as broken down in Fig. 8 by share (bars, left y-axis) and magnitude (markers, right y-axis).

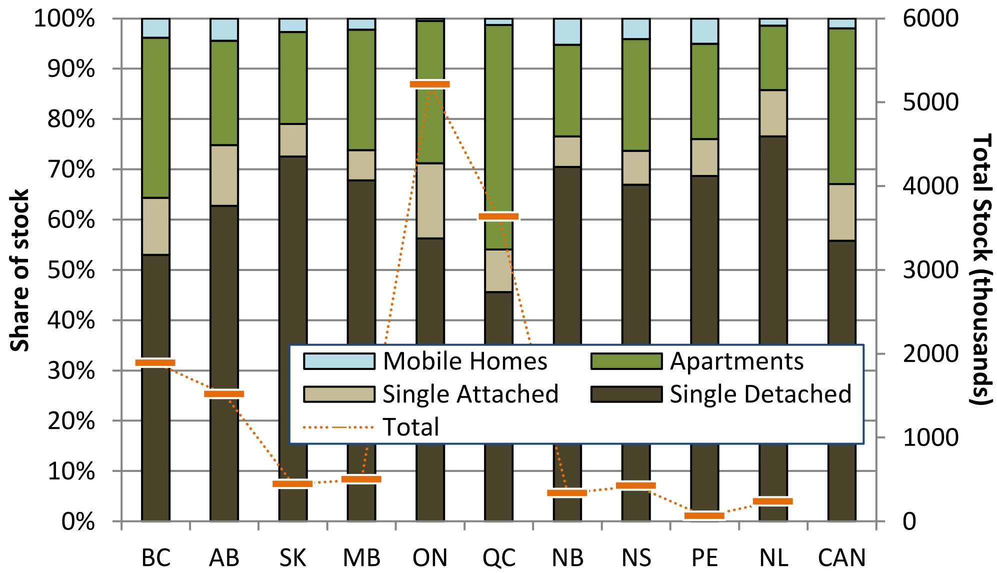

Figure 6: Breakdown by housing type [4]

Provincial housing stock is comprised of single attached, single detached, apartments, and mobile dwellings. The overall penetration of single attached and detached houses (SDAHs) is just under 70% nationally but with large variations between provinces. A noticeably lower share of Québec homes, 55%, are SDAHs compared to any other province while NL has a much above average share of SDAHs, 85%. Most dwellings are in ON and QC.

SDAHs are probably the easiest to enlist for DR, owing to the impression that owner and occupant are more likely a) to be one and the same, and thus be more willing and able to adopt new technologies and b) to have access to the required end-use devices. Enlisting apartment end-uses for DR may be more difficult, since a) implementation may require consensus from owner, tenants, or management boards and/or b) they may not have the right end-use load types, e.g., relying instead on shared (heating and cooling) systems.

This section gives a province-by-province inventory of the resources that may be amiable for use in DR programs as concluded in Section 3.1: space heating, space cooling, and water heating. It analyzes suitability from a resource availability perspective, i.e., based on how many units are available to adapt for DR, and gives estimates on their potential assuming they can be adapted for DR without requiring significant change to their base characteristics.

3.2.1. Space Heating

Electric space heating systems include all whose primary heat source is electric energy: electric baseboards, furnaces, and heat pumps (which frequently employ resistance elements for supplemental heat).[4] They are the single largest driver of residential electric demand; this fact, combined with the thermal capacity of the homes, makes them one of the leading sources of electric thermal storage capacity and DR resource potential. However, as can be seen in Table 8, electric space heating number and penetration, as a percentage of heating systems, varies widely by province.

Table 8: Number of households with electric heating systems [4]

	BC	AB	SK	MB	ON	QC	NB	NS	PE	NL
No. Electric Space Heating Systems (k)	644	97	39	204	998	2432	183	115	5	144
Penetration (%)	34%	6%	9%	41%	19%	67%	54%	27%	8%	61%

While DR can be utilize any number of loads, in practice it is technically and economically more feasible to deploy it where there are high concentrations or large populations of loads. Such locations increase the likelihood that a sufficient number of loads can adopt DR to make a measurable impact and make enrollment, management, and ICT easier by containing rollout within a reasonable geographic area. Keeping this in mind, Table 8 shows that electric space heating penetration is very good (above 40%) in QC, NL, NB, and MB and substantial in BC and NS. In ON, electric's share of heating systems ranks only above the slight numbers of AB, PE, and SK, but by numbers alone it still ranks second, only behind QC, servicing one million households.

Dwelling type, whether single detached, single attached, apartment, or other (such as mobile homes) influences heating load and thus DR potential. As mentioned earlier, it may also affect ease of ICT deployment and DR participation rates. Table 9 gives what fractions of electric space heating systems are installed in each major dwelling type. Indicators drawing on heating load (introduced next) assume that the diversified peak load of SDAHs is 7 kW and that of apartments

[4] Dual-fueled systems, e.g., wood/electric and oil/electric furnaces, are not counted for the purposes of this report. Although they can add to DR potential, their electric consumption is discouraged during peak periods and no data is available on their use during other periods.

is 3.5 kW. (Other dwelling types are not considered.) These dwellings are assumed to have storage capabilities commensurate with a two hours; this is based on the presumption that a 3°C thermostat setback is capable of removing a dwelling's heating load for two hours on a cold winter's day (before heating resumes at the lower setpoint).

Table 9: Breakdown of electric space heating systems by dwelling type [4]

	BC	AB	SK	MB	ON	QC	NB	NS	PE	NL
Single detached and attached	63%	77%	84%	73%	73%	47%	75%	74%	76%	86%
Apartment	33%	16%	15%	25%	26%	51%	20%	22%	13%	13%

Besides the above numbers and penetration, there are a number of other indicators of DR potential that also take into account the particularities of each province's electric system:

i. Maximum load as a percentage of peak provincial load
ii. Annual demand as a percentage of annual provincial demand
iii. Storage potential as a percentage of average hourly provincial demand

These indicators, whose equations are given in Appendix A, are tailored to give a better idea of space heating deployment relative to each province's demand characteristics and load composition. They are illustrated alongside electric space heating system penetration in Fig. 7.

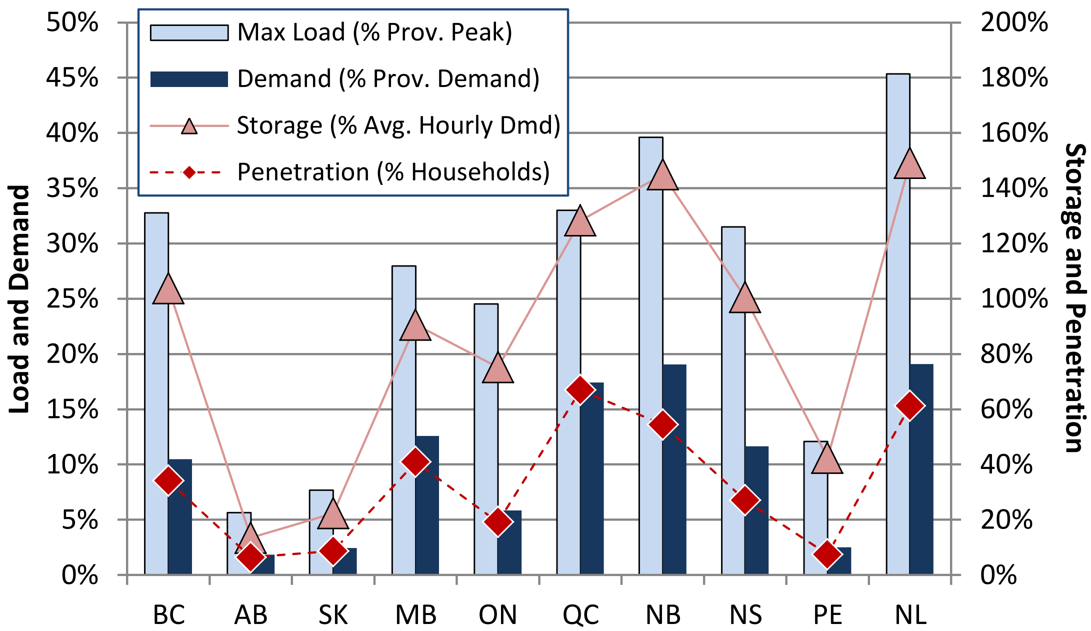

Figure 7: Indicators of space heating DR potential

Maximum space heating load as a percentage of peak provincial load (light blue bars, left axis) have been calculated using the aforementioned heat load assumptions for SDAHs and apartments. In NB and NL its value is greater than ≈40% and in BC, MB, ON, QC, and NS it falls between 25-35%. This is a different, and arguably more representative, potential distribution than penetration (diamonds, right axis). The reasons for the differences are twofold. First, the max load indicator reflects the different heating requirements of SDAH and apartments while penetration does not. This has the effect of lowering the potential, as indicated by max load, in provinces where apartments take a large share of electric heating systems (e.g., QC, Table 9). Second, as noted earlier the max load indicator takes into account system demand and the composition of loads making up its peak.

The second indicator, annual demand as a percentage of annual provincial demand (dark blue bars, left axis), follows roughly the same pattern as penetration and reveals no additional information above that gained from examining Table 8.

The last indicator (triangles, right axis) estimates space heating storage potential and reports it as a percentage of average hourly provincial demand. Based on this assessment, QC, NB, and

NL's housing stock have a high DR resource potential and BC, MB, ON, and NS's stock have a lesser but still capable potential. Table 10, based on equations given in Appendix A, presents the estimated peak space heating load and electric housing stock thermal storage capacities.

Table 10: Peak electric space heating load and thermal storage capacities

	BC	AB	SK	MB	ON	QC	NB	NS	PE	NL
Peak Load (MW)	3580	580	250	1220	6050	12500	1090	680	27	930
Thermal Storage Capacity (MWh)	7150	1160	490	2440	12100	24900	2170	1370	53	1860

Three indicators were presented clearly showing that electric space heating penetration, while useful, should not be held as the only measure of space heating DR potential. Taking into consideration all measures, the housing stocks of QC, NB, and NL appear to have the most potential, followed by BC, MB, ON, and NS.

3.2.2. Space Cooling

Space cooling/AC is only a minor consumer of electric power, but because of its coincidence with summer demand peaks it could be an important DR resource. Fig. 8 gives AC energy use as a percentage of annual system electric energy use (bars/left axis) and AC's penetration of households (markers/right axis). Room and central AC are treated separately as it can be argued that of the two, central AC has much more potential given its energy consumption. The number of households with central AC is given in Table 11.

Table 11: Number of households with central air cooling [4]

	BC	AB	SK	MB	ON	QC	NB	NS	PE	NL
No. of Central AC Households (k)	198	221	194	271	3110	524	52.3	18.0	0.5	4.8

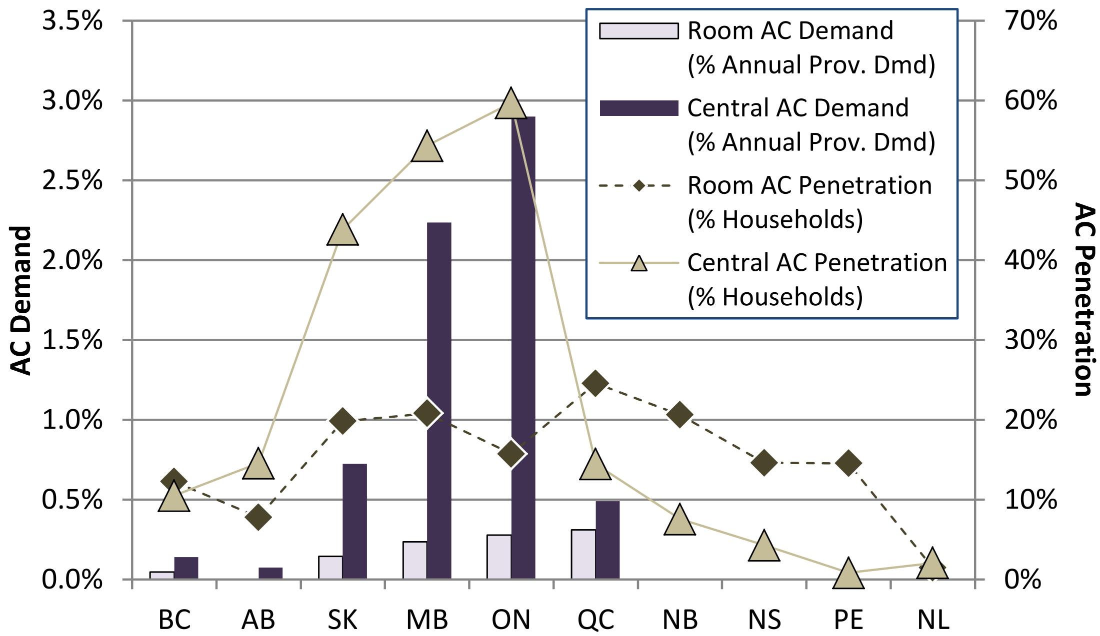

Figure 8: Space cooling DR potential indicators

AC units are common in SK, MB, and ON, where central units are present in over 40% of households. In the other provinces, where AC penetration is much lower, room units are more predominant. Taking energy consumption as an indicator of DR potential from space cooling, only MB and ON have sizable demands and therefore potential for providing DR services. At this time, further research is required to understand the potential of AC supported DR.

3.2.3. Electric Water Heaters

At first glance, EWHs have excellent potential as DR resources because of their moderate energy consumption (which is double that of space cooling) and power requirements, good thermal capacity (3-6 kWh each), and year-round availability [8]. Like space heating and cooling, their potential varies by province. Table 12 reports by province their estimated numbers and penetration as a percentage of all water heaters types.

Table 12: Number of EWHs [4]

	BC	AB	SK	MB	ON	QC	NB	NS	PE	NL
No. of EWHs (k)	676	109	72	248	1234	3312	306	216	13	209
Penetration (%)	36%	7%	16%	50%	24%	91%	91%	51%	21%	89%

By either measures, AB, SK, and PE do not have significant EWH populations. Unless localized populations exist, this scarcity may represent a commercial barrier to DR adoption as it does for space heating. ON and BC also have low EWH penetrations, 25% and 36% respectively, but their absolute numbers mean that there is yet a good case for their DR adoption[5]. Conversely, penetration in MB and NS are high (50%) and in QC, NB, and NL very high (90%+), making these provinces seemingly the best places to begin EWH DR adoption.

To further this analysis into EWH DR potential, various indicators (similar to that used in Section 3.2.1 for space heating) are proposed:

i. Maximum load as a percentage of peak provincial load
ii. Annual demand as a percentage of annual provincial demand
iii. Storage potential as a percentage of average hourly provincial demand

Their equations are given in Appendix B and values, by province, illustrated in Fig. 9. For comparison, EWH penetration as a percentage of all water heater types is also given. Table 13 gives the assumptions made on composition and attributes of each province's EWH population[6]; DR-accessible storage is the amount of energy in each EWH, stored as heat, that can be drawn upon for DR deployment [8].

[5] Anecdotally, EWHs are uncommon in southwestern ON, but have higher adoption rates in rural areas and others not served by natural gas. In BC, EWH penetration is higher on Vancouver Island and in rural areas.

[6] The compositions are again anecdotal, based on conversations with utilities and water heater suppliers in central and eastern Canada.

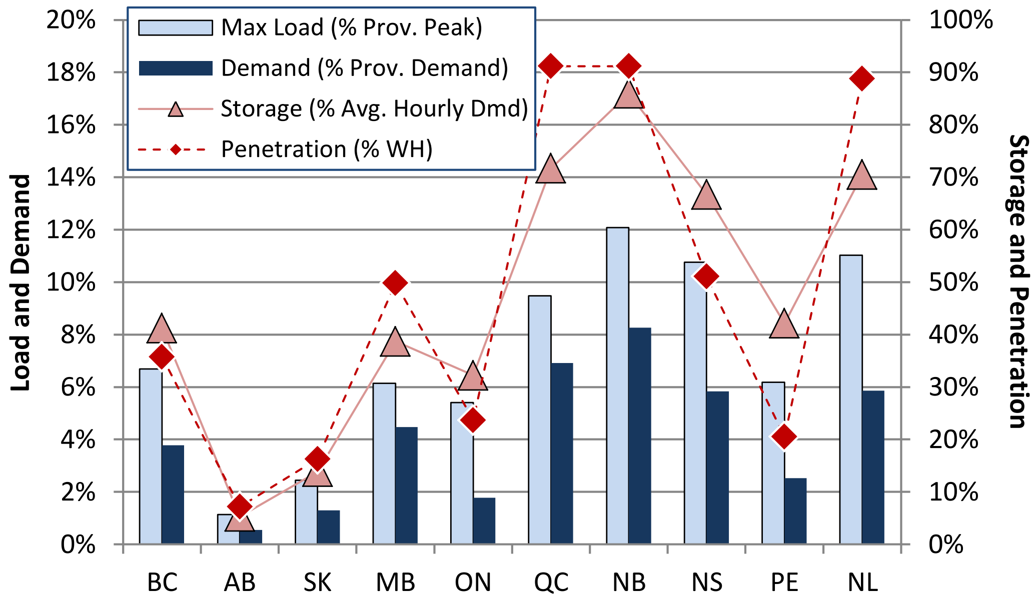

Figure 9: EWH DR potential indicators

Table 13: EWH population attributes

% of EWH Population	Tank Size	Element Rating	DR-Accessible Storage
60%	40 UK gal	3.0 kW	3 kWh
40%	60 UK gal	4.5 kW	6 kWh

Considering that at peak 30% of EWHs are drawing power, the max load indicator (light blue bars) gauges the size of any EWH DR relative to system demand. By this measure, the highest potential can be realized in QC, NB, NS, and NL and, more moderately, in BC, MB, ON, and PE. EWH DR would have negligible impact in AB and SK. The indicator roughly follows the same trend as EWH penetration, with differences attributable to the loads making up the system peak (e.g., residential, commercial, and industrial mix).

The second indicator, annual demand as a percentage of system demand (dark blue bars), follows very closely EWH penetration, thus showing no additional insight than that found from Table 12. The third indicator reports EWH thermal storage capacity, based on Table 13, as a percentage of average hourly system demand. From this indicator (triangles) findings similar to that of the first can be drawn: QC, NB, NS, and NL have the highest potential, followed by BC, MB, ON, and PE. Table 14 gives the estimated peak EWH load and thermal storage capacity used.

Table 14: EWH peak and minimum load and thermal storage capacity

	BC	AB	SK	MB	ON	QC	NB	NS	PE	NL
Peak Load (MW)	730	120	78	270	1330	3580	330	230	14	230
Min. Load (MW)	120	20	13	45	220	600	55	39	2.3	38
Thermal Storage Capacity (MWh)	2840	460	300	1040	5180	13900	1290	910	50	880

Uncontrolled and without DR, EWH demand will vary by hour with peaks and valleys like those shown in Fig. 5, affecting how much DR potential can be gained from them. In calculating peak load, and thus maximum DR potential, a peak diversified load factor of 30% was chosen. Similarly, minimum DR potential is based on the minimum load; for this, 5% diversified load factor is used. These values could also be used as a baseline for determining what response (load reduction) could be expected if all EWHs in the province were to be called for contingency reserves. For example, reserves up to 120 MW during valley periods and 730 MW during peak periods might be achievable from BC's EWHs population; comparing this to Table 4, there is potential for EWH populations to meet a substantial portion of BCs reserve needs.

The three indicators of DR potential from EWHs given in this section are mostly consistent, with high adoption potential in QC, NB, NS, and NL and moderate potential in BC, MB, ON, and PE.

3.2.4. Summary

Table 15 summarizes the prior discussions on DR resource availability. It shows, by province, each end-use's suitability as a resource for DR, based on its availability and potential capacity.

Table 15: End-use availability to supply reserve ASs (low (–), moderate (↗), and high (↑))

	BC	AB	SK	MB	ON	QC	NB	NS	PE	NL
Space Heating	↑	–	–	↗	↗	↑	↑	↗	–	↑
Space Cooling	–	–	–	↑	↑	–	–	–	–	–
Water Heating	↗	–	–	↗	↗	↑	↑	↑	↗	↑

These end-use availabilities should be considered alongside their technical capabilities, as done in the next section.

4. Overall Potential

4.1. Technical and Economic

The technical and economic potential of each residential end-use load to supply reserve ASs through DR rests on three measures: end-use load technical capability (i.e., its ability to meet AS requirements, Section 3.1), end-use availability (i.e., its presence in a given province, Section 3.2), and AS value (i.e., its potential income, Section 2.3). A rudimentary appraisal was able to rule out lighting and appliance end-uses as having significant potential based on technical capabilities. Evaluating the overall potential of the remaining end-uses (space heating, space cooling, and electric water heating) requires combining all measures, the results of which are shown in Table 16.

Table 16: Overall end-use DR potential to serve reserve ASs (low (–), moderate (↗), and high (↑))

	BC	AB	SK	MB	ON	QC	NB	NS	PE	NL
Space Heating										
Regulation	↗	–	–	↗	↑	·	–	↗	–	·
Load Following	–	–	–	–	–	–	–	↑	–	·
Spinning	↗	–	–	↗	↗	·	↑	↑	–	·
Non-Spinning	↗	–	–	↗	↗	·	↗	↗	–	·
Replacement	–	–	–	–	–	·	↑	↑	–	·
Space Cooling										
Regulation	–	–	–	↗	↗	–	–	–	–	–
Load Following	–	–	–	–	–	–	–	–	–	–
Spinning	–	–	–	–	–	–	–	–	–	–
Non-Spinning	–	–	–	–	–	–	–	–	–	–
Replacement	–	–	–	–	–	–	–	–	–	–
Water Heating										
Regulation	↗	–	–	↗	↑	·	–	↗	–	·
Load Following	–	–	–	–	–	–	–	↑	–	·
Spinning	↗	–	–	↗	↗	·	↑	↑	↑	·
Non-Spinning	↗	–	–	↗	↗	·	↗	↗	↗	·
Replacement	–	–	–	–	–	·	↑	↑	↑	·

The DR potential of each end-use to serve each of the reserve ASs has been rated high (↑), moderate (↗), or low/none (–). Where a dot (·) appears (under QC and NL), not enough information was available on AS cost to make a determination.

The availability of each end-use was first considered (Section 3.2). Since residential loads make up little of AB and SK's electrical use, their potential was given a low rating in all categories. Similarly, space cooling DR was ruled out in all but MB and ON. Next, technical potential (Section 3.1) was considered alongside availability and AS value (Section 2.3), with an emphasis on value, to determine the potential of the remaining end-uses. Value was reflected arbitrarily: costs above $8/MWh were deemed considerable and those under $4/MWh of low value.

4.2. Income per Unit

Estimates of the annual value of ASs in each province, as originally discussed and presented in Section 2.3, are given in Table 17. Note that these values reflect the value of ASs today and not the potential DR market, nor a province's openness to having ASs supplied by DR.

Table 17: Estimated annual value of ancillary services

Value ($M/year)	BC	AB	SK	MB	ON	QC	NB	NS	PE	NL
Regulation	8	16	4	2	43	·	1	4	0.1	·
Load Following	-	-	-	-	-	-	2	13	0.2	·
Spinning	14	27	9	2	23	·	2	6	0.2	·
Non-Spinning	14	25	13	2	32	·	5	5	0.4	·
Replacement	-	-	-	-	6	·	6	5	0.5	·

From AS costs (Table 5), the hypothetical annual income that individual SDAHs, in Table 18, and EWHs, in Table 19, could gain from serving as a DR resource under each of the contingency reserves ASs are appraised. (Equations used for these calculations are presented in Appendix C.) While the values are provided regardless of DR commercial viability (as discussed in Sections 3.2.1 and 3.2.3), the values of those with low feasibility are presented in [brackets].

Table 18: Annual value, per SDAH, of DR contributions to contingency reserves

Load Availability	BC	AB	SK	MB	ON	QC	NB	NS	PE	NL
Spinning Reserve ($/SDAH/year)										
15%	41	[85]	[64]	33	48	-	57	75	[57]	-
20%	54	[114]	[85]	45	64	-	76	100	[76]	-
Non-Spinning Reserve ($/SDAH/year)										
15%	41	[79]	[64]	21	41	-	30	36	[30]	-
20%	55	[105]	[85]	28	54	-	39	48	[39]	-
Replacement Reserve ($/SDAH/year)										
15%	-	-	-	-	9	-	101	84	[101]	-
20%	-	-	-	-	12	-	135	112	[135]	-

The SDAH estimates were calculated assuming that an average (i.e., diversified) heating load of 5 kW (substantial, but non-peaking) would be available from each SDAH for reserve deployment either 15% or 20% of the hours in a year ("load availability" in the above table) based on winter heating needs. Under this assumption, two hundred SDAHs (1000 kW/5 kW) can provide 1 MW of reserve. Given such an arrangement, the average annual value per SDAH is $30-100 for spinning reserves, $20-55 for non-spinning reserves, and $10-135 for replacement reserves.

Table 19: Annual value, per EWH, of DR contributions to contingency reserves

Sheddable Loads	Load Avail.	BC	AB	SK	MB	ON	QC	NB	NS	PE	NL
Spinning Reserve ($/EWH/year)											
5%	100%	10	[20]	[15]	8	12	-	14	18	14	-
15%	65%	19	[40]	[30]	16	23	-	27	35	27	-
Non-Spinning Reserve ($/EWH/year)											
5%	100%	10	[19]	[15]	5	10	-	7	9	7	-
15%	65%	19	[37]	[30]	10	19	-	14	17	14	-
Replacement Reserve ($/EWH/year)											
5%	100%	-	-	-	-	2	-	24	20	24	-
15%	65%	-	-	-	-	4	-	47	39	47	-

The EWH estimates were calculated with the same population attributes introduced in Section 3.2.3: a 60%/40% composition of 3 kW/4.5 kW element EWHs. Their values are calculated for two possible DR offerings: i) baseload, where the load available (load avail.) to be shed is 5% of the population's rated power, accessible over all hours of the year, and ii) medium-load, where the load available to be shed is 15% of the population's rated power, accessible over 65% of the year. (These two structures correspond to the base and intermediate load point on Fig. 5 and are equivalent to 5% or 15% of EWHs drawing power.) Under baseload offerings, 5560 EWHs would be required for 1 MW of shedding (reserve) and under medium-load offerings, 1850 EWHs would be required for 1 MW of shedding (albeit being available only 65% of the year).

DR under a medium-load offering (with more sheddable load but less availability) has about double the annual value per EWH as baseload offerings (with less sheddable load but 100% availability). With the former structure, EWHs have a spinning reserve value around $20-30/year and a non-spinning reserve value marginally lower. Replacement reserve is only valued a couple of dollars per EWH in ON, but an order of magnitude more in the Maritimes.

The values estimated above comprise just a few of the possible income streams that may be gained from applying DR to various residential end-use loads. Others exist; two services, for example, were left out (regulation and load following) as it was not possible to quantify them because the number of units required to meet associated reserve requirements was not known.

5. Discussion and Conclusion

Embracing smart grid-enabled residential end-use loads as demand response (DR) resources enables their participation in the grid as value-added products (rather than as just uncontrollable loads). Their value as DR resources include increased asset utilization and capital investment deferment, improved system security and reliability, and increased energy optimization. Serving ancillary services (ASs, particularly reserves), as explored in this report, are just one of many possible contributions they can make to improving system security and reliability. Together, DR opportunities can change the way utilities and operators view and interact with residential loads.

The residential sector, with its space heating, space cooling, and electric water heating loads, was found to be a good DR resource potential; across Canada, the collective potential from its space and water heating end-uses alone was estimated to be 39 GW/85 GWh, with proportionally significant contributions from all provinces but AB and SK. However, electric loads, particularly those for space and water heating, are now declining in the face of economic competition from natural gas. This may lead to losses in a good source of DR, and with it inexpensive and dependable methods to maintain system reliability and flexibility that can, e.g., assist renewables balancing and thus reduce GHGs. Maintaining the economically competitiveness of electric loads may mean having to find new revenue streams to reduce their operational costs.

One such method is using their DR capabilities to realize benefits to the grid, such as through existing ASs. There was found to exist a substantial but non-uniform market for these ASs across the country that residential loads DR could serve and draw upon for revenue streams; in this regard, the most potential proportionally (by size) was found to lie in NB and NS with moderate opportunities in BC, MB, and ON. (The potential in QC is unknown owing to lack of data.)

Alone, provisioning ASs may not be enough to make the economic case maintaining or growing these electrically fueled heating appliances, but together with other benefits it merits consideration as a valuable alternative and solution for a green energy future. It adds to an already compelling case to switch from oil heated appliances to cleaner, electrically fueled ones. Additional valued ASs could also be created that, such as ramping services [7], that match the abilities of DR to the needs of systems with high penetration renewables.

Future technical studies will need to focus on how residential loads can be capitalized for DR. It is hoped that this work has provided some direction on which loads might bear the most fruit in this regard. To have DR serve ASs, changes to regulations on how ASs are procured must also be made (as most currently do not permit such provision). Other directions in research may focus on quantifying the benefits of adding thermal or electrical storage to the grid, e.g., through electric thermal storage units or electric vehicles, or on tailoring new and existing ASs to both bring efficiencies to the electric grid and capitalize on the capabilities of DR-enabled loads.

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Appendix A. SH DR potential calculations

The following equations are behind the indicators used in Section 3.2.1 to measure the DR potential of space heating in each province.

Peak electric space heating load as a percentage of peak system load:

$$\frac{\text{Peak electric space heating load (MW)}}{\text{Peak system load (MW)}} \times 100 =$$

$$\frac{\frac{7\ \text{kW}}{1000} \times \#\ \text{electrically heated SDAHs} + \frac{3.5\ \text{kW}}{1000} \times \#\ \text{electrically heated apartments}}{\text{Peak system load (MW)}} \times 100$$

Annual space heating demand as a percentage of annual system demand

$$\frac{\text{Annual space heating demand (MWh)}}{\text{Annual system demand (MWh)}} \times 100 =$$

$$\frac{\text{Annual space heating demand (MWh)}}{\text{Average system load (MW)} \times 8760\ \text{h}} \times 100$$

Space heating storage potential as a percentage of average hourly system demand

$$\frac{\text{Space heating storage potential (MWh)}}{\text{Average hourly system demand (MWh)}} \times 100 =$$

$$\frac{\text{Peak diversified electric space heating load (MW)} \times 2\ \text{h}}{\text{Average system load (MW)} \times 1\ \text{h}} \times 100$$

where the 2 h (hours) in the numerator is a conservative estimate of how long a home's temperature may be setback without significant adverse discomfort to the occupants.

Appendix B. EWH DR potential calculations

The following equations are behind the indicators used in Section 3.2.3 to measure the DR potential of electric water heaters in each province.

Peak electric water heating load as a percentage of peak system load:

$$\frac{\text{Total electric water heater load (MW)} \times \text{peak diversified load factor}}{\text{Peak system load (MW)}} \times 100 =$$

$$\frac{\left(0.6 \times \frac{3.0\ \text{kW}}{1000} + 0.4 \times \frac{4.5\ \text{kW}}{1000}\right) \times \text{no. EWHs} \times 0.3}{\text{Peak system load (MW)}} \times 100$$

Annual electric water heater demand as a percentage of annual system demand

$$\frac{\text{Annual electric water heater demand (MWh)}}{\text{Annual system demand (MWh)}} \times 100 =$$

$$\frac{\text{Annual electric water heater demand (MWh)}}{\text{Average system load (MW)} \times 8760\ \text{h}} \times 100$$

Electric water heater storage potential as a percentage of average hourly system demand

$$\frac{\text{Electric water heater storage potential (MWh)}}{\text{Average hourly system demand (MWh)}} \times 100 =$$

$$\frac{\left(0.6 \times \frac{3.0\ \text{kWh}}{1000} + 0.4 \times \frac{6\ \text{kWh}}{1000}\right) \times \#\ \text{electric water heaters}}{\text{Average system load (MW)} \times 1\ \text{h}} \times 100$$

Appendix C. SDAH and EWH DR value calculations

The following equation is used to calculate the value of SDAHs as AS reserve resources, as populated in Table 18, per SHAH per year.

$$\frac{\text{Availability of resource (\%)} * \text{Hours in a year} * \text{AS reserve value (\$/MWh)}}{\text{\# SDAHs required to provide 1 MW of AS reserve}} =$$

$$\frac{\text{Availability of resource (\%)} * \text{Hours in a year} * \text{AS reserve value (\$/MWh)}}{\text{1 MW} \div \text{diversified load available to be shed, per SDAH}} =$$

$$\frac{\text{Availability of resource (\%)} * \text{8760 h/y} * \text{AS reserve value (\$/MWh)}}{\text{1000 kW} \div \text{ 5kW}}$$

The following equation is used to calculate the value of EWHs as AS reserve resources, as populated in Table 19, per EWH per year.

$$\frac{\text{Availability of resource (\%)} * \text{Hours in a year} * \text{AS reserve value (\$/MWh)}}{\text{\# EWHs required to provide 1 MW of AS reserve}} =$$

$$\frac{\text{Availability of resource (\%)} * \text{8760 h/y} * \text{AS reserve value (\$/MWh)}}{\text{1 MW} \div \text{diversified load available to be shed, per EWH}} =$$

$$\frac{\text{Availability of resource (\%)} * \text{8760 h/y} * \text{AS reserve value (\$/MWh)}}{\dfrac{\text{1000 kW}}{\text{diversified load (\% peak)} \times (\text{40 gal. EWH (\%)} \times \text{0.3 kW} + \text{60 gal. EWH (\%)} \times \text{4.5 kW})}} =$$

$$\frac{\text{Availability of resource (\%)} * \text{8760 h/y} * \text{AS reserve value (\$/MWh)}}{\text{1000 kW} \div \big(\text{diversified load (\% peak)} \times (0.6 \times \text{0.3 kW} + 0.4 \times \text{4.5 kW})\big)}$$