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DIFFUSION OF MULTIPLE DEMAND-SIDE LOW-CARBON INNOVATIONS IN A 1.5°C ENERGY TRANSITION

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Diffusion of Multiple Demand-Side Low-Carbon Innovations in a 1.5°C Energy Transition

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Abstract:
The rapid diffusion of low-carbon innovations has been identified as a key strategy for maintaining average global temperature rise at or below 1.5°C. Diffusion research tends to focus on a single sector, or single technology case study, and on a small scope of factors that influence innovation diffusion. This paper describes a novel methodology for identifying multiple demand-side innovations within a specific energy system context and for characterizing their impact on socio-technical energy systems. This research employs several theoretical frameworks that include the Energy Technology Innovation System framework to develop a sample of innovations; the Sustainability Transitions framework to code innovations for their potential to impact the socio-technical system; the energy justice framework to identify the potential of innovations to address aspects of justice; and how characteristics of innovations are relevant to innovation adoption. This coding and conceptualization creates the foundation for the future development of quantitative models to empirically assess and quantify the rate of low-carbon innovation diffusion as well as understanding the broader relationship between the diffusion of innovations and socio-technical system change. This research found that the majority of the innovations being offered to energy users in Ontario have incremental rather than disruptive characteristics, and general rather than technology-specific policy supports. The innovations also tend to have strong legitimacy support through discourse framing and system actors. Furthermore,

through correlation analysis, this research found that innovations with the potential to lead to system decarbonization are associated with lower rates of diffusion, while innovations with strong economic policy support and legitimacy support through discourse framing are associated with higher rates of diffusion.

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1 Introduction

Low-carbon innovations are novel products or services that result in lower carbon emissions compared to established technologies (Wilson, 2018). Eco-innovation, a term synonymous with low-carbon, green, sustainable, and environmental innovation, is defined as the "creation or implementation of new, or significantly improved, products, processes, marketing methods, organizational structures and institutional arrangements which lead to environmental improvements compared to relevant alternatives" (Karakaya et al. 2014, p. 394; OECD, 2009). The rapid diffusion of low-carbon innovations has been identified as a key strategy for maintaining average global temperature rise at or below 1.5°C (Creutzig et al. 2018; Grubler et al. 2018; Mundaca et al. 2019; Patt et al. 2019). There are many research gaps in understanding how quickly multiple low-carbon innovations can be diffused to the demand-side in an urgent and accelerated timeframe. This report describes a novel framework for identifying and analysing multiple demand-side innovations within a specific energy system context and for characterizing their impact on socio-technical energy systems.

Diffusion research tends to focus on a single sector, or single technology case study, and on a small scope of factors that influence innovation diffusion (Clausen & Fichter, 2019). Our methodology directly addresses this research gap by identifying multiple innovations and a range and combination of factors that influence diffusion, as well as how disruptive these innovations are to socio-technical systems. This research attempts to conceptualize and code the innovations according to possible factors that drive or inhibit innovation diffusion. Coding and conceptualization create the foundation for the future development of quantitative models for empirically assessing and measuring the rate of low-carbon innovation diffusion, as well as understanding the broader relationship between the diffusion of innovations and socio-technical system change.

Of interest is research by Clausen and Fichter (2016; 2019) who undertook a comprehensive and detailed cross-sector analysis of factors (i.e., drivers and barriers) that influence the diffusion of environmental product and service innovations in Germany. Based on a prior systematic review of the diffusion of innovation literature (Clausen et al., 2011), Clausen and Fichter (2016; 2019) identified 22 factors that have the potential to influence the diffusion of environmental innovations across six fields of influence: (1) product-related factors; (2) adopter-related factors; (3) supplier-related factors; (4) sector-related factors; (5) government-related factors; and (6) path-related factors (Clausen et al., 2011; Fichter & Clausen, 2016). These 22 factors and six fields of influence "provide a holistic and systematic set of variables and scales that can be used for empirical investigations" (Clausen & Fichter, 2019, p. 69). In their statistical model, 130 environmental product/service innovations were coded according to these 22 factors (variables related to diffusion) in order to determine the degree to which the factors facilitated or inhibited environmental innovation diffusion. Their research is the first of its kind and is an important contribution to sustainability transitions research because it simultaneously analyzes multiple innovations across different sectors and policy fields. While Fichter and Clausen (2016) describe their research in detail, the dependent variables they constructed cannot precisely describe the impacts of the innovations they examined on sustainability transitions because they do not account for system innovation potential through disruption.

The Sustainability Transitions Research Network (STRN) recently assessed the sustainability transitions field of research and argued that a new research agenda includes "Ethical aspects of transitions: distribution, justice, poverty". They argue that "transitions have the potential to create or reinforce injustices", but that attention to aspects of justice and democracy with sustainability transitions have been limited (Köhler et al. 2019). A focus on distributive and participatory struggles within sustainability transitions is required (Köhler et al. 2019). Our research applies elements of Clausen and Fichter's (2016; 2019) research, but differs in three key respects:

1. This research extends beyond examining diffusion dynamics to account for innovation characteristics related to capacity for system disruption, energy justice, and innovation adoption behaviour;
2. This research looks specifically at demand-side low-carbon innovations available to energy users; and
3. This research focuses specifically on the disruptive potential of the innovations on the established socio-technical system.

The conceptualization and development of four variables are presented:

1. Dissemination rate
2. System innovation
3. Innovation adoption
4. Energy justice

Rather than strictly coding the demand-side innovations for the dissemination rate and diffusion dynamics (as was done in Clausen and Fichter's (2019) research), we have developed indicators and scales for a range of concepts that influence not only innovation diffusion, but also the innovation's contribution to system change, the potential of innovations to address energy justice, and innovation characteristics relevant to innovation adoption behaviors. The demand-side innovations, coded for the aforementioned concepts, can be examined through a variety of multivariate analyses. Through quantitative analysis, we can further explore the innovations on the factors which lend to their characterization in order to improve our understanding of the potential impact an innovation can have on socio-technical system change.

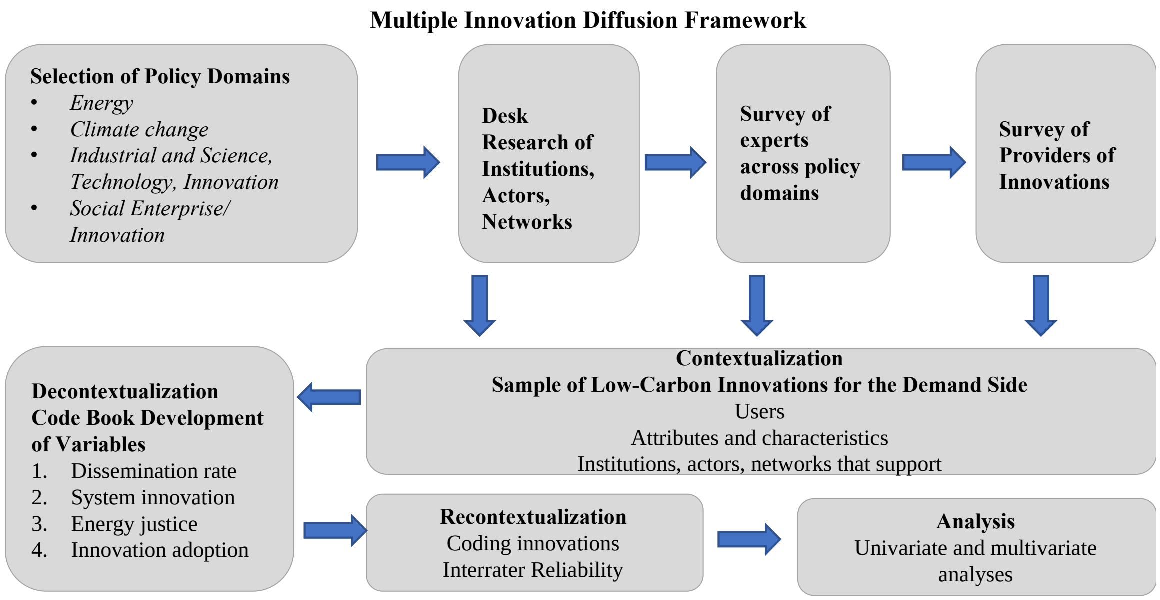
This research project is critical for building a comprehensive understanding of low-carbon innovation diffusion, and will contribute to increasing insights and research applications in this field. Energy Technology Innovation Systems, made up of actors, networks and institutions, and socio-technical systems, such as energy systems and the places where they are embedded, are different depending on the context. While this research focuses on the context of Ontario, the methodology and lessons learned can be applied to other contexts and energy systems, as the questions of impact and diffusion of innovations is a universal problem. Accordingly, this methodology and analytical framework will be of interest to researchers in the field of sustainability transitions and carbon lock-in, and to policy makers and practitioners focused on problems at the intersection of energy users, energy systems, and climate disruption.

2 Methodology

The three stages of research are:

- **Contextualization:** surveys and desk research to identify low-carbon innovations across the ETIS;
- **Decontextualization:** the development of a codebook of variables;
- **Recontextualization:** coding the innovations and analysis.

Figure 1: Research Methodology

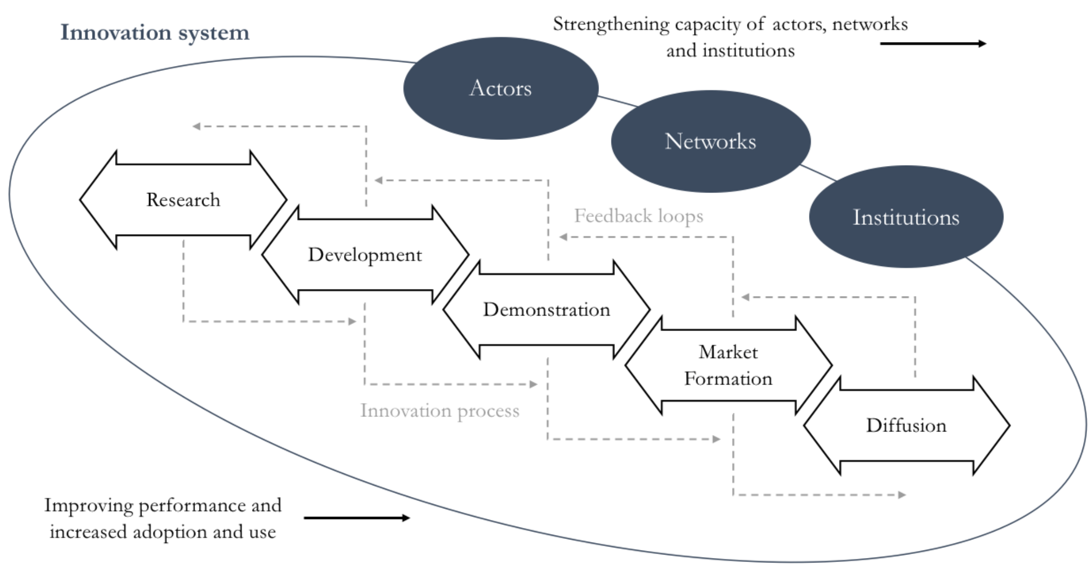


2.1 Contextualization

The unit of analysis in this research is the demand-side low-carbon energy innovation. Further, this research focuses on innovations available to energy users, such as individuals, households, organizations, and businesses, that could contribute to a low-carbon energy transition. While Clausen and Fichter's (2019) research focused on multiple sectors, our research focuses solely on the energy system. Similar to Clausen and Fichter (2019), the current research focuses on one jurisdiction, the Province of Ontario, due to proximity as well as knowledge of and access to climate change and demand-side energy policy. Further, Canada is a federalist system and energy and natural resources are the jurisdiction of the province; hence another reason for selecting the Province of Ontario rather than, for instance, Canada or a region within Ontario. In Ontario the energy system spans most of the province (remote regions in the North have independent systems) and is comprised of two (formerly three) natural gas distribution companies providing most of the province's natural gas demand, one province-wide transmission system company, and the province-wide Electricity System Operator (IESO) that manages the electricity market. In other contexts, one energy system could envelop multiple jurisdictions, or there could be multiple energy systems within a jurisdiction. Our research methodology could also be applied to these contexts.

In order to identify the innovations, we employed the Energy Technology Innovation System (ETIS), a framework that is defined in Sims Gallagher et al. (2012) and Grubler et al (2014). It has already been applied to identify support for low-carbon innovations in the Canadian context by Jordaan et al. (2017). The ETIS approach focuses on how actors, networks, and institutions influence the emergence of novel innovations (Bergek et al. 2008) from research, development, and demonstration stages to the diffusion stage (Jordaan et al. 2017), providing the knowledge and supports for socio-technical energy innovation (Sims Gallagher et al. 2012; Jordaan et al. 2017). The ETIS has different structures in different contexts, and innovations in a particular context are determined by the ETIS. Therefore, we used the ETIS as a framework to identify low-carbon innovations.

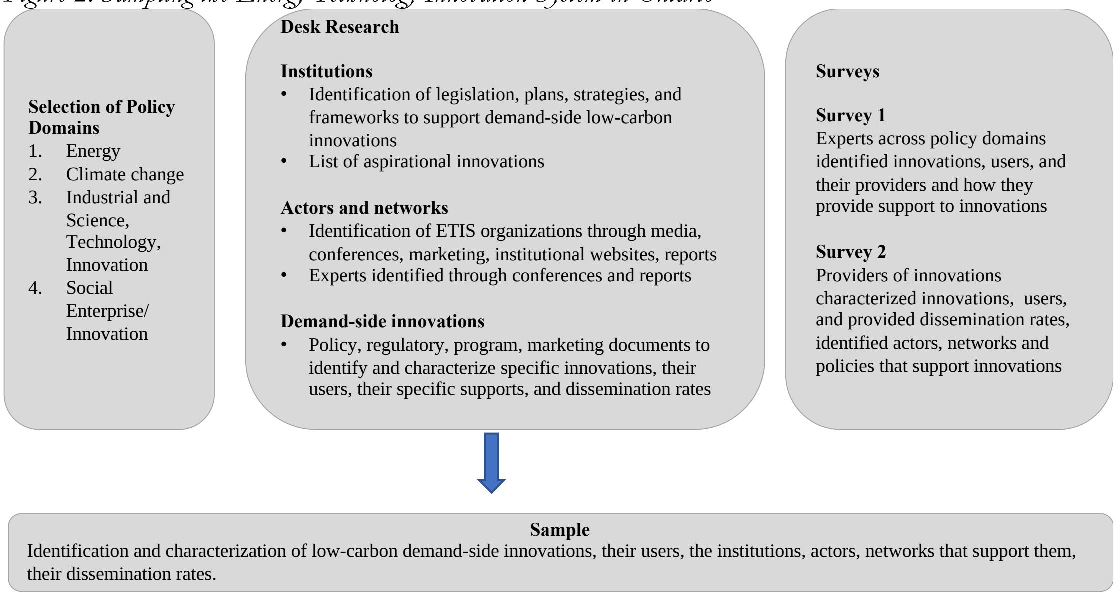
Figure 2: Innovation System Process (adapted from Jordaan et al. 2017; Grübler & Wilson 2014; Söderholm et al. 2019).



Within the ETIS, a policy domain can be used to identify a regime boundary within which governments and institutions deploy policies (Matti et al. 2017). To encourage innovation, governments and institutions deploy policy mixes (i.e., the mixture of policy instruments within or across policy domains (Gunningham and Sinclair 1999)) across multiple policy domains (Flanagan et al. 2011). Energy innovation studies investigate outcomes across multiple policy domains and regime levels over time (Matti et al. 2017). The policy domains that are typically investigated by ETIS studies include energy, environmental, science, technology and innovation, and industrial policy, but they vary by ETIS and are context dependent, defined by the institutions in a particular context.

The sampling strategy that was used to identify low-carbon innovations for energy users in Ontario is described in Figure 2. Over 15 years, between 2003 and 2018, the Province of Ontario pursued numerous decarbonization strategies that included various visions to provide energy users with demand-side innovations to engage in a low-carbon energy transition. The innovations offered over this timeframe comprise the scope of this research. In June 2018, there was an election of a Conservative provincial government and the ETIS changed dramatically, no longer supporting climate action; innovations post-election are therefore not considered. Prior to this timeframe, the ETIS policy domains specific to the context of Ontario that influence the diffusion of low-carbon innovations for the demand side were: climate change; energy; industrial and science, technology, innovation; and social enterprise and social innovation.

Figure 2: Sampling the Energy Technology Innovation System in Ontario



2.2 Desk Research

In the first stage of the research, desk research was conducted to identify institutions and their associated legislations, plans, strategies, and policy frameworks; actors and networks; and the aspirational demand-side innovations identified in all of these documents. Policy documents falling under the selected policy domains were collected and reviewed for relevant policies, actions, experts, mechanisms and desired outcomes. The details of these are provided in Table 2.1.

Table 2.1: Desk Research of the Ontario Energy Technology Innovation System

Policy Domain	Key Policies and Strategies	Actors and Networks	Mechanisms / Activities	Aspirational Low-Carbon Innovations for the Demand-Side
Energy Policy	• Ontario Energy Board Act (1998b) • Electricity Act (1998a) • Electricity Restructuring Act (2004) • Green Energy and Green Economy Act (2009) • Ontario Long Term Energy Plan (2017) (2010, 2013, 2017) • Municipal ownership of local distribution companies (early 1900s-) • Local Improvement Charges, Municipal Act 2001 (2012) • Local energy plans (2013-)	• Natural Resources Canada • Ontario Energy Board (1998-) • Ontario Ministry of Energy • Electricity System Operator (IESO) (1998-) • Quality Urban Energy Systems of Tomorrow (QUEST) (2007-) municipal network • Local electricity distribution companies • Natural gas utilities • Electricity retailers (2002-) • Natural gas retailers • Service providers	• Retailer participation in wholesale markets (1998 -) • Smart meters (2004-2010) • Time of use prices (2006-) • Electricity and natural gas demand management activities (1995-) • Local Improvement Charges can be applied to energy projects (2012-) • Municipal Energy Plan program (2013-) • Indigenous Community Energy Plan program (2013-) • GHG reporting for municipalities (2009-) • Electric Vehicle Discovery Centre (2017-)	• Purchase electricity and gas from a service provider • Real-time electricity information • Demand response • Audits for building retrofits • Rebates, coupons • Demand response • Equipment removal • Demonstration projects (e.g., micro-grid and renewable energy) • Consultations for local energy plans • Grants for local energy plans • District energy • Energy demand management • Loans for building energy retrofits
Environmental and Climate Change Policy	• Government of Canada Action Plan on Climate Change (2000; 2009; 2014) • Pan-Canadian Framework on Clean Growth and Climate Change (2016) • EnerGuide Climate Change Program (1998-2006) • ecoEnergy Climate Change Program (2007-2012) • Go Green: Ontario's Action Plan on Climate Change (2007) • Climate Change Mitigation and Low-carbon Economy Act (2016a) • Ontario's Five Year Climate Change Action Plan 2016-2020 (2016b) • Municipal Partners for Climate Protection program	• Environment Canada • Sustainable Development Technology Canada (SDTC) (2001-) (38) • Ministry of the Environment and Climate Change • Ontario Green Bank (aspirational) • Green Ontario (2017-2018) • Federation of Canadian Municipalities (1901-) • ICLEI Canada (1994-), (31) • Toronto Atmospheric Fund	• Innovation funds-Sustainable Development Technology Canada (SDTC) • Funds targeted at clean technology development • Funds targeted at renewable energy in remote and Indigenous communities • Funds targeted at low-carbon transportation • Recycled revenue from cap and trade program to Green Ontario (2017-2018) • Partners for Climate Protection program (1994-) • Create conditions for Ontarian's to choose low-carbon options	• Ontario Green Bank provides loans and information for energy retrofits • Tools, information for behaviour change • Building Retrofits • Renewable energy generation by homes and businesses • Electric Vehicles • Active Transportation • Public transit • solar photovoltaic and energy storage systems, modern wood heating pilots, air source heat pumps, ground source heat pumps, insulation, windows, smart thermostats, and social housing retrofits • Consultations and training for local energy plans • Grants for local energy plans

Policy Domain	Key Policies and Strategies	Actors and Networks	Mechanisms / Activities	Aspirational Low-Carbon Innovations for the Demand-Side
Science, Technology, and Industrial Innovation Strategy	• Ontario's innovation agenda (2008)	• Ontario Network of Entrepreneurs (ONE) • Provincial Innovation Centres (PICs) (MaRS and the Ontario Centres of Excellence) • Regional Innovation Centres • University Innovation Hubs/Centres (e.g., Waterloo Institute for Sustainable Energy, Ryerson Centre for Urban Energy)	• Incubation and acceleration services • Intermediation • Energy Transformation Network of Ontario/Ontario Smart Grid Forum (2008-) • Open innovation and crowd-sourced competitions • Advanced Energy Centre at MaRS (2014-)	• Renewable energy • smart end-use devices/appliances • advanced metering connected to utility communications; • control interface • distributed generation and storage • real-time price and demand information, automated home controls for demand response • fuel switching and energy storage • electric vehicles • micro-grids to share power and isolate • district heat • Micro-grid development • Meter Data Access Project (MDAP) • Green Button Program (standardized information for service providers to bring to customers) (2017-) • Green Button Pilot Program (2012) • Education around electricity consumption and energy savings • Enable standardized electricity consumption data • Cross-industry collaboration • Promotion of the Green Button standard
Social Enterprise and Innovation Strategy	• Ontario's innovation agenda (2008)	• Ontario Network of Entrepreneurs (ONE) • Provincial Innovation Centres (PICs) (MaRS and the Ontario Centres of Excellence) • Regional/Sectoral Innovation Centres • University Innovation Hubs/Centres • Social Enterprise Partnership • Municipalities • Public and Private Foundations • Government Program Funds • Federation of Community Power Cooperatives (FCPC) • Ontario Co-Operatives Association • The Centre for Social Innovation, • MIT Climate CoLab, • Nonprofits	• Competitions for incubation and acceleration of innovative solutions • Incubation and acceleration of social enterprise • Incubation and acceleration of energy cooperatives • Agents of Change Accelerator (2016-) • MIT Climate Co-lab (2018)	• Investments in commercial scale solar energy projects through solar bonds; • Capacity-building support for co-ops who are developing renewable energy projects and social enterprises • Clarify details about investment in renewable energy (check, for e.g. FCPC and solar share) • Small and medium enterprise climate change mitigation and adaption • Climate change mitigation, adaption and geoengineering for SMEs

Desk research across the four policy domains resulted in the identification of 32 innovations (14 active; 18 discontinued) offered to energy users in Ontario that have the potential to influence a low-carbon energy transition (Table 2.2).

Table 2.2 Innovations Identified through Desk Research

Desk Research	
44 innovations identified	10 innovations overlap with innovations identified through Survey 1 (combined with Survey 1 data)
	2 innovations had insufficient information
32 innovations identified that are relevant to the analysis	14 active innovations
	18 discontinued innovations

2.3 Survey of Experts in the Energy Technology Innovation System

During the desk research process, through the examination of conference events and reports, 435 experts were identified across the different policy domains. A list of contacts of individuals belonging to the organizations in the ETIS was developed to determine potential survey participants. Based on these experts and organizations identified through desk research, these experts were contacted to participate in an online survey titled, *Survey of Professionals* (referred to as Survey 1. 40 additional individuals were identified through chain link sampling. The number of individuals contacted and the response rate are shown in Table 2.3.

Table 2.3 Survey 1 Response Rates across Selected Policy Domains

Policy domain	**Number of individuals contacted**	**Number of individuals that completed surveys**
Energy policy	152	15
Environmental and climate change policy	47	6
Science, technology and industrial innovation strategy	121	20
Social enterprise and innovation strategy	148	23
Unknown	0	30
Other	7	0
Total	475	94

Table 2.4 Response Rates Across Type of Innovation Providers

Type of innovation provider	Number of individuals contacted	Number of individuals that completed the survey	Percentage of individuals that completed the survey (%)
Incubator/accelerator	87	2	2
Government: Indigenous	2	0	0
Government: Municipal	177	20	11
Government: Provincial	20	4	20
Government: Federal	11	2	18
Nonprofit	65	32	49
University	22	9	41
Utility	90	7	8
Consultancy	17	6	35
Conservation authority	3	1	33
Think tank/ research institute	3	0	0
Other: regulator	9	0	0
Other: group/ association/ Network	27	0	0
Other: private business	55	11	20
Total	588	94	16

Survey 1 was semi-structured survey (i.e., Survey 1). It was sent to potential participants between March and November 2017. The purpose of Survey 1 was to identify innovations under development, currently available, or intended for energy users in Ontario that have a potential to make an important contribution to a low-carbon energy transition. The survey received 94 responses, a 19.8% response rate. Participants were asked to identify up to three innovations, the organization that offers the innovation, how the innovation can influence a low-carbon energy transition, and the energy users for whom the innovation is intended. A total of 119 innovations were identified; 15 of these innovations were outside the scope of analysis; 8 were not yet marketed innovations (i.e. ideas for an innovation); and 7 were lacking in sufficient information provided by the respondents to accurately identify the innovation (Table 2.5). Innovations that fell under these three categories were removed from the data set. Survey 1 revealed 89 innovations (68 active; 21 discontinued) considered relevant to the analysis and were coded.

Table 2.5 Response to Survey of Experts across ETIS Selected Policy Domains (Survey 1)

475 surveys sent to individuals	435 individuals identified through desk research
	40 additional individuals identified through chain link sampling (53 total, 13 overlap)
135 survey responses	5 individuals declined to participate
	130 participated in the survey
	36 agreed to participate but left the survey incomplete (did not provide any innovation data)
94 completed surveys	
119 innovations identified	15 not applicable (outside scope of analysis)
	8 not yet an innovation (idea for an innovation)
	7 insufficient information provided by respondents to identify the innovation
89 innovations identified that are relevant to the analysis	68 active innovations
	21 discontinued innovations

2.4 Survey of Innovation Providers

A second survey (i.e. Survey 2) was circulated between June and October 2019. This survey was titled *Ontario's Low Carbon Transition: Learning about Services Available to Energy Users & Communities* (referred to hereon as Survey 2). The purpose of Survey 2 was to (1) gain deeper understanding of the innovations by seeking the perspective of the service providers themselves; and (2) to identify additional innovations.

Survey 2 participants were identified using the chain link sampling method employed in Survey 1 (i.e. they were identified by Survey 1 participants). Participants of Survey 2 were also invited to participate in the survey through relevant networks in Ontario (networks and associations whose members include the providers of energy services) and through relevant social media networks. It was difficult to find networks that served Indigenous communities specifically, so these communities may have been overlooked. 90 individuals were contacted to participate in the electronic survey and 17 participants completed the survey (Table 2.7). The types of survey participants that responded are identified in Table 2.6. 17 innovations were identified through Survey 2. 7 of these were already captured through Survey 1. These innovations were combined with Survey 1 data to avoid double counting. As such, 10 new innovations (9 active; 1 discontinued) identified through Survey 2 were considered relevant and were coded.

Table 2.6 Survey 2 Response Rates Across Type of Actors, Networks and Institutions

Type of actor, network or institution	**Number of individuals contacted**	**Number of individuals that completed the survey**	**Percentage of individuals that completed the survey (%)**
Incubator/ accelerator	3	3	100
Government: Indigenous	0	0	0
Government: Municipal	9	1	11
Government: Provincial	13	1	8
Government: Federal	3	0	0
Nonprofit	32	7	22
University	3	2	67
Utility	8	0	0
Consultancy	4	2	50
Conservation authority	0	0	0
Think tank/ research institute	2	0	0
Other: regulator	0	0	0
Other: group/ association/ network	0	0	0
Other: private business	13	1	8
Total	90	17	19

Table 2.7 Response to Survey of Service Providers (Survey 2)

90 individuals contacted to participate	
68 survey responses	1 individual declined to participate
	67 participated in the survey
	50 agreed to participate but left the survey incomplete (did not prove any service data)
17 participants completed the survey	7 responses described innovations from Survey 1
	10 responses identified a new innovation
10 (new) innovations identified	9 active innovations
	1 discontinued innovation

2.5 Master Dataset

Overall, a total of 131 innovations (91 active; 40 discontinued) were identified through the desk research and surveys (Table 2.8). The aim of the innovations were characterized and examples of the identified demand-side low-carbon innovations are provided in Table 2.9. Each innovation was indexed and categorized according to a template, using both the information provided by survey respondents as well as desk research on publicly available information. A research folder was created for each innovation, referred to as the innovation profiles, containing detailed background information on each innovation (such as websites, reports, marketing materials) that were collected through desk research but not captured by the template and not included in the master combined dataset.

Table 2.8 Final Sample

Method for identifying	**n**	**Status**	
		Active	Discontinued
Desk research across ETIS and 4 Policy Domains	32	14	18
Survey 1: actors, networks, institutions across ETIS + 4 policy domains, chain link	89	68	21
Survey 2: innovation providers, chain link and networks	10	9	1
Total number of innovations	131	91	40

Table 2.9 Description of Innovations in the Sample

Aim of the innovations	n	Example innovation
Battery storage	6	Community energy storage
Demand-side management	27	Residential showerhead replacement
District energy	2	Combined heat and power (CHP) incentives
Electric vehicles	9	Electric vehicle suitability assessments
Electric vehicle charging stations	5	Electric vehicle chargers grant programs
Energy efficiency	71	Financing through local improvement charges
Local energy plans	7	Capacity-building for smart energy communities
Microgrids	2	Micro-grid demonstration project
Natural gas infrastructure	1	Natural gas grant program
New construction	7	Energy efficiency incentives for new construction
Program design	1	Energy efficiency consultancy
Public/shared/alternative transportation	7	Community bike sharing services
Renewable energy (location not specified)	20	Energy efficiency retrofits for rooftop (PV) solar
Renewable energy (onsite)	12	Institutional research laboratories
Renewable energy (offsite)	4	Green electricity retailer
Retrofits/installations	34	Deep energy retrofit program
Smart meters	6	Residential energy data and analytics
Submetering	1	Commercial building metering and submetering.

2.6 Decontextualization

At this stage, each innovation was coded for a range of characteristics and factors that influence its diffusion as well as how disruptive these innovations are to socio-technical systems. This research project is critical for building a comprehensive understanding of low-carbon innovation diffusion, and will increase the replicability of the research methodology and broaden potential insights and research applications in this field. In the following sections we describe our conceptualization of and subsequent coding methods for four main variables: *Dissemination rate, System innovation, Energy justice*, and *Innovation adoption*. These constructed codes can be applied to demand-side innovations in any context.

2.6.1 Dissemination Rates

Based on the literature review, especially the study conducted by Clausen and Fichter (2019), "Dissemination rate" was used to measure the diffusion of a demand-side low-carbon innovation because it is the most straightforward way to show the state of market diffusion for each innovation. The formula to calculate the *Dissemination rate* is:

$$Dissemination\ rate = \frac{Uptake\ of\ the\ innovations}{Population\ size\ of\ the\ reference\ market}$$

Uptake data was identified through desk research and responses from Survey 2. Following the completion of Survey 2, uptake data were still missing for approximately 64 innovations. A combination of desk research and phone surveys were employed to obtain missing information for these innovations. Subsequently, uptake data for 4 innovations were obtained through phone surveys (Survey 2); 1 was obtained through re-sending the survey link and approximately 10 were obtained through additional desk research. The total number of innovations with available uptake information was 81 (out of the total 131 innovations).

The population size of the reference market was determined through desk research. The appropriate reference population for each innovation was determined by evaluating the types of users and assigning each innovation a corresponding population. Population statistics were collected through desk research and are presented in Table 2.10. Population fields with an 'unknown' population signify cases where population statistics were not found or not available through desk research.

Table 2.10 Reference Market Population Statistics (Ontario)

Types of service users	Entire population	Electricity customers	Natural gas customers
Individuals	11,240,520[a]	n/a	n/a
Households	5,169,175[a]	5,164,196[b]	3,636,582[b]
Households (homeowners)	3,582,238[a]	unknown	unknown
Households (tenants/renter)	1,559,720[a]	unknown	unknown
Households (low income)	896,405[a]	unknown	unknown
Nonprofit organizations	59,605[c]	n/a	n/a
Cooperatives	1,785[d]	n/a	n/a
Commercial businesses	1,616,212[e,f]	unknown	unknown
Small businesses	417,742[g]	unknown	unknown
Building professionals	542,800[h]	n/a	n/a
MURBs	19,415[i]	unknown	unknown
MURB units	1,411,185[i,j]	n/a	n/a
Low-rise residential buildings	511,800[i]	unknown	unknown
Utilities	61	59[k]	2[k]
Indigenous communities	141[l,m]	n/a	n/a
Municipal government	444[n]	n/a	n/a
Provincial government	1	n/a	n/a
Federal government	1	n/a	n/a
Institutions	968[o,p,q,r]	n/a	n/a
Industrial	36,355[s]	unknown	unknown
Social housing providers	1500[t]	n/a	n/a
Licensed drivers in Ontario	10,539,055[u]	n/a	n/a
Individuals living in the Waterloo region	617,870[v]	n/a	n/a
Businesses in the Waterloo region (includes non-profits)	17,429[w]	n/a	n/a
Individuals living in the City of Toronto	2,956,024[x]	n/a	n/a
Youth ages 14 to 17 in Ontario in 2010	696,549[y]	n/a	n/a
Students enrolled in elementary and secondary schools in Ontario in 2010	2,051,865[z]	n/a	n/a

(a) (Statistics Canada 2017); (b) (Ontario Energy Board 2018); (c) (Canadian Charity Law 2014); (d) (Government of Ontario 2020b); (e) (Statistics Canada 2020b); (f) (Statistics Canada 2020c) (g) (Statistics Canada 2019b); (h) (Statistics Canada 2019c); (i) (Statistics Canada 2017); (j) (Binkley 2012); (k) (Ontario Energy Board 2019). (l) (K Net Communities 2020). (m) (Métis Nations 2020); (n) (Government of Ontario 2019); (o) (Government of Ontario 2020a).; (p) (Statistics Canada 2020d).; (q) (Ontario Ministry of Education 2020); (r) (Canadian Universities 2020) (s) (Statistics Canada 2019a); (t) (Ontario Non-Profit Housing Association 2014); (u) (Road Safety Research Office 2019); (v) (Region of Waterloo 2019) (w) (Statistics Canada 2020a); (x) (City of Toronto 2018); (y) (Statistics Canada 2010).; (z) (Ontario Ministry of Education 2010).

Dissemination rates were calculated for innovations that had both population and uptake data. Overall, uptake data was found for 81 of 131 innovations; population data was available for all 131 innovations. Therefore, *Dissemination rate* was calculated for 81 innovations.

2.6.2 Variable 1: System Innovation

In sustainability transitions theory, "disruptive" or "radical" innovations emerge in the context of socio-technical regimes—the institutional structuring of existing systems that favour path dependence and incremental change (Köhler et al. 2019) . These disruptive or radical innovations (products or services) generally incorporate *new* features (attributes), which disrupt the existing technological paradigm and lead to broader socio-technical system change (Dixon et al., 2018; Wilson, 2018), including the emergence of new actors in low-carbon energy production and supply as well as regulatory interventions. New features and attributes emerge, in large part, from the innovation system (Jordaan et al., 2017; Wilson, 2018). Disruptive innovations can lead to major societal change, including the introduction of new social values and political beliefs (Dixon et al., 2018; Foxon & Pearson, 2007; Johnstone et al., 2020; Wilson, 2018).

Incremental innovations refer to improvements to products and/or services within or outside an existing technological paradigm (Dixon et al., 2018; Wilson, 2018). Incremental innovations offer improved cost-benefits to consumers for products/services in already established markets (Dixon et al., 2018). These innovations do not offer novel attributes to disrupt the socio-technical system.

In large contrast to both disruptive and incremental innovations, regime reinforcing innovations are typically path-dependent and work to stabilize the incumbent socio-technical system. This occurs by perpetuating system-reinforcing characteristics, such as operating under favorable regulations within the established regime, contributing to large sunk costs in industry investments, benefiting from established economies of scale, and preserving entrenched social norms and behavioral routines that support the incumbent regime (Geels & Johnson, 2018). These types of innovations perpetuate carbon lock-in—the path dependency of complex systems of existing technologies, institutions, and behavioral norms that act in combination to constrain the rate and magnitude of carbon emissions reductions (Seto et al. 2016).

In order to explore the factors that influence the disruptive potential of demand-side low-carbon innovations, a coding system was used based on concepts of disruptive, incremental or regime reinforcing innovations that were defined in Dixon et al. (2018), Geels (2018), Geels (2014), Johnstone et al. (2020), Johnstone & Kivimaa (2018), Rosenbloom et al. (2016), Wilson (2018), and Wilson & Tyfield (2018). The *System innovation* variable was comprised of eight variables. For each of the eight variables contributing to *System innovation*, a coding scale was developed, based on the relevant literature. The eight variables were:

1. Decarbonization
2. Decentralization
3. Democratization
4. Policy for scale-up: Economic Instruments
5. Policy for scale-up: Regulations
6. Policy for scale-up: Knowledge Creation and Diffusion
7. Legitimacy through Discourse Framing
8. Legitimacy through Actors

2.6.3 Characteristics of Disruption

The first three variables are characteristics or outcomes of disruption: *Decarbonization*, *Decentralization* and *Democratization* of the energy and socio-technical system.

2.6.3.1 Decarbonization

The fossil fuel regime remains locked-in through the complex network of technological, institutional, infrastructural and behavioral systems that support the continued use of carbon intensive technologies and act as major barriers to the adoption and diffusion of alternative low-carbon innovations (Unruh 2000; Seto et al. 2016). Carbon lock-in refers to a combination of systemic forces working together to support the dominant fossil fuel regime and constrain socio-technical system change toward low-carbon innovations, in the presence of viable low-carbon alternatives (Unruh 2000). These interconnected networks perpetuate path-dependency and carbon lock-in of socio-technical systems. Path dependency here is the continued use of a technology due to favorable market conditions and first mover advantages, despite the existence and availability of more efficient, alternative technologies (Seto et al. 2016). Hence, destabilizing the fossil fuel regime with disruptive low-carbon innovations creates critical opportunities for system change. This scale was developed to measure the degree to which an innovation removes carbon from the energy system (and supports the adoption of renewable/no carbon technologies) as an indicator of the innovation's potential to disrupt the fossil fuel regime. For a detailed breakdown and examples of the scaling system for the *Decarbonization* variable, see Table 2.11.

Table 2.11 Decarbonization Scale

Scale	Definition	Examples
-2	Strongly reinforces the incumbent fossil fuel regime and strengthens path-dependencies: Creation of new demand for fossil fuels; Fuel switch from lower *intensity* to higher intensity carbon.	• Switching from electric heating to fossil fuel heating. • Switching from natural gas to coal or oil. • New investment in fossil fuels.
-1	Slightly reinforces fossil fuel regime and path dependencies; Fuel switch from higher intensity to lower intensity carbon; Higher efficiency replacement of fossil fuel use.	• Replacement of coal or oil with natural gas. • Installing a more efficient gas furnace. • Purchasing a fuel-efficient vehicle with an internal combustion engine.
0	No detectable change/no effect/ unknown effect on the established fossil fuel regime.	• Continued path dependency and carbon lock-in.
1	Incremental innovation creating the demand for a new regime; Decrease in fossil fuel use; Improvement that is relevant to both fossil fuels and renewable energy.	• Removal of fossil fuel use. • Improvement of building envelope to reduce heat loss. • Divestment from fossil fuels (with some or no investment in renewable energy) • Investment in renewable energy (without divestment in fossil fuels). • Improvement in energy efficiency relevant to both fossil fuels and renewables.
2	Disruptive innovation potentially leading to a system transformation and the destabilization of the existing fossil fuel regime; Fuel switch away from- or removal of- fossil fuels *and* contributes to system building of renewable/no carbon energy.	• Electric vehicle as a fuel switch away from fossil fuels and has potential to support additional renewable energy. • Fuel switch to hydrogen, electricity, conservation, renewables, ground source heat pump, etc. • Large divestment from fossil fuels and investment in renewable energy.

2.6.3.2 Decentralization

The focus of this variable is on geographic or system decentralization from current centralised energy regimes, not on political decentralization. This coding is based on Lowitzsch et al.'s, (2020) conceptualization of renewable energy clusters. Renewable energy clusters are a concept based in current engineering literature and refers to designing optimal localized energy systems that may have multiple energy carriers and end-uses (Mancarella, 2014). Renewable energy clusters consist of 1) interconnectivity among a range of actors; 2) bi-directionality of energy flows that allows for prosumership, energy storage, energy sharing and peer-to-peer trading; 3) multiple renewable energy sources that can enhance complementarity; and 4) flexibility made up of energy efficiency, demand response, conservation, storage, aggregators, etc. (Lowitzsch et al. 2020). In combination, these features challenge the architecture and logic of centralized grids, and greatly enhance the ability to shift to variable renewable energy sources.

Innovations that have multiple cluster features are more disruptive and are coded as +2 on the *Decentralization* variable scale. Innovations that switch away from the centralized grid but that do not have multiple features of RE clusters are coded as +1 on the *Decentralization* scale. For a detailed breakdown and examples of the scaling system for the *Decentralization* variable, see Table 12.

Table 2.12 Decentralization Scale

Scale	Definition	Examples
-2	Strongly reinforces centralized grid	• Long-term service demand shifting from peak to off peak to flatten curve to support centralized generation • Build new connections for energy users to the centralized grid
-1	Slightly reinforces centralized grid	• Demand shifting from peak to off peak to flatten curve to support centralized generation • Switch particular use to more centralized option
0	No effect on grid	• Stays on grid, fuel switch from one centralized grid to another (e.g., gas to electricity)
1	Incremental innovation towards decentralization (switch particular use to off-grid or to single actor grid)	• Switch from centralization to distributed generation (any fuel) • Adopt an EV • Adopt storage • Invest in RE (e.g., Bullfrog Power, shares in a cooperative)
2	Disruptive innovation towards decentralization (switch particular use to off main grid to multi-actor grid)	• Switch use/join an interconnected grid (2 points or more, such as micro-grid or virtual power plant) with at least one of bi-directionality, complementarity, flexibility(Mundaca et al. 2019; Lowitzsch et al. 2020) • DG with bi-directionality (prosumership)

2.6.3.3 Democratization

The scale for energy democratization is based on whether the incumbent gains control/market share, or whether citizens or communities gain control. Incumbent energy producers have dominated energy ownership over the past decades, and mainly involve producers whose interests are enmeshed with state interests (Brisbois 2020). Incumbents are defined as "those actors who wield disproportionate influence within a field and whose interests and views tend to be heavily reflected in the dominant organization of the strategic action field" (Fligstein and McAdam 2012). Democratization has been interpreted as "the political act of creating an opening that allows alternative forms of social relations to emerge and replace existing structures of domination with processes of self-determination" (Becker and Naumann 2017). Thus, democratization is a socially, politically and economically disruptive change in the energy system. Important in democratization are energy democracy and energy citizenship frameworks which emphasize process, the empowerment of citizens, and energy users as active participants, for example as single actor ownership and prosumership or community-based ownership (Devine-wright 2007; van Veelen and van der Horst 2018); the energy democracy and citizenship frameworks informed the definition of democratization for this research.

Both communities and individuals are central to the democratization scale. Energy citizenship emphasizes the role of individual citizens as active participants, rather than passive stakeholders (Devine-wright 2007), while energy democracy focuses primarily on the collective participation of communities in energy resources (van Veelen and van der Horst 2018). Here, types of communities include both communities of place and of interest, and may include cooperatives, Indigenous communities, community investment funds, non-profit organizations, municipalities, universities, schools and hospitals (Hoicka and MacArthur 2018), and individuals, which may include individual people, homeowners and renters.

Control and ownership are also critical elements within the democratization scale. This follows from energy democracy scholarship, which emphasizes distributed ownership and enhanced community control as essential for building energy democracy (Szulecki 2018; van Veelen and van der Horst 2018). Furthermore, it should be noted that community ownership is associated with beneficial local impacts (Berka and Creamer 2018) and is seen as a particularly meaningful form of participation (MacArthur, 2016). Within our definition, the transfer of control refers to control over decision-making power concerning energy resources. A controlling share of ownership is defined here as greater than 50% of ownership. Specific community ownership types may include: full ownership, where a community holds 100% ownership; partnerships, which can vary considerably with a community holding any percentage of ownership (Campney 2019); membership in cooperatives where each member has only one vote regardless of number of owned shares, therefore distinguishing it from members from shareholders in firms (Klagge and Meister 2018); community benefit agreements, which are contracts outlining community benefits regarding a development project and result from substantial community involvement (Gross 2008); and community trusts, which are bodies where revenue, dividends and royalties are stored but ownership structure can vary (Campney 2019).

Lastly, two further considerations factored into our research. The first concerns incumbent-owned energy resources on individual or community-owned land (e.g. renting out rooftop to incumbent who is producing solar power). Here the literature is focused on ownership of energy resources and not on ownership of the land. As such, such examples were not coded as contributing to democratization. The second concerns the role of energy efficiency services. Martinez (Martinez 2017) warns of the co-optation of energy efficiency services "for the benefit of maintaining the present corporate energy structure"(p. 32). When these services remain in the domain of incumbents, this maintains current structures and was coded as a 0, i.e., the status quo. Services provided through community-scale initiatives that employ local democratic governance structures, however, challenge the current system and contribute to energy democracy (Martinez 2017). As such, energy efficiency services were only coded as contributing to democratization if they were provided by community-scale initiatives. This scale is presented in Table 2.13.

Table 2.13 Democratization Scale

Scale	Definition	Example
-2	Incumbent gains all or nearly all control and a controlling share of ownership	• Examples of near monopolies and oligopolies for incumbents, as seen in multinationals
-1	Incumbent gains more control or gains an increased share of ownership incumbent producers.	• Consolidation of mid-sized incumbents into larger companies connected the central grid • Renting out rooftop to incumbent who is producing solar power (gaining market share) • Renting solar power from incumbent (gaining market share)
0	status quo: There is no change in ownership or control between incumbent producers and communities or individuals.	• Energy efficiency services when operating in the domain of incumbents
1	Individuals and/or communities/community gains more control or gains-an increased share of ownership	• Municipal Energy Plan program (community provides input)
2	Individuals and/or communities/community gains all or nearly all control and a controlling share of ownership	• Cooperative ownership of RE • Full community or individual ownership, holding 100% ownership • Energy efficiency services when operating in the domain of community-scale initiatives

2.6.4 Policy for Scale Up

Interlocking systemic forces create socio-technical and policy inertia that sustain the existing regime and prevent the emergence of low-carbon innovations (Unruh 2000). Institutional lock-in reinforces technological lock-in (preventing new entrants from achieving market shares) through the powerful support and influence of economic, social, and political institutions and actors (Seto et al. 2016). The resistance to adopt new, innovative technologies is due in part to self-reinforcing incentives: path-dependent processes that reinforce positive feedback loops, creating further resistance to regime change among carbon intensive industries and institutions (Seto et al. 2016). Incumbent actors that benefit from the existing institutional and infrastructural configurations advocate for policies and regulations that support their interests and reinforce their industry dominance (Seto et al. 2016).

Policies that support niche innovation scale-up play an important role in influencing socio-technical regime change through the diffusion of disruptive demand-side low-carbon innovations. Transition management literature argues that policy instruments have significant impacts on the diffusion of disruptive innovations because they have the ability to embed new practices into the existing socio-technical regime and put pressure on the incumbent regime (van den Bergh and van Veen-Groot 2001; Kivimaa and Kern 2016; Seto et al. 2016).

Policy instruments can be broadly divided into three main types: (1) economic, (2) regulatory, and (3) other, such as information and education campaigns (Vining and Weimer 1992). Economic policies and regulatory policies are primarily control policies, and are intended to challenge existing social practices (Seto et al. 2016). Control policies can contribute to both creating and developing niche innovations, as well as destabilizing the existing regime, because control policies can help to create an extended level playing field for niche innovations through internalizing the environmental and social costs of carbon emissions, so that they can compete with incumbent innovations in the market (van den Bergh and van Veen-Groot 2001). Control policies include policies that use economic instruments to put pressure on the regime incumbents, such as pollution taxes, carbon trading, or road pricing. Control policies also include regulations, such as banning certain technologies or implementing import restrictions and regulations (Kivimaa and Kern 2016).

Policy instruments can be further divided into general policy instruments and innovation-specific policy instruments (Bergek and Berggren 2014). General policy instruments are policy instruments that aim at providing general support or regulations to an entire industry without pinpointing any particular technology, such as carbon tax and cap-and-trade (Bergek and Berggren 2014). Innovation-specific instruments support specific innovations Regime change is unlikely to occur without such innovation-specific policies to support niche innovation(Elzen et al. 2004).

The scales for economic and regulatory policy instruments are presented in Tables 2.14 and 2.15.

2.6.4.1 Policy for Scale-up: Economic Instruments

Table 2.14 Policy for Scale-up: Economic Instruments Scale

Scale	Definition	Examples
-2	Strongly weakens the low carbon innovations through removal of technology-specific economic instruments that has impacts on diffusion of innovations (Bergek and Berggren 2014), or polices that strongly contradicts the promotion of innovations (Lieu et al. 2018).	• Abrupt removal or cancellation of a policy or eliminates support for specific technology • Abrupt cancellation of deployment subsidies • Abrupt cancellation of low-interest loans • Abrupt cancellation of venture capital
-1	Slightly weaken the low-carbon innovations through removal of general economic instruments that have impacts on diffusion of innovations (Bergek and Berggren 2014), or polices that slightly contradicts the promotion innovations (Lieu et al. 2018).	• Abrupt removal or cancellation of a policy or eliminates support for specific industry • Abrupt cancellation of feed-in tariffs contracts • Planned removal of support--policy cap on programs, target. • Abrupt cancellation of tax exemptions
0	No detectable change/no effect/ unknown effect on scale-up	• No relevant or detectable economic policies
1	Promote innovation through implementation of general economic instruments that have impact on diffusion of innovations (Bergek and Berggren 2014)	• Presence of economic policies that provide economic support for specific industry, such as tax exemptions, cap and trade and feed-in tariffs
2	Promotes innovations through implementation of technology specific economic instruments that have impact on diffusion of innovations (Bergek and Berggren 2014).	• Presence of economic policies that provide economic support for specific technology, such as deployment subsidies and low-interest loans

2.6.4.2 Policy for Scale-up: Regulations

Table 2.15 Policy for Scale-up: Regulations Scale

Scale	Definition	Examples
-2	Strongly weaken the low-carbon innovation: Removal of innovation-specific regulations that has impact on diffusion of innovations, (Bergek and Berggren 2014), or polices that strongly contradicts the promotion of innovations (Lieu et al. 2018)	• Lower the technology-specific design standards and requirements • Create significant regulatory barriers to promote low carbon innovation such as too many restrictions on the innovations
-1	Slightly weaken the innovation: Removal of general regulatory policy instruments that have impacts on diffusion of innovations (Bergek and Berggren 2014), or polices that slightly contradicts the promotion of innovations ((Lieu et al. 2018).	• Abrupt removal or cancellation of performance standards (an absolute upper emission level) • Excessive monitoring obligation that create some hardship on innovating firms
0	No detectable change/no effect/ unknown effect on scale-up	• no relevant or detectable policies
1	Promote innovation: Presence of general regulatory policy instruments have positive impact on innovations (Bergek and Berggren 2014).	• Presence of regulations that provide general support for specific industry. • Broad target or commitment for particular sector mentioned in long-term energy plan or climate change plan • setting performance standards (an absolute upper emission level)
2	Strongly promotes innovations: Presence of technology specific regulations that has positive impact on innovations (Bergek and Berggren 2014).	• Setting higher design standards (a particular technology's usage) and mandatory requirements for specific technology

2.6.4.3 Policy for Scale-up: Knowledge Creation and Diffusion

Informational and educational policies also play an important role in supporting the socio-technical regime change. Compared to control policies aimed at challenging existing social practices, informational and educational policy interventions that facilitate knowledge creation and diffusion are argued to be more effective because they contribute to embedding new practices into the incumbent socio-technical regime (Seto et al. 2016).

Informational and educational policies can influence knowledge creation, development and diffusion, market formation, resource mobilization, and direction of research (Kivimaa and Kern 2016). Knowledge creation and diffusion is an important support for niche-level low-carbon innovations attempting to scale-up and diffuse into mainstream markets. The creation and diffusion of knowledge can be influenced by a range of policies, including educational policies, training schemes, labor-market policies, and secondment of expertise (Kivimaa and Kern 2016; Meelen et al. 2019).

The diffusion of knowledge refers to the process of "disembedding, travelling and re-embedding" of knowledge (Geels et al., 2018, p. 29). A common upscaling pattern of knowledge described in sustainability transitions literature is comprised of the "development of aggregated form of knowledge that are then circulated and recontextualized to fit different circumstance" (Geels & Johnson, 2018; Meelen et al., 2019, p. 98). The scales for the *Policy for Scale-up: Knowledge Creation and Diffusion* variable are presented in Tables 2.16.

Table 2.16 Policy for Scale-up: Knowledge Creation and Diffusion Scale

Scale	Definition	Examples
-2	Removal of policies that strengthen the network that allow actors in the pubic and private sectors whose "activities and interactions initiate, import, modify and diffuse new knowledge"(Geels et al., 2018, p. 25). Network weaknesses can hinder knowledge development because firms, institutions and networks will become locked in to the old technologies (Jacobsson and Bergek 2011).	• Removal of policies that support for the establishment of supplier-user network and/or industry-academia network for low carbon innovations
-1	Removal of policies that provide niche-level support for knowledge diffusion (Jacobsson and Bergek 2011).	• Removal of educational policies, training schemes, labor-market policies; • Cancellation of educational campaigns, secondment of expertise and workshops
0	No impact on knowledge creation and diffusion	• no relevant or detectable policies for knowledge creation and diffusion
1	Presence of policies and activities that provide niche-level support to complement or strengthen knowledge diffusion (Jacobsson and Bergek 2011).	• Presence of regulations that provide general support for specific industry. • Implementation of policies, such as educational policies, educational campaigns, training schemes, labor-market policies, secondment of expertise and workshops that provide niche-level support to knowledge diffusion
2	Presence of policies and activities that support the establishment of new networks, which can contribute to the knowledge diffusion. With networks, different actors may interact effortlessly across large distances, exchange knowledge and thus increase their contribution to upscaling (Meelen et al. 2019).	• Policies that improve supplier-user networks and/or industry-academia networks for knowledge diffusion • Create innovation platform to provide reference guidelines for best available technology(Kivimaa and Kern 2016) . • Support organizations that aim at connecting local user initiatives (Feola and Butt 2017).

2.6.5 Building legitimacy

Building legitimacy for niche innovations to support their scale-up is a key factor that influences socio-technical system disruption. Institutional and organizational legitimacy is defined as "a generalized perception or assumption that the actions of an entity are desirable, proper or appropriate within some socially constructed system of norms, values, beliefs and definitions" (Suchman 1995). Legitimacy, in the context of sustainability transitions, assesses the role of actors and institutions in supporting low-carbon innovation diffusion and incumbent regime disruption. Institutional theory suggests that building acceptance for a novel innovation and challenging the incumbent institution depends heavily on the creation of legitimacy(van Oorschot et al. 2018).

Building legitimacy of niche innovations can be as important as the technological components of the innovation (Rosenbloom et al. 2016). Legitimacy is created through a series of intentional actions and strategies deployed by system actors to build and favorably shape support for a specific technology or practice (Duygan et al. 2019). Legitimacy is often required for niche innovation scale-up to work, including resources to be mobilized, markets to form, and actors to acquire political strength (Kivimaa and Kern 2016). Building an innovation's legitimacy for socio-technical system disruption requires the presence of two factors: (1) positive discourse framing and visioning strategies by actors (Ruef and Markard 2010; Geels and Verhees 2011; Duygan et al. 2019); and (2) the presence of actors with agency facilitating the diffusion of niche innovations across multiple scales (Geels and Verhees 2011; Schlaile et al. 2017; Duygan et al. 2019). In other words, legitimacy requires a strong network of system actors that actively support the innovation across scales (or policy domains).

The literature identifies the concept of 'discourses' as central to agency and policy evolution for a sustainable transition (Duygan et al. 2019). Discourse is the creation of storylines through which system actors can "construct meanings and frame how issues should be perceived and addressed" (Duygan et al. 2019). Positive discourse framing, or narrative framing, is the articulation of a favorable vision or expectation through connecting it to the broader regime or landscape environment, whereby building legitimacy for certain innovations (Duygan et al. 2019). The collective visioning and discourse framing by system-level actors influences the development and diffusion of niche technologies (Duygan et al. 2019). Policies, visioning strategies and public statements contribute significantly to the creation of legitimacy (Kivimaa and Kern 2016) and socio-technical regime disruption requires a combination of policies that both create legitimacy for niche-innovations, as well as policies that weaken (delegitimize) the established socio-technical regime (Rosenbloom et al. 2016). It is a combination of both niche legitimization and incumbent delegitimization policies that will ultimately lead to system disruption.

The mobilization of actors with agency across multiple scales is also necessary in forming legitimacy for niche innovation scale-up (Schlaile et al. 2017), producing the conditions for socio-technical system disruption. A system disruption requires the presence of institutions, agencies, and actors with agency (those that can influence or impact the energy system) facilitating the diffusion of niche innovations across scales (Geels and Verhees 2011; Schlaile et al. 2017; Gliedt et al. 2018; Duygan et al. 2019). The literature suggests that niche innovation scale-up occurs through the interaction of (1) innovation intermediaries interacting with niche and regime-level actors; and (2) regime-level actors operating across policy domains (Loorbach et al. 2017). Innovation intermediaries interact with niche-level actors to assist in scaling-up experiments that support the low-carbon transition by encouraging technology diffusion and market adoption (Gliedt et al. 2018). Innovation intermediaries also interact with regime actors to assist in the creation of political and institutional space for subsystem changes within the regime (Gliedt et al. 2018). Regime-level actors create the conditions for system change to take place and identify opportunities for institutional change (Gliedt et al. 2018). This is the process through which disruptive niche innovations build legitimacy and achieve widespread diffusion through the support of actors operating at different levels of the system.

2.6.5.1 Legitimacy through Discourse Framing

Building the legitimacy of niche innovations supports their scale-up and facilitates their potential for to create system disruption. As mentioned above, one of the key components for building legitimacy of niche innovations is through positive discourse framing and visioning strategies carried out by system actors (Ruef and Markard 2010; Geels and Verhees 2011; Duygan et al. 2019). Developing a positive discourse surrounding a niche innovation helps to connect the innovation to the broader context (Rosenbloom et al. 2016), which, in this case, is the need to transition to a low-carbon energy system. Positive discourse framing can take place within a single policy domain or span multiple policy domains creating impact at the system level. This scale was developed in order to measure the degree of positive discourse framing surrounding an innovation as an indicator of the innovation's legitimacy, which in turn influences diffusion.

For a detailed breakdown and examples of the scaling system for the *Legitimacy through Discourse Framing variable*, see Table 2.17.

Table 2.17 Legitimacy through Discourse Framing Scale

Scale	Definition	Examples
-2	*Strongly weaken* the legitimacy of niche innovations constraining diffusion and scale-up through the removal of supportive plans/strategies delivered by system actors; Presence of plans/strategies spanning *across policy domains* that strengthen the incumbent socio-technical regime.	• Losing credibility when government cancels or removes strategies, leading to the phase out of specific innovations. • Presence of action plans, annual reports, and/or policy documents that actively support and positively frame the incumbent socio-technical regime that span policy domains (e.g. energy policy *and* environment and climate change policy).
-1	*Slightly weaken* the legitimacy of niche innovations constraining diffusion and scale-up through the weakening of supportive plans/strategies delivered by system actors; Presence of plans/strategies limited to a *single policy domain* that strengthen the incumbent socio-technical regime.	• Presence of government policy documents, strategies, plans or reports that positively frame competing fossil fuel intensive technologies within a single policy field (e.g. energy policy).
0	No/unknown impact on legitimacy.	• No relevant or detectable strategies.
1	*Slightly strengthen* the legitimacy of niche innovations in support of diffusion and scale-up through the presence of plans/strategies that create positive discourse framing within a *single policy domain*.	• Action plans, annual reports, policy documents and strategies, etc., that positively frame discourse surrounding the niche innovation within a single policy domain being pushed forward by system actors.
2	*Strongly strengthen* the legitimacy of niche innovations in support of diffusion and scale-up through the presence of plans/strategies that create positive discourse framing *across policy domains*.	• Action plans, annual reports, policy documents and strategies, etc., that positively frame discourse surrounding a niche innovation across policy domains being pushed forward by a strong network of system actors (government agents, industry associations, actor networks).

2.6.5.2 Legitimacy through actors and networks

The second key component for building legitimacy of niche innovations is through the presence of actors with agency supporting the diffusion of niche innovation across multiple scales (Geels and Verhees 2011; Schlaile et al. 2017; Duygan et al. 2019). As outlined in the literature, a strong network of actors (including individuals, organizations, and institutions) with agency working to support the innovations within and across scales is a strong indicator of legitimacy. This requires a combination of interaction between niche-level, intermediary, and regime-level actors supporting and advocating for niche scale-up within a policy domain as well as the presence of regime-level actors supporting niche innovation across policy domains. The presence of both these factors create the necessary conditions for system disruption through legitimation. This variable is coded for the types of actors with agency supporting the scale-up of the innovations within and across policy domains as a strong indicator of legitimacy.

For a detailed breakdown and examples of the scaling system for the *Legitimacy through Actors* variable, see Table 2.18.

Table 2.18 Legitimacy through actors and networks Scale

Scale	Definition	Examples
-2	Strong network of incumbent regime actors operating *across* policy domains to constrain the delivery and diffusion of the niche innovation and preserve incumbent regime.	• Governments actors (municipal, provincial and/or federal) and incumbent utilities actively opposing the innovation across policy fields, sectors, industries. • Presence of fossil fuel advocacy groups. • Industry actors and industry associations that actively work to preserve the incumbent fossil fuel regime
-1	Presence of incumbent regime actors operating within a *single* policy domain to constrain the delivery and diffusion of the niche innovation and preserve incumbent regime.	• Government actors and/or incumbent utilities opposing the innovation within a single policy field, sector, industry. • Actor support for innovations that have a competitive advantage or act as barriers to market entry.
0	Silo of niche-level *actors* operating within a *single* policy domain facilitating the diffusion of the innovation. Impact negligible to low-carbon innovation.	• Support for the innovation from individual firms or small networks within a single policy field, sector, industry. • Absence of government-level support.
1	Presence of innovation intermediary actors without presence of regime-level actors operating *across* policy domains facilitating the diffusion of the niche innovation. This includes regime-level actors within a single policy domain or niche-level actors operating across policy domains.	• Support from government actors within a single policy domain. • Support for the innovation from incubators, accelerators, intermediaries that span policy domains in the absence of regime-level actors.
2	Strong network of regime-level actors and intermediaries operating *across* policy domains facilitating the diffusion of the niche innovation.	• Support from government actors across policy domains (e.g. energy and environment policy) • Different types and/or multiple organizations, institutions, and networks actively supporting the innovation. • Presence of actors operating within and across all levels: niche, intermediary, regime.

2.7 Variable 2: Energy Justice

Another important factor in characterizing the potential for socio-technical system change through disruptive innovation is the concept of energy justice. Energy justice is defined through its concern with who is involved, who gains and/or benefits, and who is marginalized, or more specifically, the distribution of costs, benefits, and procedures (Benjamin K Sovacool and Dworkin 2015; Jenkins et al. 2016; Benjamin K Sovacool et al. 2016). It has emerged as a useful analytical tool for considering the framing of energy problems (Benjamin K Sovacool and Dworkin 2015). Our framework for assessing energy justice draws from Sovacool and coauthors (Benjamin K Sovacool and Dworkin 2015; Benjamin K. Sovacool et al. 2016a; Köhler et al. 2019). Four indicators were developed in relation to four corresponding energy justice principles (availability, affordability, due process, and transparency and accountability (see Table 2.19). These principles were selected due to the possibility of examination within the scope of the available data. The indicators were considered for 12 types of energy users, which emerged from policy documents related to the innovations, and were not pre-determined. The energy users included governments (including federal, provincial and municipal), households (where homeowners, low income households and tenants are coded individually), Indigenous communities, individuals, the institutional sector, non-profit organizations, the private sector (including industry and other private businesses) and utilities. Based on these theoretical explorations of energy justice, and the range of indicators across various actor types, justice is best coded as "presence" or "lack of presence" of justice. The innovations were coded according to the following indicators to show the presence of justice, not the degree of it and binary coding was used for determining presence (or lack of presence) of the justice indicators.

Table 2.19 Energy Justice Indicators

Indicator	Coding Approach for Assessing Indicators	Principle	Definition of Principle
Availability	This indicator assesses whether or not the innovation intends to improve availability of supply, infrastructure, energy efficiency, conservation, transportation, storage and/or distribution of energy.	Availability	Broadly, availability draws from the idea that "people deserve sufficient energy resources of high quality" (Sovacool et al., 2016, p. 14). Sovacool and Dworkin (2015) emphasize concerns related to supply and reliability, as well as technological innovations enhancing conservation, transportation, storage and distribution of energy, including investment in such factors.
Affordability	This indicator assesses whether or not the innovation intends to reduce cost of supply, infrastructure, conservation, transportation, storage and/or distribution of energy for each user type.	Affordability	Affordability draws from the idea that "the provision of energy services should not become a financial burden for consumers, especially the poor" (Sovacool et al., 2016, p. 14). Furthermore, affordability concerns energy bills that do not overly burden consumers, as well as stable and equitable prices (Sovacool & Dworkin, 2015).
Information	This indicator assesses whether or not the innovation provides targeted information about supply, infrastructure, conservation, transportation, storage and/or distribution of energy for each user type.	Good Governance	Sovacool and Dworkin (2015)identify "good governance" as a principle of energy justice, where access to information about energy and the environment is a central element of "good governance."
Involvement	This indicator assesses whether or not each type of actor was involved (through engagement and consultation efforts) in the development of the innovation.	Due Process	Due process, for the purposes of this research, draws primarily from the idea that "communities must be involved in deciding about projects that will affect them" (Sovacool & Dworkin, 2015, p. 439).

2.8 Variable 3: Innovation Adoption

Energy user participation is critical to a low-carbon energy transition (Creutzig et al. 2016; Seto et al. 2016; Pallett et al. 2019a). To mitigate climate change, individuals, households and organizations are expected to engage in multiple activities that co-evolve with institutions and infrastructures (Seto et al. 2016). Low-carbon energy transitions depend on the engagement of energy users with demand-side innovations and, in this context, it is specifically this engagement that is of interest. How energy behaviours, practices and decisions can be influenced has been an area of study for decades (Kempton and Montgomery 1982; Stern 1999; Abrahamse et al. 2005; Kastner and Stern 2015), especially as demand for energy and the services it provides continue to rise (IEA 2017). According to a review study, decision making surrounding energy use is dependent on myriad factors/variables (Wilson and Dowlatabadi 2007). The adoption of energy efficiency measures varies according to several characteristics, including demographics (Das et al. 2018). Despite many studies that have examined correlates and predictors in this area generally known as pro-environmental behaviour (P. C. Stern 2000; Kaiser et al. 2005; Oreg and Katz-Gerro 2006; Bamberg and Möser 2007; Fielding et al. 2008; Milfont et al. 2010), what constitutes environmental behaviour varies and problematically many studies have failed to explicitly provide a definition of it. Jorgenson et al. (2019) define pro-environmental behaviour as "private-sphere environmental action at the level of individual persons"(p. 164).

Recently, studies have begun to examine a diverse range of participation and public engagement such as activism, community action, behaviour change, consultation, surveys, workshops and practices (Pallett et al., 2019). Jorgenson et al. (2019) present a framework that captures a broader range of behaviours by a broad range of actors that can impact system change. Their framework distinguishes between public/private; individual/collective; direct/indirect environmental actions by individuals or organizations (Jorgenson et al. 2019). The environmental action that our study focuses on is the adoption of innovation(s), be it a behaviour, a technological innovation, or a new practice. Our variable *Innovation adoption* is broader than pro-environmental behaviour, and narrower than the participation and public engagement defined by Pallet et al. (2019) or environmental action defined by Jorgenson et al. (2019), as we are specifically addressing innovations that address the energy system as a socio-technical system.

We have, in this dataset, captured some of these potential variables related to *Innovation adoption*; these were not all determined a priori. *Innovation adoption* related variables were determined and, in some cases constructed, after data collection. It should be noted that the presence or lack of these characteristics is not equivalent to the demonstration of *Innovation adoption*. In fact, these factors are what is deemed to contribute (potentially) to *Innovation adoption* and is what (Larson et al. 2018) (above) notes as the correlates and predictors of pro-environmental behaviour.

Table 2.20 identifies the *Innovation adoption* variables and their justification, through the literature that they are based in. The variables contribute to better understanding of *Innovation adoption* in the context of innovation diffusion and incorporate various types of variables to explain a significant environmental behaviour (Stern, 2000). Innovations were coded according to these factors for the presence or lack of presence of them and so all are coded in binary form.

Table 2.20 Innovation Adoption Variables (all are measured as binary variables)

Overarching variable grouping area	Variable	Justification for use
Incentives	Payment for electricity produced	Behaviour may be altered through offering financial or other material incentives.(Stern 1999; Abrahamse et al. 2005)
	Grant	
	Pay per performance	
	Rebate	
	Tax credit	
	Other/not specified	
	Non-material incentives	
Financing	Bonds	Behaviour may be altered through offering specific type of monetary rewards (Stern 1999; Abrahamse et al. 2005)
	Loans	
	Local improvement charges	
	On-bill	
	Other/not specified	
Feasibility of participation	Availability	Demand side can be dependent on information (Abrahamse et al. 2005; Palensky and Kupzog 2013) Our energy justice variable measures feasibility of participation (Stern 1999; Kuzemko et al. 2017).
	Affordability	
	Information	
	Involvement	
Type of behavior intervention	Antecedent intervention	Antecedent influence prior to behaviour, consequence is after. (Abrahamse et al. 2005)
	Consequence intervention	
Impact	Decarbonization	When looking at pro-environmental behaviour or environmental action it is important to know the impact it will have (a way to know its significance) (Jorgenson et al., 2019; Larson et al., 2018; Pallett et al., 2019). Our decarbonization, decentralization, democratization variables can be used as a proxy for measuring impact.
	Decentralization	
	Democratization	
Type of service	Policy	Innovations when applied to the demand side, to a specific program (Kivimaa and Martiskainen 2018) or policy goal (e.g., (Rosenow et al. 2017) Type of policy can make a difference to adoption of an innovation (Stern, 2000)
	Program	
	Product	
	Project	
	Service	

2.9 Recontextualization

The first step in the coding process was to locate information about the innovations that were identified. Profiles of the innovations were constructed by combining the findings from the desk research contained in Table 1, the survey results, and additional desk research specific to the innovation. Website pages, reports, and relevant documents pertaining to the innovation were identified and used to find the following information for each innovation:

1. Who provided the innovation (organization name and type);

2. How the innovation was provided to energy users (e.g. material incentives, informational mechanisms);
3. The aim of the innovation (e.g. energy efficiency, demand-side management);
4. The part of the energy system the innovation addresses (e.g. electricity, natural gas);
5. If the innovation flexibility, complementarity, inter connectivity and bi-directionality);
6. Who uses the innovation (e.g. individuals, households, private businesses);
7. How the innovation influences user behavior (e.g. antecedent interventions, consequence interventions);
8. Who was involved in the development, delivery, and funding of the innovation (e.g. governments, non-profits, intermediaries, utilities).
9. Prominent networks (e.g. industry and trade associations);
10. Strategies, reports and planning documents (e.g. energy and environmental plans);
11. Policies, regulations, and relevant legislation.

Some of the documents consulted included Electricity Conservation Reports; Natural Gas demand-side management program reports; Cap and trade program and revenue recycling reports; Green Energy and Green Economy Act (2009); and the Ontario Long-term energy plans (all years).

Based on this information, the information relevant for coding each specific innovation was written into a coding log. For example, the coder retrieved the original documents and innovation profile for more detailed information about the specific coding category. If more information was required to determine a value, the coder retrieved the original survey response or conducted additional desk research as needed, which included internet searches and the review of policy documents not captured in the above-mentioned coding resources.

Once the necessary information about an innovation was compiled in the coding log, the researchers systematically coded each innovation for all eight variables in accordance with the *System innovation* coding framework. Codes were initially recorded in the coding logs and then transferred to Excel codebooks.

2.9.1 System Innovation

In this study, two coders were responsible for coding 131 demand-side low-carbon innovations. In order to ensure a significant level of agreement (consistency) between the two coders, Cohen's Kappa statistic was employed to measure interrater reliability. Interrater reliability measures the extent to which members in the coding team assign the same value to the same variable (McHugh 2012). The Cohen's Kappa statistic is frequently used to indicate the interrater reliability (McHugh 2012). The formula to calculate Cohen's Kappa coefficient is:

$$K = \frac{P_0 - P_e}{1 - P_e}$$

P_0 is the "relative observed agreement among raters", and P_e is the "hypothetical probability of chance agreement" (Cohen 1960). The Cohen's Kappa statistic hypothesizes that if the result of the test is higher (closer to 1), then the two researchers had more agreement on the values assigned to a set of variables If the Cohen's Kappa coefficient is closer to zero, there is less agreement between researchers; if the coefficient is closer to one, there is a higher level of agreement between researchers. The Cohen's Kappa reference table can be found in Table 2.21, which demonstrates the six-score range of Cohen's Kappa statistic and the degree of agreement each of them represents. The aim was to ensure that there was, at minimum, substantial agreement between the researchers coding the innovations.

Table 2.21 Cohen's kappa Reference Table

Score Range	Degree to Agree
Less than or equal to 0	No agreement
0.01 – 0.20	None to slight
0.20 – 0.40	Fair
0.41 – 0.60	Moderate
0.61 – 0.80	Substantial
0.81 – 1.00	Almost perfect

Table 2.22 Results of Cohen's Kappa Calculation

Variable	1st round	2nd round	3rd round	4th round	5th round	6th round
Decarbonization	0.467	0.528	0.818			
Decentralization	0.368	0.455	1			
Democratization	0.783	0.715	0.905			
Economic Instruments	0.623	0.633	0.931	0.9	0.9	
Regulation	0.219	0.643	0.779	0.75	1	
Knowledge Creation & Diffusion	0.405	0.706	0.891			0.882
Discourse Framing	0.697	0.702	0.935			
Actors	0.671	0.605	0.860			

Interrater reliability was assessed in six rounds, all identified in Table 2.22. In the first round, two coders coded the eight *System innovation* variables for 20 low-carbon demand-side innovations and interrater reliability was assessed. To improve the level of agreement between the two researchers, additional steps were taken.

In the second round, for variables that received a Kappa score below 0.6 in the first round, the two coders reviewed each other's coding logs to assess the reasoning behind any disagreement and recoded the same 20 cases. For the variables that received a score above 0.6, the two coders coded 5 additional innovations. The scores for variables *Decarbonization* and *Decentralization* were still below 0.6. Some of the other variables were still between 0.6 and 0.8.

In the third round, a meeting was scheduled to go through the logic for the *Decarbonization* and *Decentralization* variables carefully and in detail. The two coders recoded these variables for the same 20 innovations and coded an additional 5 innovations. For the other variables with Kappa scores between 0.6 and 0.8, the coders compared only the specific innovations that they had coded differently. They discussed the logic and information used for coding these variables in order to resolve any remaining differences in coding strategies. The two coders recoded the same 25 innovations for the variables *Economic instruments, Legitimacy through Discourse Framing*, and *Legitimacy through Actors*. For these variables, the researchers recoded the same 20 innovations and an additional 5 innovations for the variables *Regulations* and *Knowledge Creation and Diffusion*. These scores revealed substantial agreement for *Regulations* and almost perfect agreement for the remaining seven variables. It was determined that this level of agreement between researchers was appropriate and interrater reliability was confirmed. Following these three rounds of interrater reliability tests, the two coders continued to code the remaining 106 low-carbon demand-side innovations independently, which were divided evenly between the two coders.

After producing a descriptive analysis of the results of variable distributions across innovation cases, it was determined that the documents required for coding of all three policy variables (*Economic Instruments, Regulations,* and *Knowledge Creation and Diffusion*) were not comprehensive. The team clarified the examples in the coding scale tables, and gathered additional documents. These policy variables for 131 innovations were recoded by one coder. In the fourth, fifth and sixth rounds of interrater reliability, the second coder recoded the policy variables for 20 innovations based on the new coding scale tables and information in order to improve the Kappa scores. Between rounds four and five the two researchers discussed their coding logic to improve the score of the regulation variable.

2.10 Energy Justice Variable

Coding was completed by one author, with support from all co-authors, using information provided by survey respondents, as well as desk research obtained through publicly available information, primarily from websites associated with the identified innovations.

2.11 Innovation Adoption

Coding was completed by one author, with support from the co-author with expertise in pro-environmental behaviour using information provided by survey respondents, as well as desk research obtained through publicly available information, primarily from websites associated with the identified innovations.

2.12 Correlation Analysis

2.12.1 Comparing Individual System Innovation Variables and Dissemination Rate

This research is interested in understanding the following question: what is the relationship between each *System innovation* variable (1–8) and the *Dissemination rate* for each innovation in the dataset that has available uptake data?

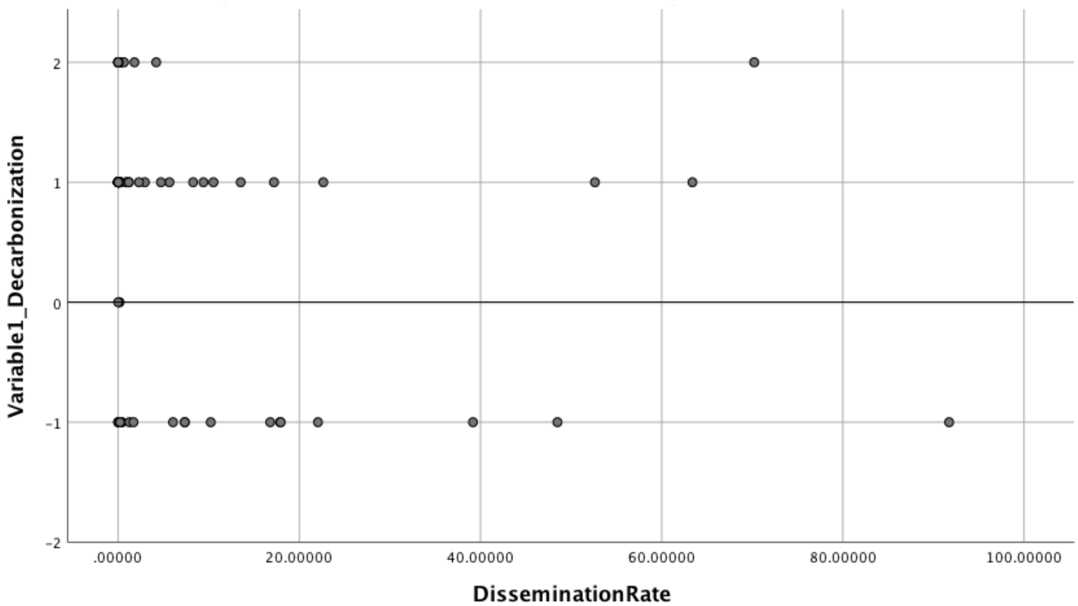
Recall, the *System innovation* variables include:

1. Decarbonization
2. Decentralization
3. Democratization
4. Policy for Scale-up: Economic Instruments
5. Policy for Scale-up: Regulations
6. Policy for Scale-up: Knowledge creation and Diffusion
7. Legitimacy through Discourse Framing
8. Legitimacy through Actors

To respond to this research question, a correlation statistic was used to measure the association (relationship) between the *System innovation* variables and *Dissemination rate*. A correlation statistic provides information about the strength and direction of the relationship between two variables (Noack 2018). Pearson's correlation and Kendall's tau-b correlation coefficients were both assessed in this analysis.

Pearson's correlation coefficient was initially assessed for its applicability to the sample. In order for a Pearson's correlation to be applicable, four key assumptions must be met: (1) the variables are continuous; (2) there is a linear relationship between the variables; (3) there are no significant outliers; and (4) the variables are normally distributed (Noack, 2018). A scatterplot diagram can be used to determine whether the relationship is linear, detect outliers, and graphically present the relationship between two continuous variables (Noack, 2018). A scatterplot diagram was created for each of the eight *System innovation* variables. The scatterplot diagrams show no linear relationship between the variables. For example, Figure 3 presents the scatterplot diagram created for mapping the relationship between the *Decarbonization* variable and *Dissemination rate*. Because there is no linear relationship between the two variables, the Pearson's correlation coefficient was not suitable for this sample.

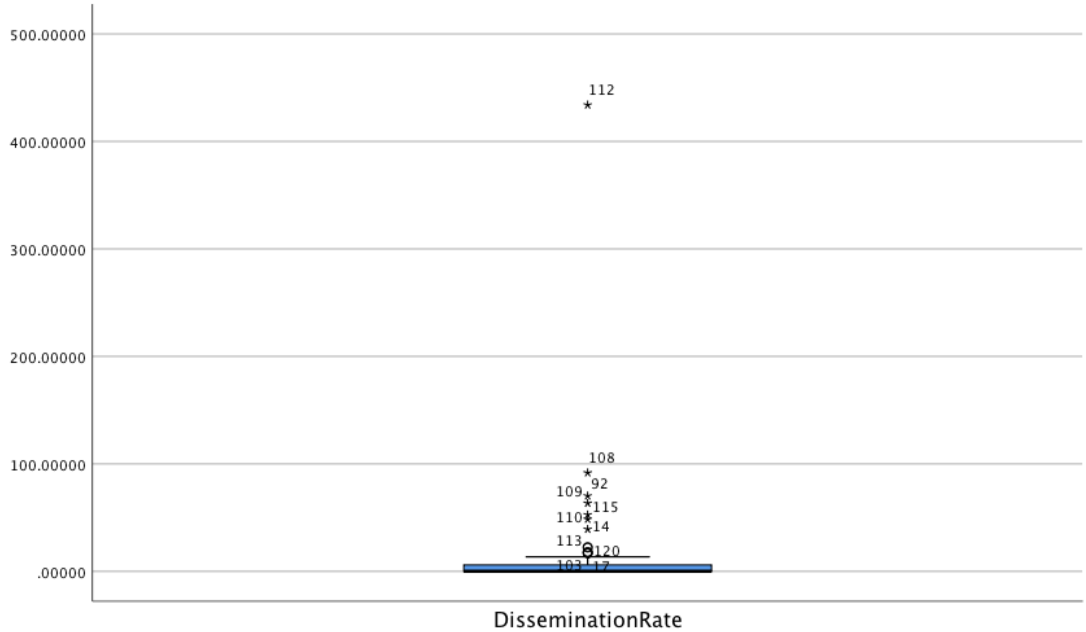
Figure 3 Simple Scatter Plot of Decarbonization by Dissemination Rate



Kendall's tau-b correlation coefficient was determined to be a more suitable metric of association between the variables in this analysis, as it is a non-parametric alternative when the sample has failed to meet the assumptions of Pearson's correlation test (Noack, 2018). Both Kendall's tau-b correlation coefficient and Spearman's correlation coefficient are calculated based on the ranks of the data, not from their actual values (Akoglu, 2018). Kendall's tau-b (τ_b) correlation coefficient was chosen over Spearman's because the scores of certain variables (e.g. *Democratization*) are clustered around 0 and +1. According to Akoglu (2018), it is more suitable to use Kendall's tau-b correlation coefficient over Spearman's when the same rank is repeated many times in a small dataset.

Prior to running the Kendall's tau-b correlation coefficient, the *Dissemination rate* outliers were assessed through a stem-and-leaf plot. A boxplot was created to show the results of the stem-and-leaf plot, presented in Figure 4. Thirteen values are identified as outliers (extreme values). The *Dissemination rate* of innovation #112 is clearly an outlier; not only does it stand out, but it's an impossible *Disseminate rate* value as it surpasses 100% dissemination. The explanation for this discrepancy is that innovation #112 is a coupon program provided by the Independent Electricity System Operator (IESO), and the number of coupons sent out to energy users was used as the uptake data (numerator) in the calculation of *Dissemination rate*. However, the numerator should be the number of people who have received the coupons. As the exact number of people who have received the coupons through this program cannot be found, it was determined by the research team that this data point should be removed.

Figure 4 Dissemination Rate Boxplot



After removing innovation #112 as an outlier, Kendall's tau-b correlation analysis was run for the *System innovation* variables and *Disseminate rate*. An additional 12 outliers were detected and removed, and Kendall's tau-b correlation was run again. Since there is no significant difference between the results of Kendall's tau-b correlation analysis with and without these 12 outliers, it was decided that the additional 12 outliers would remain in the analysis and be reported in the results. Therefore, only 1 outlier (innovation #112) was removed from the Kendall's tau-b correlation analysis assessing the relationship between the *System innovation* variables and *Dissemination rate*.

2.12.2 Comparing the System Innovation Composite Variable with Dissemination Rate

This research is also interested in understanding the following question: what is the relationship between the *System innovation* variables (1–8) in composite with *Dissemination rate* for the innovations in the dataset that has available uptake data?

To respond to this research question, a correlation statistic was used to measure the association (relationship) between *System Innovation Score* and *Dissemination rate*. For a detailed description of the method used to run the correlation analysis, see Methods section 2.12.1 above.

3 Results

3.1 Descriptive Statistics

The descriptive statistics presented below detail the results from coding the 131 innovations in accordance with the analytical framework for measuring *System innovation*, as developed by the research team and outlined in the Methods section 2.6. The *System innovation* variable is comprised of eight variables (influencing factors). The innovations were given scores on a scale from -2 to +2, which measures the degree to which the innovations are disruptive, incremental, or regime reinforcing across the *System innovation* variables. The eight variables include:

1. Decarbonization
2. Decentralization
3. Democratization
4. Policy for scale-up: Economic Instruments
5. Policy for scale-up: Regulations
6. Policy for scale-up: Knowledge Creation and Diffusion
7. Legitimacy through Discourse Framing
8. Legitimacy through Actors

Table 3.1 presents a summary of the distribution results across the eight System Innovation variables.

Table 3.1 Distribution of System Innovation variables

Variable	**Scores**					
	-2	**-1**	**0**	**1**	**2**	**Total**
Decarbonization	1 0.8%	32 24.4%	3 2.3%	68 51.9%	27 20.8%	131 100.0%
Decentralization	1 0.8%	9 6.9%	6 4.6%	105 80.2%	10 7.6%	131 100.0%
Democratization	0 0.0%	2 1.5%	98 47.8%	29 22.1%	2 1.5%	131 100.0%
Policy for Scale-up: Economic	0 0.0%	5 3.8%	27 20.8%	77 58.8%	22 16.8%	131 100.0%
Policy for Scale-up: Regulations	0 0.0%	0 0.0%	28 21.4%	99 75.8%	4 3.1%	131 100.0%
Policy for Scale-up: Knowledge	0 0.0%	1 0.8%	83 63.4%	38 29.0%	9 6.9%	131 100.0%
Legitimacy: Discourse Framing	1 0.8%	0 0.0%	13 9.9%	35 26.7%	82 62.6%	131 100.0%
Legitimacy: Actors	0 0.0%	1 0.8%	18 13.7%	22 16.8%	90 68.7%	131 100.0%

The four composite scores are the result of combining specific *System innovation* variable scores to produce an overall combined score for a particular subset of variables. The four composite scores include:

1. Composite Characteristic Score, combined score of the *Decarbonization*, *Decentralization*, and *Democratization* variables.

2. Composite Policy Support Score, combined score of the *Policy for scale-up: Economic Instruments*, *Regulations*, and *Knowledge Creation and Diffusion* variables.
3. Composite Legitimacy Support Score, combined score of the *Legitimacy through Discourse Framing* and through *Actors* variables.
4. Composite Support Score, combined score of the *Policy for scale-up: Economic Instruments*, *Regulations*, and *Knowledge Creation and Diffusion;* and *Legitimacy through Discourse Framing* and through *Actors* variables.

Finally, the *System Innovation Score* is the result of combining all eight *System innovation* variable scores to achieve an overall score across all eight variables.

Table 3.2 presents a summary of the central tendency and dispersion results from the *System innovation* variable scores and the composite scores.

Table 3.2 Summary of System Innovation variable and composite score statistics

Variable	Mean Score	Mode Score	Standard Deviation	Observed Range	Possible Range
Decarbonization	+0.67	+1	1.084	(-2 – +2)	(-2 – +2)
Decentralization	+0.87	+1	0.673	(-2 – +2)	(-2 – +2)
Democratization	+0.24	0	0.494	(-1 – +2)	(-2 – +2)
Policy for Scale-up: Economic	+0.89	+1	0.719	(-1 – +2)	(-2 – +2)
Policy for Scale-up: Regulations	+0.82	+1	0.461	(0 – +2)	(-2 – +2)
Policy for Scale-up: Knowledge	+0.42	0	0.632	(-1 – +2)	(-2 – +2)
Legitimacy: Discourse framing	+1.50	+2	0.738	(-2 – +2)	(-2 – +2)
Legitimacy: Actors	+1.53	+2	0.758	(-1 – +2)	(-2 – +2)
Composite Characteristic Score	+1.78	+2	1.755	(-5 – +6)	(-6 – +6)
Composite Policy Support Score	+2.12	+2	1.130	(-1 – +5)	(-6 – +6)
Composite Legitimacy Supports Score	+3.04	+4	1.389	(-3 – +4)	(-4 – +4)
Composite Support Score	+5.16	+7	1.960	(0 – +8)	(-10 – +10)
System Innovation Score	+6.94	+7	2.674	(-1 – +12)	(-16 – +16)

3.1.1 Decarbonization

The *Decarbonization* variable is an indicator of the innovation's potential to disrupt the fossil fuel regime. The mean score for the *Decarbonization* variable is +0.67 (Table 3.2). The minimum score an innovation received on the *Decarbonization* scale is -2 and the maximum score is +2.

Table 3.3 outlines the frequency distributions observed in the coding of the *Decarbonization* variable. Only one innovation strongly reinforces the incumbent fossil fuel regime and strengthens path-dependency (-2), while 32 innovations (24%) slightly reinforce the fossil fuel regime and path dependency (-1). Three innovations have no known or detectable impact on the fossil fuel regime (0). There are 68 innovations (52%) that create demand for a new regime or decrease the use of fossil fuels (+1), and 27 innovations (21%) that have the potential to lead to a system transformation and the destabilization of the existing fossil fuel regime (+2). More than 70% the innovations contribute to decarbonizing the existing fossil fuel regime (i.e. were coded as either a +1 or +2).

Table 3.3 Decarbonization distribution

Decarbonization Score	Frequency	Percent	Cumulative Percent
-2: Strong system reinforcing	1	0.8	0.8
-1: System reinforcing	32	24.4	25.2
0: No impact on system	3	2.3	27.5
1: Incremental	68	51.9	79.4
2: Disruptive	27	20.8	100.0
Total	131	100.0	-

To illustrate these findings, Table 3.4 presents an innovation example for each category on the *Decarbonization* coding scale.

Table 3.4 Decarbonization coding examples

Decarbonization Score	Example Innovation	Description
-2: Strong system reinforcing	Natural gas grant program	Funds the building of new natural gas infrastructure so that more Ontario communities will have access to natural gas.
-1: System reinforcing	Heating and cooling incentives	Rebates for upgrading residential natural gas heating and cooling equipment (such as furnaces and air conditioners).
0: No impact on system	Energy education and capacity building program	Funds projects to help build knowledge and skills around managing and generating energy. No change to fossil fuel system.
1: Incremental	Toronto green building standards	Building performance standards to reduce energy use and greenhouse emissions in new developments.
2: Disruptive	Electric vehicle charging stations	Offers grants to cover the purchase and installation cost of public electric vehicle supply equipment and chargers.

3.1.2 Decentralization

The *Decentralization* variable measures degree to which an innovation has the potential to disrupt the centralized energy grid and enhance the transition towards a decentralized energy system. The mean score for the *Decentralization* variable is +0.87 (Table 3.2). The minimum score an innovation received on the *Decentralization* scale is -2 and the maximum score is +2.

Table 3.5 outlines the frequency distributions observed in the coding of the *Decentralization* variable. Only one innovation strongly reinforces the centralized grid (-2), while nine innovations slightly reinforce the centralized grid (-1). Six innovations have no relevant or detectable effect on the grid (0). There are 105 innovations (82%) that are incremental innovations towards decentralization (+1), and ten innovations (6%) that are disruptive innovations leading to decentralization (+2). Nearly 90% of the innovations contribute to system decentralization from the established centralised energy grid (i.e. were coded as either a +1 or +2).

Table 3.5 Decentralization distribution

Decentralization Score	Frequency	Percent	Cumulative Percent
-2: Strongly system reinforcing	1	0.8	0.8
-1: System reinforcing	9	6.9	7.6
0: No impact on system	6	4.6	12.2
1: Incremental	105	80.2	93.9
2: Disruptive	10	7.6	100.0
Total	131	100.0	-

To illustrate these findings, Table 3.6 presents an innovation example for each category on the *Decentralization* coding scale.

Table 3.6 Decentralization coding examples

Decentralization Score	Example Innovation	Description
-2: Strong system reinforcing	Natural gas grant program	Expands access to Ontario's centralized natural gas system.
-1: System reinforcing	PeakSaver PLUS	Demand shifting from peak to off peak to flatten curve, supporting centralized generation.
0: No impact on system	Home renovation tax credit	Tax relief for home renovation expenditures without a requirement to improve energy efficiency or conservation, thereby having no impact on grid decentralization.
1: Incremental	High-rise retrofit improvement program	Makes low-cost financing available to undertake a variety of building energy efficiency and conservation improvements.
2: Disruptive	Power House pilot program	Technology collects solar energy through distributed solar panels and converts it into electricity. Electricity is stored (battery), used, or sent to the grid.

3.1.3 Democratization

The *Democratization* variable measures the degree to which an innovation has the potential to redistribute ownership and control from incumbent producers to individuals and/or communities. This variable considers both the ownership and control of energy activities as indicators for energy democratization. The mean score for the *Democratization* variable is +0.24 (Table 3.2). The minimum score an innovation received on the *Democratization* scale is -1 and the maximum score is +2.

Table 3.7 outlines the frequency distributions observed in the coding of the *Democratization* variable. No innovations contribute to the incumbent gaining all or nearly all control and a controlling share of ownership (-2). Two innovations contribute to the incumbent gaining more control or an increased share of ownership (-1). There are 98 innovations (75%) that have no influence on the ownership or control between incumbent producers and individuals/communities (0). There are 29 innovations (22%) that contribute to individuals and/or communities gaining more control or an increased share of ownership (+1). Two innovations contribute to individuals and/or communities gaining all or nearly all control and a controlling share of ownership (+2). The majority of the innovations have no impact on the ownership and control structures within the energy system (i.e. were coded as 0).

Table 3.7 Democratization distribution

Democratization Score	Frequency	Percent	Cumulative Percent
-2: Strongly system reinforcing	0	0.0	0.0
-1: System reinforcing	2	1.5	1.5
0: No impact on system	98	74.8	76.3
1: Incremental	29	22.1	98.5
2: Disruptive	2	1.5	100.0
Total	131	100.0	-

To illustrate these findings, Table 3.8 presents an innovation example for each category on the *Democratization* coding scale.

Table 3.8 Democratization coding examples

Democratization Score	Example Innovation	Description
-2: Strong system reinforcing	No innovations were strongly system reinforcing.	-
-1: System reinforcing	Large renewable procurement	Provides the incumbents with a stronger voice and additional opportunities to control the development of renewable energy projects.
0: No impact on system	Green bonds	Services offers improved energy efficiency and a switch to renewable energy while operating in the domain of the incumbents. No shift in control and/or ownership.
1: Incremental	Residential Green Button program	Through information, offers energy users more control over their energy consumption, but no changes to ownership.
2: Disruptive	Feed-in-Tariff program through registered renewable energy cooperatives.	Renewable energy cooperatives facilitate community-owned renewable energy projects in Ontario.

3.1.4 Summary of Characteristic Variables

The results for the characteristics variables (*Decarbonization, Decentralization, Democratization*) demonstrate a tendency for the innovations to have incremental characteristics or have little to no impact on the system *Democratization*. The *Decentralization* variable has the highest mean score (+0.87) followed by the *Decarbonization* variable (+0.67). The *Democratization* variable has the lowest mean score (+0.24). In addition, the most common score for the *Decarbonization* and *Decentralization* variables is +1, or incremental, while the most common score for *Democratization* is 0, or no impact. The *Decarbonization* variable also has more variability than the other characteristics, with a standard deviation of 1.08. The *Decentralization* and *Democratization* variables have less variability, with standard deviations of 0.67 and 0.49, respectively.

3.1.5 Composite Characteristic Score

Table 3.9 presents the frequency distribution findings for the *Composite Characteristics Score*, which captures the combined score of the three characteristic variable scores (*Decarbonization, Decentralization, Democratization*), with a scale that and ranges from -6 to +6. For example, if an innovation were coded as +2 for all three characteristic variables, the innovation's *Composite Characteristics Score* would be +6. The majority of the innovations have a score between 0 and +4, meaning that in most cases, there is at least one variable that was coded as incremental. An example of an innovation that has a score of +4 is the CUTRIC Electric Bus project, which is a project innovation researching zero emission battery electric and fuel cell electric buses. Two innovations have a score of +6, meaning that they are disruptive across all three characteristics variables. An example of an innovation that has a score of +6 is the Feed-in-Tariff program through Registered Renewable Energy Cooperatives, which supports the generation of renewable energy in Ontario through community power cooperatives that finance community-owned renewable energy projects, such as wind and solar. Nearly 40% of the innovations have a *Composite Characteristics Score* of +2 and roughly 60% of the innovations have a score of either +2 or +3. These findings suggest that, on average, most of the innovations have incremental characteristics.

Table 3.9 Composite characteristics distribution

Score	Frequency	Percent	Cumulative Percent
-6	0	0.0	0.0
-5	1	0.8	0.8
-4	0	0.0	0.8
-3	0	0.0	0.8
-2	8	6.1	6.9
-1	1	0.8	7.6
0	23	17.6	25.2
1	5	3.8	29.0
2	50	38.2	67.2
3	29	22.1	89.3
4	9	6.9	96.2
5	3	2.3	98.5
6	2	1.5	100.0
Total	131	100.0	-

3.1.6 Policy for scale-up: Economic Instruments

The *Policy for scale-up: Economic Instruments* variable measures the level of economic policy support an innovation receives through economic policy instruments that support or weaken innovation scale-up and diffusion. The mean score for the *Policy for scale-up: Economic Instruments* variable is +0.89 (Table 3.2). The minimum score an innovation received is -1 and the maximum score is +2.

Table 3.10 outlines the frequency distributions observed in the coding of the *Policy for scale-up: Economic Instruments* variable. None of the innovations have strongly weakened levels of economic policy supports for scale-up and diffusion (-2), and five innovations (4%) have slightly weakened levels of economic policy support for scale-up and diffusion (-1). There are 27 innovations (21%) that have no relevant or detectable economic policy supports that impact scale-up and diffusion (0). There are 77 innovations (59%) that have general economic policy support for scale-up and diffusion (+1), and 22 innovations (17%) that have strong economic policy support for scale-up and diffusion (+2). Around 75% of the innovations have at least some support through economic policy instruments (i.e. coded as either a +1 or +2).

Table 3.10 Policy for scale-up: Economic Instruments distribution

Economic Instruments Score	Frequency	Percent	Cumulative Percent
-2: Strongly weakens	0	0	0
-1: Slightly weakens	5	3.8	3.8
0: No impact on system	27	20.6	24.4
1: Supports	77	58.8	83.2
2: Strongly supports	22	16.8	100.0
Total	131	100.0	-

To illustrate these findings, Table 3.11 presents an innovation example for each category on the *Policy for scale-up: Economic Instruments* coding scale.

Table 3.11 Policy for scale-up: Economic Instruments coding examples

Economic Instruments Score	Example Innovation	Description
-2: Strongly weakens	No innovations have strongly weakened support	-
-1: Slightly weakens	SolarShare community solar bonds	Cancellation of the Feed-in-Tariff program removed general economic policy instruments that impact diffusion of renewable energy investment projects.
0: No impact on system	CarbonShift Tracker	No relevant or detectable economic policy instruments found.
1: Supports	Electric and hydrogen vehicle incentive program	General economic policy support for low-carbon vehicles through Ontario's climate change action targets set out in the 2007 Go Green: Climate Action Plan and in the 2017 Long Term Energy Plan.
2: Strongly supports	Automated Peak Saver/ Demand Response for households and commercial electricity customers	Economic incentives were provided for this specific technology in Ontario's electricity conservation and demand-side management policy.

Table 3.12 outlines the breakdown of the economic policy instruments by instrument type for the innovations that were analysed. The most common type of economic policy instruments are incentives (70%), and the most common type of economic incentives are rebates (25%), followed by grants (18%). Financing is the second most common type of economic instrument (21%), with a fairly even spread across bonds, loans, local improvement charges, and other (or not specific). There are five non-material incentives observed across the innovations, and only one disincentive. These findings demonstrate that there is a strong emphasis on material incentives for economic policy instruments supporting the scale-up and diffusion of the innovations, and less emphasis on financial incentives for the innovations.

Table 3.12 Types of Economic Instruments and their distribution

Type of Economic Instrument		Frequency	Percent of Total Economic Instrument
Material Incentives	Payment for electricity produced	6	9
	Grant	13	18
	Pay per performance	1	1
	Rebate	18	25
	Tax credit	4	6
	Other/not specified	8	11
	Total (Material Incentives)	50	70
Non-Material Incentives	Pro-environmental behaviors (e.g. choosing a zero-carbon mode of transportation for commuting)	5	7
Disincentives	Price on carbon (cap and trade)	1	1
Financing	Bonds	4	6
	Loans	4	6
	Local improvement charges	3	4
	On-bill	1	1
	Other/not specified	3	4
	Total (Financing)	15	21

3.1.7 Policy for scale-up: Regulations

The *Policy for scale-up: Regulations* variable measures the level of regulatory policy support an innovation receives through regulations that support or weaken innovation scale-up and diffusion. The mean score for *Regulations* variable is +0.82 (Table 3.2). The minimum score an innovation received is 0 and the maximum score is +2.

Table 3.13 outlines the frequency distributions observed in the coding of the Policy for scale-up: *Regulations* variable. None of the innovations have strongly weakened levels of regulatory policy support for scale-up and diffusion (-2), and none of the innovations have slightly weakened regulatory policy support for scale-up and diffusion (-1). There are 28 innovations (21%) that have no relevant or detectable regulatory policy supports that would impact the scale-up and diffusion of the innovation (0). There are 99 innovations (76%) that have general regulatory policy support for scale-up and diffusion (+1). Only four innovation has strong regulatory policy support for scale-up and diffusion (+2).

Table 3.13 Policy for scale-up: Regulations distribution

Regulations Score	Frequency	Percent	Cumulative Percent
-2: Strongly weakens	0	0	0
-1: Slightly weakens	0	0	0
0: No impact on system	28	21.4	21.4
1: Supports	99	75.8	96.9
2: Strongly supports	4	3.1	100.0
Total	131	100.0	-

To illustrate these findings, Table 3.14 presents an innovation example for each category on the *Policy for scale-up: Regulations* coding scale.

Table 3.14 Policy for scale-up: Regulations coding examples

Regulations Score	Example Innovation	Description
-2: Strongly weakens	No innovations have strongly weakened support	-
-1: Slightly weakens	No innovations have weakened support	-
0: No impact on system	Save on Energy	No relevant or detectable regulations found.
1: Supports	Municipal energy plan program	General regulatory support provided under Ontario's Community Energy Planning effort, as outlined in the 2017 Long-Term Energy Plan and the 2007 Go Green: Climate Action Plan.
2: Strongly supports	Zero carbon building standards	Sets higher design emissions standards for buildings and is a mandatory requirement.

3.1.8 Policy for scale-up: Knowledge Creation and Diffusion

The *Policy for scale-up: Knowledge Creation and Diffusion* variable measures the level of knowledge creation and diffusion policy support an innovation receives through information and education policies that support or weaken innovation scale-up and diffusion. The mean score for the *Knowledge Creation and Diffusion* variable is +0.42 (Table 3.2). The minimum score an innovation received is -1 and the maximum score is +2.

Table 3.15 outlines the frequency distributions observed in the coding of the *Knowledge Creation and Diffusion* variable. No innovations have strongly weakened levels of informational or educational policy support for scale-up and diffusion (-2), while only one innovations (3%) have slightly weakening levels of informational or educational policy support for scale-up and diffusion (-1). There are 83 innovations (63%) that have no relevant or detectable informational or educational policy supports that would impact the scale-up and diffusion of the innovation (0). There are 38 innovations (29%) that have general informational or educational policy support for scale-up and diffusion (+1). Nine innovations have strong informational or educational policy support for scale-up and diffusion (+2). The majority of the innovations have no relevant or detectable support for knowledge creation and diffusion (i.e. were coded as 0).

Table 3.15 Policy for scale-up: Knowledge Creation and Diffusion distribution

Knowledge Creation and Diffusion Score	Frequency	Percent	Cumulative Percent
-2: Strongly weakens	0	0.0	0.0
-1: Slightly weakens	1	0.8	0.8
0: No impact on system	83	63.4	64.1
1: Supports	38	29.0	93.1
2: Strongly supports	9	6.9	100.0
Total	131	100.0	-

To illustrate these findings, Table 3.16 presents an innovation example for each category on the *Policy for scale-up: Knowledge Creation and Diffusion* coding scale.

Table 3.16 Policy for scale-up: Knowledge Creation and Diffusion coding examples

Knowledge Creation and Diffusion Score	Example Innovation	Description
-2: Strongly weakens	No innovation was coded as strongly system reinforcing	-
-1: Slightly weakens	Toronto green building standards	Removal of the Ontario Climate Action Plan: Programs and Initiatives 2017-18, which provided $9.6 million for low-carbon building retrofit and construction training and skills development for future construction workers.
0: No impact on system	Electricity conservation and demand-side management program: incentives for commercial retrofits	No relevant or detectable knowledge creation and diffusion policies found.
1: Supports	Green Button program	Consultation policy workshops were held with a wide variety of stakeholders, including utilities, customers, government, non-profit groups and etc.
2: Strongly supports	QUEST Caucuses	A national network includes eight provincial and regional Caucuses, their related Working Groups, and a reach of thousands of stakeholders to support governments, utilities and energy service providers, the real-estate sector, and the product and professional service sector, to support Smart Energy Communities.

Table 3.17 outlines the breakdown of the informational policy instruments by instrument type for the innovations that were analysed. The most common type of informational policy instruments are capacity-building, training, and education instruments, accounting for 27%. Audits are the second most common informational policy instrument, accounting for 14%, followed by instruments aimed at the advancement of data, accounting for 15%. The least common forms of informational policy instruments are benchmarking and lobbying, both accounting for only 4%. These findings demonstrate that there is a strong emphasis on informational policy instruments that offer capacity-building, training, and education to support the scale-up and diffusion of the innovations. Research and network building are not common types of informational policy instruments.

Table 3.17 Types of informational policy instruments and their distribution

Type of Informational Instrument	Frequency	Percent
Audit	20	14
Advancement of data	16	15
Benchmarking	4	4
Building a network	8	6
Capacity-building, training, education	37	27
Certification/Standard	6	6
Lobbying	4	4
Research	9	9
Total (Informational Instruments)	104	100

3.1.9 Summary of Policy Supports

The results for the policy support variables (*Economic Instruments, Regulations, Knowledge Creation and Diffusion*) demonstrate a tendency towards incremental level policy support for scale-up across the innovations, particularly for the *Economic Instruments* and *Regulations* variables, while there seems to be less support for *Knowledge Creation and Diffusion* across the innovations. The *Economic Instruments* variable has a mean score of +0.89, the *Regulations* variable has a mean score of +0.82, and the

Knowledge Creation and Diffusion variable has a lower mean score of +0.42. In addition, the most common score for the *Economic Instruments* and *Regulations* variables is +1, or incremental, while the most common score for the *Knowledge Creation and Diffusion* variable is 0, or no impact. *Economic Instruments* also have more variability than the other characteristics, with a standard deviation of 0.719. This finding tells us that the *Economic Instruments* variable values are spread out over a wider range of scores than the other characteristics. *Regulations* and *Knowledge Creation and Diffusion* has less variability, with standard deviations of 0.461 and 0.632, respectively.

3.1.10 Composite Policy Support Score

Table 3.18 presents the frequency distribution findings for the *Composite Policy Support Score*, which captures the combined score of the three policy support scores (*Economic Instruments, Regulations, Knowledge Creation and Diffusion*), with a scale that ranges from -6 to +6. For example, if an innovation was coded as +2 for all three policy supports, the innovation's *Composite Policy Support Score* would be a +6. The majority of the innovations have a score between 0 and +4 across the policy support variables. Only one innovation has a negative policy support score (less than zero), and 37% of the innovations have a policy support score of +3 and above. Only one innovation has a score of +5, a home retrofit program offered by Pocket Change which receives strong policy support and was a key action in the Ontario's Climate Change Action Plan (2016-2020), a five-year plan aimed at helping Ontario fight climate change over the long term. The Pocket Change home retrofit program is also supported by a range of incentives and rebates offered by the City of Toronto and Province of Ontario through energy efficiency programs and the Home Energy Loan Program. No innovations have a score of +6, meaning that no innovations have strong policy support across all three policy support variables. Nearly 40% of the innovations have a score of +2, suggesting that policy support tends to be incremental rather than disruptive.

Table 3.18 Composite policy support distribution

Score	Frequency	Percent	Cumulative Percent
-6	0	0.0	0.0
-5	0	0.0	0.0
-4	0	0.0	0.0
-3	0	0.0	0.0
-2	0	0.0	0.0
-1	1	0.8	0.8
0	12	9.2	9.9
1	19	14.5	324.4
2	51	38.9	63.4
3	35	26.7	90.1
4	12	9.2	99.2
5	1	0.8	100.0
6	0	0.0	
Total	131	100.0	

3.1.11 Legitimacy through Discourse Framing

The *Legitimacy through Discourse Framing* variable measures the level of legitimacy support an innovation receives through discourse framing by system actors working to support or weaken innovation scale-up and diffusion. The mean score for the *Legitimacy through Discourse Framing* variable is +1.50 (Table 3.2). The minimum score an innovation received is -2 and the maximum score is +2.

Table 3.19 outlines the frequency distributions observed in the coding of *Legitimacy through Discourse Framing* variable. Only one innovation has strongly weakened levels of legitimacy support through the removal of plans and strategies that positively frame the innovation across policy domains (-2), and no innovations have weakened legitimacy support through the removal plans and strategies that positively frame the innovation within a single policy domain (-1). There are 13 innovations (10%) that have no relevant or detectable plans or strategies that impact legitimacy support for the innovation (0). There are 35 innovations (27%) that have legitimacy support through plans and strategies that positively frame the innovation within a single policy domain (+1), and 82 innovations (63%) that have strong legitimacy support through plans and strategies that positively frame the innovation within and across policy domains (+2). The majority of the innovation (89.3%) have some degree of positive discourse framing (i.e. were coded as either a +1 or +2).

Table 3.19 Legitimacy through Discourse Framing distribution

Discourse Framing Score	Frequency	Percent	Cumulative Percent
-2: Strongly weakens	1	0.8	0.8
-1: Slightly weakens	0	0.0	0.8
0: No impact on system	13	9.9	10.7
1: Supports	35	26.7	37.4
2: Strongly supports	82	62.6	100.0
Total	131	100.0	-

To illustrate these findings, Table 3.20 presents an innovation example for each category on the *Legitimacy through Discourse Framing* coding scale.

Table 3.20 Legitimacy through Discourse Framing coding examples

Discourse Framing Score	Example Innovation	Description
-2: Strongly weakens	Cap and trade program	Loss of credibility and weakened legitimacy through the removal of supportive plans/strategies delivered by system actors.
-1: Slightly weakens	No innovations are system reinforcing	-
0: No impact on system	Energy benchmarking courses	No relevant strategies that impact legitimacy were found.
1: Supports	Green bonds	Presence of strategies that positively frame discourse surrounding green bonds within the environmental policy domain, including in the 2016 Pan-Canadian Framework on Clean Growth and Climate Change and in the 2017 Ontario Financing Authority Annual Report, which encourage climate finance and the introduction of Provincial green bonds.
2: Strongly supports	Community energy storage project	Energy and battery storage promoted in energy, environment, and innovation plans/strategies, including in Ontario's Climate Change Action Plan (2016-2020) and Ontario's Long-Term Energy Plan (2017).

3.1.12 Legitimacy through Actors

The *Legitimacy through Actors* variable measures the level of legitimacy support an innovation receives through the presence of actors and actor networks working to support or weaken innovation scale-up and diffusion. The mean score for the *Legitimacy through Actors* variable is +1.53 (Table 3.2). The minimum score an innovation received is -1 and the maximum score is +2.

Table 3.21 outlines the frequency distributions observed in the coding of the *Legitimacy through Actors* variable. No innovations have strongly weakened legitimacy support through networks of incumbent regime actors operating across policy domains to constrain the diffusion of the innovation (-2), and only one innovation has weakened legitimacy support through the presence of incumbent regime actors operating within a single policy domain (-1). There are 18 innovations (14%) that have a silo of niche-level actors providing legitimacy support within a single policy domain (0). There are 22 innovations (17%) that have legitimacy support through the presence of innovation intermediaries (+1), and 90 innovations (69%) that have strong legitimacy support through the presence of both innovation intermediaries and regime-level actors (+2). The majority of the innovation (85.5%) have support from actors with agency operating across policy domains (i.e. were coded as either a +1 or +2).

Table 3.21 Legitimacy through Actors distribution

Actors Score	Frequency	Percent	Cumulative Percent
-2: Strongly weakens	0	0.0	0.0
-1: Slightly weakens	1	0.8	0.8
0: No impact on system	18	13.7	14.5
1: Supports	22	16.8	31.3
2: Strongly supports	90	68.7	100.0
Total	131	100.0	-

To illustrate these findings, Table 3.22 presents an innovation example for each category on the *Legitimacy through Actors* coding scale.

Table 3.22 Legitimacy through Actors coding examples

Actors score	Example Innovation	Description
-2: Strongly weakens	No innovations are strongly system reinforcing	-
-1: Slightly weakens	Cap and trade program	Presence of incumbent regime policy actors working to constrain the delivery and diffusion of the cap and trade program.
0: No impact on system	Community investor management services	Silo of niche-level actors from non-profits and cooperatives operating within the social enterprise and innovation strategy policy domain to support the provisioning of community investor management services.
1: Supports	CarbonShift Tracker	Presence of community leaders working to deliver the carbon tracking service, but actor networks and efforts limited to residential greenhouse gas reduction; absence of wide-spread scale-up through support of regime-level actors.
2: Strongly supports	Municipal energy plan program	Multiple regime-level actors supporting program diffusion across policy domains, including provincial and municipal governments and the Federation of Canadian Municipalities.

3.1.13 Summary of Legitimacy Supports

The results for the *Legitimacy* support variables (*Discourse Framing* and *Actors*) demonstrate a tendency towards a disruptive level of legitimacy support across the innovations. The Discourse Framing variable has a mean score of +1.5 and the *Legitimacy through Actors* variable has a mean score of +1.53, which is only slightly higher. In addition, the most common score for both *Legitimacy through Discourse Framing* and *Legitimacy through Actors* variables is +2, or disruptive. Both legitimacy variables also have similar variability, with a standard deviation of 0.74 for *Discourse framing* and 0.76 for *Actor*s.

3.1.14 Composite Legitimacy Support Score

Table 3.23 presents the frequency distribution findings for the *Composite Legitimacy Supports Score,* which captures the combined score of the two legitimacy support scores (*Discourse framing* and *Actors*), with a scale that ranges from -4 to +4. For example, if an innovation were coded as +2 for both legitimacy supports, the innovation's *Composite Legitimacy Supports Score* would be a +4. The majority of the innovations have a score between 0 and +4 across the legitimacy support variables. Only one innovation has a score below zero and 60% of the innovations have a score of +4, meaning that they have disruptive legitimacy supports for both Discourse framing and Actors. Approximately 83% of the innovations have a score between +2 and +4. These findings suggest that the legitimacy supports tend to provide a disruptive rather than incremental level of supports.

Table 3.23 Compost legitimacy support distribution

Score	Frequency	Percent	Cumulative Percent
-4	0	0.0	0.0
-3	1	0.8	0.8
-2	0	0.0	0.8
-1	0	0.0	0.8
0	7	5.3	6.1
1	14	10.7	16.8
2	18	13.7	30.5
3	13	9.9	40.5
4	78	59.5	100.0
Total	131	100.0	-

3.1.15 Composite Support Score

Table 3.24 presents the frequency distribution findings for the *Composite Support Score*, which captures the combined score of the five support scores (*Economic Instruments, Regulations, Knowledge Creation and Diffusion, Legitimacy through Discourse Framing, and Legitimacy through Actors*) with a scale that ranges from -10 to +10. For example, if an innovation was coded as +2 for all five support variables, the innovation's *Composite Support Score* would be a +10. The majority of the innovations have a score between +1 and +7 across the support variables. An example of an innovation that has a score of +7 is the EnerGuide for residential retrofits program, which offered retroactive grant funding for home energy efficiency improvements. An example of an innovation that has a score of +8 is the Green Ontario Fund, which is a program innovation offered by the Government of Ontario providing tailored information and incentives for specific energy savings technologies and retrofits, including smart thermostats, PV solar systems, and ground source heat pumps. The Green Ontario Fund also receives strong legitimacy support from Provincial Government actors and agencies, such as the IESO. Very few innovations have a score below +1, meaning that most innovations, on average, have at least one incremental support. If an innovation was coded as a +1 across all five support variables, the *Composite Support Score* would be a +5. Nearly 40% of the innovations have a *Composite Support Score* between a +6 and a +7, meaning that, on average, these innovations have a more incremental level of supports. Overall, these findings demonstrate a wide variation in how the innovations scored, suggesting that there is a notable difference in the level of policy and legitimacy support that the low-carbon demand-side innovations are receiving.

Table 3.24 Composite supports distribution

Score	Frequency	Percent	Cumulative Percent
-10	0	0.0	0.0
…	…	…	…
-1	0	0.0	0.0
0	2	1.5	1.5
1	5	3.8	5.3
2	8	6.1	11.5
3	11	8.4	19.8
4	19	14.5	34.4
5	20	15.3	49.6
6	27	20.6	70.2
7	28	21.4	91.6
8	11	8.4	100.0
9	0	0.0	-
10	0	0.0	-
Total	131	100.0	-

In summary, the legitimacy support variables tend to score higher than the policy support variables, meaning that there are stronger legitimacy supports for the innovations than policy supports. This finding demonstrates that there is generally stronger support for innovation scale-up through positive discourse framing and support from system actors and actor networks than through economic, regulatory and informational policy supports.

3.1.16 System Innovation Score

Table 3.25 presents the frequency distribution findings for the *System Innovation Score*, which captures the combined score of the eight *System innovation* variable scores and with a scale that ranges from -16 to +16. For example, if an innovation was coded as +2 for all eight support variables, the innovation's *System Innovation Score* would be a +16. The majority of the innovations have a score between +3 and +12 across the eight variables, meaning that there tends to be a wide variation how the innovations score. Very few innovations (less than 2%) have a score below a +1, meaning that most innovations, on average, have at least one variable that was coded as incremental. Only one innovations has a score below zero, the Natural Gas Grant Program, which has the lowest score of all the innovations (-1), due mainly to the strongly system reinforcing characteristics. If an innovation was coded as a +1 across all eight *System innovation* variables, the *System Innovation Score* would be an +8. Nearly 57% of the innovations have a score of +8 or lower, while only 43% of the innovations have a score above +8. Only 2 innovations have a score of +12, both Feed-in-Tariff programs, which encourage and promote greater use of renewable energy resources for electricity generating projects in Ontario, and which have generally disruptive characteristics and strong policy and legitimacy supports. On average, these findings suggest that the innovations have more incremental characteristics and supports than disruptive ones.

Table 3.25 System Innovation score distribution

Score	Frequency	Percent	Cumulative Percent
-16	0	0.0	0.0
…	…	…	…
-2	0	0.0	0.0
-1	1	0.8	0.8
0	1	0.8	1.5
1	2	1.5	3.1
2	3	2.3	5.3
3	9	6.9	12.2
4	11	8.4	20.6
5	6	4.6	25.2
6	19	14.5	39.7
7	22	16.8	56.5
8	15	11.5	67.9
9	18	13.7	81.7
10	15	11.5	93.1
11	7	5.3	98.5
12	2	1.5	100.0
13	0	0.0	-
14	0	0.0	-
15	0	0.0	-
16	0	0.0	-
Total	131	100.0	-

3.2 Correlation Analysis

The Kendall's tau-b correlation results were assessed at both the 0.05 and 0.01 levels of significance. If the significance value (p-value) is less than the 0.05 level of significance, the correlation is statistically significant (i.e. it did *not* occur by chance). If the significance value (p-value) is greater than the 0.05 level of significance, the correlation is not statistically significant (i.e. it occurred by chance). If the significance value (p-value) is less than the 0.01 level of significance, the correlation is highly statistically significant.

The characteristics of Kendall's tau-b are presented in Table 3.26 (Clausen & Fichter, 2019), which identifies the strength of the correlation between two variables based on the results of the correlation coefficient (τ_b). According to these characteristics, if the correlation coefficient is between 0.0 and 0.05, there is no correlation between the two variables; if the correlation coefficient is between 0.05 and 0.2, there is a weak correlation between the two variables; if the correlation coefficient is between 0.2 and 0.5, there is a medium correlation between the two variables; and if the correlation coefficient is above 0.5, there is a strong correlation between the two variables.

Table 3.26 Characteristics of Kendall's Tau-b

Coefficient	Correlation Strength
$0.0 \leq \tau_b < 0.05$	No correlation
$0.05 \leq \tau_b < 0.20$	Weak correlation
$0.20 \leq \tau_b < 0.50$	Medium correlation
$0.5 \leq \tau_b$	Strong correlation

3.2.1 Correlation Analysis for the System Innovation Variables and Dissemination Rate

Of the eight *System innovation* variables analysed for their correlation with *Dissemination rate*, only three resulted in statistically significant associations. *Decarbonization* and *Policy for Scale up: Economic Instruments* have a highly statistically significant correlation with *Dissemination rate* (at a 0.01 level of significance), and *Legitimacy through Discourse Framing* has a statistically significant correlation with *Dissemination rate* (at a 0.05 level of significance). The *Decentralization, Democratization, Regulations, Knowledge Creation and Diffusion,* and *Legitimacy through Actors* variables do not have a statistically significant correlation with *Dissemination rate*. The following sections (3.2.1.1 to 3.2.1.3) describe the correlation analysis results for the three *System innovation* variables with statistically significant correlations to *Dissemination rate*.

3.2.1.1 Decarbonization and Dissemination Rate

Table 3.27 presents the findings from the Kendall's Tau-b correlation analysis for assessing the relationship between the *Decarbonization* and *Dissemination rate* variables. The correlation coefficient (τ_b) is -0.234 and the p-value is 0.008, which is a highly statistically significant correlation at the 0.01 level ($p = 0.008 < 0.01$). According to the characteristics of Kendall's Tau-b (see Table 3.26), this correlation is of medium strength, as it falls in the 0.2 to 0.5 range. The correlation coefficient for *Decarbonization* and *Dissemination rate* is negative, meaning that there is an inverse relationship between the two variables.

Table 3.27 Kendall's Tau-b Correlation: Decarbonization and Dissemination Rate

			Decarbonization	Dissemination Rate
Kendall's tau-b	Decarbonization	Correlation Coefficient	1.000	-.234**
		Sig. (2-tailed)	.	.008
		N	131	80
	Dissemination Rate	Correlation Coefficient	-.234**	1.000
		Sig. (2-tailed)	.008	.
		N	80	80

**. Correlation is significant at the 0.01 level (2-tailed).

3.2.1.2 Policy for Scale-up: Economic Instruments and Dissemination Rate

Table 3.28 presents the findings from the Kendall's Tau-b correlation analysis for assessing the relationship between the *Policy for scale-up: Economic Instruments* and *Dissemination rate* variables. The correlation coefficient (τ_b) is +0.276 and the p-value is 0.001, which is a highly statistically significant correlation at the 0.01 level ($p = 0.001 < 0.01$). According to the characteristics of Kendall's Tau-b (see Table 3.26), this correlation is of medium strength, as it falls in the 0.2 to 0.5 range. The correlation coefficient for *Economic Instruments* and *Dissemination rate* is positive, meaning that there is a direct relationship between the two variables.

Table 3.28 Kendall's Tau-b Correlation: Economic Instruments and Dissemination Rate

			Economic Instruments	Dissemination Rate
Kendall's tau-b	Policy for scale-up: Economic Instruments	Correlation Coefficient	1.000	.276**
		Sig. (2-tailed)	.	.001
		N	131	80
	Dissemination Rate	Correlation Coefficient	.276**	1.000
		Sig. (2-tailed)	.001	.
		N	80	80

**. Correlation is significant at the 0.01 level (2-tailed).

3.2.1.3 *Legitimacy through Discourse Framing and Dissemination Rate*

Table 3.29 presents the findings from the Kendall's Tau-b correlation analysis for assessing the relationship between the *Legitimacy through Discourse Framing* and *Dissemination rate* variables. The correlation coefficient (τ_b) is +0.178 and the p-value is 0.049, which is a statistically significant correlation at the 0.05 level ($p = 0.049 < 0.05$). According to the characteristics of Kendall's Tau-b (see Table 3.26) this correlation is weak, as it falls in the 0.05 to 0.2 range. The correlation coefficient for *Legitimacy through Discourse Framing* and *Dissemination rate* is positive, meaning that there is a direct relationship between the two variables.

Table 2.29 Kendall's Tau-b Correlation: Discourse Framing and Dissemination Rate

			Discourse Framing	Dissemination Rate
Kendall's tau-b	Legitimacy through Discourse Framing	Correlation Coefficient	1.000	.178*
		Sig. (2-tailed)	.	.049
		N	131	80
	Dissemination Rate	Correlation Coefficient	.178*	1.000
		Sig. (2-tailed)	.049	.
		N	80	80

*. Correlation is significant at the 0.05 level (2-tailed).

3.2.2 Correlation Analysis for System Innovation Composite Scores and Dissemination Rates

3.2.2.1 *System Innovation Score and Dissemination Rate*

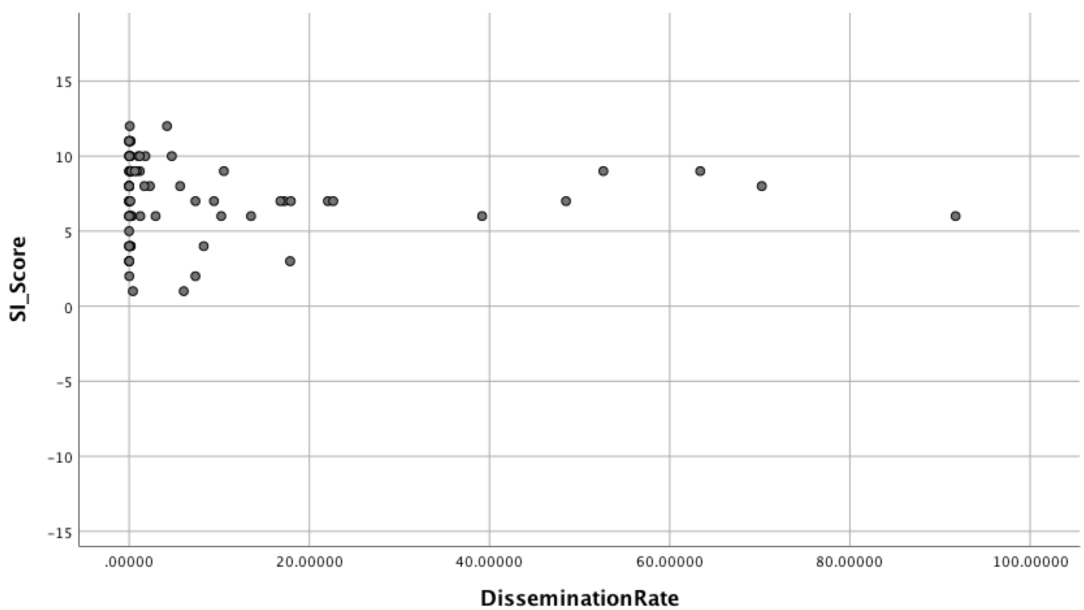
Table 3.30 presents the findings from the Kendall's Tau-b correlation analysis for assessing the relationship between the *System Innovation Scores* and *Dissemination rates*. The correlation coefficient (τ_b) is -0.024 and the p-value is 0.760, which means there is not a statistically significant correlation between the *System Innovation Score* and *Dissemination rate* ($p = 0.760 > 0.05$). According to the characteristics of Kendall's Tau-b (see Table 3.26), there is no correlation between the two variables, as the correlation coefficient falls in the 0.0 to 0.05 range. The correlation coefficient for the *System Innovation Score* and *Dissemination rate* is negative, meaning that there is an inverse relationship between the two variables.

Table 3.30 Kendall's Tau-b Correlation: System Innovation Score and Dissemination Rate

			SI Score	Dissemination Rate
Kendall's tau-b	System Innovation Score	Correlation Coefficient	1.000	-0.024
		Sig. (2-tailed)	.	.760
		N	131	80
	Dissemination Rate	Correlation Coefficient	-0.024	1.000
		Sig. (2-tailed)	.760	.
		N	80	80

Figure 5 presents a scatterplot diagram depicting the relationship between the *System Innovation Score* and *Dissemination rate.*

Figure 5 Simple Scatter Plot of System Innovation Score by Dissemination Rate



3.2.2.2 Composite Characteristic Score and Dissemination Rate

Table 3.31 presents the findings from the Kendall's Tau-b correlation analysis for assessing the relationship between the *Composite Characteristic Scores* and *Dissemination rates.* The correlation coefficient (τ_b) is -0.222 and the p-value is 0.008, which is a highly statistically significant correlation at the 0.01 level ($p = 0.008 < 0.01$). According to the characteristics of Kendall's Tau-b (see Table 3.26), this correlation is of medium strength, as it falls in the 0.2 to 0.5 range. The correlation coefficient for the *Composite Characteristic Score* and *Dissemination rate* is negative, meaning that there is an inverse relationship between the two variables.

Table 3.31 Kendall's Tau-b Correlation: Composite Characteristic Score and Dissemination Rate

			Characteristic Score	Dissemination Rate
Kendall's tau-b	Composite Characteristic Score	Correlation Coefficient	1.000	-0.222
		Sig. (2-tailed)	.	.008
		N	131	80
	Dissemination Rate	Correlation Coefficient	-0.222	1.000
		Sig. (2-tailed)	.008	.
		N	80	80

**. Correlation is significant at the 0.01 level (2-tailed).

3.2.2.3 Composite Support Score and Dissemination Rate

Table 3.32 presents the findings from the Kendall's Tau-b correlation analysis for assessing the relationship between the *Composite Support Scores* and *Dissemination rates*. The correlation coefficient (τ_b) is 0.161 and the p-value is 0.048, which is a statistically significant correlation at the 0.05 level ($p = 0.048 < 0.05$). According to the characteristics of Kendall's Tau-b (see Table 3.26), this correlation is weak, as it falls in the 0.05 to 0.2 range. The correlation coefficient for the *Composite Support Score* and *Dissemination rate* is positive, meaning that there is a direct relationship between the two variables.

Table 3.32 Kendall's Tau-b Correlation: Composite Support Score and Dissemination Rate

			Support Score	Dissemination Rate
Kendall's tau-b	Composite Support Score	Correlation Coefficient	1.000	.161*
		Sig. (2-tailed)	.	.048
		N	131	80
	Dissemination Rate	Correlation Coefficient	.161*	1.000
		Sig. (2-tailed)	.048	.
		N	80	80

*. Correlation is significant at the 0.05 level (2-tailed).

4 Conclusion

The analytical framework presented in this paper describes a novel approach for identifying multiple demand-side low-carbon innovations, and for predicting their impact on socio-technical systems change. This research directly addresses the tendency of diffusion research to focus on a single technology and a small scope of factors that influence innovation diffusion by instead identifying multiple innovations and a range and combination of system factors. This framework and methodology contribute to the field of sustainability transitions and carbon lock-in, and can be applied by policy makers and practitioners focused on problems at the intersection of energy users, energy systems, and climate disruption to empirical data in their jurisdictions. While this research focuses on the context of Ontario, the analytical framework and lessons learned can be applied to other contexts.

This research project builds on our comprehensive understanding of low-carbon innovation diffusion, and will contribute to broadening insights and research applications in this field. The analytical framework presented in this report can respond to a variety of research questions through qualitative and quantitative statistical analysis. The analyses described in this report are just a few key examples of the potential applications of the analytical framework. Industry experts and professionals can use this type research to map the current landscape of low-carbon innovations being offered to energy users, to inform and facilitate system-wide decarbonization and an accelerated transition to a low-carbon energy system.

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