Modeling demand-side low-carbon innovations and their potential to impact on socio-technical energy systems

Yuxu Zhao, Christina Hoicka, Maria-Louise McMaster, Runa Das

Funding provided by

Energy Modelling Initiative
Bringing the Tools to Support Canada's Energy Transition

YORK U
Faculty of Environmental and Urban Change

SSHRC CRSH

Smart Prosperity Institute

Literature

- Numerous studies show that a demand-side transition to electricity plays an important role in deep emission reductions (Bataille et al., 2015; Creutzig et al., 2018; Mundaca et al., 2019; Sakamoto et al., 2021).
- Decarbonized electrification on the demand-side can be achieved through the diffusion of demand-side electrification-related innovations (Sakamoto et al., 2021).
- The extent to which this transformation can be implemented is limited to the disruptive characteristics of the innovation and the diffusion rate of the innovation (Dixon et al., 2018; Wilson, 2018).

Research gaps

- Research gaps in understanding how quickly multiple demand-side low-carbon innovations can be diffused in an urgent and accelerated time frame.
- Diffusion of Innovation research tends to focus on a <u>single technology</u> or case study, or on a <u>small scope of influencing factors.</u>
- In order to address this gap, this research:
    - Analyses multiple (131) low-carbon innovations on the demand side;
    - Analyses a broad range of influencing factors.

Research

Research Question

How, and to what extent, do demand-side low-carbon innovations contribute to decarbonized electrification?

1. Factors that affect the diffusion of demand-side low-carbon innovations
2. Factors that affect the disruptive impact of innovations on decarbonized electrification.

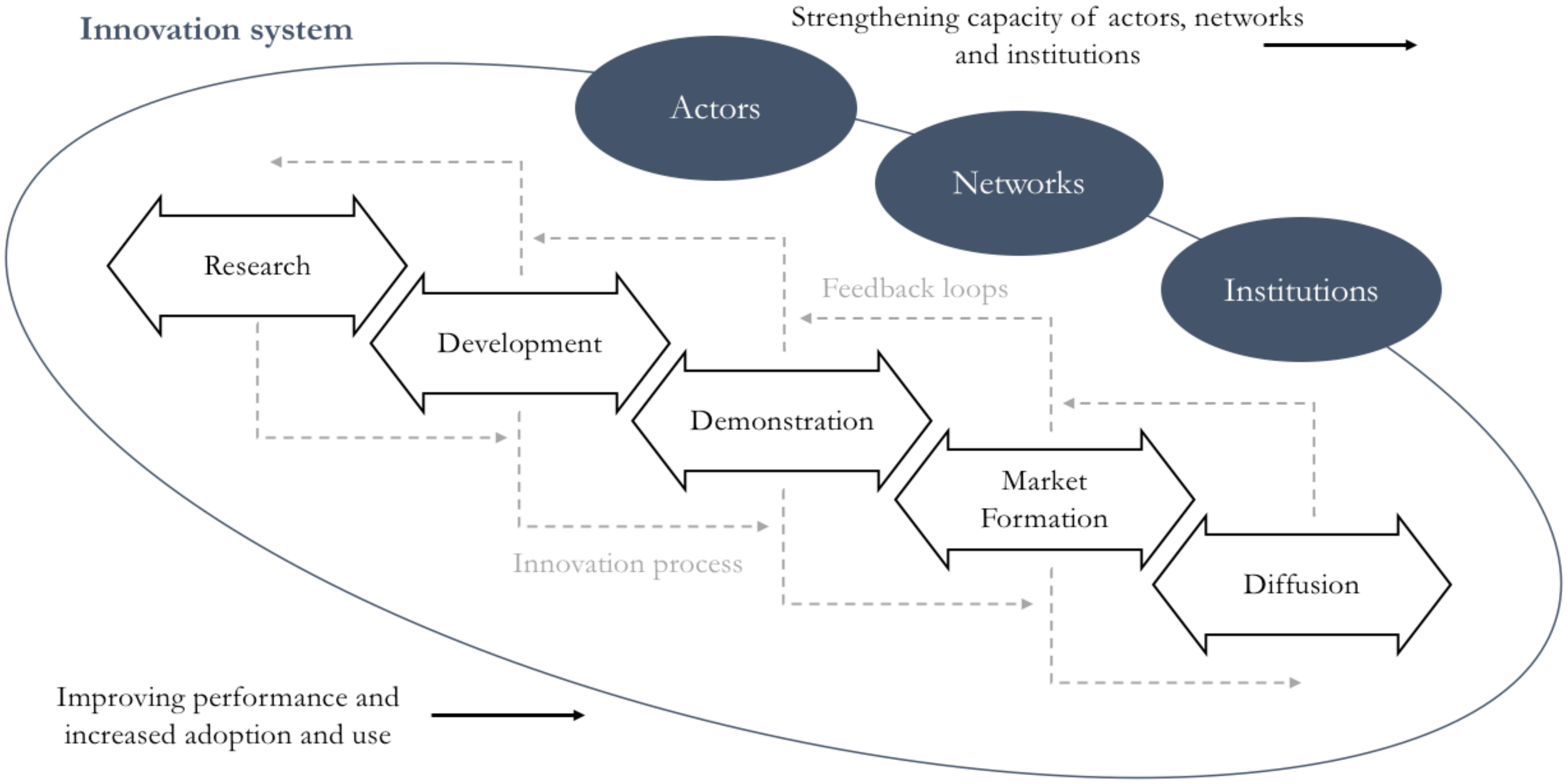
Models

Kendall's tau-b correlation

1. Relationship between factors that influence the diffusion of innovations;
2. Relationship between drivers and inhibitors of scale-up, and disruptive characteristics of innovations.

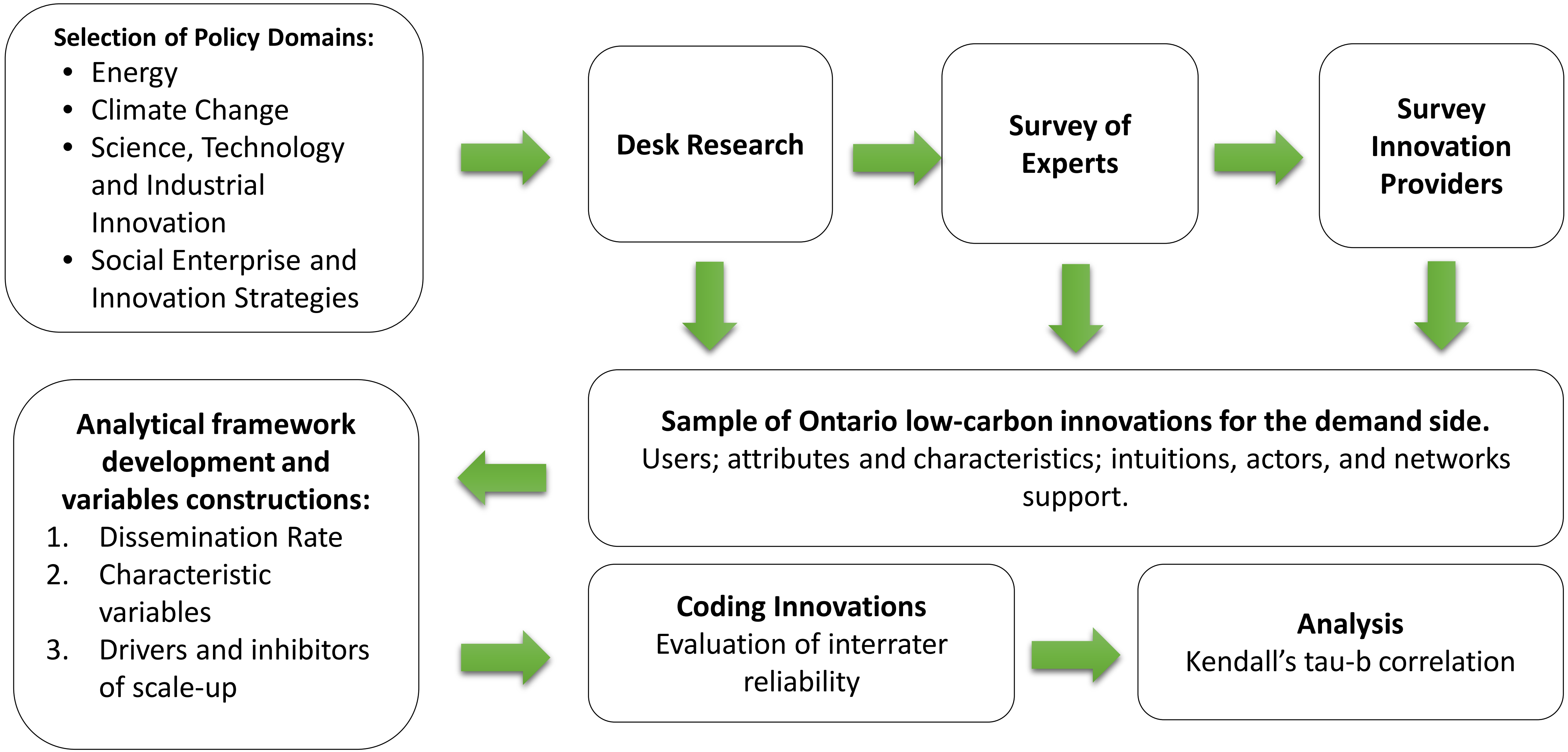
Sampling Frame and Data Collection

131 low-carbon demand-side innovations were identified



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

Research Design



Electrification Framework

- Six types of electrification-related innovations:
  - Using renewable energy sources;
  - Increasing the capacity of electricity storage;
  - Transport electrification;
  - Improving the performance of the electricity grid;
  - Reducing electricity use and carbon emissions with energy conservation, energy efficiency and demand-side management.
  - Fuel switching from a non-electricity carrier to electricity.
- 114 innovations that address electrification were identified (out of 131 demand-side low-carbon innovations)

Analytical Framework and Variable Construction

Diffusion Variable:

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

Characteristic Variables:

1. Decarbonization
2. Decentralization
3. Democratization

Drivers and inhibitors of scale-up

1. Policy for scale-up: Economic instruments
2. Policy for scale-up: Regulations
3. Policy for scale-up: Knowledge creation and diffusion
4. Legitimacy through discourse framing
5. Legitimacy through actors and networks

Analytical Framework and Variable Construction

- Generic Scale of Disruption

Score	Scale Definition	Literature
-2	Strongly reinforcing the regime	(Dixon et al., 2018; Geels, 2018; Johnstone et al., 2020; Johnstone & Kivimaa, 2018; Rosenbloom et al., 2016; Wilson, 2018; Wilson & Tyfield, 2018)
-1	Slightly reinforcing the regime	
0	No change to the regime	
1	Incremental change to the regime	
2	Disruptive leading to regime transformation	

Modelling results

Kendall's Tau-b Correlation: relationships between each variable and dissemination rate

Variables	Relation to dissemination rate
Decarbonization	-.189*
Decentralization	-0.143
Democratization	-0.096
Policy for scale-up: economic instruments	.304**
Policy for scale-up: regulations	-0.003
Policy for scale-up: knowledge creation and diffusion	-0.046
Legitimacy through discourse framing	.173
Legitimacy through actors and networks	0.067

* significant at 5% level, ** significant at 1% level

Modelling results

Kendall's Tau-b Correlation: relationships between characteristics and drivers or inhibitors of scale-up

Variables	Decarbonization	Decentralization	Democratization
Policy for scale-up: economic instruments	-0.202*	-0.037	-.250**
Policy for scale-up: regulations	-0.043	0.053	0.069
Policy for scale-up: knowledge creation and diffusion	-0.020	-0.109	-0.052
Legitimacy through discourse framing	0.105	0.286**	0.281*
Legitimacy through actors and networks	0.156	0.362**	0.234*

* significant at 5% level, ** significant at 1% level

Modelling results

Table 8 Kendall's Tau-b Correlation: relationships between two legitimacy support variables

Variables	Legitimacy through discourse framing
Legitimacy through actors and networks	0.700**

* significant at 5% level, ** significant at 1% level

Modelling Analysis

1. Innovations with the potential to lead to decarbonized electrification are associated with lower rates of diffusion.
2. Innovations with technology-specific economic policy support are associated with higher rates of diffusion.
3. Innovations with the potential to lead to decarbonized electrification are associated with less technology-specific economic policy support.

↓

More technology-specific economic policy instruments are needed to accelerate dissemination of demand-side electrification-related innovations.

Modelling Analysis

4. Innovations with the potential to lead to decentralization and democratization are associated with more legitimacy support.
5. Legitimacy through actors tends to be a precondition to legitimacy through discourse framing.

Legitimacy support is an important driving or inhibiting force for innovations to lead to decentralization and democratization. A strong network of system actors should be established to increase the legitimacy support.

Usability for policy design

- To examine how to drive or inhibit diffusion of an innovation within a particular context.
- To determine whether, across a mix of innovations in a particular energy system, system reinforcing innovations are receiving more policy and legitimacy support than disruptive innovations that support decarbonization and electrification pathways.
- To support decision making about how to provide optimal policy and legitimacy support to the right mix of low-carbon innovations to diffuse into markets and support decarbonization and electrification pathways.

Accessibility

- The models are accessible and transparent.
- Software used in this research: Qualtrics, Excel, Google docs and SPSS Statistics are all accessible online.

ELSEVIER

MethodsX

Volume 8, 2021, 101295

Method Article

Methodology to identify demand-side low-carbon innovations and their potential impact on socio-technical energy systems

Christina E. Hoicka [a], Runa R. Das [b], Yuxu Zhao [a], Maria-Louise McMaster [a], Jenny Lieu [c], Susan Wyse [a]

Being integrated to a national modeling platform

- The analytical framework and lessons learnt from these research models can be applied to other contexts.
- Workshops with practitioners or policy makers from all provinces
- Benefits:
  - Filling data gaps
  - Improvements and expansion of the research models.

Thank you!

Website: https://socialexergy.ca
Twitter: @socialexergy