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# The role of energy technology innovation in reducing greenhouse gas emissions: A case study of Canada

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ABSTRACT

Understanding the influence of energy technology innovation in reducing a country's greenhouse gas emissions requires a systematic review to characterize the existing system. A comprehensive data review of available financing mechanisms and investments by government and industry is undertaken for the case of Canada, coupled with an organized examination of existing international, federal, and regional climate policies that advance innovation. Results indicate that investments from early research and development through to capital expenditures are heavily weighted towards fossil fuels. Though federal efforts to meet international commitments have been unsuccessful, regions implementing high carbon fuel phase-out, renewable portfolio standards, and feed-in-tariffs were found to be successful in reducing emissions. Financing for clean energy projects is readily available; however, there is no complete database available for investors to discover these opportunities. To enhance clean energy innovation in Canada and enable success in emissions reductions, we suggest that investments (from research and development to capital expenditures) and regional policies should be aligned with federal commitments, along with clear communication of available financing to attract clean energy investors. Our approach to a systematic review is broadly applicable to other regions where there is interest in understanding and improving the role of innovation in reducing greenhouse gas emissions, particularly in countries with federalist political systems and large fossil fuel reserves.

## 1. Introduction

Climate change is one of the most pressing challenges in energy policy due to the increasing risks to human and natural systems predicted by climate science combined with the uncertainty in the magnitude and pace of the overall impacts [1]. As stated by the Intergovernmental Panel on Climate Change (IPCC) [1]: "human influence on the climate system is clear, and anthropogenic emissions of greenhouse gases are the highest in history." The role of energy technology innovation in reducing emissions is becoming increasingly recognized in the transition to more sustainable, lower carbon energy [2,3]. There have been a number of calls for research to improve the role of innovation and innovation systems in this transition [4–6]. At the same time, it has become a prominent subject in politics and policy, with a recognized need to create demand for clean energy through policy along with strategic investments in research, development, demonstration and deployment (RD3) [2,7]. Climate policy, investments, and financing should be coordinated with careful thought about the role that energy technology innovation can play in reducing emissions.

While there are many confounding factors that influence a region's overall greenhouse gas emissions, we provide one possible perspective that emphasizes the role of innovation. International commitments made through the United Nations Framework Convention on Climate Change (UNFCCC) are consistently not realized in Canada. The country has substantial fossil fuel resources and operates within a federalist political system, making it a useful case for countries with similar socio-political contexts. Previously, Canada committed to reduce its economy-wide greenhouse gas emissions to 17% below 2005 levels by 2020 for the Copenhagen Accord, in alignment with the United States [8]. With the measures applied, Canada's annual emissions are expected to be 727 megatonnes of carbon dioxide equivalent (Mt $CO_2$ eq) in 2020 [9]. This is 130 Mt $CO_2$ eq lower than where emissions would have been in 2020 if no measures had been taken; however,

*Abbreviations and units:* R & D, Research and development; RD & D, Research, development, and demonstration; RD3, Research, development, demonstration and deployment (RD3); ETIS, Energy technology innovation system; ETI, Energy technology innovation; CAPEX, Capital expenditures; IEA, International Energy Agency; IPCC, Intergovernmental Panel on Climate Change; NEB, National Energy Board; StatsCan, Statistics Canada; Mt, Megatonnes; CO2 eq, Carbon dioxide equivalent

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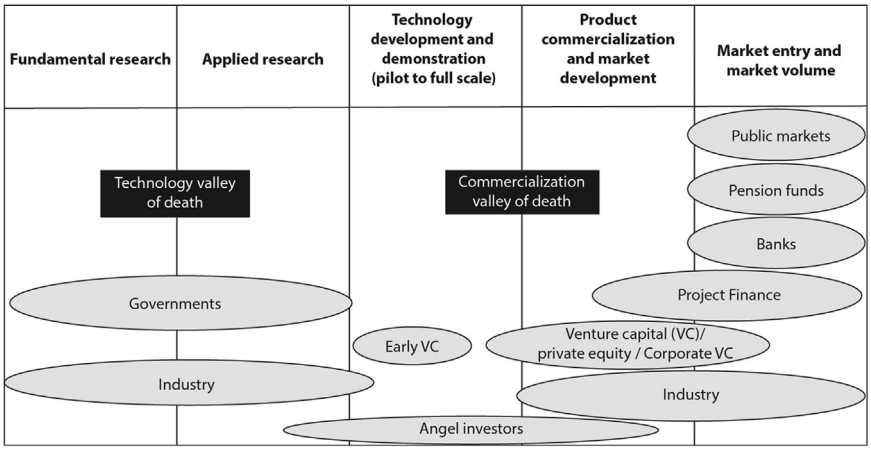


**Fig. 1.** Illustrative depiction of actors in the innovation system and the funding gaps, also referred to as the Innovation Gaps or Valleys of Death (adapted from [23,24]). Two valleys of death have been noted for clean energy innovation: (1) the technology valley of death that occurs between the first and second stages of technological development (between fundamental and applied research), and (2) the commercialization valley of death that occurs as entrepreneurs attempt to raise capital for demonstration through to the first commercial-scale facility [23].

emissions would not be low enough to meet the commitments made during the Copenhagen Accord. Canada would have yet to reduce another 116 Mt $CO_2$ eq to meet the target. The latest commitment includes an emission reduction of 30% of 2005 levels by 2030 [10], providing a new window of opportunity to achieve emission reduction goals. The ability of decision-makers to reduce emissions can be improved by energy technology innovation (defined here as the process by which individuals, firms and organizations develop and implement the use of new energy products, designs, processes and methods) [11]. In order to advance clean energy innovation, a comprehensive strategy is required that includes coordination between the public and private sectors [12].

We use Canada as a case study in the development of a systematic review to understand better the role of a country's energy technology innovation in meeting international commitments. The review characterizes Canada's energy technology innovation system relative to overall emissions performance. The current investment portfolio for low-carbon technologies and available financing mechanisms are examined alongside an organized presentation of existing policies to incentivize clean energy innovation. Data were analyzed on government and industry investments in innovation of technologies that have delivered or promise to deliver on greenhouse gas reductions. Available financing mechanisms were compiled from numerous databases. Where data were incomplete, a questionnaire was deployed to the developer of the mechanism to gain a more complete understanding of the available funding. Research has shown that when there are no policies to create a market for clean technologies (or “market pull”), policies and investments to advance technology innovation (or “technology push”) have yielded lower returns [13]. Therefore, we compiled existing climate policies at the international, federal, regional, and provincial government levels and categorized them as technology push and market pull. Results from the policy and investment review are discussed relative to actual performance in greenhouse gas emission reductions at each level of government. Generating an understanding of the potential impact of policies and investments relative to greenhouse gas emissions performance can support the development of guidance for national governments in realizing reduction targets and climate goals. Our approach to a systematic review can be applied broadly across governance levels and regions to understand better the improvements that can be made to innovation systems.

## 2. Energy technology innovation: a systems approach

To capture the complex suite of investments, policies, and actors involved across iterative innovation stages, scholars suggest employing a systems approach [6]. The assessment of an energy technology innovation system (ETIS) can be undertaken quantitatively or qualitatively [6]. In this study, we review both policies and quantitative data on investments and financing in light of their potential correlations with greenhouse gas emissions performance. Previous studies have focused on investments [2,7], the importance of policy design and implementation in achieving clean energy innovation [14–16], specific types of technologies (e.g. tidal [17], PV [18] and wind [18,19], with relatively few focusing on practical applications of ETIS theory (e.g. [20]). Studies have either focused on specific components of ETIS in particular regions or countries (e.g. [2,21]), across countries [19,20], or on the theoretical contribution of ETIS to innovation literature more broadly [6]. While theories of innovation include ETIS [5], the authors have yet to find a systematic review of a country's ETIS discussed relative to GHG emissions performance in a federal political system such as Canada's. To better understand and provide recommendations for improving an innovation system (rather than recommendations specific to a technology, for example), it is important to understand all involved technologies, investments, and the actors [6]. While most available data relates to federal spending in R & D, spending related to demonstration and deployment (having stronger ties to private investment) must also be understood [3,22]. Our review has been developed to improve our understanding of the role of energy technology innovation in supporting a country's reduction of greenhouse gas emissions in light of international agreements. We use Canada as a case study; therefore, the federalist political system necessitates an understanding of federal policy in addition to provincial and territorial policy.

Governments can and often do play a significant role in advancing innovation. For example, the innovation gap (or valley of death) is created by a period of low funding intensity along the innovation process (Fig. 1). The lower funding intensity may be a result of higher capital risk and lower financing due to investor risk aversion. In order to bridge the innovation gaps, the government can implement carbon regulation (e.g. taxes), subsidize research and development (R & D) by private corporations, sponsor graduate fellowships, support university and national laboratory research, offer innovation prizes, and provide funding opportunities to large-scale demonstration projects [25,26]. If not carefully planned and implemented, government activity can also widen the innovation gap [27]. First, if the emphasis is placed on basic research, output from research activities may be inflated when compared to what the private sector is willing to fund in later stages of the innovation sequence. Second, if government funding is concentrated solely on early R & D, less attention may be placed on intermediate-stage activities necessary to bridge the innovation gaps or

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