Transforming Green Financing: A Study of Blockchain Integration into the Canada Greener Homes Grant

By

Alexander Zelenski

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Abstract

This study explores the integration of blockchain technology into the Canada Greener Homes Grant (CGHG) program to enhance its operational and economic efficiency. Using a mixed-methods approach, it compares two scenarios - the current operational framework (baseline) and a blockchain-enhanced scenario from 2021 to 2031 to inform Canada's efforts to achieve its sustainability goals. The scenarios are built from projections that facilitate a comparative analysis of key variables, including funds disbursed, household participation, energy bill savings, pollution savings, and administrative time and expenditure. Cost-benefit and effectiveness analyses are employed to assess the economic impacts of blockchain integration into the CGHG. Preliminary findings suggest that using blockchain technology could significantly reduce administrative and financial friction and improve the overall operational and economic efficiency of the CGHG program. Recommendations for Natural Resources Canada detail how blockchain technology could be further examined to advance sustainability and economic efficiency in future green incentive programs.

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List of Key Abbreviations and Acronyms

ATIP	Access to Information and Privacy
CBR	Cost-Benefit Ratio
CER	Cost-Effectiveness Ratio
CGHG	Canada Greener Homes Grant
CGHI	Canada Greener Homes Initiative
COP	Conference of Parties
dApp	Decentralized Application
DeFi	Decentralized Finance
DLT	Distributed Ledger Technology
IEA	International Energy Agency
LEM	Local Energy Market
NRCan	Natural Resources Canada
PCAIS	Pan Canadian Artificial Intelligence Strategy
PoS	Proof of Stake
PoW	Proof of Work
UNFCCC	United Nations Framework Convention on Climate Change

Introduction

In the closing decade of the 20th century, the World Wide Web, or Web 1.0, made its debut and opened the door to the digital age, marking the beginning of a new epoch which would fundamentally reshape global, social, political, and economic landscapes. This new epoch fostered an unprecedented level of connection, setting the stage for an era where information and data were to become drivers of innovation and progress. As the Web evolved, it transformed from a static repository of information to a dynamic ecosystem fostering economic growth, influencing advancements across various sectors through the strategic application and commercialization of data. However, the potential of the Web extends far beyond its primary applications in everyday tasks such as communication, commerce, and finance. While critical to modern economies, they are only the tip of the iceberg.

Until now, the sustainability sector has been constrained by the architectural limits of early Web iterations. The initial phase, Web 1.0, also known as the “read-only” Web, offered limited functionality, primarily allowing users to access information without the means to engage or contribute. While revolutionary in expanding access to information, this phase could not enable the dynamic collaboration and community-driven innovation essential for sustainability initiatives.

Web 2.0, characterized by a shift to greater interactivity, user-generated content, and collaborative platforms, has enhanced collective action and networking ability. However, despite these advancements, Web 2.0 falls short in ensuring scalability, data security, and transparency, elements which are crucial for sustainability efforts. These architectural constraints of the Web have hindered the sector’s ability to implement advanced digital solutions for real-time data monitoring, transparent reporting, and, most importantly, engaging stakeholders in collective action toward sustainability goals. The literature discussing the capabilities and limitations of Web 1.0 and 2.0 concludes that, while they have laid the foundation for digital innovation, the sustainability sector eagerly awaits the next leap forward in the Web to realize its digital transformation potential fully.

Web 3.0, with blockchain at its forefront, signals a potential paradigm shift, offering a promising horizon for sectors such as sustainability that have been slow to embrace digital transformation. Characterized by decentralization, immutable record keeping, and enhanced security, blockchain offers a new pathway for creating efficient and accountable systems in sustainability initiatives such as the Canada Greener Homes Grant. However, while blockchain technology holds significant promise, its adoption must be approached with caution. As with any new technology, the benefits come with associated trade-offs, in the case of blockchain the two key areas most relevant to this research are the environmental and equity implications of blockchain. The environmental implications of blockchain are directly associated with the validation of transactions (the creation of a new “block”) within a blockchain network. This process of validating transactions is governed by what are known as consensus mechanisms – the rules that allow participants in a blockchain network to agree on the validity of transactions. Some of these processes are highly energy and water intensive as they require vast amounts of computational power to solve complex mathematical algorithms (Srivastava, 2024). For instance, Bitcoin, one of the most widely used blockchain protocols uses around 110 TWh each year, equal to the energy consumption of a small nation like Malaysia, or

Sweden, which can undermine existing sustainability initiatives if not addressed adequately (Clarke, 2023). Moreover, blockchain introduces equity and power implications. While decentralization is often expected to democratize control, blockchain remains vulnerable to the concentration of power and influence. The design of many protocols can, paradoxically, lead to the concentration of a small group of individuals who are early adopters, individuals with access to greater computational resources, and individuals with a deep technical understanding of the technology. Furthermore, the technical complexity of blockchain may create barriers to entry for marginalized communities or less tech-savvy individuals, potentially exacerbating existing digital divides. Ensuring equitable access and broad participation in blockchain-based sustainability initiatives will be essential to avoid perpetuating inequality. Both the environmental and equity implications of blockchain are discussed in more depth throughout the literature review and discussion sections of this thesis.

As blockchain reshapes sectors, initiatives such as the Canada Greener Homes Grant present a compelling opportunity to explore how blockchain could be leveraged for better financial, environmental, and social outcomes. The Canada Greener Homes Grant was designed to encourage homeowners to undertake energy-efficient retrofits by providing financial incentives. Government data indicates that thus far the program has played a key role in promoting energy bill savings and greenhouse gas reductions from households, which contribute a significant share of the 13% of emissions generated by buildings across Canada (NRCan, 2022).[1] However, the current system incurs substantial administrative costs and faces operational inefficiencies. This study investigates blockchain's potential to address the existing ecosystem fragmentation within the CGHG by answering the question: How can blockchain technology optimize the operational and economic efficiency of the Canada Greener Homes Grant for households in Canada? This research hypothesizes that integrating blockchain technology into Natural Resource Canada's (NRCan) digital infrastructure will significantly reduce the degree of ecosystem fragmentation by addressing the administrative and financial frictions associated with current processes. Blockchain has the potential to reduce the time taken to complete administrative steps in enrolling and distributing funds to homeowners for energy retrofits, thus freeing up further funds that can drive emissions reductions. This could improve the economic efficiency of allocating environmental and clean technology incentives to households, enabling Canada to become a leader in leveraging digital technologies for sustainable development.

Adoption of new technologies is rarely easy or costless. To realize any benefits of blockchain adoption, future program designers will need to carefully consider the challenges this new technology presents. Different blockchains can have different environmental footprints, and hence, accounting for this in decisions around adopting different protocols will be consequential for the net emission reductions that can be achieved. It is not advisable to adopt a technology that reduces emissions in one place

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[1] These estimates may, however, overestimate the emissions reductions, given independent research has indicated less realized energy savings from certain of the recommended retrofits included in the Greener Homes Grant program (Papineau, Rivers, & Yassin, 2024). For more information, see Maya Papineau, Nicholas Rivers, & Kareman Yassin, *Household benefits from energy efficiency retrofits: Implications for net zero housing policy*, Carleton Economics Working Papers, https://carleton.ca/economics/wp-content/uploads/cewp24-05.pdf (accessed September 10, 2024).

(households) by raising emissions in another (server farms). Similarly, blockchain may empower certain economic actors and differentially affect households, giving some easier access to government programs and erecting new barriers for other households. Any efficiency gains to be realized by blockchain need to be considered in relation to these downside risks.

The remainder of this paper is structured as follows. The first chapter reviews literature and case studies to frame the significance of Web 3.0, with a specific emphasis on blockchain, as a potential catalyst for sustainable development. Chapter two outlines the methodologies employed in this study and anticipated outcomes. Chapter three presents the results of the analysis and discusses them. Chapter four deliberates on the implications of these findings, drawing parallels and contrasts with existing literature. Chapter five concludes by highlighting this study's key findings and recommendations to guide policymakers and future research on blockchain technology for sustainable development in Canada.

Chapter 1: Literature Review

The following literature review explores five main areas: the current state of sustainable development globally and within Canada, the potential of Web 3.0 and blockchain technology, applications of blockchain for sustainable development, important considerations in blockchain development, and the policy opportunities and challenges of blockchain technology in Canada. Through a systematic exploration of peer-reviewed sources, case studies, industry reports, and government reports, this review provides context to the relevance of blockchain integration for sustainable development within Canada's public digital infrastructure. Furthermore, this review will provide foundational insights, further examined in Chapters 2 and 3 of this thesis.

1.1 The State of Sustainable Development Globally and in Canada

In the last several decades, the international community has significantly increased its focus on environmental sustainability, with landmark events such as the Rio Earth Summit in 1992 marking the high points in the hope for a future of effective global environmental governance. The Rio Earth Summit set the stage for a more united global effort to tackle environmental issues, leading to the adoption of Agenda 21 and the establishment of the United Nations Framework Convention on Climate Change (UNFCCC). The UNFCCC entered into force in 1994, creating a framework for international cooperation to limit global temperature increases and has been a cornerstone in the global fight against climate change. Importantly, it established the Conference of Parties (COP), a decision-making body instrumental in advancing climate change initiatives at a global level (United Nations Framework Convention on Climate Change, accessed January 15th, 2024.).

The significance of the UNFCCC becomes evident when considering subsequent climate agreements. For instance, the 1997 Kyoto Protocol, the Copenhagen Accord in 2009 and the Paris Agreement in 2015 were all outcomes of the COP processes established by the UNFCCC. While the Copenhagen Accord aimed to build momentum towards a binding global agreement, it fell short. However, it set the stage for the more successful Paris Agreement, which, for the first time, united almost every country in a single agreement to mitigate emissions leading to climate change and devise adaptation strategies for addressing the ongoing and growing consequences of climate change for countries around the world. Overall, the Paris Agreement set a long-term goal of limiting temperature increase below 2°C compared to pre-industrial levels, with the aspiration of limiting the increase to less than 1.5°C. More specifically, the Agreement calls for emissions to peak by 2025 and decline sharply by 43% by 2030 (United Nations Climate Change, accessed November 10th, 2023). Despite the positive intentions behind these initiatives, challenges such as their non-binding nature, loopholes, and lack of transparent cooperation have hindered their full effectiveness. Nevertheless, the evolution of these agreements under the UNFCCC underscores the increasing recognition and commitment of the international community to address climate change comprehensively (Maizland, 2023).

Reducing emissions at scale requires systemic transformations that facilitate extensive cross-sector collaboration and place a heightened emphasis on the residential sector. The nature of global efforts is currently too fragmented and too slow, as indicated by the International Energy Agency (IEA) in their “Net Zero by 2050” report. The IEA emphasizes the need for annual clean energy investments to triple to around $4 trillion by 2030 to meet the 2050 net-zero targets. Moreover, the Agency estimates that around $90 billion of public funding is urgently needed to demonstrate projects before 2030, far exceeding the current budget of approximately $25 billion. However, achieving these ambitious goals cannot rely solely on investment but also requires significant behavioural changes from citizens, which will account for around 4% of cumulative emissions reductions (IEA, 2021). A transition of this scale and speed cannot be sustained without deeper collaboration amongst diverse stakeholders across governmental, commercial, and residential sectors.

Canada’s role in this landscape is paradoxical. On the one hand, Canada has made notable strides in the environmental and clean technology sector. The country has an expanding portfolio of clean technology projects and has committed to doubling its public investment in clean energy Research, Development, and Deployment (RD&D), meeting its targets ahead of schedule. At the macro level, some notable accomplishments include renewable electricity generation, which has increased by 23% between 2012 and 2020, the creation of 115 thousand energy sector jobs in 2021, and CAD 180 billion in GDP in 2021 (NRCan, 2022). At the residential level, Canada has introduced the Canada Greener Homes Initiative, a portfolio of programs with a combined value of approximately CAD 15 billion dollars. The CGHI was designed to enable households to become more energy efficient, save money, and actively participate in Canada’s energy transition (NRCan, 2024b). Unfortunately, despite increasing investment into environmental and clean technology initiatives, Canada remains a major global emitter, contributing 1.63% to global emissions and ranking first in emissions per capita (Neofytou et al., 2020). Data shows a grim reality that a significant share of Canadian households still spend an unsustainable proportion of their income on energy, underscoring the social dimensions of the energy transition. NRCan defines energy poverty as 10% or more of income spent on energy needs, and currently, 6% of Canadians are facing energy poverty, and this figure is expected to increase (NRCan, 2022). With buildings, including homes, accounting for 13% of Canada's GHG emissions, many homeowners are at risk of being left behind in the energy transition (Government of Canada, accessed November 18th, 2023). In addition to an already lagging ecosystem, one of the CGHI's core programs, the CGHG, has been shut down less than two years since its launch in 2021 due to the pool of funds, valued at CAD 7 billion, being utilized at a faster rate than anticipated (NRCan, 2024b). While the program's popularity is evident, it also highlights a fundamental flaw in the system's design that leaves many households behind in this vital transition.

Despite global momentum facilitated by the Paris Agreement, a divide exists between national goals and on-the-ground realities. Canada's considerable emissions footprint and inefficient resource allocation need to be at the forefront of scholarly discourse and policy considerations as the world navigates the complexities of the energy transition.

1.2 Web 2.0 vs Web 3.0

Having explored the global and Canadian landscape of sustainable development, this section delves into a new frontier, Web 3.0 and blockchain. The evolution of the internet has shaped how we, as individuals and as a collective, interact with information and one another. To date, there have been three iterations of the Web, each more advanced than the last. Web 1.0, also known as the “read-only” Web, had limited capabilities, only allowing users to read static content, with no ability to engage with it. Web 2.0 transformed this landscape by enabling users not only to read but also to create new content and interact with it, fostering a greater degree of collaboration and information sharing. This iteration of the Web revolutionized the flow of information and, as a result, was a key driver of globalization (Getting, 2007). While the most prominent and widely used version of the Web today, its architecture that has led to closed ecosystems can impede innovation and competition (Tapscott, 2023, p.17). The limitation of Web 2.0 is its inability to enable certain forms of collective action through the creation of mutual trust among exchanging and interacting parties (Ping-Kuo & Yong, 2023). As well, Web 2.0 has led to an ecosystem that has become so mature and robust that a systemic redesign is virtually impossible given the presence of large actors such as Meta (formerly Facebook) and Google. Organizations such as these rely on user information such as names, payment information, and metadata of photos and videos to curate unique experiences and drive advertising revenues, without which they would not be where they are today (Panahi, 2010).

Web 3.0 offers the potential to address these weaknesses. In this iteration of the Web, data is not only generated but also understood and processed by machines in a way that is like human cognition (Rudman & Bruwer, 2016). Web 3.0 removes the need for intermediaries or third parties and gives users direct ownership of their digital identity and assets. Smart contracts can be self-enforcing, eliminating the need for legal intermediaries, and the distributed storage and processing of information disempowers platform intermediaries, like Google, that base their business models on the aggregation and proprietary ownership of individual data. It represents the shift from an internet of information to an internet of value (Tapscott, 2023, pp. 17-18). This new frontier has unlocked potential that can enable stakeholders to collaborate on and develop solutions at scale which can more effectively address Canada's sustainable development goals. Such potential is already being realized by companies that are using Web 3.0 in supply chain management and the sharing of knowledge about sustainability (Ping-Kuo & Yong, 2023). Web 3.0 is "like an organism or ecosystem of organisms, such as a coral reef growing from a small beginning to a vast, connected organism. Just as different species of a coral reef make up a reef, different kinds of Web 3.0 innovations make up this interdependent technology ecosystem" (Tapscott, 2023, p.33).

One of the foundational elements of Web 3.0 that enables such an ecosystem to exist in the first place is blockchain. Unlike traditional databases, which are centrally managed, blockchain uses distributed ledger technology (DLT), meaning that data is stored across multiple devices (nodes) within a synchronized network. This ensures that no single entity controls the entire data set, making it more secure and transparent. The blockchain architecture is such that each "block" contains data in the form of a list of records or transactions, chronologically linked to the previous block to form a "chain". The nature of this structure makes it extremely challenging for past records to be altered, which reinforces the system's integrity (De Filippi & McMullen, 2018).

Blockchain networks rely on consensus mechanisms to validate and secure transactions. The most widely known mechanism, proof-of-work (PoW), is used by protocols such as Bitcoin and involves participants, also known as "miners", competing to solve complex mathematical puzzles to add the next block of transactions to the blockchain. While PoW is effective in ensuring security, it is extremely energy-intensive. This process requires significant computational power, leading to high electricity consumption and water usage. For instance, Bitcoin alone consumes approximately 110 TWh of electricity annually comparable to the total energy usage of a small nation like Malaysia or Sweden (Clarke, 2023). In addition to its energy demands, Bitcoin's water consumption in 2021 exceeded 1,600 gigalitres. To put this into perspective, a recent study found that the entire traditional finance system (bank notes, bank branches, ATMs, cashless transactions) combined consumes around 1,800 gigalitres of water annually (Singh, 2023). This implies that Bitcoin's water footprint alone could soon rival or even surpass, that of the entire traditional financial sector. Such levels of energy and water usage have raised significant concerns about the environmental sustainability of PoW blockchain systems, particularly considering global efforts to reduce carbon footprints.

In response to these concerns, newer blockchain models, such as those using proof-of-stake (PoS), have emerged as a more energy-efficient alternative. In PoS, participants are chosen to validate transactions based on how much they have invested or "staked" in the system, as opposed to relying on energy-intensive computations. This significantly reduces the energy consumption associated with validating transactions. However, critics argue that PoS may lead to the centralization of power, as those with more resources can gain a greater presence on the network because PoS prioritizes those participants in the blockchain that have been there longest or are most invested in the chain (Investopedia, 2024). This raises concerns about equity and fairness for those directly participating in blockchain operations, such as miners. For instance, PoW creates a race for computing power, benefiting those with greater resources, while PoS may further entrench wealthier participants' control of the network.

Moreover, a separate equity issue exists for those who simply use the blockchain's services and are neither miners nor validators. The equity concerns in this context revolve around ensuring that all participants regardless of their technological or economic resources, can access and benefit from these services equally. This is particularly critical in public sector applications where the primary goal is to distribute benefits equitably and inclusively.

To illustrate the contrast in mechanisms between Web 2.0 and Web 3.0 and clarify the tangible benefits of Web 3.0, consider the following examples. In the realm of Web 2.0, platforms like Facebook and Google operate on a centralized server model where the service provider owns the data and controls the interaction. For instance, Facebook's use of personalized advertising is based on collecting extensive user data to target advertising effectively. These types of models create an ecosystem where the platform's value increases with the data it collects, often at the expense of user privacy. Moreover, by exemplifying the "walled garden" approach, they limit interoperability and innovation by keeping users within a closed ecosystem (Tapscott, 2023, pp. 146-147).

Conversely, Web 3.0 initiatives such as Ethereum and other decentralized finance (DeFi) platforms challenge this model by offering a decentralized architecture. The Ethereum protocol, for instance, enables the development of smart contracts and decentralized applications (dApps) that operate without any central authority, giving users full control over their digital assets and interactions. DeFi platforms, built on blockchain protocols like Ethereum, allow for financial services (e.g., lending, borrowing, and earning interest) that are transparent, peer-to-peer, and without traditional financial intermediaries (Tapscott, 2023, p.26). Another example is the InterPlanetary File System (IPFS), a protocol for storing and sharing files in a distributed file system. IPFS is a stark contrast to the traditional Web 2.0 file-sharing services. With IPFS, files are broken down into pieces and then stored across multiple nodes in a network. This method improves file delivery speed and, more importantly, reduces the risk of censorship, as there is no single point of failure which can take the content offline (IPFS, accessed December 22nd, 2023). These examples demonstrate Web 3.0's potential to foster innovation, enhance data security and user autonomy, and provide a more equitable digital ecosystem by addressing some of the limitations that have emerged in Web 2.0's centralized, data-exploitative models.

1.3 A Guide to Blockchain Application Development

This section outlines the factors contributing to the cost of developing and operating blockchain applications. Blockchain applications use established blockchain protocols as a foundational layer, providing the infrastructure and rules for their operation. This infrastructure includes consensus mechanisms, cryptographic hashing, and data distribution methods. Examples of blockchain protocols include Bitcoin, Ethereum, and Algorand, each designed with specific features and security measures to support various use cases.

Blockchain applications often termed decentralized applications (dApps), leverage these protocols to develop specific functionalities or services tailored to meet particular business or organizational requirements. These applications employ blockchain for various tasks, including tracking asset ownership, executing smart contracts, or managing real-time data across distributed networks. By building upon the infrastructure provided by blockchain protocols, these applications inherently adopt the security, transparency, and immutability characteristics of blockchain (Srivastava, 2024). The following explores the various elements that determine the complexity and cost of developing blockchain applications as explained by Srivastava (2024), the co-founder and director of Appinventiv, an international organization specializing in blockchain applications with over 3000 applications built for startups and enterprise companies such as Google, Ikea, and Adidas.

Determinants of Blockchain Complexity:

Given that blockchain technology allows data to be stored across a network of computers rather than a single location, dApps can vary widely in complexity due to several key factors:

1. <u>Consensus Mechanism:</u> This is essentially the rulebook for how asset transactions, whether information or money, are verified on the blockchain. Just as different games have different rules, blockchain has different applications that use different consensus mechanisms to agree on the validity of transactions. The choices of consensus mechanisms are what affect how quickly and securely transactions are processed, which can influence the application's efficiency and the cost of operation.
2. <u>Protocol Selection:</u> The protocol is like the operating system (eg. Windows or macOS) for a blockchain application. Protocols like Ethereum, Blockchain, or

Algorand offer different built-in capabilities and tools that simplify certain tasks or provide specialized functionalities. Choosing a protocol that does not align well with the application can lead to higher development costs and longer timelines due to the need for customization.

3. <u>Development Stack:</u> This includes the programming languages, tools, and technologies used to build the application itself. The technologies chosen must work well together and be suitable for the application's goals. Incompatible or outdated tools can complicate the development process and increase costs.
4. <u>API Integration and Development:</u> APIs (Application Programming Interfaces) allow different software programs to communicate with one another. Developing custom APIs if existing ones do not suffice can significantly increase complexity and costs.
5. <u>User Interface (UI)/User Experience (UX) Design:</u> UI and UX design involve the application's design layout, determining how users interact with it. This is very similar to how a store influences customers to buy products and navigate shopping. A complex user interface can make the application difficult to use, potentially requiring a more sophisticated design solution to ensure it is user-friendly.
6. <u>Level of Decentralization:</u> Decentralization refers to how data is distributed across multiple computers instead of stored on one server. Ultimately, greater decentralization generally means better security and resilience to data loss or hacking. Increasing the level of decentralization can complicate the development

and maintenance of applications, as it involves managing more connections and ensuring consistent performance across different nodes.

Understanding how these complexities translate into tangible development costs and timelines is important for enterprises and investors to prepare financially and strategically for any blockchain implementation.

Cost Estimation Based on Complexity:

The complexity of blockchain applications, influenced by their design and technical requirements, directly impacts their development costs and required timeframes. To illustrate this, Table 1 categorizes blockchain applications based on their complexity and outlines the associated costs and development timelines.

Table 1. Cost and Time Estimation for Blockchain Applications Based on Complexity.

App Type	Description	Cost	Time Frame
Low Complexity dApp	Payment apps developed around existing cryptocurrencies, Basic smart contract development.	\$40k to \$60k	3 to 6 months
Medium Complexity dApp	Moderate decentralization: Architecture has both centralized and decentralized elements.	\$60k to \$150k	6 to 8 months
High Complexity dApp	Healthcare app development; Modern Web 3.0-based decentralization.	\$150k to \$300k	9+ months

Note. Table retrieved from Srivastava *(2024).*

Project Milestone Cost Allocation:

Understanding the various stages of cost distribution is equally important as it helps plan and manage resources effectively throughout the project lifecycle. Table 2 shows how costs are typically allocated towards different project milestones, providing a snapshot of the financial commitment required at each stage.

Table 2. Percentage of Cost Allotted to Project Milestones.

Project Milestone	Percentage of Cost Associated
Initial Consult	5%
UI/UX Design	10%
Development	45%
Quality Assurance	25%
Deployment and Maintenance	15%

Note. Table retrieved from Srivastava (2024).

By linking the theoretical determinants of blockchain complexity with the practical cost implications, stakeholders can better navigate the complexities of blockchain technology adoption. The following section explores specific blockchain applications in the context of sustainable development to provide a better understanding of what these applications look like in practice and what they can achieve.

1.4 Blockchain for Sustainable Development

Blockchain technology is increasingly recognized for its potential to revolutionize sustainable development, enabling unprecedented collaboration across residential, commercial and governmental sectors. A crucial cross-cutting benefit of this technology is its ability to improve transparency and reduce transaction costs, particularly in markets that involve invisible product and service attributes. Work in sociology and economics (Akerlof, 1970; Shapiro, 1987) have noted the important role of credible signaling institutions in establishing trust between buyers and sellers of goods when the attributes of the goods are hard to observe. Many applications of blockchain operate to offer this credible signal in a manner that is more efficient and decentralized than would be the case using other mechanisms like legal contracts or field and desk audits. Existing applications include seafood traceability (Shamsuzzoha et al., 2023), conflict mineral tracking (Kapoor et al., 2022) as well as applications in various efforts to meet new deforestation-free requirements of the EU Deforestation Regulations (Forest Stewardship Council, accessed April 18th, 2024).

In the energy space, two pioneering initiatives that demonstrate the application of blockchain technology are Powerledger and the Brooklyn Microgrid project, each with its unique approach and scope. These are reviewed below to detail some of the advantages of blockchain technologies in practice.

Powerledger, an Australian-based company, uses a public blockchain to democratize the global energy market. This application allows for modular, scalable solutions across three main areas: energy trading and traceability, flexibility, and environmental commodities trading. Powerledger's use of the Sonala blockchain protocol enables them to accommodate thousands of transactions per second at a low cost. This offers a solution that is both fast and energy-efficient (Powerledger, 2024). Moreover, Powerledger's application has demonstrated scalability and international applicability with over 30 clients across 10 countries (PowerLedger, accessed November 15th, 2023). The project's global reach indicates the adaptability of blockchain to different regulatory and market environments, showcasing a model that can be replicated and scaled across different countries.

In contrast, the Brooklyn Microgrid project emphasizes a more localized approach to energy trading. It employs the Ethereum blockchain protocol to create a Local Energy Market (LEM) that facilitates peer-to-peer energy trading amongst residential stakeholders within a community. This model enhances transparency, reduces electricity costs, and improves grid efficiency by allowing consumers to trade their excess energy directly through a dApp with other community members (Brooklyn Energy, accessed November 15th, 2023). The Brooklyn Microgrid's technology supports the development of self-sustaining and sustainable energy systems, showcasing the potential of blockchain in local energy markets and its benefits for community self-sufficiency.

While both cases illustrate blockchain’s versatility in addressing sustainable development at localized and international levels, cautionary notes offered by critics should also be considered. One of the primary concerns surrounding blockchain technology, particularly in energy systems, is its scalability. As discussed by Wang et al. (2021), while blockchain can support decentralized and transparent energy trading, many blockchain networks – especially those reliant on consensus mechanisms such as PoW, struggle with handling large volumes of transactions efficiently. In high-volume trading environments such as national energy grids, the inherent limitations of blockchain systems can result in latency issues and congestion, significantly reducing the speed of transactions.

In addition to scalability issues, blockchain presents environmental challenges as previously discussed in Section 1.2. While projects such as Powerledger rely on more energy-efficient protocols, many blockchain-based solutions use energy-intensive consensus mechanisms such as PoW, resulting in high consumption of electricity and water, which conflict with many of the sustainability goals projects aim to achieve (Schinckus, 2020).

Moreover, the decentralized nature of blockchain can complicate regulatory oversight and enforcement. For instance, in the event of a security breach or dispute, it may be difficult to determine liability or hold participants accountable in a decentralized system (Wang et al., 2021).

These limitations suggest that while blockchain technology holds significant promise in the energy sector, it is not a silver bullet. Powerledger and the Brooklyn Microgrid are early adopters of blockchain technology and while not perfect, they are stimulating the market for new blockchain-based solutions which over time can help drive innovation to ensure that blockchain applications in energy systems are scalable, secure, and environmentally sustainable.

1.5 The Policy Relevance of Blockchain, Opportunities and Challenges

In Canada, the policy implications of blockchain are profound, offering a path toward a paradigm shift to autonomous, transparent, and secure systems. Canada has already begun making significant strides in this area, with both the federal and provincial governments recognizing the transformative potential of digital technologies. A key milestone in this progress was the establishment of Canada's Digital Charter in 2019, which set out a comprehensive framework for Canada's digital future. The Digital Charter outlines ten guiding principles aimed at fostering trust in the digital economy while balancing innovation with ethical considerations, namely privacy, security, and equitable access to technology. This vision is particularly relevant in the context of blockchain technology, which inherently aligns with several of the Charter's core principles, making it a potential enabler of Canada's broader digital transformation goals. (Innovation, Science and Economic Development Canada, accessed April 12th, 2024). Most importantly, the Digital Charter is not just a framework for digital ethics but also a roadmap for fostering innovation while safeguarding the public interest. It provides policymakers with valuable insights and resources which can help assess the potential integration of blockchain into existing programs such as the CGHG.

Canada's interest in blockchain extends beyond theoretical applications; the National Research Council (NRC) has actively explored blockchain technology's potential through its pilot programs. For instance, in 2018, the NRC successfully implemented an Ethereum-based public ledger system to increase transparency in government contracts. The pilot program, which allows the public to monitor contracts in real-time, demonstrated blockchain's ability to foster trust in public administration by ensuring accountability and reducing the potential for corruption (NRC, 2023). Pilots such as this highlight the government's interest in blockchain as a tool for improving transparency in public sector operations, aligning with the principles outlined in the Digital Charter.

From an economic perspective, blockchain technology has the potential to create significant positive externalities and drive substantial growth in Canada's GDP. Recent developments among blockchain platforms illustrate how models are being developed to reduce the high energy costs of certain blockchain approaches. Ethereum's move from a

PoW to a PoS approach to consensus led to a dramatic drop in energy use, suggesting that there may be blockchain models that can be used which do not come with the huge energy consumption associated with Bitcoin (Allison, 2023). This aligns with the priorities highlighted in Canada’s 2023 Economic Report, which emphasizes the need to strengthen local supply chains, assist businesses with energy costs, and support technology adoption. By aligning with and enhancing the country's economic priorities, blockchain can act as a catalyst for development in sectors such as finance, healthcare, energy, and more (Ontario Chamber of Commerce, 2023).

However, as the federal and provincial governments embrace the potential of blockchain technology, they must also address the accompanying implementation and operational challenges. One of the key challenges lies in the capacity constraints associated with blockchain. While pilot projects such as the NRC initiative have proven successful, they also expose the need for highly specialized skills to design, deploy and maintain blockchain systems. Currently, most public sector agencies lack the technical capacity and expertise to handle such sophisticated technology on a larger scale. Blockchain technologies require professionals with advanced knowledge in cryptography, distributed systems, and smart contract development which are emerging professional fields meaning a limited supply of skilled labor (Cote & Vu, 2023). Addressing this skills gap will likely involve significant investments in training and reskilling existing staff or hiring new talent with the appropriate expertise. Without sufficient capacity, the federal and provincial governments may struggle to scale blockchain initiatives effectively, limiting their potential to transform public services like energy incentives under the CGHG.

Another key barrier to blockchain adoption in Canada is blockchain’s decentralized nature which poses a direct challenge to existing regulatory frameworks, which are predominantly centralized governance structures. For instance, issues related to data privacy, identity verification, and jurisdictional disputes become increasingly complex in a decentralized blockchain network. Policymakers must rethink traditional regulations and adapt them to fit the unique features of blockchain technology, ensuring that regulatory oversight is effective without stifling innovation. This challenge is particularly relevant in areas like financial services and energy systems, where compliance with security and data protection standards is critical (De Filippi & McMullen, 2018).

Lastly, as blockchain technology evolves, policymakers must stay ahead of the rapid pace of change in the Web 3.0 ecosystem. The continuous development of blockchain models, such as Ethereum's shift from PoW to PoS, demonstrates the need for governments to not only adopt blockchain technology but also ensure they have mechanisms in place to adapt to ongoing advancements. The government must develop flexible regulatory frameworks that can evolve alongside the technology while balancing innovation with the necessary security and privacy measures. This is important to foster public trust and ensure that blockchain adoption is responsible and effective in the long term (Tapscott, 2023, pp. 216-217).

In conclusion, while blockchain integration offers significant potential for enhancing Canada’s digital economy and public administration, it also brings a range of policy challenges. Addressing these challenges requires a collaborative approach involving stakeholders across various sectors, continuous learning and adaptation, and developing flexible, forward-looking regulatory frameworks. Only by navigating these challenges effectively can Canada fully harness the potential of blockchain for sustainable economic growth and societal benefit.

Chapter 2: Methodological Approach

This study employs a mixed-methods approach to explore and assess the operational and economic efficiency of the CGHG program administered by NRCan through the integration of blockchain technology. Mixed-methods research is selected for this study as it combines quantitative and qualitative research techniques and approaches, providing a comprehensive analysis by integrating numerical data with contextual insights.

Comparative Scenarios:

This methodology compares two distinct scenarios—a baseline scenario and a blockchain-enhanced scenario—to delineate the current operational landscape and project a potential future state influenced by the adoption of blockchain technology. This approach is aligned with methodologies used in the Canadian Energy Systems Analysis Research (CESAR) Scenarios by the Transition Accelerator (Lof & Layzell, 2019), which evaluates the impact of technological integration on supply distribution networks in Canada.

Scenario-based analysis was selected for this research as it provides not only quantitative outcomes but also a narrative about how different futures could unfold, making it easier to communicate findings to policymakers who may be more interested in the practical implications of blockchain technology rather than statistical predictions alone. Additionally, it is also important to note that scenario-based modelling allows for conditions that assume smooth implementation of optimal outcomes, often excluding the influence of political decisions, regulatory barriers, or individual decision-maker actions.

Therefore, while this study's scenarios do not account for political or regulatory obstacles, this approach is consistent with the norms in modelling, where the goal is to highlight potential impacts under optimal conditions before factoring in additional real-world constraints in future research.

1. Baseline Scenario: This scenario reflects the operational and economic efficiency of the CGHG, assuming the status quo of current program processes is maintained.
2. Blockchain Scenario: This scenario reflects the operational and economic efficiency of the CGHG, assuming blockchain technology is integrated into program processes as of 2024.

The temporal scope selected for these scenarios is 2021 to 2031, aligning with Canada's Canada Greener Homes Initiative portfolio and Canada's 2030 strategic objectives for sustainable development. The temporal scope thereby allows for the evaluation of these scenarios in the context of national goals. The data in this study is obtained from various sources, including the parliamentary library, government reports, industry reports, and consultations with subject matter experts. The study recognizes that the current CGHG ended in April 2024. In this respect, the study's scenarios can be viewed as an opportunity to inform future program design. The discussion section in Chapter 4 also discusses the challenges that may arise when program durability is in question.

Types of Analyses Conducted:

This study employs a combination of comparative and economic analyses to evaluate the impact and efficiency of the CGHG program under the two scenarios.

1. Comparative Analysis: Evaluates and compares key variables across both scenarios to understand the implications of blockchain technology. The variables being compared across scenarios include:
    - *Funds Disbursed (FD):* Total financial incentives disbursed to participating households.
    - *Household Participation (HP):* Number of households engaged with and benefiting from the CGHG program.
    - *Household Energy Bill Savings (ES):* Financial savings from energy-efficiency retrofits.
    - *Pollution Cost Savings (PS):* Financial savings from reduced pollution due to retrofits.
    - *Administrative Time (AT):* Total duration of the administrative process.
    - *Administrative Expenditure (AE):* Annual expenses associated with administering the program.
    - *Administrative Expenditure per Household (AEH):* The cost of administration per individual household.
2. Economic Analysis: Assesses the economic viability of implementing blockchain technology by examining:
    - *Net Benefits (NB):* Net financial gain or loss associated with the program.
    - *Cost-Benefit Ratio (CBR):* Efficiency of the program.

- *Cost Effectiveness Ratio (CER):* Effectiveness of the CGHG program in achieving energy and pollution savings.

2.1 Limitations

This study acknowledges several limitations, which are addressed by making core assumptions detailed in section 2.2 below.

2. Aggregated Data Utilization: This study's data is predominantly aggregated, which may result in outputs that are not as detailed at the granular level. This means the analysis cannot directly account for heterogeneity at the household level. The discussion chapter offers a qualitative discussion of this limitation, and potential consequences of assumptions made to highlight how further investigation can account for the importance and consequences of household heterogeneity.
3. Technological Novelty and Diversity: The wide variety of blockchain protocols and applications currently available in the market introduces a significant degree of uncertainty regarding the identification of the most suitable solutions for public sector use. This may restrict the study to theoretical projections rather than extensive empirical validations.
5. Regulatory and Policy Dynamics: The study may not fully account for the dynamic nature of regulatory and policy environments, which could affect the feasibility of the proposed technological integration. As noted, the existing CGHG program came to an end in April 2024. Future programs’ role out and continuity are a source of uncertainty.

6. Adoption Rate Uncertainty: The study may overestimate or underestimate the rate at which blockchain technologies are adopted within the CGHG program, affecting the accuracy of findings and recommendations.
6. Unaccounted Variables: Some secondary and tertiary variables may not be accounted for in this study, which may offset the economic implications of the real-world outcomes. These include socio-economic factors, unforeseen technological advantages, and market fluctuations.

2.2 Assumptions

To address the limitations of this study, this research is anchored in a few core assumptions that underly the methodological approach.

1. Program Renewal: The CGHG program will be renewed from 2028 until 2031 to align with the projection period selected for this study. The study models the implementation of the CGHG as a continuous process until 2031 in order to focus the comparison on the implications of blockchain technology.
2. Technical Expertise and Infrastructure: The federal and provincial governments have the infrastructure and technical expertise necessary to develop and integrate a blockchain application into existing digital public infrastructure.
3. Public Trust and Participation: Residential stakeholders are willing to participate in blockchain-based incentive programs and there is public trust in the use of blockchain technology for this purpose.
4. Market Stability: The market for environmental and clean technologies in Canada is stable and will continue to grow, thereby justifying investment in blockchain technologies to optimize green incentive programs.

5. Integration with Existing Systems: The blockchain application will be designed to seamlessly integrate with existing systems and infrastructures. This integration will minimize disruptions and additional costs associated with implementing new technologies.

2.3 Mapping the CGHG Administrative Process

The administrative process of the CGHG is a critical component of this study as it directly impacts the associated costs and benefits analyzed. By mapping out these processes, both the internal steps taken by NRCan, and the external steps taken by homeowners, a comprehensive foundation for comparative analysis is established. This detailed mapping in Table 3 ensures clarity in the procedural aspects and highlights potential areas for efficiency improvements through blockchain integration.

Table 3. CGHG Administrative Process Overview

Steps	**Description**
Step 1: Homeowner Application	Homeowners create an account on the NRCan portal and provide property documentation, renovation plans, tax history, and other relevant information. The application is assigned to program staff for evaluation.
Step 2: Eligibility Confirmation	Program staff review the application and confirm eligibility.
Step 3: Scheduling of Pre-Retrofit EnerGuide Evaluation	Program staff assign an Energy Advisor to homeowners, who then schedule the EnerGuide evaluation.
Step 4: Completion of Pre-Retrofit EnerGuide Evaluation	The Energy Advisor completes the pre-retrofit EnerGuide evaluation.
Step 5: Pre-Retrofit EnerGuide Evaluation Upload to NRCan Portal	The Energy Advisor uploads the EnerGuide report to the NRCan portal for approval. Program staff notify homeowners to proceed with home retrofits.

Step 6: Completion of Retrofits by Homeowner	Homeowners complete their home retrofits, including selecting service providers, obtaining technology, and overseeing installation.
Step 7: Scheduling of post-retrofit EnerGuide Evaluation.	Homeowners schedule the post-retrofit EnerGuide evaluation upon completion of their home retrofits.
Step 8: Completion of Post-Retrofit EnerGuide Evaluation.	The Energy Advisor completes the post-retrofit evaluation and provides an estimate of the eligible grant amount.
Step 9: Post-Retrofit EnerGuide Evaluation Upload to NRCan Portal	The Energy Advisor uploads the post-retrofit EnerGuide report to the NRCan portal for approval. Program staff notify homeowners to submit receipts.
Step 10: Submission of Receipts by Homeowner	Homeowners submit receipts for all expenses incurred during the home retrofits.
Step 11: Confirmation of Grant Amount	Program staff confirm the final grant amount homeowners are eligible to receive upon receipt submission.
Step 12: Grant Disbursement	Upon confirmation of the final amount, checks are sent to homeowners via mail.

Note. The steps in this table were consolidated through existing source material from NRCan, (accessed November 22nd, 2024, a,b,c,d) and consultations with NRCan staff.

2.4 Variables Considered in Analyses

2.4.1 Variables Considered for Comparative Analysis

Given that the CGHG was actively ongoing at the time this study commenced, certain challenges arose regarding the availability of data. To overcome this issue, several measures were undertaken. Firstly, an access to information and privacy (ATIP) request was submitted to obtain performance results of the CGHG from 2021-2023. Although this request provided useful information, much of it was aggregated, so further investigation was required to break it down for the study. Over three months, multiple sessions with NRCan staff took place to gain insights into the ATIP data provided. While the staff could not fully disclose detailed data due to the ongoing nature of the program, they shared helpful source material and resources, which aided in making the assumptions detailed throughout the methodology.

Several key variables across both scenarios were analyzed for a comprehensive comparative analysis. These variables form the basis for evaluating the CGHG program's economic efficiency, operational performance, and overall impact and are all measured annually.

Table 4. Variables Considered in Baseline and Blockchain Scenarios.

Variable Name	**Unit**	**Description**	**Purpose**
Funds Disbursed	CAD (2021)	The total amount of financial incentives disbursed to participating households for home retrofits.	To measure the program’s financial reach and scale under each scenario.
Household Participation	Number	The total number of households that successfully engaged with and benefited from the CGHG program.	To assess the program’s accessibility and attractiveness to homeowners.
Energy Bill Savings	CAD (2021)	The total amount of energy bill savings as the result of retrofits completed under the CGHG program.	To evaluate the program’s effectiveness in promoting energy efficiency.
Pollution Savings	CAD (2021)	The total amount of pollution savings expressed in dollar value from retrofits completed under the CGHG program. The assumed value per ton of CO2e used to calculate savings is set at CAD 50.	To measure the environmental impact in terms of pollution reduction.
Administrative Time	Days	The total number of days associated with the CGHG administrative process for an individual household.	To evaluate the program’s administrative time efficiency.

Administrative Expenditure	CAD (2021)	The total expenses incurred each year to administer and deliver the CGHG program.	To analyze the cost-efficiency of the program's administrative processes under each scenario.
Administrative Expenditure per Household	CAD (2021)	The cost of administering the CGHG program per household.	To analyze the cost reduction in cost reduction per household.
Net Benefits	CAD (2021)	The net gain or loss of the CGHG program.	To analyze the net gain or loss brought about by blockchain integration.
Cost Benefit Ratio	Ratio	A ratio that compares the total economic benefits (energy bill savings and pollution savings expressed in dollar value) to the total costs (funds disbursed and administrative expenditure).	To assess the economic viability and efficiency of the program.
Cost Effectiveness Ratio	Ratio	A ratio that indicates the cost required to achieve the unit of benefit in consideration (kWh and tCo2e).	To assess the cost-effectiveness of the benefits achieved by the CGHG program.

Note. Data was aggregated from multiple sources, including Energyhub (2023), NRCan (2024a), and NRCan (2024b).

By using these variables and projecting them into the future, this study quantitatively calculates the long-term implications of the CGHG program. These projections serve as important benchmarks for comparison across both scenarios, allowing for a detailed analysis of potential improvements to the continued challenges within the system. To achieve these projections, the study employs specific mathematical models using the variables detailed in Table 4 above. The methodologies and equations used to model these projections are detailed in the sections which follow.

2.4.2 Control Variables

Control variables are also considered as they help to standardize and isolate the comparative analysis. They ensure that the impact of the independent variables is examined independently without being affected by other factors.

Table 5. Control Variables

Variable	**Value**	**Justification**
Discount Rate	4%	This rate reflects the value of money, inflation, and the opportunity cost of capital, making it appropriate for the long-term financial analysis being considered in this study. The rate of 4% is selected as it represents a balanced midpoint approach between the government borrowing rate (1.5% to 2.5%) and the social discount rate (3% to 5%). This rate also incorporates a risk premium to account for uncertainties in future benefits and costs.
Average Fund Disbursement per Household	CAD 4200	This value, derived from historical CGHG reports, provides a standardized estimate of the average value of funds disbursed to a single household.
Average Annual Energy Bill Savings per Household	CAD 386	Derived from historical CGHG reports, this value provides a standardized estimate of annual savings for households implementing energy-efficient upgrades.
Social Cost of Carbon	CAD 50/tCO2e	Based on data from the federal government. This value provides an estimate of the social cost of carbon emissions. This figure is used to quantify the benefits of pollution reduction.
Average Pollution Reduction per Household	1.2 tCO2e	Derived from historical CGHG reports. This value estimates the reduction in GHG emissions per participating household per annum.

Note. Data was aggregated from multiple sources: NRCan (2024b) and Government of Canada (2023).

2.5 General Methodologies

This section outlines the general methodologies applied in both the baseline and blockchain scenarios to establish a consistent framework for evaluating the CGHG's operational and economic efficiency. These methodologies include calculating household energy bill savings, pollution cost savings, administrative time components, and administrative expenditures, ensuring that comparisons between scenarios are fair and meaningful.

2.5.1 Household Energy Bill Savings

Household energy bill savings play a significant role in assessing the environmental impact of the CGHG program. To calculate these savings, this study considers historical data on energy consumption and previous retrofit savings to project future savings. The calculation involves multiplying the number of households that received funding each year by the average energy bill savings, which, according to NRCan, amounts to CAD 386 annually. Additionally, to reflect the present value of money in the projections, the discount rate denoted as *r* is applied. Lastly, the formula used considers the remaining years in the projection period by multiplying them by the annual energy bill savings to calculate the cumulative energy bill savings for households.

(1) $$\boldsymbol{EnergyBillSavings_t} = \left(\frac{HouseholdParticipation_{\,t} \times 386}{(1+r)^t}\right) \times YearsRemaining$$

2.5.2 Pollution Savings

Pollution savings is another important metric for gauging the environmental impact of energy-efficient upgrades undertaken by households. It involves multiplying the average tCO2e reduction per household (as per NRCan, set at 1.2 tons) by the annual number of participating households. To determine the financial savings associated with emissions reduction, the cost of pollution, set at CAD 50, is multiplied by the volume of pollution. The discount rate, denoted as *r*, is applied to reflect the present value of money in the projections. This ensures that the financial savings are accurately represented in today's terms. The formula used is as follows:

$$\textbf{(2)}\ \boldsymbol{PollutionSavings_t} = (HouseholdParticipation_t \times 1.2) \times \left(\frac{50}{(1+r)^t}\right)$$

2.5.3 Homeowner Administrative Time

The time homeowners spend completing administrative tasks related to the CGHG program is an important factor in assessing the program's operational efficiency. However, the data at this time is negligible and inconsistent due to regional variability in the availability of service providers and the volume of applications. Thus, estimating the times associated with Steps 1, 6, 7, and 10 is required. These estimations are detailed below in Table 6.

Table 6. Estimations of Homeowner Steps

Step	Approach	Admin Time (Days)
Step 1: Homeowner Application	Assuming all documents are readily available a minimum and maximum application time are	0.059

	calculated, and the average of these times is taken to determine the admin time of this step.	
Step 6: Completion of Retrofits by Homeowner	Due to high national variability, a more liberal estimation is undertaken. This estimation is based on anonymous homeowner reviews and experiences from blog posts and community pages. It accounts for selecting an energy provider, selecting an eligible product, and having the actual retrofits completed, which takes time.	90.000
Step 7: Scheduling of post-retrofit EnerGuide Evaluation.	This estimation is based on homeowner experiences from blog posts and community pages.	14.000
Step 10: Submission of Receipts by Homeowner	This assumes that receipts are readily available and that homeowners can easily upload documentation.	0.020

Note. Estimations are based on qualitative and quantitative data from multiple sources including NRCan (2024a) and Reddit (2023).

2.5.4 Total Administrative Time

The total administrative time includes the time spent by homeowners and NRCan program staff throughout the CGHG process. This comprehensive measure accounts for all activities involved in the application, evaluation, and approval process. The formula used is as follows:

(3) $\boldsymbol{TotalAdminTime_t} = \sum Step\ 1,2,3,\ldots,12.$

2.5.5 Administrative Efficiency

The administrative process efficiency for each year is determined by comparing the current year's total administrative time to the previous year's total administrative time.

This ratio indicates how much the administrative time has improved or worsened and is calculated as follows:

$$\textbf{(4)}\ \boldsymbol{AdminEfficiency_t} = \frac{TotalAdminTime_t}{TotalAdminTime_{t-1}}$$

2.5.6 Administrative Expenditure

The administrative expenditure refers to the total costs incurred each year in administering the CGHG program, including salaries and overheads. Three steps are taken to calculate the administrative expenditure. First, the cost per unit of administrative time is calculated. Second, the administrative savings are calculated. Third, the administrative expenditure is calculated. These steps are detailed below:

Step 1 – Calculating Cost Per Unit of Administrative Time:

The cost per unit of administrative time is calculated by applying a growth rate based on historical data. The growth rate is derived by analyzing year-over-year changes in administrative costs, allowing for a direct calculation as seen below:

$$\textbf{(5)}\ \boldsymbol{CostPerUnitTime_t} = CostPerUnitofTime_{t-1} \times (1 + GrowthRate)$$

Step 2 – Calculating Administrative Savings:

The administrative savings are calculated by multiplying the time saved (the difference between the previous year's and the current year's administrative time) by the cost per unit of administrative time from the previous year. Additionally, the discount rate, denoted as *r*, is applied to reflect the present value of money in the projections. The formula used is as follows:

$$\textbf{(6) } \boldsymbol{AdminSavings_t} = \frac{(TotalAdminTime_{t-1} - TotalAdminTime_t) \times CostPerUnitTime_{t-1}}{(1+r)^t}$$

Step 3 – Calculating Administrative Expenditure

The current year's administrative expenditure is determined by subtracting the administrative savings from the previous year's administrative expenditure. The discount rate, denoted as *r*, is applied to reflect the present value of money in the projections, as seen in the formula below:

$$\textbf{(7) } \boldsymbol{AdminExpenditure_t} = \frac{AdminExpenditure_{t-1} - AdminSavings_t}{(1+r)^t}$$

2.5.7 Administrative Expenditure per Household

The administrative expenditure per household yields valuable insights into the cost of administration per household and offers a more nuanced perspective than the expenditure for the entire program. This is calculated by dividing the administrative expenditure for the year by the number of participating households in that year. The formula used is as follows:

$$\textbf{(8) } \boldsymbol{AdminExpenditurePerHousehold_t} = \frac{AdminExpenditure_t}{HouseholdPartcipation_t}$$

2.6 Baseline Scenario Methodology

The baseline scenario is designed to assess the operational and economic efficiency of maintaining the current CGHG program as it is through until 2031. Sections 2.6.1 through 2.6.3 breakdown the specific methodological approaches utilized to calculate program outcomes under the baseline scenario.

2.6.1 Projecting Funds Disbursed

The projection of funds disbursed across all provinces and territories is based on historical data available for the CGHG from 2021 to 2023. To calculate the funds disbursed from 2024 to 2031 a growth rate approach is used. This method ensures consistency across all regions, while also accommodating provinces and territories with limited historical data, such as Nova Scotia and Nunavut.

The growth rate is calculated by analyzing the historical data for the CGHG, determining the average annual rate of change in funds disbursed from 2021 to 2023. Additionally, the discount rate, denoted as *r*, is applied to reflect the present value of money in the projections. The formula used is as follows:

$$\text{(9)}\ \boldsymbol{FundsDisbursed_t} = \frac{FundsDisbursed_{t-1} \times (1+GrowthRate)}{(1+r)^t}$$

2.6.2 Projecting Household Participation

To determine the number of participating households under the baseline scenario, the annual funds disbursed each year are divided by the average disbursement rate per household, CAD 4,200, according to NRCan. This method provides a standardized approach for calculating household participation that aligns with historical data trends. The formula for this calculation is shown below:

$$\text{(10)}\ \boldsymbol{HouseholdParticipation_t} = \frac{FundsDisbursed}{4200}$$

2.6.3 Projecting NRCan Administrative Time

As established in Section 2.5, administrative times are segmented by the steps associated with the CGHG process and categorized based on responsibility for execution and completion. This delineation is important for understanding and optimizing the distribution of tasks between homeowners and NRCan program staff.

While the administrative times associated with homeowner-focused steps (Steps 1,6,7, and 10) are consistent across both scenarios, the times associated with the NRCan program staff exhibit variability and offer potential efficiency gains. These steps include evaluating applications, coordinating energy assessments, reviewing submitted retrofit documentation, and final approval and disbursement of funds (Steps 2,3,4,5,8,9,11,12). Calculating these administrative times required a segmented approach, as seen below.

Step 1 – Determining Initial Administrative Times

Initially, administrative times for each relevant step are derived from NRCan's program standards, parliamentary requests, and publicly available homeowner testimonials. These times are detailed in Table 7 below.

Table 7. Initial NRCan Administrative Times

Step	**Initial Administrative Time (Days)**
Step 2: Eligibility Confirmation	40.000
Step 3: Scheduling of Pre-Retrofit EnerGuide Evaluation	14.000
Step 4: Completion of Pre-Retrofit EnerGuide Evaluation	0.125
Step 5: Pre-Retrofit EnerGuide Evaluation Upload to NRCan Portal	30.000

Step 8: Completion of Post-Retrofit EnerGuide Evaluation.	0.125
Step 9: Post-Retrofit EnerGuide Evaluation Upload to NRCan Portal	30.000
Step 11: Confirmation of Grant Amount	40.000
Step 12: Grant Disbursement	30.000

Note. Data was aggregated from multiple sources: NRCan (2024a), NRCan (accessed November 22nd, 2024, a,b,c,d), and Capture Energy (accessed March 24th, 2024)

Step 2 – Calculating Efficiency Gains:

Using historical CGHG program data from 2021-2023 provided by NRCan, efficiency factors are calculated to determine the percentage reduction in administrative times observed during this period. The historical data covers two distinct phases of the program.

- Phase 1: Initial program steps, including eligibility confirmation, pre-retrofit evaluation scheduling, and pre-retrofit EnerGuide evaluation upload to the NRCan portal.
- Phase 2: Later steps of the program, including post-retrofit activities such as final evaluations and fund disbursement.

The efficiency factors are calculated as the percentage reduction in administrative times observed from 2021 to 2023. These factors are then applied to the initial values detailed in Step 1 to calculate the administrative times for the projection period. It is important to clarify that the efficiency factors are not applied as continuous annual improvements. Instead, they represent the overall improvement observed from 2021 to 2023. These factors are applied once to the initial administrative times to reflect the efficiency gains achieved up to 2023. This adjustment is then carried forward consistently throughout the projection period (2024-2031).

Step 3 – Establishing Floors

The final step involves establishing minimum time requirements for NRCan's internal processes. Once these processes reach a certain point, it is assumed they cannot be further optimized and are expected to take at least one business day to complete. While the assumption of one business day may either overestimate or underestimate the efficiency plateau, it is an area for future research to explore.

2.7 Blockchain Scenario Methodology

The blockchain scenario is designed to evaluate the operational and economic efficiency of the CGHG under the assumption that blockchain technology will be integrated into the program processes in 2024. The methodological approaches in this scenario closely mirror the baseline scenario regarding the variables considered. However, the key differences lie in the multipliers used to reflect the integration of blockchain technology into various program elements. These adjustments aim to capture the potential benefits of blockchain, such as reduced administrative times, increased household participation, and accelerated fund disbursement. Sections 2.7.1 through 2.7.5 break down the methodological approaches to calculate the program outcomes under the blockchain scenario.

2.7.1 Projecting Household Participation

Step 1 – Calculating the Adoption Rate of Blockchain Technology:

In this scenario, household participation is projected before fund disbursement, with blockchain adoption being a key variable directly impacting other calculations. The assumption that the participation rate in the CGHG will grow at the same rate as blockchain technology is based on the premise that as digital solutions like blockchain become more integrated into public and private systems, the general acceptance and adoption of such technologies will accelerate across sectors. This assumption is supported by several reports, including those from the Bank of Canada (Balutel et al., 2021) and KPMG (2024), which provide reliable data points on blockchain adoption trends in Canada.

Blockchain technology has experienced exponential growth in industries that require transparency, security, and efficiency, and it is expected that public trust in these platforms will increase as blockchain becomes more embedded in public programs like CGHG. This growing trust could motivate more homeowners to participate, particularly as they recognize the benefits of blockchain for managing financial incentives and energy bill savings data.

To ensure that the forecasted household participation rate reflects up-to-date blockchain adoption trends, historical growth rates from the aforementioned sources were used. The formula used to calculate the adoption rate is as follows:

$$\textbf{(11)}\ \boldsymbol{AverageAdoptionRate} = \frac{\sum AdoptionRate_{\mathbf{2017,\ldots,2023.}}}{\mathbf{7}}$$

Step 2 – Calculating Household Participation:

The average blockchain adoption rate is utilized to calculate yearly household participation. This process involves adjusting the baseline household participation by a factor that accounts for the expected increase due to blockchain integration. Specifically, the household participation from the baseline projection is multiplied by a factor of 1.18, which reflects the current level of participation (represented by 1) combined with the average blockchain adoption rate of 0.18. This ensures that the projected participation accurately reflects the enhanced engagement anticipated with the integration of blockchain technology. The formula used to calculate household participation is as follows:

(12) $\boldsymbol{HouseholdParticipation} = (BaselineHouseholdParticipation) \times (1 + 0.18)$

2.7.2 Projecting Funds Disbursed

To project the funds disbursed in this scenario, household participation in each year is multiplied by the average disbursement rate per household, set at CAD 4,200. This average rate is based on existing reports from NRCan, ensuring the calculations reflect historical data. Additionally, the discount rate, denoted as *r*, is applied to reflect the present value of money in the projections. The formula used is as follows:

(13) $\boldsymbol{FundsDisbursed_t} = \frac{HouseholdParticipation_t \times 4200}{(1+r)^t}$

2.7.3 Projecting NRCan Administrative Time

The methodology for calculating administrative times in the CGHG process overseen by NRCan up to 2023 follows the same approach detailed in Section 2.6.3. Starting in 2024, blockchain technology will be integrated into the CGHG program, leading to a new standardized approach for calculating administrative times. This approach leverages the operational efficiencies of the Ethereum blockchain protocol, which is the most widely used protocol for building applications, supporting almost half a million developers building thousands of applications (Tapscott, 2023, p58).

The operational efficiency in reference focuses on two key metrics: Time to Finality (TTF) and Block Creation Time (BTC). TTF represents the time it takes for a transaction to be considered final and irreversible. At the same time, BTC measures the time it takes to create a new block on the Ethereum blockchain, including all transactions within that block. By summing these two metrics, a comprehensive measure of the new administrative time for steps overseen by NRCan is obtained from 2024 onwards.

(14) $\boldsymbol{AdminTime_t} = TTF + BTC$

2.7.4 Calculating CAPEX of Blockchain Application

The capital expenditure (CAPEX) of the blockchain application hypothesized in this study is an additional variable considered under this scenario as it provides insights into the policy and financial requirements necessary to implement such a system. While not the primary focus of this study, calculating the CAPEX helps provide a more comprehensive understanding of the potential investment needed. The calculation draws from existing blockchain development practices and applications detailed in Sections 1.3 and 1.4, and it assumes a high-complexity application due to the level of decentralization required, integration of smart contracts, interoperability and security requirements.

Given the application’s use within a government agency, the cost calculation will be at the higher end of the spectrum. The CAPEX formula is derived from industry standards ensuring applicability to the CGHG program. The cost components considered in this calculation include:

- Consultation Costs: Initial consultations are required to define the project scope, requirements, and feasibility. These costs account for 5% of the total CAPEX.
- Design Costs: These include the user interface, user design, and architectural design of the blockchain application. Design costs account for 10% of the total CAPEX.
- Development Costs: This involves the actual coding, development of smart contracts, and integration with existing systems. Development costs are the largest component, accounting for 45% of the total CAPEX.
- Quality Assurance Costs: Testing is required to ensure the blockchain application meets all performance and security requirements. Quality assurance costs account for 25% of the total CAPEX.
- Deployment Costs: These cover the application's installation, configuration, and initial set-up. They account for 15% of the total CAPEX.

Given these cost factors, the CAPEX formula used is as seen below:

(15) $\boldsymbol{CAPEX} = ConsultationCost + DesignCost + DevelopmentCost + QualityAssuranceCost + DeploymentCost$

2.7.5 Calculating Training Costs

As with any new technology, there is an associated learning curve, and in this scenario, it applies to both NRCan program staff and homeowners. Training costs are an important consideration to ensure the seamless integration of blockchain technology into the CGHG program. For NRCan program staff, workshops and technical training are required to equip them with the necessary skills to manage and utilize the updated CGHG system. On the other hand, public awareness campaigns and resources are essential for homeowners to educate them on interacting with the new blockchain system to ensure increased participation. The specific methodologies utilized to determine the training costs for NRCan program staff and homeowners are detailed below:

<u>Method 1 – Calculating Training Costs for NRCan Staff:</u>

The training cost for NRCan staff is calculated as a one-time expense, assuming that staff will have sufficient knowledge to develop and conduct internal training sessions after the initial training. The training program is divided into two main components:

1. <u>Initial Introduction to Fundamentals:</u> This training focuses on understanding blockchain principles, decentralized ledger technology, and smart contracts. As per existing industry training, it consists of 30 sessions over three months (Coursera, accessed April 28th, 2024).
2. <u>Application-Specific Training:</u> This training focuses on understanding how blockchain is applied in the specific context of the CGHG. Per industry training options, it is assumed to occur over 12 weeks (Falawadiya et al., 2022).

The number of NRCan program staff undergoing training is determined using historical employment data from Statistics Canada. Since the introduction of the CGHI in 2021, NRCan has experienced an increase in staff. This growth is associated with the CGHI launch, and the additional employees are factored in to calculate the staff who will undergo training.

(16) $\boldsymbol{NRCanTraining} = (IntroductoryCourse + ApplicationSpecificTraining) \times NumberofStaff$

Method 2 – Calculating Training Costs for Homeowners:

Unlike the NRCan program staff, the training for homeowners is an ongoing process, as each homeowner is a unique applicant. The resources considered to train and inform homeowners on the blockchain application, and its functionalities take the form of online guide videos. This format is selected as it aligns with the existing method used within the CGHG to increase awareness and provide support to homeowners. While training can be more extensive, strictly online support modules are considered for the scope of this study. The specifications of the online support modules are detailed below.

- Content Development: Three five-minute videos which explain blockchain fundamentals, blockchain relevance in the context of the CGHG, and the specific blockchain functionalities the homeowner will utilize.
- Production: Assuming moderate complexity for each video (including graphics and animations), a higher cost of CAD 5000 per minute is assumed for production.

(17) $\boldsymbol{HomeownerTraining} = TotalLengthofVideos \times CostPerMinute$

2.8 Economic Analysis Methodology

The economic analysis assesses the financial viability and broader economic implications of the CGHG program when comparing the baseline scenario to the blockchain scenario. The findings of this analysis will critically inform the policy recommendations and strategic decisions regarding the future of the CGHG program.

2.8.1 Net Benefits

Net benefits represent the difference between the total benefits and costs of the CGHG program. This metric provides a direct measure of the program's economic value, capturing both the financial savings from energy efficiency and pollution reduction and the costs involved in administering and delivering the program. The energy and pollution savings are calculated as a product of financial savings resulting from energy-efficient upgrades over the projection period, while the administrative expenditure and funds disbursed are calculated as costs incurred to achieve the benefits over the projection period. The formula used is seen below:

(18) $$\boldsymbol{NetBenefits_t} = (EnergySavings_t + PollutionSavings_t) - (FundsDisbursed_t + Ad\min E\,xpenditure_t)$$

2.8.2 Cost-Benefit Ratio

The CBR is another important metric, represented as a ratio that quantifies the benefit received per unit of cost incurred. In the context of economic analysis, it helps to determine which scenario delivers the most value relative to the investment made. The CBR is calculated by dividing the total benefits (financial energy and pollution savings) by the total costs (admin expenditure and funds disbursed). A CBR greater than 1 indicates that the total benefits exceed the total costs, suggesting that the program is economically viable and profitable. Conversely, a CBR of less than 1 indicates that the costs outweigh the benefits, implying that the program may not be economically justified. A CBR equal to 1 means that the benefits equal the costs. The formula used is as follows:

(19) $$CBR = \frac{Total\ Benefits_t(Energy\ Savings + Pollution\ Savings)}{TotalCost_t\ (Admin\ Expenditure + Funds\ Disbursed)}$$

2.8.3 Cost-Effectiveness Ratio

Cost-effectiveness analysis is employed to evaluate the program's effectiveness by comparing the total costs to the specific outcomes achieved. This analysis determines which of the two scenarios achieves household energy savings and pollution reduction at the lowest cost. In this context, the outcomes are expressed in specific, quantifiable terms such as energy savings (measured in kilowatt-hours, kWh) and pollution reduction (measured in tons of CO2 equivalent, tCO2e). The CER is calculated to express the cost per unit of outcome achieved, for instance, dollars per kWh saved or dollars per ton of CO2e reduced. The formula used is as follows:

(20) $CER_t = \frac{TotalCosts_t}{TotalBenefits\,(kWh, tCO2_t)}$

Chapter 3: Analysis and Observations

This chapter offers a complete assessment of the CGHG program under two potential future states. The first is the baseline, where the CGHG continues to be implemented as it has been to date. The second is one in which blockchain technology is integrated into the CGHG program. The analysis examines key variables such as funds disbursed, household participation, energy and pollution savings, administrative time, and administrative expenditure for both scenarios. Furthermore, an economic analysis is carried out to assess the viability of blockchain technology relative to the current system, focusing on net benefits, cost-benefit ratios, and cost-effectiveness ratios.

3.1 Comparative Analysis

This comparative analysis examines key metrics, including funds disbursed, household participation, energy bill savings, pollution reduction, and administrative expenditures. It evaluates the financial and operational efficiencies achieved through blockchain integration compared to the traditional baseline approach. The results from this analysis will establish the basis for the economic analysis which follow, providing comprehensive insight into blockchain's potential transformation in green financing programs such as the CGHG.

3.1.1 Comparative Analysis of Funds Disbursed and Household Participation

Funds disbursed and household participation are two interlinked variables which provide valuable insights into the CGHG’s scale. The funds disbursed represent the financial resources allocated to homeowners to implement energy-efficient improvements. At the same time, household participation reflects the number of households that have successfully engaged with and benefited from the program. Figures 1 and 2 visualize the trends in funds disbursed and household participation, respectively, highlighting a faster increase in both metrics under the blockchain scenario compared to the baseline. The following paragraphs provide a closer examination of these trends.

In the baseline scenario, the CGHG program disburses CAD 4.65 billion over the projection period from 2021 to 2031. The annual disbursement starts at CAD 9.15 million in 2021 and increases progressively as the program expands and engages more households. Household participation in the baseline scenario totals 1,001,241 households over the same period, beginning with 2,718 households in 2021 and gradually increasing yearly.

In contrast, the blockchain scenario demonstrates a higher total disbursement of CAD 4.96 billion over the same ten-year period, reflecting an increase of CAD 305 million in funds disbursed. Once again, it is worth noting that the blockchain application was only implemented in 2024. Consequently, a direct comparison between the years 2024-2031 shows that the blockchain scenario disbursed an additional CAD 757 million compared to the baseline. Moreover, household participation in the blockchain scenario totals 1,182,053 households, with an accelerated increase in participation rates post-2024. As for household participation, a direct comparison between the years 2024-2031 reveals that the blockchain scenario successfully engaged 180,313 more households than the baseline scenario.

The higher disbursement rates are driven by the uptake of blockchain-enabled enhancements, which create a higher level of participation in this scenario than the baseline. All participating households will also benefit from faster application processing times, grant estimations, and fund disbursement times, which are detailed below.

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Figure 1. CGHG Funds Disbursed Baseline vs Blockchain

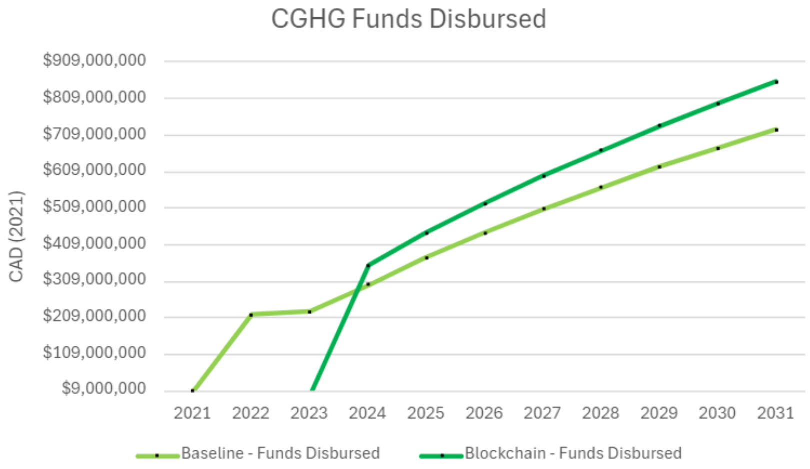
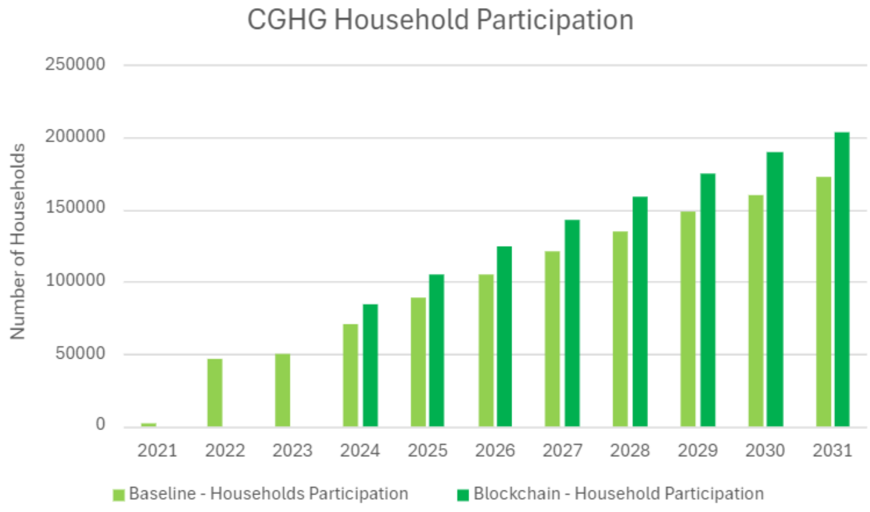
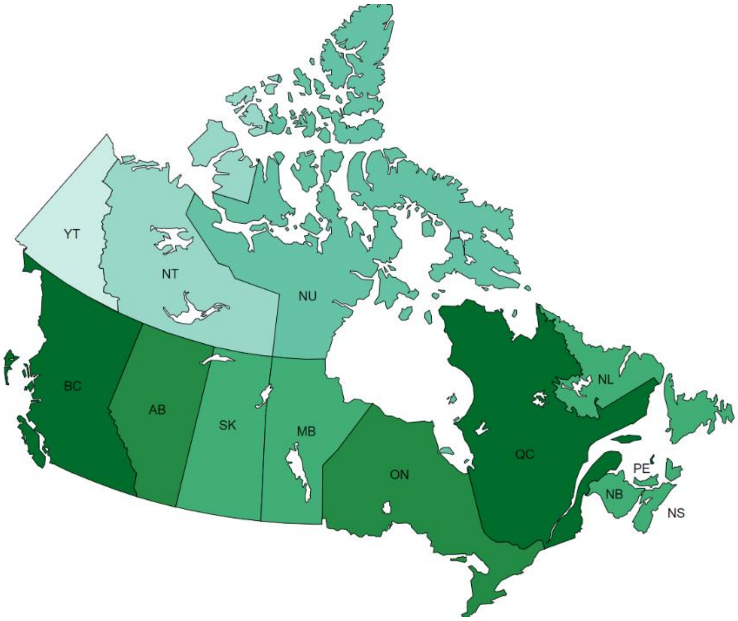


Figure 2. CGHG Household Participation, Baseline vs Blockchain



From a provincial standpoint, British Columbia, Quebec, Alberta, and Ontario exhibited the highest disbursement levels across both the baseline and blockchain scenarios. These findings are consistent with these regions' population density and economic size, which naturally demand higher energy efficiency interventions due to larger residential sectors and greater environmental footprints. Figure 3 below illustrates a heatmap of fund disbursement at a regional level, providing insights into the geographical distribution of funds over the projection period. The darker green shades indicate levels of higher disbursement, while the lighter shades indicate lower disbursement levels over the entire projection period.

Figure 3. Heatmap of Regional Fund Disbursement



3.1.2 Comparative Analysis of Household Energy and Pollution Savings

Household energy and pollution savings are two variables which provide insights into the environmental impact of the CGHG program. Energy bill savings represent the reduction in household energy consumption due to energy efficiency upgrades, while pollution savings reflect the reduction in GHGs resulting from these upgrades.

The results of the baseline analysis suggest that the CGHG program is anticipated to yield substantial energy and pollution savings over the projection period. More specifically, the baseline scenario projects cumulative energy bill savings amounting to CAD 1.54 billion from 2021 to 2031. This figure factors in the compounding effect of energy bill savings year over year, with earlier participating households contributing more to overall savings due to longer periods of accumulated savings. This compounding effect is evident in Figure 4, with the highest energy bill savings occurring in 2024, 2025, and 2026. Initial energy bill savings start at CAD 8.4 million in 2021 and increase steadily as more households participate and benefit from energy-efficient home upgrades. As for pollution savings, the baseline scenario anticipates a total cost saving from pollution reduction at CAD 51.23 million over the projection period. This figure is based on the average reduction in pollution per household, multiplied by the cost of pollution set at CAD 50 per tCO2e, and the number of participating households each year. Pollution savings start at CAD 130,721 in 2021 and escalate consistently as the program expands, as depicted in Figure 5.

In the blockchain scenario, pollution savings are higher, but energy bill savings are lower over the projection period. The households in the baseline scenario in 2021-2023 contributed to higher energy bill savings due to the compounding effect, as there are more remaining years in the projection period. From 2024 to 2031, the blockchain scenario achieves cumulative energy bill savings of CAD 1.41 billion, approximately 8% less than the baseline. However, considering the energy bill savings between 2024, when the blockchain application is deployed, and 2031, the blockchain scenario outperforms the baseline by CAD 216 million. In the blockchain scenario, energy bill savings follow a similar upward trajectory as the baseline scenario but at a higher rate.

As for pollution savings, the blockchain scenario projects a total cost saving from pollution reduction at approximately CAD 53.87 million over the projection period. The increased number of participating households and the enhanced efficiency of blockchain technology contribute to higher annual pollution savings. By 2031, the annual pollution savings reached CAD 8.24 million compared to CAD 6.98 million in the baseline scenario.

These findings suggest that blockchain technology amplifies the program's environmental benefits, making it a valuable tool for achieving its long-term sustainability objectives, as discussed in more detail in Chapter 4.

Figure 4. Cumulative Household Energy Bill Savings, Baseline vs Blockchain

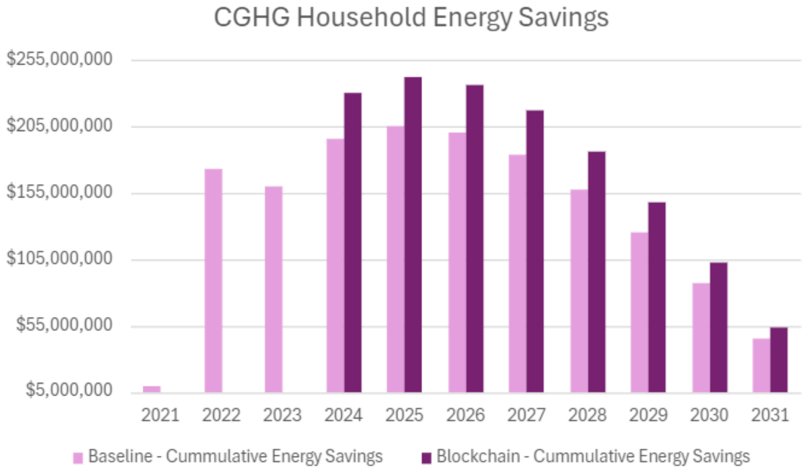
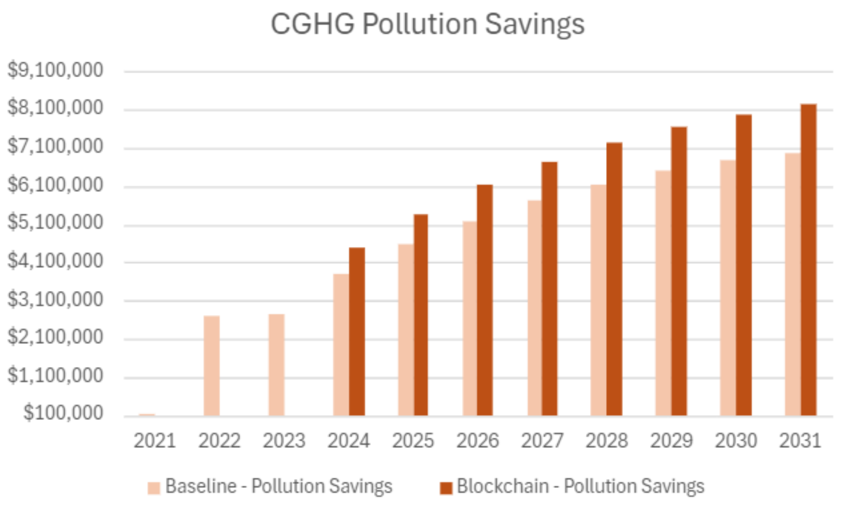


Figure 5. Household Pollution Savings, Baseline vs Blockchain



3.1.3 Comparative Analysis of Administrative Time

A total of 12 administrative times were considered in this analysis, each corresponding to a step in the CGHG process. As highlighted in Chapter 2, the administrative times for Steps 1, 6, 7, and 10 are homeowners' responsibility, while the remainder of the steps fall under the responsibility of NRCan program staff. While the steps managed by homeowners present little opportunity for optimization through blockchain integration, the steps managed by NRCan do. Table 8 showcases the average improvement of each step given the integration of blockchain technology over the projection period. It is observed that steps subject to blockchain enhancements experienced notable improvements in administrative processes, leading to a reduction of over 70% in processing times. The following paragraphs examine each of the steps in more detail.

In Step 2, there was an average improvement of 79.28%, highlighting the significant enhancement in efficiency resulting from blockchain's ability to streamline the verification of applicant eligibility. This is due to the automation of verification processes, which reduces the time required for NRCan program staff to manually cross-reference applications with eligibility criteria. Consequently, NRCan staff can process a higher volume of applications and expedite the scheduling of energy evaluations. As a result, Step 3 demonstrated an average improvement of 78.46%, indicating substantial improvements in the time taken to schedule a pre-retrofit EnerGuide evaluation. This considerable reduction in administrative time in the early stages of the CGHG process allows homeowners to proceed promptly with their retrofits after their initial applications.

Following the completion of retrofits and post-retrofit evaluations, the grant confirmation and disbursement process also experiences substantial reductions in administrative times. Specifically, Step 11 achieves an average reduction of 79.43% due to the automated estimation of the grant amount to be disbursed to homeowners. The use of smart contracts to execute upon the submission of receipts and estimate the grant amount based on pre-determined program criteria eliminates the delays previously caused by manual confirmation of the grant amount by NRCan program staff. Finally, in Step 12, the actual grant disbursement experiences an improvement of 79.97%. The transition from checks deposited via mail to electronically and securely disbursed funds enables homeowners to receive their grants significantly faster. While administrative times decrease drastically for Steps 2,3,11, and 12 it is important to note that they do not consider a learning curve for program staff which may have yielded different degrees of improvement. The implications of these improvements are discussed in more detail in Chapter 4.

Table 8. Average Improvement of Administrative Times with Blockchain Integration.

CGHG Step	**Average Improvement (%)**
Step 1: Homeowner Application	0.00
Step 2: Eligibility Confirmation	79.28
Step 3: Scheduling of Pre-Retrofit EnerGuide Evaluation	78.46
Step 4: Completion of Pre-Retrofit EnerGuide Evaluation	0.00
Step 5: Pre-Retrofit EnerGuide Evaluation Upload to NRCan Portal	0.00
Step 6: Completion of Retrofits by Homeowner	0.00
Step 7: Scheduling of post-retrofit EnerGuide Evaluation.	0.00
Step 8: Completion of Post-Retrofit EnerGuide Evaluation.	0.00
Step 9: Post-Retrofit EnerGuide Evaluation Upload to NRCan Portal	0.00
Step 10: Submission of Receipts by Homeowner	0.00
Step 11: Confirmation of Grant Amount	79.43
Step 12: Grant Disbursement	79.97

3.1.4 Comparative Analysis of Administrative Expenditure

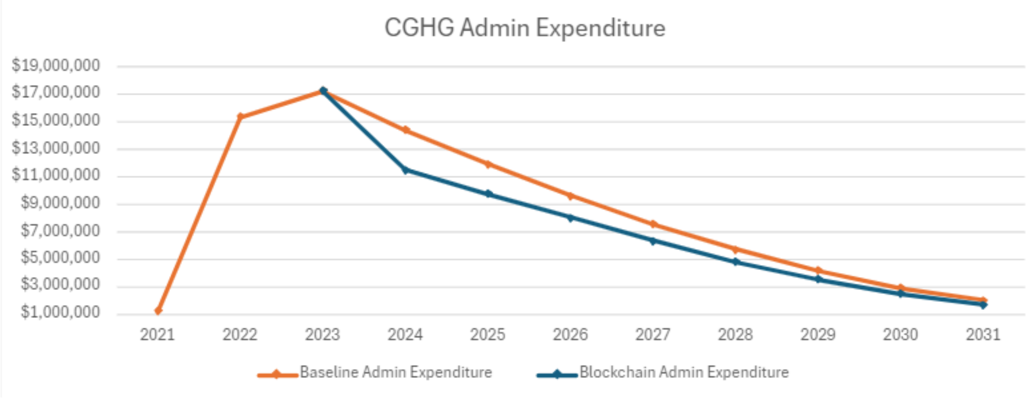
The administrative expenditure of the CGHG program provides insights into the expenses related to delivering benefits such as energy and pollution savings. Unlike the previous variables examined, this comparative analysis of administrative expenditure considers three distinct categories, each incorporating additional factors. The first category, depicted in Figure 6, illustrates the costs strictly associated with improvements in administrative times. The second category, depicted in Figure 7, includes the capital expenditure for designing and deploying the blockchain application. The final category, depicted in Figure 8, accounts for the training costs necessary for both homeowners and NRCan program staff to familiarize themselves with the blockchain application and navigate the updated steps within the CGHG process. This segmented approach provides a more accurate understanding of the integration of the blockchain application. The following paragraphs discuss these categories and their implications in more detail.

In Figure 6, administrative expenditure decreases over time in both scenarios due to improved administrative efficiency, enabling the management of more applications. The orange line represents the baseline scenario, indicating an initial low administrative expenditure of CAD 1.2 million in 2021. This amount then sharply increases to CAD 15.38 million in 2022 and CAD 17.28 million in 2023. The initial low expenditure is attributed to the program's launch phase, where workflows and staffing requirements were still being established. The subsequent increase reflects the costs of scaling up the program, hiring additional staff, and implementing more robust workflows.

Conversely, the deployment of the blockchain application in 2024, depicted by the blue line, results in a substantial reduction in administrative expenditure of CAD 11 million over the projection period. This significant decrease is attributed to the enhanced administrative process efficiency brought about by blockchain technology, which was previously discussed in Section 3.1.3. Although the baseline scenario also experiences a decrease in costs over time due to gradual operational improvements, it is not as pronounced as the reduction observed with blockchain integration.

It is important to note that while administrative efficiency plateaus, starting in 2027 for the baseline scenario and in 2025 for the blockchain scenario, Figure 6 illustrates that administrative costs continue to decrease over time. This declining trend is due to the discounting process, which reduces the value of future expenses to reflect their present value, resulting in lower present values for future costs. While the discount rate partially explains the decreasing values over time, this study did not assume a specific portion of the expenditure allocated to staffing wages. Should this have been considered, the rate of decline may have potentially been less pronounced, particularly in the baseline scenario. This consideration is discussed in more detail in Chapter 4.

Figure 6. CGHG Admin Expenditure



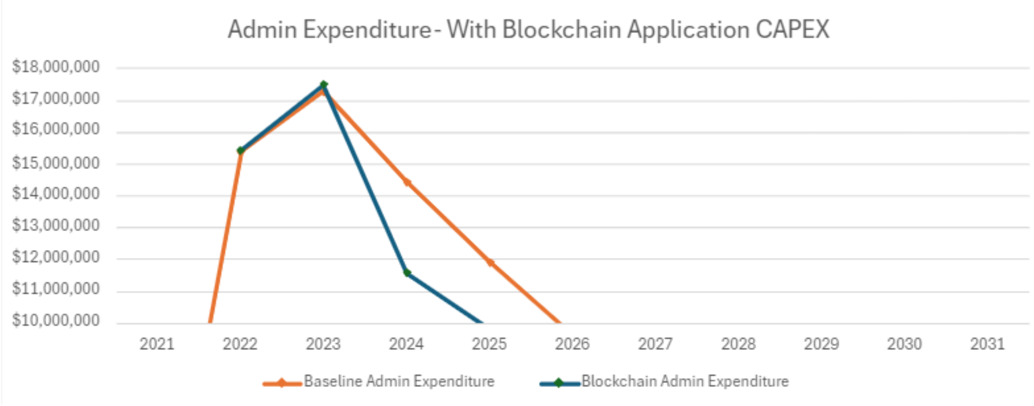
When accounting for the development, testing, and deployment costs associated with the blockchain application, the administrative expenditure figures show slight changes, specifically between 2021 and 2023, as illustrated in Figure 7. This figure is zoomed in to highlight the deviation in cost. Although the primary focus of this study is not the CAPEX of the blockchain application, taking these costs into account provides valuable insights into the financial requirements for deploying such a system. The estimated CAPEX is CAD 300,000, this budget covers multiple stages of the development which are broken down below:

- <u>Consultation (2022):</u> The consultation phase involves engaging experts to understand the specific needs and requirements of NRCan for integrating blockchain technology into the CGHG program. This phase costs CAD 15,000 and includes stakeholder meetings, feasibility studies, and strategic planning sessions.

- Design (2022): The design phase focuses on creating a detailed blueprint for the blockchain application. This includes user interface design, user experience design, and system architecture planning. The cost for this phase is CAD 30,000, and it ensures that the application is both user-friendly and technically sound.
- Development (2023): This phase accounts for the largest portion of the budget, with a cost of CAD 135,000. It involves the actual coding and programming of the blockchain application.
- Quality Assurance (2023): Quality assurance is a phase that helps ensure the reliability and performance of the blockchain application. This phase costs CAD 75,000 and involves extensive testing to identify and fix bugs, optimize performance, and ensure compliance with all regulatory and security standards.
- Deployment (2024): The final phase involves deploying the blockchain application into the CGHG program. This includes configuring servers, setting up network security, and ensuring seamless integration with the existing CGHG systems. The deployment phase costs CAD 45,000 and covers initial support and monitoring to address any issues that arise post-launch.

These cost factors are depicted by the slight deviation seen by the blue line spiking over the orange line between 2022 and 2024. The cost is stacked on top of the baseline administrative expenditure to reflect the additional expenses for NRCan.

Figure 7. CGHG Admin Expenditure with Blockchain Application CAPEX.

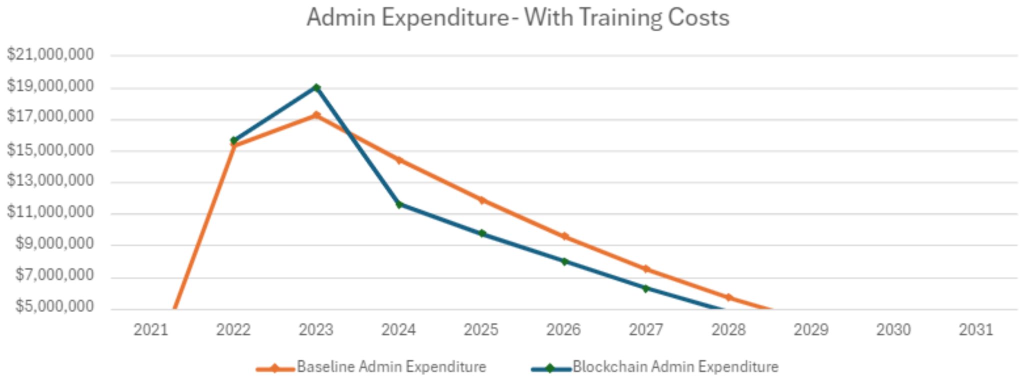


The final consideration regarding administrative expenditure is the inclusion of training costs to accurately reflect the expenses associated with the deployment of the blockchain application. These expenses cover the cost of sessions and the development of resources necessary to train both homeowners and NRCan program staff. For NRCan program staff, the training encompasses the acquisition of new knowledge and skills. More specifically, an introductory training that provides them with the knowledge of blockchain fundamentals followed by intensive hands-on training to familiarize them with the new blockchain application being implemented into the CGHG program. These trainings are calculated to cost CAD 257,431 and CAD 1.5 million, respectively. These expenses are assumed to be a one-time cost as NRCan will be capable of developing internal training materials post-deployment.

Moreover, to ensure homeowners can seamlessly interact with the blockchain system, user-friendly instructional videos similar to those currently used by NRCan will also be developed. The cost of developing these training videos is calculated to cost CAD 66,000, assuming a formal production process.

When these training costs are incorporated, the initial phase of blockchain deployment becomes more costly, as depicted by the pronounced blue line relative to the orange line. These additional expenses provide a holistic view of the financial implications of deploying the blockchain application within the CGHG program. By accounting for the initial investment in training staff and homeowners, the program is more likely to experience a smooth transition.

Figure 8. CGHG Admin Expenditure with Blockchain Training Costs.



3.1.5 Comparative Analysis of Administrative Expenditure Per Household

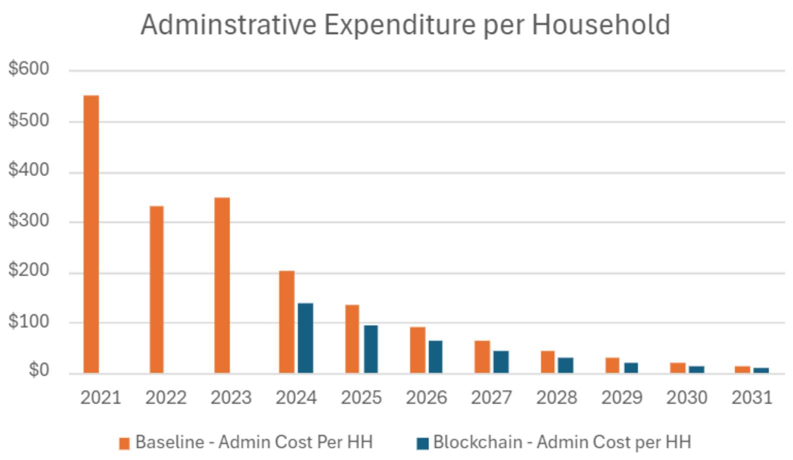
Taking a closer look at the per-household administrative expenditure provides a more nuanced understanding of the expenditure associated with efficiency gains resulting from integrating blockchain within the CGHG program. Figure 9 illustrates the administrative costs per household for both the baseline and blockchain scenarios over the projection period.

In the baseline scenario, the administrative cost per household starts at CAD 550 in 2021, reflecting the initial workload of processing applications, managing data, and establishing an efficient workflow. As processes become more streamlined, the cost per household decreases, and by 2031, it will reach CAD 11.45, representing a 97% improvement from the base year.

In contrast, the blockchain scenario shows a more significant and rapid reduction in administrative costs per household. Once integrated into the CGHG in 2024, the administrative costs per household immediately drop to CAD 137.37. This downward trend continues for the rest of the projection period, with the administrative cost per household reaching CAD 8.17 in 2031. This reduction highlights the long-term benefits of blockchain integration, resulting in substantial cost savings for NRCan.

This analysis suggests that blockchain technology not only accelerates the reduction of administrative costs but also achieves greater cost efficiency per household in the long run. Additionally, the consistently lower costs in the blockchain scenario underscore the potential for NRCan to allocate more resources toward achieving the program's sustainability goals rather than being hindered by high administrative expenses. Lastly, it is important to note that, similar to Figure 6, the rate of decline may potentially be less pronounced should a clear portion of the administrative expenditure have been allocated to staffing wages, which would remain relatively consistent over time.

Figure 9. Administrative Expenditure per Household



3.2 Economic Analysis

This section delves into the economic analysis of the CGHG, with a focus on three key financial metrics: net benefits, cost-benefit ratios, and cost-effectiveness ratios. By examining these economic indicators, an understanding of the financial advantages of blockchain integration will be established. This analysis not only highlights the monetary benefits but also lends some insight into the program's overall effectiveness, thus providing a strong framework for the appraisal of economic feasibility and sustainability of blockchain deployment within the CGHG.

3.2.1 Net Benefits Analysis

At first glance, the net benefits for the CGHG reveal that under both the baseline and blockchain scenarios, the CGHG shows a net loss each year over the projection period, as illustrated in Table 9. The baseline scenario shows an initial net loss of approximately CAD 969 thousand in the first year, with the net loss increasing progressively each year to reach approximately CAD 673.75 million by the final year, resulting in a cumulative net loss of CAD 3.15 billion over the projection period.

Similarly, the blockchain scenario also shows an initial net loss of approximately CAD 129 million upon its deployment in 2024. The net loss remains consistently higher than that of the baseline throughout the projection period, leading to a total net loss of CAD 3.54 billion by 2031. Upon closer examination, it becomes evident that while the administrative expenditure component of the cost is lower, the disbursed funds are significantly higher, contributing to the greater net loss.

After analyzing net benefits, it becomes evident that the calculations likely need to capture secondary and tertiary economic impacts, such as the effects on the labour force, market dynamics for environmental and clean technology manufacturers, and broader economic multipliers. Further research is necessary to include these indirect benefits and to develop a more comprehensive understanding of the economic impact of the CGHG program; this is discussed in more detail in Chapter 4.

Table 9. Net Benefits, Baseline vs Blockchain

Year	Baseline Net Benefits (CAD 2021)	Blockchain Net Benefits (CAD 2021)
2021	-969,058.409	
2022	-56,175,622.477	
2023	-80,545,887.631	
2024	-114,176,499.555	-129,265,130.795
2025	-175,396,401.228	-202,700,187.553
2026	-246,268,846.812	-287,277,813.708
2027	-324,312,335.411	-380,123,691.775
2028	-407,532,901.316	-478,961,566.242
2029	-494,369,738.556	-581,950,958.224
2030	-583,506,333.027	-687,550,270.382
2031	-673,758,922.996	-794,368,675.164

3.2.2 Cost Benefit Analysis

In considering the CBR, this study evaluates the benefits gained per unit of cost incurred. Table 10 reveals that in both scenarios, the costs outweigh the benefits, as indicated by CBR values less than 1. However, the benefits are notably higher under the blockchain scenario. Over the projection period, the blockchain scenario demonstrates an average CBR of 0.402, while the baseline scenario demonstrates an average CBR of 0.339. This means that, on average, for the baseline scenario, only 33.9% of the cost is received in benefits for every unit of cost incurred. For the blockchain scenario, only 40.2% of the cost is received in benefits for every unit of cost incurred. Looking more closely at individual years, it is apparent that with time, the CBR declines as the costs increase faster than the benefits, as also seen in the net benefit analysis.

While neither scenario achieves a CBR greater than 1, the blockchain scenario consistently demonstrates a higher CBR than the baseline, indicating a better relative return per dollar invested. However, further research is recommended to capture a more comprehensive spectrum of benefits to obtain a more accurate CBR; this is discussed in more detail in Chapter 4.

Table 10. CBR, Baseline vs Blockchain

Year	Baseline CBR	Blockchain CBR
2021	0.906	
2022	0.758	
2023	0.668	
2024	0.636	0.757
2025	0.545	0.646
2026	0.455	0.539
2027	0.369	0.436
2028	0.287	0.340
2029	0.210	0.249
2030	0.139	0.164
2031	0.072	0.084

3.2.3 Cost-Effectiveness Analysis

The CER, which measures the cost per unit of benefit achieved, is examined to determine which of the two scenarios achieves the highest level of energy savings and pollution reduction at the lowest cost. The results are divided and discussed into two segments: the CER of energy savings and the CER of pollution reduction.

Energy Savings CER:

The CER of energy savings is calculated by dividing the total costs by the energy saved (measured in kWh) in a year as a result of energy-efficient retrofits by homeowners. The CER value indicates the cost of saving one-kilowatt hour (kWh) of energy. The results shown in Table 11 below indicate nearly identical results across both scenarios. In the initial years, the CER values are relatively low (0.24-0.52), indicating a low cost for saving energy. This is likely a result of fewer participating households in the early stages of the program. However, in later years, the CER value increased between 1 and 3, suggesting that the marginal cost of saving additional energy rises over time. The CER analysis of energy savings reveals that there is no discernable advantage provided by blockchain technology in terms of energy savings, as both scenarios show a relatively similar level of cost-effectiveness.

Table 11. CER or Energy Savings, Baseline vs Blockchain

Year	Baseline CER (CAD/kWh)	Blockchain CER (CAD/kWh)
2021	0.21	
2022	0.26	
2023	0.29	
2024	0.31	0.30
2025	0.36	0.36
2026	0.43	0.43
2027	0.54	0.53
2028	0.69	0.69
2029	0.96	0.96
2030	1.49	1.49
2031	3.10	3.10

Pollution Savings CER:

The CER of pollution savings is calculated by dividing the total costs by the tCO2e reduced in a year. The CER value indicates the cost per tCO2e reduced in a given year. The results shown in Table 12 below indicate that, unlike the CER of energy savings, the CER of pollution savings declines over time.

While the value of the CER is substantially higher than the CER of energy savings, this reflects the higher units of measurement (tCO2e), broader scope, and more expensive measures required to achieve pollution reduction.

The average CER for the baseline scenario over the projection period is 3,697.29 CAD, whereas the average for the blockchain scenario is 3,542.82 CAD. This indicates that, on average, the blockchain scenario can reduce one tCO2e for 154.47 CAD less than the baseline. These results indicate that, over time, the program can reduce emissions for less cost, which is a strong indicator of the program's environmental effectiveness and contribution to pollution reduction.

Table 12. CER of Pollution Savings, Baseline vs Blockchain

Year	Baseline CER (CAD/tCO2e)	Blockchain CER (CAD/tCO2e)
2021	3,958.99	
2022	4,143.33	
2023	4,075.62	
2024	3,669.09	3,614.48
2025	3,611.72	3,577.81
2026	3,576.03	3,553.77
2027	3,552.06	3,537.03
2028	3,535.24	3,525.14
2029	3,523.41	3,516.71
2030	3,515.16	3,510.82
2031	3,509.54	3,506.81

Chapter 4: Discussion

In this chapter, the findings from Chapter 3 are critically discussed, focusing on the implications, significance, and limitations of the study. The results will be analyzed within the specific context of NRCan's CGHI and the broader context of sustainable development in Canada to gain a comprehensive understanding of the implications of blockchain technology. This discussion will also explore the practical and theoretical contributions of the study, address any limitations encountered during the research, and propose directions for future research. Finally, it will suggest recommendations for policymakers and practitioners based on the insights gained from this study. Through these discussions, this chapter aims to contribute to the ongoing discourse on the role of digital technologies in advancing sustainable development.

4.1 Implications for Natural Resource Canada's Greener Homes Initiative

The CGHI portfolio, operated by NRCan, consists of four constituent programs, all aimed at supporting homeowners in transitioning their homes to be more environmentally friendly through the adoption of green technologies. Unfortunately, the CGHG program is no longer operational as of April 2024 due to administrative backlogs and the depletion of funds. This study provides important lessons that might have led to different outcomes for the CGHG program had they been applied earlier.

A key issue explored in this research was the operational and economic impact of ecosystem fragmentation. In the context of this study, ecosystem fragmentation refers to the disjointed nature of processes and systems that arise from the involvement of multiple stakeholders using different platforms and procedures. Specifically, this fragmentation manifests in complex stakeholder interactions, which prolong processes due to the need for extensive coordination and communication (Tapscott & Tapscott, 2016, p.38). Various stakeholders, such as federal and provincial agencies, contractors, and homeowners, often use separate platforms and systems, leading to duplicated workflows and inefficiencies. For instance, in Quebec and some eastern provinces, separate application portals are used, adding to the complexity and inhibiting a seamless, unified approach to program implementation.

However, integrating blockchain technology can significantly reduce these inefficiencies. By automating key processes such as application approval, grant estimation and confirmation, and grant disbursement, certain steps within the CGHG process can be streamlined from several weeks to just a few minutes. Although these steps are complex, blockchain technology ensures they remain secure and robust, enabling homeowners to receive relevant information and benefits more quickly, likely resulting in higher levels of participant satisfaction.

While this study's quantitative findings are specific to the CGHG, the observed trends and use cases for blockchain in program processes apply to other constituent programs within the CGHI. Other programs aimed at improving energy efficiency, promoting renewable energy sources, and enhancing the overall sustainability of residential properties could benefit from similar blockchain integrations. By adopting blockchain technology, these programs can achieve higher administrative efficiency and improved stakeholder engagement, leading to more effective and scalable solutions for Canada's sustainable development goals.

4.2 Implications for Policy and Practice

The integration of blockchain technology into public programs such as the CGHG has profound regulatory, security, and scalability implications. While this research focuses on specific outcomes of the CGHG program, it sets a premise for broader discourse on policy implications. The decentralized nature of blockchain introduces a significant shift from traditional centralized systems, which will inevitably introduce numerous unknowns that need to be addressed.

As highlighted in Chapter 1, many government-operated programs are centralized in their nature, meaning that data flows through government workflows and is owned in some capacity by the government once shared by applicants. Blockchain, however, introduces elements of decentralization by verifying information through interoperability with multiple servers, such as those managed by financial institutions, utility companies, and property registries. This shift grants applicants more autonomy over their data and enhances efficiency gains, as they are no longer solely dependent on a centralized authority for validation processes (Nofer et al., 2017). NRCan, on the other hand, can benefit from reduced administrative costs and improved data integrity.

However, this change in the nature of centralization brings about significant regulatory and legal challenges. The decentralized nature of blockchain means that traditional data governance and control mechanisms will need to be re-evaluated. For instance, questions regarding data ownership, privacy, and security become more complex when data is distributed across multiple nodes rather than being stored within a single centralized entity. Regulatory frameworks will need to adapt to address issues such as data breach responsibilities, compliance with privacy laws, and ensuring the authenticity and integrity of decentralized data.

Furthermore, the implications extend beyond NRCan alone. Other governmental agencies and public sector programs that might consider adopting blockchain technology will face similar regulatory challenges. The need for a unified approach becomes critical, as discrepancies between different agencies’ policies could lead to inefficiencies and legal ambiguities. This necessitates a collaborative effort among policymakers, legal experts, and technologists to develop guidelines that can be universally applied to different public programs.

While blockchain technology offers substantial benefits in terms of autonomy and efficiency for applicants and cost reductions for NRCan, the transition introduces numerous regulatory and legal complexities which need to be considered.

4.3 Recommendation for Further Research

The quantitative findings of this research are based on specific assumptions within the scenario-building and projection exercises. Consequently, while the trends accurately illustrate the potential implications of blockchain technology, the precise data outputs may not capture the exact financial, environmental, or social benefits realized. Therefore, additional research is necessary to enhance the robustness of the outcomes associated with the CGHG program. Key areas that would benefit from further investigation include the adoption rates of blockchain technology by homeowners, the detailed modelling of associated costs, the comprehensive modelling of benefits, employing different analytical frameworks, and the modelling of the blockchain application itself. These elements are discussed in greater detail below, highlighting the need for a deeper understanding to support the scalability and effectiveness of the CGHG program.

A first set of considerations turns to questions about households. The analysis assumed a specific rate of adoption of blockchain technology by Canadian homeowners, which directly influences their ability and willingness to enroll in a government incentive program built on a blockchain platform. However, the actual adoption rate may vary and may proceed differently than anticipated, including declining over time following a diffusion of innovation sigmoidal curve (Rogers, 1983). This might mean that the heightened enrollment projection in the blockchain scenario overstates what we can expect from the use of this technology, which would lessen the monetary benefits from increased pollution reductions and energy savings. Additionally, it is important to consider that there could be significant variations across different households that affect the adoption rate of blockchain technology. Factors such as technological literacy, access to necessary resources, socioeconomic status, and individual preferences may all play a role in determining how quickly and effectively homeowners adopt the new system. Understanding these differences is crucial for accurately predicting participation rates and ensuring the successful implementation of the CGHG program. For this reason, as better insights into the public integration of blockchain are developed in the coming years, future research should utilize more accurate figures to understand not only the rate of adoption but also the personas of homeowners who are most likely to encounter challenges and those who are most likely to adopt blockchain. This deeper understanding will enable the development of targeted strategies to support and encourage broader adoption, ensuring the benefits of blockchain are accessible to all segments of the population.

A second set of considerations turns our attention to NRCan. The modelled scenarios adopted a specific perspective on the capital and operational costs associated with NRCan developing and deploying the blockchain application. The actual costs may likely be higher than assumed, as the CGHG is just one program within a much larger portfolio of green initiatives operated by NRCan. Consequently, if NRCan decides to integrate blockchain technology across multiple initiatives, the capital costs could be significantly higher. Additionally, training costs, initially considered a one-time expense, may be ongoing, necessitating periodic updates and continuous education for staff and users. Lastly, while both the blockchain and baseline scenarios experienced significant decreases in administrative expenditure over the projection period (as seen in Figure 6), this study did not account for the specific proportion of expenditure allocated to staffing and wages. As a result, the analysis may not fully reflect the costs associated with staffing wages, potentially causing the reported expenditure to be underestimated. Given these factors, future research should delve deeper into the cost implications of implementing blockchain technology in the public sector. Such research may reveal that while blockchain offers substantial efficiency benefits, these benefits might be less pronounced when considering the broader and potentially recurring costs involved.

A third set of issues concerns the findings of the economic analysis that revealed negative net benefits. While it is not uncommon for public programs to experience losses in certain years, the consistent year-over-year negative results suggest that not all benefits resulting from the CGHG were accounted for. As previously mentioned in Chapter 3, these secondary and tertiary benefits include labour force stimulation, market stimulation, increased energy security, advancements in green technology adoption, and enhanced public health outcomes due to reduced pollution. Although the energy and pollution benefits examined in this study demonstrate that the CGHG is highly effective in achieving its environmental objectives, little is known about the broader social and economic implications. Future research should consider a broader set of variables to more accurately reflect the comprehensive economic benefits of the CGHG program, including its impact on employment, technological innovation, and overall societal well-being.

The fourth set of considerations for future research relates to the potential use of different analytical frameworks. While scenario-based analysis offered a practical narrative to explore the implications of blockchain, other models, such as systems dynamics modelling and Monte Carlo simulations, could provide more nuanced insights into how policy impacts evolve over time, especially when accounting for the interactions between various system components. These alternative frameworks could also offer a more detailed understanding of how power dynamics might develop, which is a critical factor when introducing blockchain into public sector programs. However, the relative novelty of blockchain introduces a degree of uncertainty, making it challenging to predict these dynamics with precision at this stage.

Lastly, as emphasized throughout this thesis, blockchain technology remains a relatively novel and multi-faceted technology. This study focused exclusively on the time efficiency achieved by blockchain, particularly within the Ethereum protocol. However, there are additional factors to consider, such as consensus mechanisms, smart contract design, and more. Future research should aim for a more comprehensive understanding of blockchain applications, taking into account the broader benefits and costs that extend beyond administrative time.

4.4 Recommendation for Implementation

This closing section of the discussion outlines actionable steps for NRCan to implement blockchain technology into the GGHG program should they choose to re-activate it. A more detailed briefing note is available in Appendix D. In brief, a strategic five-step approach is recommended to integrate blockchain technology into the CGHG process successfully.

Prior to outlining the five-step strategic approach, it is important to acknowledge that Canada's broader digital adoption efforts have faced some criticism, particularly regarding the federal government's ability to adapt and implement new technologies. As highlighted by Cote and Vu (2023), despite significant investments in digital service delivery, the federal government has struggled to meet expectations, with Canada falling from 3rd place in 2010 to 32nd in 2022 in the United Nations e-government development index. Issues such as IT infrastructure, fragmented systems, and a heavy reliance on external contractors have inhibited the government's ability to deliver digital services effectively. A report from the federal auditor general revealed that two-thirds of IT systems in federal departments are in poor health, including citizen-facing programs such as employment insurance. These issues raise concerns about the feasibility of seamlessly implementing blockchain technology within the CGHG program, as they point to systemic obstacles to digital adoption. Without significant improvements in technology management, staff training, and equitable access for all Canadians, including those in rural and underserved communities, blockchain implementation may encounter the same hurdles that have affected other federal digital initiatives. Keeping these considerations in mind, a five approach to implementing blockchain technology into the CGHG is provided below.

Step 1: Addressing Key Research Areas

The first step is to address the areas for further research highlighted in Section 4.3 by leveraging the expertise of internal NRCan experts or forming partnerships with think tanks and graduate-level researchers. This will allow NRCan to gain a more comprehensive understanding of unknown elements such as the specific blockchain protocols best suited for the program, potential regulatory and legal challenges, and the socio-economic impact on different demographics. By conducting thorough research in these areas, NRCan can build a solid foundation for the successful re-activation of the CGHG program with blockchain integration.

Step 2: Pilot Program

The second step involves conducting a pilot program to integrate blockchain technology into the CGHG program. This pilot should focus on a select group of applicants to test the system's effectiveness and identify any implementation challenges. Key aspects to be tested include the efficiency of the application approval process, the accuracy of grant estimation and confirmation, and the speed of grant disbursement. The pilot should also evaluate the blockchain system's interoperability with existing platforms used by various stakeholders, such as financial institutions and energy companies.

Step 3: Comprehensive Evaluation

The third step is to perform a comprehensive evaluation following the pilot program. This evaluation should measure the impact of blockchain integration on operational efficiency, administrative cost savings, and homeowner satisfaction. It should involve collecting quantitative data on metrics such as processing times, administrative expenditures, and the number of successful applications processed. Additionally, qualitative feedback from homeowners and NRCan staff should be gathered to assess user experience and identify areas for improvement.

Step 4: Policy Development

The fourth step is to develop policies and guidelines for the full-scale deployment of blockchain technology based on the findings from the comprehensive evaluation. These policies should address data privacy and security concerns, establish standards for interoperability with other systems, and outline procedures for ongoing blockchain application maintenance and updates. Clear guidelines should be provided to NRCan staff and homeowners to ensure smooth adoption and use of the new system.

Step 5: Stakeholder Engagement and Public Awareness

Finally, the fifth step involves stakeholder engagement to ensure a smooth transition to the new system. This includes conducting informational sessions and training programs for NRCan staff, energy advisors, and clean technology manufacturers and distributors. Additionally, public awareness campaigns should be launched to inform homeowners about the benefits of the blockchain-integrated CGHG program and how to participate. Engaging with stakeholders throughout the process will help gather valuable feedback, build trust, and ensure the successful implementation of the blockchain technology.

In conclusion, by following this strategic five-step approach, NRCan can effectively integrate blockchain technology into the CGHG program, optimizing its efficiency, reducing administrative costs, and enhancing its overall economic viability. This approach will contribute significantly to Canada’s sustainable development goals and position NRCan as a leader in leveraging innovative technologies for sustainable development.

Chapter 5: Conclusion

The Canada Greener Homes Grant program represents a critical intersection where the adoption of innovative technologies can redefine its efficiency and impact. This study has examined the operational and economic implications of incorporating blockchain technology into the program, comparing it against the existing system. The findings present a compelling case for blockchain as a transformative tool that can significantly enhance the program's operational and economic performance.

The blockchain-enhanced Canada Greener Homes Grant demonstrates a notable increase in total funds disbursed, achieved with substantially lower administrative costs both at the aggregate level and the household level. This efficiency not only underscores the superior allocation of resources but also translates into higher environmental and social benefits. By automating transactions through smart contracts, blockchain technology addresses many of the time-intensive inefficiencies of the current system, paving the way for a more streamlined workflow for program staff and more a user-friendly program for homeowners.

Moreover, the cost-benefit and cost-effectiveness analyses further validate the economic advantages of blockchain integration. The blockchain scenario consistently outperforms the baseline, highlighting its potential to deliver substantial economic savings over time. These results suggest that blockchain technology is not just a viable alternative but a superior solution for economically optimizing the Canada Greener Homes Grant program.

The implications of this integration extend beyond the program itself. On a macroeconomic scale, the adoption of blockchain technology aligns with Canada's 2030 sustainable development goals, fostering a low-carbon economy and stimulating the environmental and clean technology market. This transition can drive innovation, create job opportunities, and support economic growth, contributing to broader national and international climate commitments. These implications should be at the forefront of future academic research.

In conclusion, the integration of blockchain technology into the Canada Greener Homes Grant Program offers a transformative opportunity to enhance its efficiency, economic viability, and overall impact. The study provides a road map for leveraging blockchain to optimize the Canada Greener Homes Grant program, ensuring that it not only meets but exceeds its goals of promoting energy efficiency and sustainability. As Canada continues to pursue its ambitious climate and sustainability targets, the adoption of innovative solutions like blockchain will be crucial in driving progress and achieving lasting success.

Appendices

Appendix A: Equations

(1) $\boldsymbol{EnergyBillSavings_t} = \left(\frac{HouseholdParticipation\ _t \times 386}{(1+r)^t}\right) \times YearsRemaining$

(2) $\boldsymbol{PollutionSavings_t} = (HouseholdParticipation_t \times 1.2) \times \left(\frac{50}{(1+r)^t}\right)$

(3) $\boldsymbol{TotalAdminTime_t} = \sum Step\ 1,2,3, \ldots ,12.$

(4) $\boldsymbol{AdminEfficiency_t} = \frac{TotalAdminTime_t}{TotalAdminTime_{t-1}}$

(5) $\boldsymbol{CostPerUnitTime_t} = CostPerUnitofTime_{t-1} \times (1 + GrowthRate)$

(6) $\boldsymbol{AdminSavings_t} = \frac{(TotalAdminTime_{t-1} - TotalAdminTime_t) \times CostPerUnitTime_{t-1}}{(1+r)^t}$

(7) $\boldsymbol{AdminExpenditure_t} = \frac{AdminExpenditure_{t-1} - AdminSavings_t}{(1+r)^t}$

(8) $\boldsymbol{AdminExpenditurePerHousehold_t} = \frac{AdminExpenditure_t}{HouseholdPartcipation_t}$

(9) $\boldsymbol{FundsDisbursed_t} = \frac{FundsDisbursed_{t-1} \times (1+GrowthRate)}{(1+r)^t}$

(10) $\boldsymbol{HouseholdParticipation_t} = \frac{FundsDisbursed}{4200}$

(11) $\boldsymbol{AverageAdoptionRate} = \frac{\sum AdoptionRate_{\mathbf{2017,\ldots,2023.}}}{\mathbf{7}}$

(12) $\boldsymbol{HouseholdParticipation} = (BaselineHouseholdParticipation) \times (1 + 0.18)$

(13) $\boldsymbol{FundsDisbursed_t} = \frac{HouseholdParticipation_t \times 4200}{(1+r)^t}$

(14) $\boldsymbol{AdminTime_t} = TTF + BTC$

(15) $\boldsymbol{CAPEX} = Consultation + Design + Development + QualityAssurance + Deployment$

(16) $\boldsymbol{NRCanTraining} = (IntroductoryCourse + ApplicationSpecificTraining) \times NumberofStaff$

(17) $\boldsymbol{HomeownerTraining} = TotalLengthofVideos \times CostPerMinute$

(18) $\boldsymbol{NetBenefits_t} = (EnergySavings_t + PollutionSavings_t) - (FundsDisbursed_t + Ad\min E\,xpenditure_t)$

(19) $CBR = \frac{Total\ Benefits_t(Energy\ Savings + Pollution\ Savings)}{TotalCost_t\ (Admin\ Expenditure + Funds\ Disbursed)}$

(20) $CER_t = \frac{TotalCosts_t}{TotalBenefits\ (kWh, tCO2_t)}$

Appendix B: Tables

Table 1. Cost and Time Estimation for Blockchain Applications Based on Complexity.

App Type	Description	Cost	Time Frame
Low Complexity dApp	Payment apps developed around existing cryptocurrencies, Basic smart contract development.	$40k to $60k	3 to 6 months
Medium Complexity dApp	Moderate decentralization: Architecture has both centralized and decentralized elements.	$60k to $150k	6 to 8 months
High Complexity dApp	Healthcare app development; Modern Web 3.0-based decentralization.	$150k to $300k	9+ months

Note. *Table retrieved from Srivastava (2024).*

Table 2. Percentage of Cost Allotted to Project Milestones.

Project Milestone	Percentage of Cost Associated
Initial Consult	5%
UI/UX Design	10%
Development	45%
Quality Assurance	25%
Deployment and Maintenance	15%

Note. *Table retrieved from Srivastava (2024).*

Table 3. CGHG Administrative Process Overview

Steps	Description
Step 1: Homeowner Application	Homeowners create an account on the NRCan portal and provide property documentation, renovation plans, tax history, and other relevant information. The application is assigned to program staff for evaluation.
Step 2: Eligibility Confirmation	Program staff review the application and confirm eligibility.
Step 3: Scheduling of Pre-Retrofit EnerGuide Evaluation	Program staff assign an Energy Advisor to homeowners, who then schedule the EnerGuide evaluation.

Step 4: Completion of Pre-Retrofit EnerGuide Evaluation	The Energy Advisor completes the pre-retrofit EnerGuide evaluation.
Step 5: Pre-Retrofit EnerGuide Evaluation Upload to NRCan Portal	The Energy Advisor uploads the EnerGuide report to the NRCan portal for approval. Program staff notify homeowners to proceed with home retrofits.
Step 6: Completion of Retrofits by Homeowner	Homeowners complete their home retrofits, including selecting service providers, obtaining technology, and overseeing installation.
Step 7: Scheduling of post-retrofit EnerGuide Evaluation.	Homeowners schedule the post-retrofit EnerGuide evaluation upon completion of their home retrofits.
Step 8: Completion of Post-Retrofit EnerGuide Evaluation.	The Energy Advisor completes the post-retrofit evaluation and provides an estimate of the eligible grant amount.
Step 9: Post-Retrofit EnerGuide Evaluation Upload to NRCan Portal	The Energy Advisor uploads the post-retrofit EnerGuide report to the NRCan portal for approval. Program staff notify homeowners to submit receipts.
Step 10: Submission of Receipts by Homeowner	Homeowners submit receipts for all expenses incurred during the home retrofits.
Step 11: Confirmation of Grant Amount	Program staff confirm the final grant amount homeowners are eligible to receive upon receipt submission.
Step 12: Grant Disbursement	Upon confirmation of the final amount, checks are sent to homeowners via mail.

Note. The steps in this table were consolidated through existing source material from NRCan, (accessed November 22nd, 2024, a,b,c,d) and consultations with NRCan staff.

Table 4. Variables Considered in Baseline and Blockchain Scenarios.

Variable Name	**Unit**	**Description**	**Purpose**
Funds Disbursed	CAD (2021)	The total amount of financial incentives disbursed to participating households for home retrofits.	To measure the program's financial reach and scale under each scenario.
Household Participation	Number	The total number of households that successfully engaged with and benefited from the CGHG program.	To assess the program's accessibility and attractiveness to homeowners.
Energy Bill Savings	CAD (2021)	The total amount of energy bill savings as the result of retrofits	To evaluate the program's effectiveness

		completed under the CGHG program.	in promoting energy efficiency.
Pollution Savings	CAD (2021)	The total amount of pollution savings expressed in dollar value from retrofits completed under the CGHG program. The assumed value per ton of CO2e used to calculate savings is set at CAD 50.	To measure the environmental impact in terms of pollution reduction.
Administrative Time	Days	The total number of days associated with the CGHG administrative process for an individual household.	To evaluate the program's administrative time efficiency.
Administrative Expenditure	CAD (2021)	The total expenses incurred each year to administer and deliver the CGHG program.	To analyze the cost-efficiency of the program's administrative processes under each scenario.
Administrative Expenditure per Household	CAD (2021)	The cost of administering the CGHG program per household.	To analyze the cost reduction in cost reduction per household.
Net Benefits	CAD (2021)	The net gain or loss of the CGHG program.	To analyze the net gain or loss brought about by blockchain integration.
Cost Benefit Ratio	Ratio	A ratio that compares the total economic benefits (energy bill savings and pollution savings expressed in dollar value) to the total costs (funds disbursed and administrative expenditure).	To assess the economic viability and efficiency of the program.
Cost Effectiveness Ratio	Ratio	A ratio that indicates the cost required to achieve the unit of benefit in consideration (kWh and tCo2e).	To assess the cost-effectiveness of the benefits achieved by the CGHG program.

Note. Data was aggregated from multiple sources, including Energyhub (2023), NRCan (2024a), and NRCan (2024b).

Table 5. Control Variables

Variable	Value	Justification
Discount Rate	4%	This rate reflects the value of money, inflation, and the opportunity cost of capital, making it appropriate for the long-term financial analysis being considered in this study. The rate of 4% is selected as it represents a balanced midpoint approach between the government borrowing rate (1.5% to 2.5%) and the social discount rate (3% to 5%). This rate also incorporates a risk premium to account for uncertainties in future benefits and costs.
Average Fund Disbursement per Household	CAD 4200	This value, derived from historical CGHG reports, provides a standardized estimate of the average value of funds disbursed to a single household.
Average Annual Energy Bill Savings per Household	CAD 386	Derived from historical CGHG reports, this value provides a standardized estimate of annual savings for households implementing energy-efficient upgrades.
Social Cost of Carbon	CAD 50/tCO2e	Based on data from the federal government. This value provides an estimate of the social cost of carbon emissions. This figure is used to quantify the benefits of pollution reduction.
Average Pollution Reduction per Household	1.2 tCO2e	Derived from historical CGHG reports. This value estimates the reduction in GHG emissions per participating household per annum.

Note. Data was aggregated from multiple sources: NRCan (2024b) and Government of Canada (2023).

Table 6. Estimations of Homeowner Steps

Step	Approach	Admin Time (Days)

Step 1: Homeowner Application	Assuming all documents are readily available a minimum and maximum application time are calculated, and the average of these times is taken to determine the admin time of this step.	0.059
Step 6: Completion of Retrofits by Homeowner	Due to high national variability, a more liberal estimation is undertaken. This estimation is based on anonymous homeowner reviews and experiences from blog posts and community pages. It accounts for selecting an energy provider, selecting an eligible product, and having the actual retrofits completed, which takes time.	90.000
Step 7: Scheduling of post-retrofit EnerGuide Evaluation.	This estimation is based on homeowner experiences from blog posts and community pages.	14.000
Step 10: Submission of Receipts by Homeowner	This assumes that receipts are readily available and that homeowners can easily upload documentation.	0.020

Note. Estimations are based on qualitative and quantitative data from multiple sources including NRCan (2024a) and Reddit (2023).

Table 7. Initial NRCan Administrative Times

Step	Initial Administrative Time (Days)
Step 2: Eligibility Confirmation	40.000
Step 3: Scheduling of Pre-Retrofit EnerGuide Evaluation	14.000
Step 4: Completion of Pre-Retrofit EnerGuide Evaluation	0.125
Step 5: Pre-Retrofit EnerGuide Evaluation Upload to NRCan Portal	30.000
Step 8: Completion of Post-Retrofit EnerGuide Evaluation.	0.125
Step 9: Post-Retrofit EnerGuide Evaluation Upload to NRCan Portal	30.000
Step 11: Confirmation of Grant Amount	40.000
Step 12: Grant Disbursement	30.000

Note. Data was aggregated from multiple sources: NRCan (2024a), NRCan (accessed November 22nd, 2024, a,b,c,d), and Capture Energy (accessed March 24th, 2024).

Table 8. Average Improvement of Administrative Times with Blockchain Integration.

CGHG Step	Average Improvement (%)
Step 1: Homeowner Application	0.00
Step 2: Eligibility Confirmation	79.28
Step 3: Scheduling of Pre-Retrofit EnerGuide Evaluation	78.46
Step 4: Completion of Pre-Retrofit EnerGuide Evaluation	0.00
Step 5: Pre-Retrofit EnerGuide Evaluation Upload to NRCan Portal	0.00
Step 6: Completion of Retrofits by Homeowner	0.00
Step 7: Scheduling of post-retrofit EnerGuide Evaluation.	0.00
Step 8: Completion of Post-Retrofit EnerGuide Evaluation.	0.00
Step 9: Post-Retrofit EnerGuide Evaluation Upload to NRCan Portal	0.00
Step 10: Submission of Receipts by Homeowner	0.00
Step 11: Confirmation of Grant Amount	79.43
Step 12: Grant Disbursement	79.97

Table 9. Net Benefits, Baseline vs Blockchain

Year	Baseline Net Benefits (CAD 2021)	Blockchain Net Benefits (CAD 2021)
2021	-969,058.409	
2022	-56,175,622.477	
2023	-80,545,887.631	
2024	-114,176,499.555	-129,265,130.795
2025	-175,396,401.228	-202,700,187.553
2026	-246,268,846.812	-287,277,813.708
2027	-324,312,335.411	-380,123,691.775
2028	-407,532,901.316	-478,961,566.242
2029	-494,369,738.556	-581,950,958.224
2030	-583,506,333.027	-687,550,270.382
2031	-673,758,922.996	-794,368,675.164

Table 10. CBR, Baseline vs Blockchain

Year	Baseline CBR	Blockchain CBR
2021	0.906	
2022	0.758	

2023	0.668	
2024	0.636	0.757
2025	0.545	0.646
2026	0.455	0.539
2027	0.369	0.436
2028	0.287	0.340
2029	0.210	0.249
2030	0.139	0.164
2031	0.072	0.084

Table 11. CER or Energy Savings, Baseline vs Blockchain

Year	Baseline CER (CAD/kWh)	Blockchain CER (CAD/kWh)
2021	0.21	
2022	0.26	
2023	0.29	
2024	0.31	0.30
2025	0.36	0.36
2026	0.43	0.43
2027	0.54	0.53
2028	0.69	0.69
2029	0.96	0.96
2030	1.49	1.49
2031	3.10	3.10

Table 12. CER of Pollution Savings, Baseline vs Blockchain

Year	Baseline CER (CAD/tCO2e)	Blockchain CER (CAD/tCO2e)
2021	3,958.99	
2022	4,143.33	
2023	4,075.62	
2024	3,669.09	3,614.48
2025	3,611.72	3,577.81
2026	3,576.03	3,553.77
2027	3,552.06	3,537.03
2028	3,535.24	3,525.14
2029	3,523.41	3,516.71
2030	3,515.16	3,510.82
2031	3,509.54	3,506.81

Appendix C: Figures

Figure 1. CGHG Funds Disbursed Baseline vs Blockchain

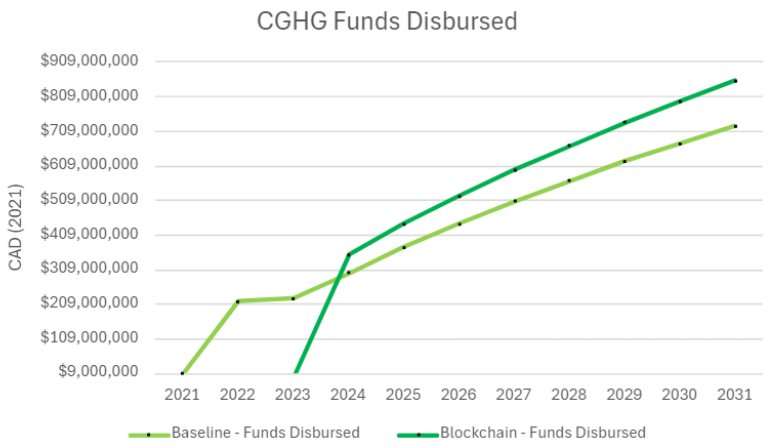


Figure 2. CGHG Funds Disbursed, Baseline vs Blockchain

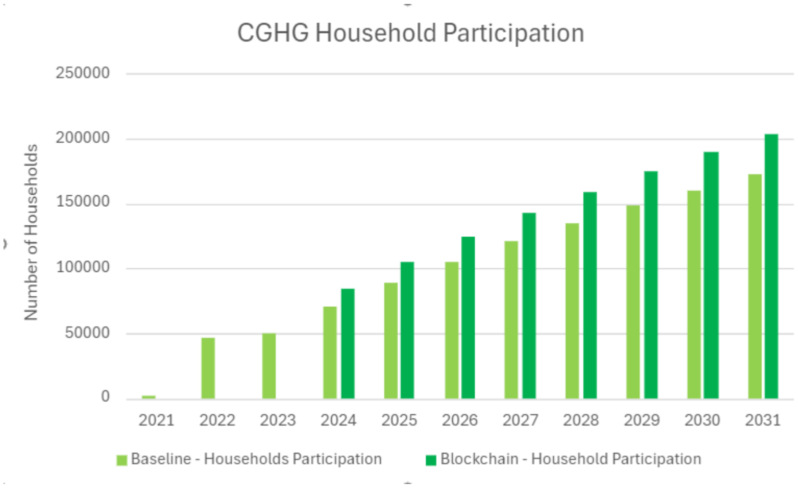


Figure 3. Heatmap of Regional Fund Disbursement

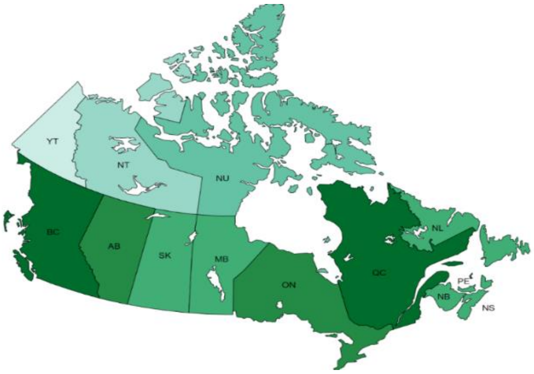


Figure 4. Cumulative Household Energy Bill Savings, Baseline vs Blockchain

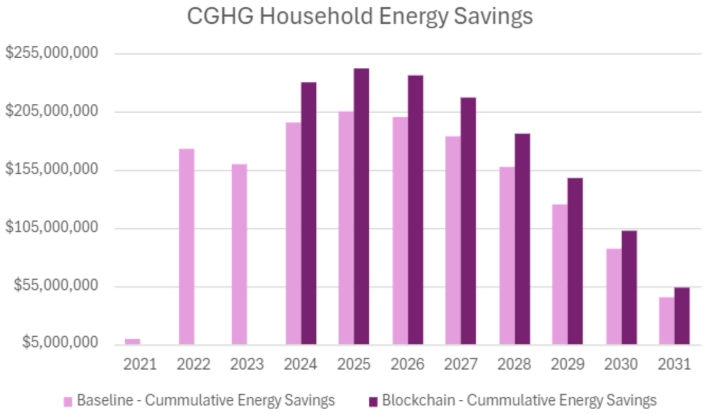


Figure 5. Household Pollution Savings, Baseline vs Blockchain

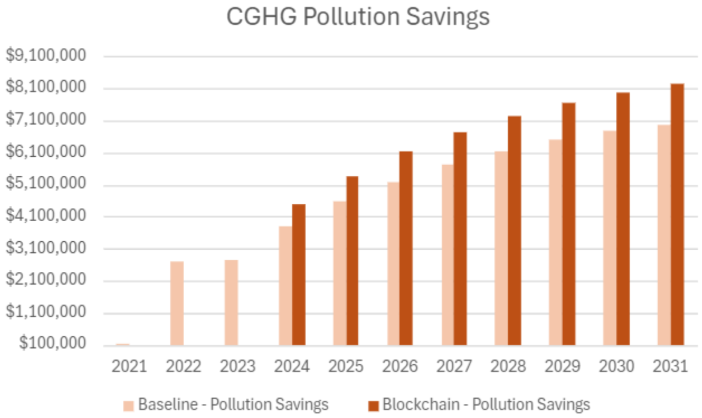


Figure 6. CGHG Admin Expenditure

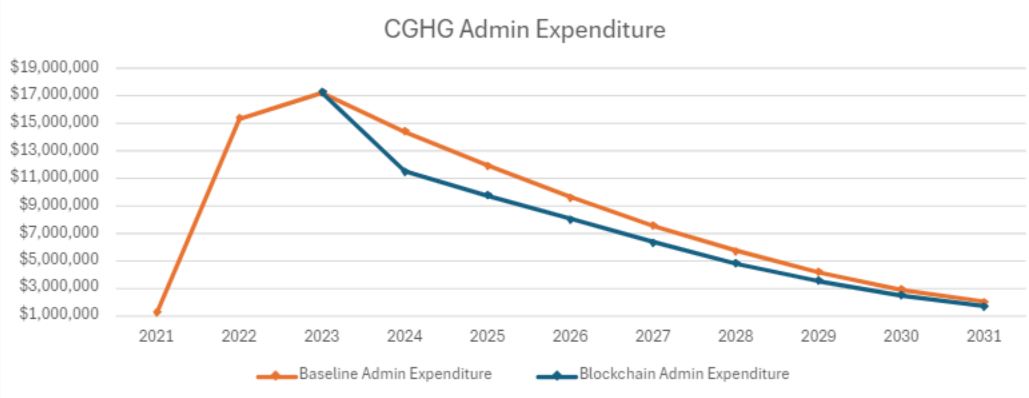


Figure 7. CGHG Admin Expenditure with Blockchain Application CAPEX.

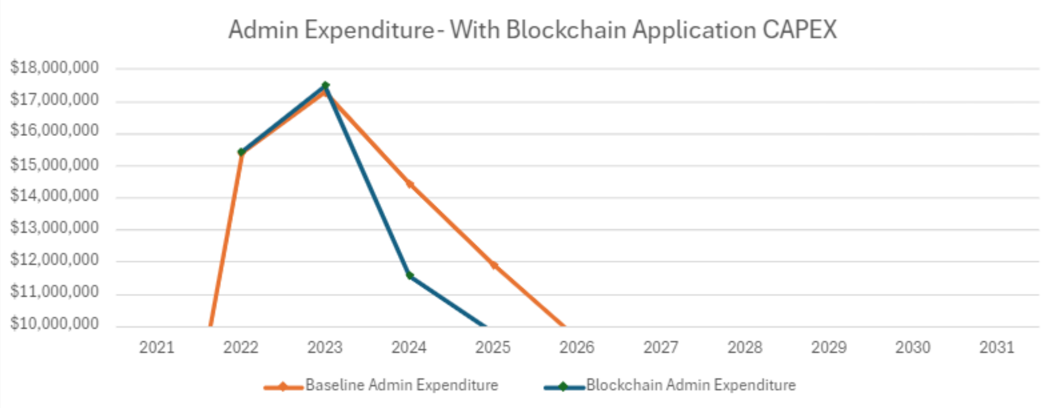


Figure 8. CGHG Admin Expenditure with Blockchain Training Costs.

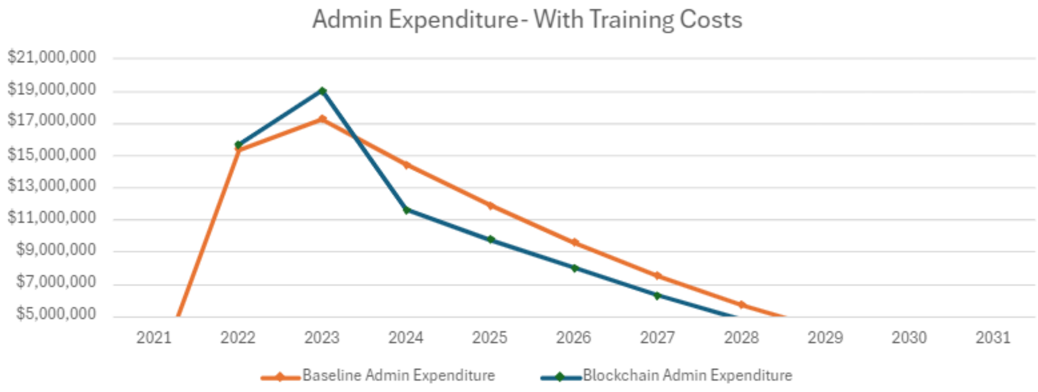
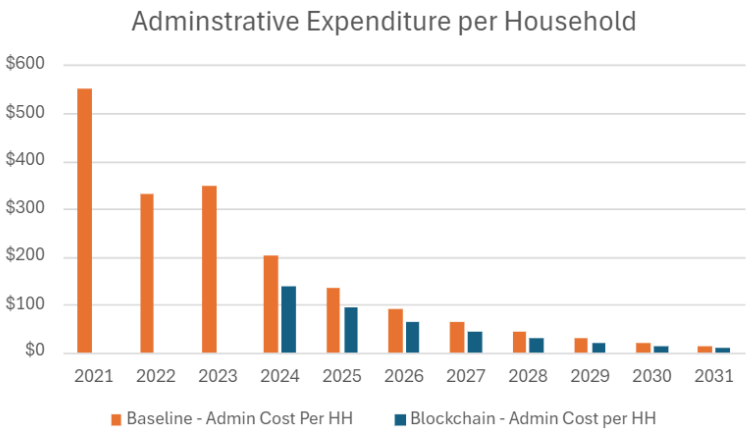


Figure 9. Administrative Expenditure per Household



Appendix D: Recommendation to the Minister

MEMORANDUM TO THE MINISTER OF NATURAL RESOURCES CANADA

Subject: Enhancing the Canada Greener Homes Grant program through blockchain integration.

FOR DECISION

SUMMARY

The purpose of this briefing note is to provide you with a policy recommendation based on a recent study analyzing the economic efficiency of integrating blockchain technology into the Canada Greener Homes Grant program. The findings indicate that blockchain integration can significantly enhance the program's operational efficiency, reduce administrative costs, and improve the overall economic viability of the program. This recommendation seeks to leverage these insights to optimize the Canada Greener Homes Grant program for better sustainability outcomes.

BACKGROUND:

The Canada Greener Homes Grant was designed to encourage homeowners to undertake energy-efficient retrofits by providing financial incentives. The program has been instrumental in promoting energy bill savings and reducing greenhouse gas emissions across Canada to date. However, the current system incurs substantial administrative costs and faces operational inefficiencies. A recent study was conducted to evaluate the potential benefits of integrating blockchain technology into the program. The study compared the current system's baseline scenario with the blockchain-enhanced scenario, focusing on key metrics such as funds disbursed, household participation, energy bill savings, pollution savings, and administrative expenditure.

ANALYSIS AND FINDINGS:

1. <u>Economic Efficiency:</u> The blockchain scenario demonstrated substantially higher total funds disbursed compared to the baseline scenario. This increase in funds was achieved at a significantly lower administrative cost, indicating a more efficient allocation of resources. The CBR under the blockchain scenario, although not reaching one, was consistently higher than that of the baseline scenario post-2024, indicating a more favorable cost-benefit outlook.
2. <u>Operational Efficiency:</u> The integration of blockchain technology can streamline administrative processes, reduce processing times, and improve overall user experience. Smart contracts can automate transactions and ensure transparency, reducing the risk of fraud and errors.
3. <u>Implications for Homeowners:</u> Homeowners would benefit from faster processing of applications and disbursement of funds, reducing wait times and making the program more accessible and attractive.
4. <u>Broader Economic Implication:</u> The adoption of blockchain technology could stimulate the clean technology market, drive innovation and create new job opportunities, contributing to economic growth and sustainability.

COMMUNICATIONS IMPLICATIONS:

Blockchain technology for the Canada Greener Homes Grant Program will position Natural Resources Canada as a leader in leveraging innovative technologies for sustainable development. Clear communication of the benefits and improvements brought about this integration will be essential to gain public and stakeholder support.

NEXT STEPS:

1. <u>Pilot Implementation:</u> Conduct a pilot program to integrate blockchain technology into the Canada Greener Homes Grant program, focusing on a select group of applicants to test the effectiveness of the system and address any implementation challenges.
2. <u>Comprehensive Evaluation:</u> Perform a comprehensive evaluation of the pilot program to measure its impact on operational efficiency, cost saving, and homeowner satisfaction.
3. <u>Policy Development:</u> Develop policies and guidelines for the full-scale implementation of blockchain technology into the Canada Greener Homes Grant program based on the findings from the pilot evaluation.
4. <u>Stakeholder Engagement:</u> Engage with stakeholders, including homeowners, energy advisors, and clean technology manufacturers and distributors to gather feedback and ensure a smooth transition to the new system.

RECOMMENDATION:

It is recommended that Natural Resources Canada proceeds with a pilot implementation of blockchain technology into the Canada Greener Home Grant program, followed by a comprehensive evaluation and full-scale rollout based on the pilot success. This approach will optimize the program's efficiency, reduce administrative costs, and enhance the overall economic viability of the program, contributing to Canada’s Sustainable Development Goals.

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