A feasibility analysis of transactive energy systems in Ontario

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Foreword

This section describes the nature and role of the research presented in this paper in fulfilling the requirements of the Master of Environmental Studies degree. My Area of Concentration focuses on learning about different implementation strategies and programs for sustainable energy across the globe, and comparing these to the systems in place in key Canadian provinces when it comes to the energy sector, specifically Ontario. My research topic is linked to this by applying an innovative and modern sustainable energy project, a blockchain-enabled microgrid that utilizes smart contracts and works on the concept of transactive energy, that has been implemented in various jurisdictions around the world to the Ontario context.

The Major Paper allows me to combine my learning objectives, stated as energy and climate change, sustainable energy policy, and markets for new energy systems and technologies by assessing the requirements needed for a socio-technical transition in Ontario's energy sector towards an electricity system that includes distributed energy resources (DERs) by way of transactive energy systems.

The first learning component, energy and climate change, is satisfied by the Major Paper by its focus on leveraging an innovative energy technology as a solution for climate change. The paper explores what types of energy solutions exist for climate change, the depth and severity of climate change as a pressure-exerting threat to Ontario, and how transactive energy can be applied to combat this pressure.

The second learning component, sustainable energy policy, is satisfied by the political lens in which the Major Paper is written. Much of the paper is spent detailing the socio-political context in Ontario as it relates to the energy sector and how transactive energy can fit into this paradigm.

The final learning component, markets for new energy systems and technologies, is satisfied by the nature of the technology being considered in the paper. Transactive energy systems are by definition a new energy technology. The Major Paper’s consideration of existing business cases that use transactive energy systems and its exploration of the private sector impacts of the socio-technical transition in question meet the requirements for this learning component.

Abstract

This research paper explores the potential for transactive energy systems (TESs) and blockchain-enabled microgrids (BEMs) to be integrated into Ontario's existing electrical grid as a sustainable energy solution for climate change, while also delivering economic and reliability benefits to consumers and other stakeholders. The multi-layer perspective (MLP) framework is applied to assess whether or not a socio-technical transition is possible and/or likely in Ontario, and how this transition might occur. These questions are answered by relying primarily on industry and academic literature in the form of technical whitepapers, academic journal articles and theses. Several case studies are also presented to show how TESs and BEMs have been integrated into existing grids in a variety of jurisdictions around the world. Areas of future research are presented following the case studies to highlight important yet unexplored topics concerning TESs in Ontario. The paper concludes that the blockchain component of BEMs is unnecessary, given Ontario's incompatible cultural and political context with the technology's value proposition. However, the paper finds that TESs are likely to be adopted in Ontario, and in some cases, they already have been to a limited extent, as can be seen in the cases of Alectra Utilities and Opus One Solutions. This adoption of TESs in the province is considered to be the beginning of the reconfiguration path transitional pathway, as identified in the MLP literature.

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Definitions

- **Consumer credit risk** – the risk of energy consumers defaulting on their electricity bills
- **Crypto-currency** – a type of digital currency that is usually enabled using blockchain technology and operates independent of a centralized bank or governing body.
- **Energy intensity** – the amount of energy consumed per person or per dollar of economic output
- **Fiat currency** – currency whose value is derived by a government, and is not tied to any physical commodity. Traditional paper currencies (such as CAD or USD) are fiat currencies. This term is often used when discussing cryptocurrencies to differentiate between what is considered traditional currency and cryptocurrency when one is being exchanged for the other.
- **Microgrid** – a collection of interconnected buildings with their own energy generation capacity allowing them to operate as a small energy network. Usually includes small-scale energy generation technologies, an energy storage facility of some sort, and a small-scale distribution network connecting all of the participating buildings.
- **Peer-to-peer energy transaction** – an exchange of energy for some sort of currency occurring between two individuals, at least one of which having some sort of energy generating capacity.
- **Prosumer** – an energy consumer that also has the ability to produce energy.
- **Renewable energy** – energy that is generated without consuming depletable fuel sources. Instead, only fuel sources that are entirely regenerative or are infinitely available can be used, such as sunlight, wind, ocean tides, biomass, and more.
- **Sustainable energy** – *See pages 16 & 17 for the full definition*

Acronyms

- **BEM** – blockchain-enabled microgrid
- **CC** – climate change
- **CCAP** – Climate Change Action Plan
- **CO_2-eq** – carbon dioxide equivalent
- **DER** – distributed energy resource
- **DSO** – distribution system operator (synonymous with ‘utility’ and ‘LDC’)
- **EE** – energy efficiency
- **ETNO** – Electricity Transformation Network of Ontario
- **EVIP & EHVIP** – Electric Vehicle Incentive Program & Elective and Hydrogen Vehicle Incentive Program
- **FIT** – feed-in tariff
- **GEA** – Ontario Green Energy and Green Economy Act
- **IESO** – Independent Electricity System Operator
- **IoT** – internet of things
- **LDC** – local distribution company (synonymous with ‘utility’ and ‘DSO’)
- **MLP** – multi-layer perspective
- **OEB** – Ontario Energy Board
- **O&M** – operations and maintenance
- **OMENDM** – Ontario Ministry of Energy, Northern Development and Mines
- **P2P** – peer-to-peer
- **PC** – Progressive Conservative party of Ontario
- **PV** – photovoltaic (referring to photovoltaic solar modules)

- **RE** – renewable energy
- **REC** – renewable energy certificate
- **TES** – transactive energy system
- **TSO** – transmission system operator

Introduction

Ontario and the global climate crisis

The global climate crisis is becoming a topic of increasing public salience. Since over 155 countries pledged to act to reduce greenhouse gas (GHG) emissions to limit global warming to a 2-degree Celsius maximum increase relative to a pre-industrial baseline via the 2015 Paris Agreement, corporations and governments are beginning to be held accountable for their carbon footprints (United Nations Framework Convention on Climate Change, n.d.). This accord was signed and ratified by Prime Minister Trudeau's government in one of his first major acts as Prime Minister of Canada. Following this pledge, the Canadian federal government began working on country-wide programs to reduce national GHG emissions levels, including but not limited to the Federal Carbon Tax, which recently came into effect in Ontario, renewable energy (RE) incentive programs, and a push for the development of energy efficiency (EE).

These energy-focused policies coincided with many Ontario policies and programs, including the GreenON EE retrofit financing program, the Electric and Hydrogen Vehicle Incentive Program (EHVIP), continued financing of RE (mainly solar PV and wind) projects through feed-in tariff (FIT) contracts, a renewed RE financing model that replaced the FIT program known as Net Metering, Smart Meter installations across the province, and more. These initiatives, while celebrated by some, were also seen as poor allocations of public funds by critics of the sustainability movement and climate change (CC) deniers. With the election of Ontario Premier Doug Ford in the summer of 2018, all of these programs were terminated.

In Ontario, issues surrounding energy are a contentious topic, and the problem of rising electricity bills was at the core of all major campaigns in the June 2018 provincial election. The

Liberal party's inability to provide the public with a confident and reliable plan to lower hydro rates provided the Progressive Conservatives (PC) with a substantial weakness to leverage. Keeping with typical PC mantra, Ontario's current government values economic growth, usually by embracing traditional business operations for the province, above all else. This approach to economic development partially explains the continued investment in the Darlington nuclear plant refurbishment (although this refurbishment was announced under the previous Liberal government of Kathleen Wynne). This approach, however, potentially leaves room for disruptive technologies to emerge within Ontario's energy sector, if these technologies can be proven to promise economic growth and save Ontarians money on their energy bills while meeting all of the requirements that the current energy regime does.

Transactive energy systems as a possible solution

One such disruptive technology is the transactive energy system (TES). A transactive energy system can be understood as an energy system whose members can both produce and consume energy, and who can trade energy amongst themselves to share one member's excess production with other members of the system. There are various examples of such systems being implemented around the world in a variety of forms, be it electricity-based or heating-based. This paper focuses on the electrical TES, more specifically the blockchain-enabled microgrid (BEM) form of a TES.

A BEM is a TES that employs blockchain technology to facilitate the transaction piece of the TES's operation. Recent advances in the IT sector, including disruptive technologies such as artificial intelligence (AI), internet of things (IoT), machine learning (ML), and blockchain, have led corporations and governments across the globe to recognize the inevitability and importance of embracing and encouraging the development of the tech. Southern Ontario, in particular, has become a hotbed for IT start-ups, with many tech-based companies coming from the Toronto-Waterloo Corridor. One such company, Opus One Solutions Energy Corporation, based out of Toronto, has identified the need for transactive mechanisms and distributed energy resources (DERs) to play a part in the changing energy landscape. They note the traditional energy system structure of bulk power systems being planned and operated on the principles of dynamically balancing supply and demand and using economic value (dollars) as a key parameter in doing so. This is contrasted with the distribution system's traditional planning being dictated by physical (geographic) and long-term financial (such as long-term payback time) parameters, and the traditional operations being dictated by physical parameters. This paradigm is shifting due to the increasing adoption of DERs, making transactive mechanisms an appealing solution for more integrated planning and operations of the evolving energy system (Opus One Solutions Energy Corporation, 2016).

Blockchain-enabled microgrids could provide a scalable, sustainable solution to the troublesome problem of electricity affordability in Ontario. This solution would come in the form of the increased adoption of DERs and RE by way of BEM integration into Ontario's grid. Such a project could: make electricity more affordable in Ontario, provide consumers with greater energy autonomy, reduce the amount of tax dollars spent on nuclear refurbishments, increase overall EE in Ontario, improve grid resilience and flexibility by diversifying electricity generation, help establish a culture of conservation in the province, and create new economic development in the burgeoning technology sector in the province (Gass, Echeverría & Asadollahi; 2017). However, blockchain-enabled microgrids come with a few caveats: a transition from central to distributed energy generation, obvious advantages for those living in densely-populated areas and urban centers, and potentially high capital costs.

This paper assesses the potential for a socio-technical transition in Ontario's energy sector to integrate transactive energy systems into its electricity system. It explores the province's political, economic, and social landscape to understand if transactive energy systems could contextually fit as a solution for electricity affordability and energy sector sustainability in the province. This analysis also involves a deep-dive into blockchain's applications in the energy sector, including a discussion on whether or not blockchain is necessary for the successful integration of TESs into the Ontario grid, and an exploration of the added value that blockchain brings to a TES. The analysis is conducted by considering several case studies of TESs and BEMs from around the world to apply a lessons-learned approach. The information that is gathered is viewed using the multi-layer perspective (MLP) framework, which explores the state of sociotechnical landscape pressures, institutional regimes, and niche innovations to uncover whether or not regime disruption is likely, and to envision how said disruption could be expected to occur.

Methods & background materials

Before assessing TESs' feasibility in Ontario's electricity sector, some context must be established. This section of the paper begins by presenting the ontological and epistemological approaches used throughout the research and writing of this report. What follows is a thorough explanation of the MLP framework and its application in this paper. The proceeding sub-section defines and explains some technical terms, such as blockchain, TES, BEM, sustainable energy, and more. Finally, an explanation of the research methods is presented in the closing sub-section.

Theories of science

The ontological and epistemological approaches for any research project can be understood as the pre-existing assumptions about knowledge, truth, and the processes for uncovering knowledge and truth that a researcher brings with themselves to the project. In layman's terms, they could be taken to be the bias that a researcher brings to their project, despite any attempts, no matter how extensive, made to reduce bias in the name of objective, academic research. Where ontology refers to what an individual accepts to be knowledge and truth, epistemology refers to what methods said individual considers to be acceptable means for establishing knowledge and truth. These are important to consider, as there is countless academic literature that exists where one report comes to a conclusion that is in direct conflict and opposition to another report, yet both reports claim to be completely objective and empirical.

This conflict can be seen with climate change deniers, who are founded in their beliefs due to a (comparatively small) minority of scientists around the world who present alternative scientific explanations for the global shifts in climate that are being observed. While the vast majority of scientists explain these occurrences with CC, global warming, and other anthropocentric causes, some exist who offer other explanations, such as the world simply going through yet another warm age, to be followed by another ice age. Regardless of how small the minority of climate change denying science is, it deserves to be acknowledged if only to be omitted from this report.

With this in mind, the ontological approach of this report could be summarized as the traditional natural sciences ontology, meaning that what is accepted as fact by the majority of the global natural sciences community is also accepted as fact by this report, with the following two distinctions:

- Climate change exists and is a real threat to the future of life on Earth.
- There is an approaching planetary deadline to limit global warming to 2 degrees Celsius by 2050. Failure to meet this goal will result in irreversible, catastrophic changes to the global climate system.
    - This distinction should be taken with a grain of salt, as it could be argued that irreversible, catastrophic changes to the global climate system have already begun.

The epistemological approach used throughout the writing of this report also aligns with the majority of the global natural sciences community, meaning that the methods and justifications used to conclude that CC and global warming are real and present are accepted by this report to be sound. It is important, here, to note that this paper is assessing a *socio-technical* transition, which necessarily implies that social as well as technological factors must be considered in the understanding of solutions for the problems being faced by Ontario’s energy sector. For example, if one was to consider the high levels of carbon emissions from the transportation sector to be a problem, then a technological solution could be to replace the internal combustion engine vehicle with a less emissive alternative, perhaps a hydrogen fuel-cell vehicle. A social solution for this problem could be to have less single-occupancy commutes by implementing carpooling as a fix, or perhaps to encourage commuters to live closer to their places of work to negate the need for commuting by an internal combustion engine vehicle. The difference between these two types of solutions is of some consequence, as new technologies often incur high capital costs, and social changes often encounter strong opposition from those who find stability and security in the status quo. The solution of TESs and BEMs for Ontario's energy sector-related problems is both a social and technological solution, in that it encourages a social shift towards decentralization and it promotes the adoption of new technologies in the form of RE and blockchain. The barriers to adopting both types of solutions are explored in later sections of this paper.

Theoretical approach

The MLP framework presents three levels of analytical concepts, the "sociotechnical landscape", "sociotechnical regime", and "technological niche" (Geels & Schot, 2007).

- *Technological niche* – The technological niche level acts as an "incubation room" for new technological innovations to be nurtured by a small group of actors, usually entrepreneurs or engineers. These innovations are often in the early stages of development and are on the cusp of being market-ready. In the niche level, such innovations are protected from the selection process of the mainstream market, allowing them to develop in a safe environment, however, this also shields them from mass adoption. Changes in the niche level usually occur on a short time scale. In the energy sector, TESs and BEMs could be considered as niche-innovations.
- *Sociotechnical regime* – The socio-technical regime can be understood as the status quo or the institutional norms of a given sector or industry. It is a broader level than the

technological niche level, encompassing the technologies, behaviours, policies, rules & regulations, systems and actors of the current market. It is stable in that it is predictable and well-understood by industry professionals; however, this stability is also a form of inertia that resists the adoption of niche-innovations if no external pressure is applied to the regime. Changes in the regime level usually occur on a medium time-scale, if they happen at all (a matter of years, but usually only when initiated by external pressures). In the energy sector, the existing regulatory institution set by the Ontario Ministry of Energy, Northern Development and Mines, along with its associated actors could broadly be considered as the sociotechnical regime.

- *Sociotechnical landscape* – The sociotechnical landscape is represented by the environment that surrounds the technological niche and sociotechnical regime levels, and it operates outside of their influence. The landscape level is much broader than either of the other two levels, as such it can act as an external pressure that, when applied to the regime level, can create an opportunity for niche-innovations to break into the mainstream market. Changes at the landscape level occur on a much slower timescale than the other two levels, on the order of decades as opposed to years. In the energy sector, climate change and the demand for less environmentally-harmful energy production could be considered as landscape pressures.

These levels can interact with each other to result in different types of sociotechnical transitions. The multi-level interactions can occur in either a reinforcing or a disruptive manner. Reinforcing interactions do not drive transitions as they occur when the sociotechnical landscape supports the regime. Alternatively, when the sociotechnical landscape applies pressure on the socio-technical regime, an opportunity for the technological niche-innovation to disrupt the institutional norm by being adopted in some way by the socio-technical regime is created. These disruptions are known as “transitions pathways”, and they describe the different ways in which the niche-innovation disrupts the regime, and to what degree it is adopted. The following are the four pathways as defined by Geels & Schot (2007), based on the timing and nature of the multi-level interactions:

- *Transformation path* – this pathway involves moderate landscape pressures (‘disruptive change’) and under-developed niche-innovations. The landscape pressures exerted on the regime are enough to incite a push for change from regime actors, however, niche-innovations are not developed to the point of getting adopted. Thus, regime actors react by modifying and reorienting their developmental activities. This path results in new regimes eventually being borne out of old ones due to slow adjustments in regime networks, although the regime structure remains unchanged and many regime actors withstand the transition.
- *De-alignment and re-alignment path* – this pathway is marked by a sudden, strong landscape pressure (‘avalanche change') that causes a lack of trust in the regime on the part of regime actors. This sudden lack of trust leads to the de-alignment of the regime, and an opening for niche-innovations to flourish. However, just as the transformation path, there are no adequately-developed niche-innovations to be adopted. This results in a prolonged period of experimentation on, development of, and competition between several niche-innovations to try to replace the eroded regime, after which one niche eventually is adopted and the regime is re-aligned around this innovation.
- *Technological substitution path* – when significant (though not necessarily sudden) landscape pressures are exerted on the regime, but now the niche-innovations are market-

ready, then technological substitution occurs. Sufficiently-developed niches, an entrenched regime, and sudden, strong landscape pressures characterize this pathway. When the landscape exerts pressure on the regime, regime actors resist the adoption of the niche-innovation. The result of this pathway is the replacement of the current regime technology with the new niche-innovation technology. The resistance of regime actors ends with their replacement as well, meaning that this pathway is also characterized by significant changes to the regime beyond just the technological substitution itself – regime actors and institutions are replaced as well.

- *Reconfiguration path* – this pathway is marked by a lack of resistance to niche-innovation adoption by the regime. This willingness to adopt results in innovative technologies being absorbed into the current regime, with no initial disruption occurring. Geels & Schot note that this is similar to the transformation path in that regime actors remain unchanged; however, it differs in that the adoption of these innovations leads to fundamental changes in regime architecture. The niche-innovations spur a reconfiguration of the regime by regime actors who explore the possibilities of the newly-adopted technologies. This is a deeper and more substantial change than the transformation path.

Later sections of this paper identify the landscape pressures, institutional regimes, and niche-innovations present in Ontario's energy sector and the case for BEM adoption in the province. The likely transitional pathways that could be followed are then described and justified.

Technical context

This sub-section explores the technical concepts of sustainable energy and blockchain used in this paper to provide context to the problems and solutions proposed throughout. Straightforward definitions for these terms and others (i.e. microgrid, TES, BEM, RE, etc.) are provided in the Definitions and Acronyms sub-sections at the beginning of this paper.

Sustainable energy

Adapting the definition of sustainability given in the Brundtland Report to apply to energy, 'sustainable energy' can be defined as energy production that meets the demand of the present without compromising future generations' abilities to meet their own energy needs (Brundtland and World Commission on Environment and Development, 1987). This interpretation means that today's energy generation methods cannot take away from future generations' abilities to produce their energy, which implies that the environment must be preserved and that natural resources must be sustained. This definition can be expanded by including the requirements for a sustainable energy system as they are outlined by Jaccard (2005). The two requirements taken from Jaccard's definition include:

1) *A sustainable energy system must have good prospects for enduring indefinitely in terms of the type and level of energy services it provides.*

2) *The extraction, transformation, transport, and consumption of energy must be benign to people and ecosystems. (Jaccard, 2005)*

Winfield's chapter in Gibson's (2017) book on sustainability assessment extends the definition of sustainable energy further by highlighting that Jaccard's definition of a sustainable energy system focuses on socio-ecological integrity, economic efficiency, and avoidance of path dependence and geopolitical risk in energy sources (Gibson, 2017). This is contrasted with Gibson et al.'s (2005) approach to sustainable energy, where a focus on distributional justice and democratic governance is applied. Winfield's emphasis on avoidance of path dependence is an important consideration when defining sustainable energy because a major reason for the planet's current energy paradigm being so heavily entrenched in the use of fossil fuels is path dependence. Path dependence can be understood in this context as present-day energy system decisions being dependent on energy system decisions made in the past, thus limiting future decisions to a certain path that was determined before these decisions became relevant or important.

The energy system in Ontario is highly reliant on nuclear fission generation, and it is a completely centralized grid. Choices such as making long-term investments into the commissioning and refurbishing of nuclear power plants have affected how modern-day decisions about the future of Ontario's grid have been made. A grid that relies less on centralized generation and more on DERs would be more flexible and responsive to either anticipated or unforeseen challenges and changes in the energy sector. This flexibility can apply to more than environmental and economic challenges. It can also apply to socio-political and physical challenges such as dramatic shifts in government support for certain energy generation methods or sudden loss of natural resources that supply the current energy paradigm. This understanding satisfies the precautionary elements of both Gibson and Jaccard's definitions for sustainable energy, including catastrophic event risk avoidance, democratic governance, and geopolitical risk avoidance. All of these considerations inform the following definition of 'sustainable energy' for this paper:

A 'sustainable energy' technology refers to a technology that satisfies the following criteria:

- *The generation and consumption of energy is done in such a way as to be benign to people and to the environments within which the energy was generated & consumed*

- *The longevity of the energy system is infinite, meaning that the methods of energy generation and consumption must be likely to either endure indefinitely or be adaptable to new economic or environmental challenges without sacrificing the quality of energy services being provided*

- *The technology makes energy accessible and democratically available to all members of its society.*

This definition highlights how important creating a culture of conservation is to ensure that energy resources are not depleted to such low levels that future generations are put at risk. Present-day renewable energy generation technologies, such as solar photovoltaic cells, wind turbines, and hydro dams mostly fit this definition in that they enable the current generation's energy needs to be met without the overconsumption of natural resources. This definition also allows for the development of DERs (of which both solar PV and small-scale wind turbines are great examples) as a means for establishing a long-lasting energy system.

Blockchain

There are a lot of misconceptions surrounding the term ‘blockchain’ that have led to several incorrect interpretations of the word. Many of these misconceptions are derived from the common tendency to equate ‘blockchain’ with ‘crypto-currency’, or perhaps more accurately, ‘Bitcoin’. One analogy can help to clarify the distinction between the terms: blockchain is a founding technology in much the same way as the internet is a founding technology upon which many applications are based, whereas crypto-currencies (one of which being Bitcoin) are mere applications of blockchain tech, similar to how Facebook or Google are websites based on the technology of the internet. In other words, blockchain is to Bitcoin what tissue is to Kleenex.

Blockchain is, for all intents and purposes, a digital ledger. The technology differs from a traditional ledger in its unique characteristics, namely that it is: decentralized, distributed, secured, and transparent. It is made decentralized and distributed by existing digitally online, meaning that any information stored on a blockchain is stored simultaneously at several sites. This distribution makes the information more secure, as it exists at multiple sources at once, as opposed to traditional ledgers where copies would be made and distributed in a time-consuming manner between participants. The security of blockchain also exists in the encryption of the information – while data is stored in a completely transparent manner, it is encrypted in such a way that only participants can access the data, and any additions or changes made to the data must follow a strict protocol called a consensus. Consensus refers to all participants in the blockchain (or perhaps a majority, depending on the structure of the blockchain) being required to agree to alter the information stored on the blockchain before changes are made. Another crucial security factor is the immutable nature of the ‘blocks' that make up the blockchain. For new entries to be stored on the blockchain, they must build upon previous entries in the system which themselves cannot be modified. This transparency, security, and distribution results in participants being able to confidently store their information in a decentralized system without having to trust each other.

This last point, that of trusting other participants, is where the true value of blockchain rests. The common example used to demonstrate the benefits brought on by blockchain is the financial sector, where there are many actors (customers/clients, banks, insurers, regulators, auditors, governments, etc.) who are involved in a large system and must share information, however they do not all necessarily trust each other's records. So, the traditional model follows that each participant keeps copies of information and constantly cross-checks their information with the other participants'. With a blockchain, however, the participants do not need to trust each other, because the information is not stored with any one member, rather it is simultaneously held by all members, and no changes or additions to the information can be made without the consent of all members of the network.

One final remark about blockchain is the variety of ways in which it can be structured. Blockchains can exist in many configurations which dictate which users can interact with the information stored on the blockchain, how they can interact with it, and how consensus is established. These different types of blockchains are called *public blockchains*, *consortium blockchains*, and *private blockchains*. They can be described as follows:

- *Public blockchains* – a blockchain network in which anyone can join and participate in establishing a consensus. This type of blockchain architecture is fully decentralized, however it is inefficient because as the number of users participating in the network increases, the computational demand also increases.
- *Private blockchains* – a blockchain network in which a governing user decides on what users can be allowed to join the network and how consensus is established. While the users that are a part of the network benefit from having access to transparent, immutable information, this architecture is quite similar to a traditional (i.e. non-blockchain) system that operates using a centralized authoritative figure to make executive decisions for the

network, thus largely negating one of the key values brought on by blockchain: decentralization.

- *Consortium blockchains* – a sort of combination between a public and private blockchain, this architecture is characterized by a group of users acting as a governing body for the entire network, and these users must come to their own consensus before making network-wide decisions. This allows for partial decentralization while minimizing efficiency losses when user numbers increase.

It follows that blockchain is only an attractive solution for industries in which actors are forced to interact with each other by sharing information but they do not trust each other. Not all industries fit this description, and the socio-political contexts surrounding each industry can have drastic effects on whether or not its members trust each other. Ontario's energy sector is an example of a network of actors who do not necessarily trust each other (this is explored in later sections of this paper). Alternatively, Denmark's energy sector is comprised of actors who largely have faith in one another, and this is in large part due to the Danish culture's general trust in government.

Research methods

This research project relies mostly on qualitative research methods due to the lack of publicly available quantitative data, such as component costs and long-term financial impacts, on BEMs and TESs. A 'lessons learned' approach is used by considering several case studies where TESs, and in some cases where BEMs have been established. The political, economic, and social contexts of each case are assessed to determine which factors were most influential and most heavily impacted by the energy projects. These analyses inform the conclusions drawn for Ontario's context. Professionals in various fields related to TESs, including the blockchain/IT, energy project development, and energy policy spaces are consulted to source expert input on the research topic. Expert insights are also obtained by attending various energy-focused conferences.

The case studies were selected based on the following criteria:

- The company must have projects that operate using transactive mechanisms and/or blockchain technology.
- Sufficient literature beyond press releases must exist detailing the mechanisms employed in the project(s), preferably in the form of technical papers.
- All companies should operate in different jurisdictions with different cultural, economic, political, regulatory, and physical (meaning grid infrastructure, available natural resources, etc.) parameters.
- Each company should employ different TES and/or BEM models to provide a broad perspective on the capabilities of the technologies.

Based on these criteria, the case studies that are considered in this paper are:

1) LO3 Energy
2) Power Ledger
3) Electrify
4) Electron
5) Opus One Solutions

The information for all of these case studies was gathered from technical documents published by the project developers, usually in the form of technical whitepapers. In some cases, such as with the LO3 Energy project, academic sources were available as well. Some information was also obtained by attending conferences and hearing representatives from the companies speak about their operations, as was the case with Opus One Solutions.

The case studies were assessed based on the transactive and blockchain-enabled technologies that they use and how these are used. Quantitative evaluative criteria were not deemed necessary. This is because the aim for including these case studies was not to help in designing a TES or BEM project in Ontario, but rather to help in identifying what applications of TES and/or BEM models could be contextually appropriate for Ontario. One primary goal for the case studies is to determine whether or not the blockchain component of BEMs brings enough added value to the project to warrant its inclusion, as several industry professionals at various conferences have negatively pointed to blockchain's use in the energy sector as unnecessary and simply following a broad technology industry trend.

The evaluative criteria could thus be described as such:

- Firstly, does the project make use of blockchain technology?
    - If yes, how so? What is the added benefit of including blockchain in the project?
    - If not, why? Could adding a blockchain component to the project generate untapped value?
- How does the transactive component of the project bring value to the stakeholders involved? Key stakeholders for this question's purposes include the DSO, consumer, and the project developer.
- What project characteristics are transferable to the Ontario context? Do these reflect improvements that could be made or shortcomings when compared to Ontario's case?

This paper uses information from the case studies to conclude whether or not blockchain is a necessary component of a successful TES. This information is then used to assess whether or not a TES, with or without blockchain, could be successfully integrated into Ontario's electricity system. In this statement, successful integration refers to the project being adopted in Ontario with minimal resistance from the established regime actors, who are defined later in this paper.

Problem analysis

Ontario energy context

Historical and present-day Ontario energy sector

Ontario's sustainable energy history consists of several significant changes made to the energy sector across several decades. To keep this section relevant to the research question being discussed in this paper, only the past decade is explored hereafter; specifically, from the Ontario Green Energy and Green Economy Act (GEA) up until the present day. The GEA, and its rather controversial feed-in tariff (FIT) program provided to the Ontario Progressive Conservative (PC) party with grounds to challenge the then-in-power Liberal party, under the direction of then-Premier Kathleen Wynne, based on claims of overspending public funds. This, along with other factors, played a large role in former Premier Wynne’s defeat in the 2018 provincial election to current Premier Doug Ford, who has made several drastic reductions to the province’s green energy program/policy portfolio. What follows is an explanation of how and why the GEA was introduced, some descriptions of the government policies and programs meant to increase green energy adoption in Ontario under the GEA, an outline of the 2015 Paris Accord commitments made by Ontario, and the subsequent repealing of green energy efforts under the newly-elected PC Ontario government. Understanding this context is crucial to understanding how a disruptive technology, such as TESs, meant to stimulate the green energy sector might be received in Ontario.

The GEA was established in 2009 under the premiership of Premier Dalton McGuinty as a means of promoting renewable energy use in Ontario’s electrical grid (McKitrick & Green, 2013). Ontario was amid an endeavour to phase out coal-powered electricity generation during the time of the adoption of the GEA. Phasing out coal was undertaken as a reaction to the poor air quality within the province. The GEA provided an opportunity to improve air quality while also reducing the province's dependence on fossil fuels for energy (Ontario Ministry of Energy, 2015). The key component of the GEA that attracted the most attention from energy providers and energy consumers was the FIT program which was to be administered by the Independent Electricity System Operator (IESO).

The FIT program was based on a similar program that showed much success in Germany. The program aimed to incentivize renewable energy project installations within the province of Ontario by way of a long-term contract that guaranteed above-market rates for renewable energy generation. This program promised renewable energy developers high rates of return on their project investments for periods that typically ran in the range of 20 years. The aim of the program, along with others under the GEA, was to attract investors to invest in the green energy sector in Ontario and to create jobs as part of a larger provincial goal of developing the broader green sector.

It is important to note that the GEA did not cite reducing electricity costs in Ontario as one of its primary goals. The main goal of the program was mainly to reduce air pollution in the province and to create ‘green jobs' to benefit Ontario's economy. A report from the Ontario Clean Air Alliance (Cundiff, 2015) points out quite clearly that while pricing the solution for improving air quality in Ontario was a factor in deciding how to do so, it took a back seat to the health concerns associated with low-quality air. The GEA placed great importance in improving air quality in Ontario and that it proposed that the FIT program be the flagship for phasing out coal-fired power generation in the province in an economic manner.

Other notable programs introduced in Ontario during the era of the GEA include the Cap & Trade program, the Electric Vehicle Incentive Program and Electric and Hydrogen Vehicle Incentive Program (EVIP & EHVIP, respectively), and GreenON. The Cap & Trade program was introduced in Ontario in 2017. It was meant to help reduce GHG pollution and combat climate change by disincentivizing carbon emissions. Businesses would be financially rewarded by emissions reductions. This program was introduced as Ontario's alternative to the federally-imposed carbon tax, which would serve as a backstop if a province should not launch their own carbon pricing scheme (Government of Ontario, a; n.d.).

In addition to making EVs more affordable, the EVIP was intended to create jobs by increasing the number of EVs that were being manufactured in Ontario (Ontario Ministry of Environment and Climate Change, 2018). The provincial government's goals for the EVIP were to have 5% of all passenger cars either sold or leased be EVs by 2020 (Ontario Ministry of Environment and Climate Change, 2018). The overall goal of Ontario's climate change strategy was to reduce GHG emissions to 80% below 1990 levels by 2050 (Government of Ontario, 2015). To summarize, the major goals of the EVIP were:

- To make EVs more affordable (reduce the capital cost gap between EVs and ICEVs)
- To have 5% of all sold/leased passenger cars in Ontario be EVs.
- To reduce provincial GHG emissions to 80% below 1990 levels by 2050 (CCS goal that can be extended to the EVIP because the EVIP was introduced under the CCS umbrella).
- To develop the EV automotive market in Ontario.

The GreenON rebate program was another incentive program that targeted residential homeowners by rewarding them for energy efficiency retrofits made to their homes. Like the EVIP, it was a part of Ontario's Climate Change Action Plan (CCAP) that was introduced under

Premier Wynne. This, along with the other incentive programs, were all funded by Ontario's Green Investment Fund, which had green job creation and GHG emissions reductions as primary goals. These goals were set to help Ontario reach various targets established at COP21 while also maintaining economic prosperity. (Government of Ontario, b; n.d.; Government of Ontario, c; n.d.)

The Ontario provincial election in the summer of 2018 saw Doug Ford elected as Premier. Several of his first acts as Premier were to roll back funding or cancel green policies and programs, including all of the programs listed previously in this section. As a result, much of the green energy sector expansion that was underway during the time preceding Premier Ford's election has either been stunted or halted altogether. This poses as a barrier for innovation in the green energy sector, as government support for lightly-tested technologies such as TESs is less likely under a premiership that discourages green sector growth. However, some have prospered in this political climate, including Toronto-based energy companies Opus One and Peak Power, and the planned smart city development Sidewalk Toronto. All of these are examples of companies that are implementing TESs, and they are explored in further detail in later sections of this paper. Their existence demonstrates that the political barriers to green sector growth are not insurmountable, meaning that more innovative projects could potentially be launched in Ontario's green energy sector.

In addition to the success of a handful of innovative energy companies in Ontario, a recent announcement from the Progressive Conservative party's federal leader, Andrew Scheer, relating to his climate change plan as part of his party's 2019 federal election platform bodes somewhat well for the smart energy industry. In his announcement, Scheer indicated that he plans on ridding Canada of the federal carbon tax, opting for a financial disincentive tool to coerce the private sector into green tech development. He plans to set an emissions cap for all industries, and once an organization surpasses that cap, they must pay into a fund that will be used to finance green tech development (Tasker, 2019). Scheer stated that this is a better tool for tackling climate change because it helps spur the growth of the Canadian cleantech sector. While the announcement was lacking in details, especially specific examples of what these emissions caps might be set to, it does represent the recognition from the PC party of the opportunities for cleantech growth and the urgency of climate change action. It should be noted that Scheer does not speak for Premier Ford. However, with the two being members of the same political party, cooperation and support from Ford in this endeavour is not wholly unimaginable, which could mean that a similar program might be born out of Ford's premiership regardless of the federal election results.

Ontario energy sector in MLP terms

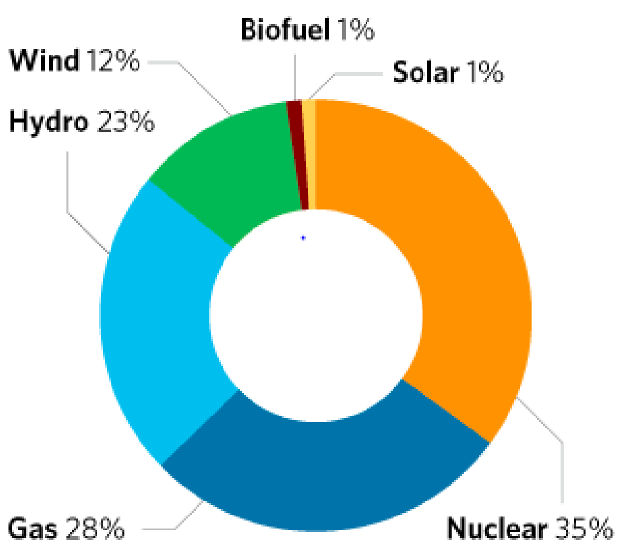
As was previously identified in this paper, the energy sector in Ontario has socio-technical landscapes, regimes, and niches that exist within it. This subsection serves to explicitly identify and flesh out each of these components to allow for the socio-technical transition analysis to be completed. The crucial level that must be carefully defined when assessing socio-technical transitions using the MLP framework is the regime level. This is because the transition is in effect the changing of the regime level. So, this explicitly defines the Ontario energy sector actors that make up the socio-technical regime, followed by a definition of the socio-technical niche that is spurring change at the regime level and the socio-technical landscape that is applying pressure on the regime.

Socio-technical regime in Ontario

All of the regime actors in Ontario's electricity sector are described below. Following the description of these actors is a description of climate change and how it relates to the policy and regulatory regime in Ontario, and more broadly to the regime in Canada.

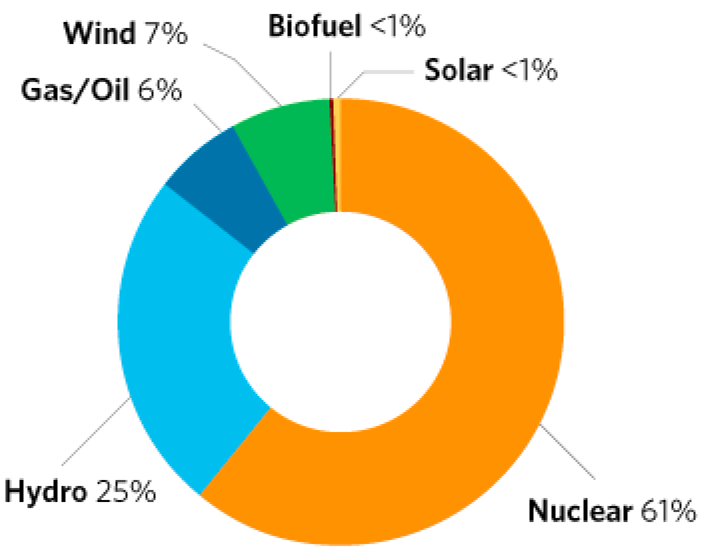
Electricity generators

Electricity generators produce electricity through various methods. In Ontario, the majority of electricity is generated using nuclear fission, with hydro-electric power following in terms of percentage of the provincial capacity's production. Although nuclear only accounts for about a third of the installed electrical capacity of the province, it outputs over 60% of the electricity consumed in Ontario (see Figure 1 & Figure 2).



Nuclear	13,009 MW or 35%
Gas/Oil	10,277 MW or 28%
Hydro	8,499 MW or 23%
Wind	4,486 MW or 12%
Biofuel	295 MW or 1%
Solar	424 MW or 1%

Figure 1: Ontario 2019 installed capacity by generation type. (Independent Electricity System Operator, n.d.)



Nuclear	90.1 TWh or 61%
Hydro	36.2 TWh or 25%
Gas/Oil	9.6 TWh or 6%
Wind	10.7 TWh or 7%
Biofuel	0.4 TWh or <1%
Solar	0.6 TWh or <1%

Figure 2: Ontario 2016-2018 average annual energy output by generation type. (Independent Electricity System Operator, n.d.)

Electricity transmitters

Electricity transmitters operate the transmission grid in Ontario. Transmission is differentiated from distribution by the nodes between which the electricity is being transported. Transporting electricity from its point of generation to the LDCs is referred to as electricity transmission. This type of transportation of electricity is done using high-voltage power lines due to the dangerously high levels of voltage present during transmission, hence the need for LDCs to reduce the voltage at the distribution level. It is important to note the distinction between the transmitters that *own and operate* the transmission grid and the IESO that *manages and directs the flow of electricity* on the transmission grid (see more on the IESO below).

Energy retailers

Ontarians have the option of either purchasing their energy (electricity or gas) from the utility that presides over the region in which they live, or signing a contract with a private company that sells energy, known as an energy retailer.

Independent Electricity System Operator (IESO)

The IESO is responsible for managing the transmission of electricity in Ontario. As stated above, electricity transmission occurs between the generator and the utility, however, some large industrial consumers of electricity also have direct connections to the transmission grid. The transmission of electricity falls under the domain of the Transmission System Operator (TSO), which is the IESO in Ontario.

Ontario Energy Board (OEB)

The OEB is the regulator of the energy sector in Ontario. They are responsible for licensing energy retailers, electricity transmitters, the IESO, and LDCs, as well as setting the rates for electricity generation, transmission, and sale.

Ontario Ministry of Energy, Northern Development and Mines (OMENDM)

The OMENDM is the branch of the provincial government of Ontario that is responsible for developing and enforcing policies and programs within the energy sector. The primary tools used to set these policies/programs are laws and regulations.

Utilities/local distribution companies (LDCs)

As was stated above, electricity transmission occurs between the point of generation and the utility. Once the electricity has reached the utility, the voltage is dropped to safer levels so that electricity can be distributed to individual consumers at the household or commercial level. There are many utilities in Ontario, each of which operating with a strictly governed jurisdiction within which they can sell electricity. Consumers do not have a choice over which utility they can purchase electricity from – they can only purchase electricity from the utility that is responsible for the area in which their property is, or they can purchase electricity from an energy retailer.

COP21, and the Pan-Canadian Framework

While climate change can be thought of as a landscape pressure due to its independence from any influence from Ontario – climate change is a global phenomenon that can be contributed to at the regional level, but its effects are not restricted by any borders – the regulatory and political commitments made by the various levels of government in Canada rest firmly within the socio-technical regime level. The federal government announced its intentions for pursuing climate change mitigation action in 2015 with Prime Minister Trudeau's attendance at the COP 21 conference in Paris. Upon returning from the conference and ratifying the terms of the agreement, the Canadian Federal Government formed the Pan-Canadian Framework on Clean Growth and Climate Change. This framework is built on four pillars (Federal Government of Canada, 2016):

- Putting a price on carbon pollution
- Enacting complementary measures to increase emissions reductions across the Canadian economy
- Establishing measures for climate change adaptation and building more resilience across the country
- Accelerating innovation, supporting the cleantech industry, and creating jobs

This framework establishes a nation-wide responsibility for provinces and territories to limit their environmental impact via carbon emissions reductions while fostering economic growth within the cleantech industry. It also represents the acknowledgement by the Canadian government of the reality of climate change and its impacts not only on the global environment but also on the potential for economic growth.

These commitments to act on climate change exert significant pressure on Ontario, and specifically on Ontario's energy sector, by creating requirements for innovation and change within the sector. The Pan-Canadian Framework identified electricity generation as the fourth-largest source of GHG emissions in the country (Federal Government of Canada, 2016). As such, the framework developed an approach to electricity that focuses on increasing the share of renewably-generated electricity in the nation's grid and modernizing electricity systems. These two requirements create an opportunity for TESs and BEMs, being an example of a modern electricity solution built on renewable energy generation.

The federal requirement for a price on carbon has perhaps less of an impact on TES/BEM adoption in Ontario. This is because Ontario's electricity generation is already largely carbon-free, being made up primarily by nuclear fission and hydro-electric generation (National Energy Board, n.d.). The previous Environmental Commissioner of Ontario evaluated the energy use by generation type in the province (including transportation, heating, industrial use, and electricity) and concluded that only 2% of the electricity used in Ontario comes from fossil fuels, and thereby is carbon-emitting (Environmental Commissioner of Ontario, 2019). With such minimal GHG emissions being the result of electricity generation in Ontario, and with the current pushback from the provincial government against the federally-mandated carbon price of $50/metric ton of CO_2-eq emissions, it is unlikely that the carbon price is a significant source of pressure on the Ontario energy regime.

The final pillar of the Pan-Canadian Framework, which aims to boost economic growth by supporting clean tech jobs and accelerating innovation, synchronizes well with TES and BEM adoption in Ontario. Not only are TESs and BEMs innovations that fall neatly into the realm of technologies that the Pan-Canadian Framework seeks to develop, but they also represent the current trend of a growing technology and IT sector in Ontario that promises the creation of jobs in an industry that is also targeted by the Pan-Canadian Framework.

The combination of the reality of climate change and the federally-mandated actions to combat it exert significant pressure on Ontario’s energy regime, regardless of their acknowledgement by the provincial government.

Socio-technical niche in Ontario

As this paper is assessing the potential for TESs and BEMs to advance from the niche level to the regime level, it follows that they are considered to be socio-technical niches. This statement is supported by the fact that they are market-ready technological developments but they have yet to achieve widespread adoption in the energy sector, both within and beyond Ontario’s borders. Because this technology is a relatively new one, it is being nurtured by a small group of actors in the global energy sector. Although these actors are not necessarily directly associated with one another, as they are scattered across the globe, many of them are attempting to differentiate themselves from each other by deploying TESs and BEMs in alternative implementations. This network of diverse project approaches is leading to the rapid advancement of the technology – several of these approaches are explored in the case studies section of this paper. Supporting the development of this niche technology is the advancement of several other related technologies, such as energy storage technologies, renewable energy generation, DERs, blockchain technologies, AI, and more. All of these innovations lay the foundation upon which BEMs and TESs are built.

Socio-technical landscapes in Ontario

As was defined above, the landscape level surrounds the niche and regime levels of the MLP framework, and it operates outside of their influence. The defining feature of the socio-technical landscape is that it exerts external pressure that creates an opportunity for niche-innovations to disrupt the regime. This definition results in the following major pressures that are considered by this paper to act as socio-technical landscapes for the adoption of TESs and BEMs into Ontario's energy system: climate change, Ontario's ongoing economic restructuring, the centralized structure of Ontario's electricity system, and the growing demand for / trend towards energy system decentralization.

Climate change

As was noted above, climate change as a global phenomenon exists beyond the influence of Ontario's socio-technical regime, yet it does exert considerable landscape pressure on Ontario, and all of Canada for that matter. Flood-related damage has been identified as Canada's most costly insurance cost (Intact Centre on Climate Adaptation, 2018). With an increasing number of extreme weather events including floods, wildfires, and droughts occurring across Canada, the need to respond and prevent future catastrophes is growing. While wildfires have largely been limited to the provinces of British Columbia and Alberta, and therefore have no direct effect on Ontario, floods have been a growing concern in Ontario. Ottawa was recently impacted by severe floods throughout the area, leading to blackouts and significant property damage; and Toronto Island was flooded in the summer of 2018 and again in the spring of 2019, leading to an extended closure of the island and resultant revenue loss for the city. These events impress the importance of establishing a resilient electricity system to ensure that blackouts do not occur when floods strike.

Economic restructuring

This landscape pressure highlights Ontario's economic transition away from heavy, energy-intensive industry towards service and knowledge-based activities. Ontario's economy was founded on natural resource extraction and industrial activities. This is perhaps best demonstrated by the layout of the province's capital city, Toronto. Toronto's waterfront is dotted with abandoned or repurposed factories and manufacturing plants which tended to produce large amounts of air pollution. This resulted in residential areas in Toronto being located further north in the city, to be beyond the reach of smog and air pollutants. The city's transition to a service and knowledge-based economy has resulted in less manufacturing operations, causing less air pollution, which in turn has led to condominium and apartment development along the waterfront.

The economic reform in Ontario is well documented. One report from the Neptis Foundation identified Ontario's trend towards a services- and knowledge-based economy as far back as in 2003. This report also highlights the rise of knowledge-based innovations and various sector decentralization (Gertler, 2003). Figure 3 shows that this trend continues to the present day, with the traditionally goods-based economy in Ontario shifting over the past decade to become a services-based economy. The report from which this figure was pulled explicitly states that Ontario is preparing itself for a future economy that is services and knowledge-based (Ontario Ministry of Finance, 2017).

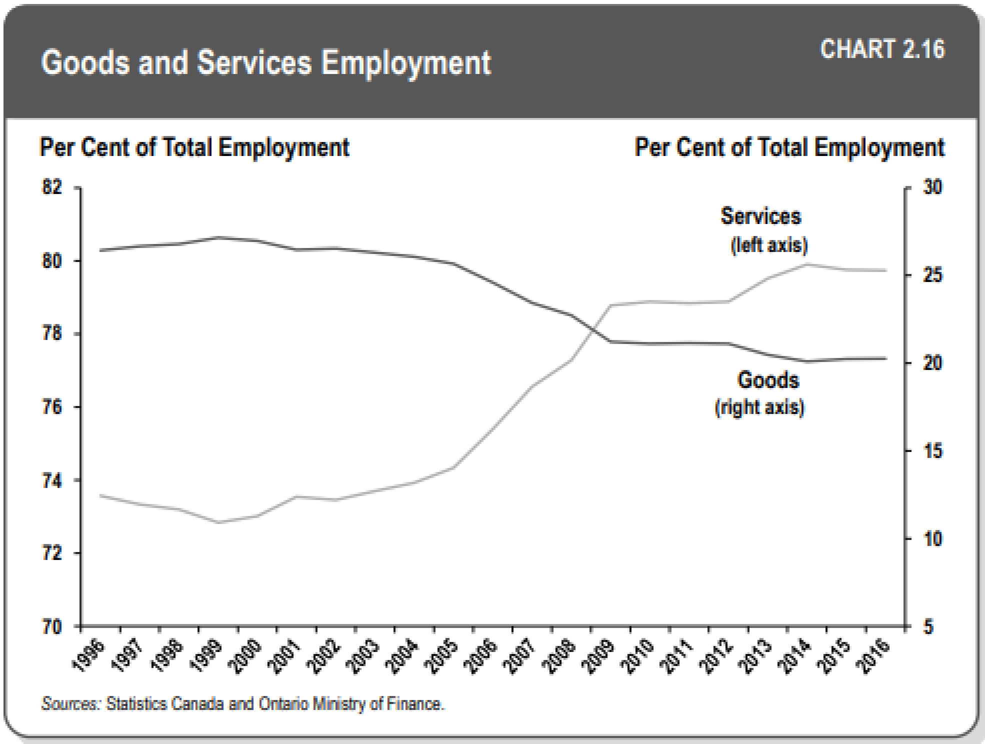


Figure 3: Employment in goods and services sectors - Ontario trends (Ontario Ministry of Finance, 2017)

This paper has already discussed the ongoing IT surge happening in the Toronto-Waterloo corridor which demonstrates how the restructuring of Ontario's economy is creating an environment in which tech companies can thrive. This transformation opens a window of opportunity for innovative technology companies in all sectors, including the energy sector, with particular emphasis on companies whose operations involve electricity generation and distribution. The rise in smart energy technologies such as DERs, RE, smart meters, smart electrical appliances, blockchain, and AI coincides is chipping away at the traditional electricity generation methods and distribution models, exerting pressure on the regime to shift accordingly.

Centralized grid structure

Contrary to the other landscape pressures in this list, the centralized grid structure in Ontario acts as more of a barrier to socio-technical regime change than a pressure to influence change.

Ontario has a highly centralized, hierarchical grid structure, as identified by the IESO, who states that Ontario's current electricity system is structured as a "one-way, top-down" system "dominated by large, centralized generating facilities and electric utilities" (Independent Electricity System Operator; 2018, b). This results in a certain inertia that resists regime disruptions and is difficult to overcome. This is confirmed by the Toronto Region Conservation Authority, who commissioned a report that identified Ontario's centralized grid structure as a barrier to distributed renewable energy adoption in the province (Etcheverry et al., n.d.).

Ontario's grid, as discussed before, is comprised primarily of hydro and nuclear generation. This leads to generation in the province being centralized around these two sources for electricity generation, and around natural gas both for thermal energy generation and for peak electricity generation. The prominence of nuclear generation in the province has established an influential and deep-rooted nuclear lobby in Ontario, while the cheap price for natural gas has created a near monopoly for the technology in thermal energy generation.

At the distribution level, the electricity system is also centralized as consumers don't have a choice for who provides their energy. The province is partitioned into distribution jurisdictions, each of which with their respective default utilities for electricity and thermal energy. Consumers can choose to purchase their energy from an energy retailer, but the default option is always to have the consumer's energy provided by their regional utility. Purchasing energy from a retailer could result in lower energy bills, but this requires agreeing to a fixed price per kWh and the signing of a contract that complicates the process when compared to the default option of purchasing energy from a utility. Compounding this complication is the risk of having energy retailers take advantage of unwitting consumers, which has led to several warnings and regulatory safeguards being put in place by the OEB to protect consumers.e

Even when Ontarians want to remove themselves from the grid, there are substantial regulatory hurdles, permits and paperwork, and grid disconnection fees that must be completed/paid before they can disconnect. This results in Ontarians being trapped, in a sense, into sourcing their electricity from the utility.

The centralized characteristics of Ontario's electricity distribution network and electricity generation counteracts the other landscape pressures detailed in this section. In essence, this pressure supports the existing socio-technical regime by acting as a regulatory barrier to grid decentralization and expanding RE/DER capacities. However, there is another landscape pressure that opposes the stagnation caused by Ontario's centralized grid structure, the growing trend of decentralization and DER adoption, that is explored in the following sub-section.

Decentralization and increased adoption of DERs

Electricity system decentralization is a movement that is gaining traction in grids around the world, including in Canada. The Canadian Electricity Association envisions that the national electricity system will integrate more DERs to become more decentralized by 2050 (Canadian Electricity Association, 2014). This sentiment is shared by key actors in Ontario's energy sector, including the OEB, IESO, and not-for-profits/NGOs. Recall that the OEB and IESO are defined as key players in the socio-technical regime in question in this paper according to the MLP framework.

The increasing adoption of DERs (including EVs) and the tendency of industrial and commercial consumers to depend less on grid electricity and more on electricity that they produce themselves are growing trends that have been identified by the OEB. This has led the OEB to also recognize the inevitability of DER integration into the electricity system (Ontario Energy Board Modernization Review Panel, 2019; Ontario Energy Board, 2017).

The Pembina Foundation, a Canadian NGO whose primary focus is the analysis of energy production/consumption and its resultant impacts on societies and the environment, has also acknowledged the growth of grid decentralization and DERs in Ontario. They consider the trend to be of enough significance to necessitate a response to its growth by grid operators. (Angen & Jeyakumar, 2016)

The IESO reports that it is researching DERs and decentralized grid structures as well. It is doing this in the name of maintaining and improving forecasting capabilities, and to preserve the reliability of the provincial grid. They also recognize the appeal of becoming a prosumer by acknowledging the increasing popularity of consumers making the transition to becoming prosumers by adopting DERs. The IESO ascribes this transition to consumers recognizing that taking advantage of DERs allows them to make more informed choices (Independent Electricity System Operator; 2018, a).

The IESO formed the Ontario Smart Grid Forum in 2009, which included members from utilities, industry associates, not-for-profits, public agencies, academia, and the Ministry of Energy. This forum later changed its name to the Electricity Transformation Network Ontario (ETNO) and has been leading discussions around grid innovation and transformation in the province in an attempt to keep grid operators and electricity system design ahead of upcoming trends. Their most recent publication identified several trends that are not being adequately addressed in Ontario, including: "electric vehicles, smart appliances, stationary energy storage, distributed generation, building energy management systems, microgrids and controllable devices constituting the Internet of Things (IoT)" (Electricity Transformation Network Ontario, 2019). This same document states that growing technological and policy options, including blockchains, transactive energy, and peer-to-peer DER markets, although not yet market-ready, are changing (and potentially facilitating) the "goal of maximizing consumer choice through competition, market access, and open reliability standards." They have even gone so far as to propose different electricity system designs that could harness DERs more effectively, with transactive energy being one of the prominent design options.

With so many regime actors responding to the pressure exerted by the trend of grid decentralization and DER adoption by consumers, it is clear that this should be considered a landscape pressure.

Table 1: Summary of MLP levels

MLP framework level	Definition
Socio-technical niche	Transactive energy systems and blockchain-enabled microgrids
Socio-technical regime	Ontario energy sector actors, including: • Electricity generators • Electricity transmitters • Energy retailers • IESO • OEB • OMENDM • LDCs COP21 commitments and Pan-Canadian Framework on Clean Growth and Climate Change
Socio-technical landscape	Climate change Growing trend of electricity system decentralization and consumer DER adoption Economic restructuring Centralized grid structure

Current impacts of Ontario energy sector

To understand which transition pathway is likely to be taken (if any) in Ontario when it comes to the question of integrating TESs into its electricity system, we must first assess the impacts that this system has on Ontario. Understanding these impacts illuminates what stands to be gained and/or lost by altering the electricity system. This section explores the current economic, environmental, and social impacts of Ontario's existing electricity system.

Economic impacts

Ontario, being an economic powerhouse in Canada due to the nation's largest city, Toronto, residing within the province's borders, contributes a great deal towards Canada's national GDP. The energy sector in Ontario was responsible for $15,896,000,000.00 of nominal GDP contributions in 2017. That same year, the province was second to Alberta for the number of energy sector jobs it created, with 42,618 jobs representing ~4.7% of energy sector jobs in the country (Natural Resources Canada; n.d., b). Alberta's leadership in energy sector job numbers can be attributed to jobs in the oil and natural gas sector, which is not the type of jobs that the Pan-Canadian Framework seeks to create in the first place. According to a report published by the Environmental Commissioner of Ontario, the Pan-Canadian Framework's energy efficiency recommendations are estimated to yield a net growth of about 53,000 jobs and $12.5 billion of annual GDP growth in Ontario (Environmental Commissioner of Ontario, 2019). There is evidence to suggest that Ontario's second-place status to Alberta in energy sector jobs is shifting, though, as the Ontario Ministry of Economic Development, Job Creation and Trade states that there are now more direct clean energy jobs than direct jobs in the oil sands, and employment across the full cleantech sector is even higher – and increasing (Ontario Ministry of Economic Development, Job Creation and Trade, n.d.).

Ontario is a leader when it comes to cleantech job creation. The province's cleantech sector consists of over 5,000 companies, employs approximately 130,000 individuals, and generates about $19.8 billion in annual revenues (Ontario Ministry of Economic Development, Job Creation and Trade, n.d.). At the end of 2015, there were 1872 jobs in the cleantech sector, 80%

of which were in smart cities, energy & power tech, and advanced materials & manufacturing subsectors (Greenwood & Quaiser, 2017).

Across cleantech sub-sectors, there are four initial focus areas where Ontario is demonstrating significant strengths, is growing quickly, and has the potential to thrive globally. These are Energy Generation and Storage, Energy Infrastructure, Bio-products and Bio-chemicals, and Water and Wastewater. (Ontario Ministry of Economic Development, Job Creation and Trade, n.d.). These statistics indicate that Ontario's electricity system is responsible for significant employment and is a strong source of revenue for the province. Even more so, cleantech in the province is on the rise, meaning that more entrants into the job market and private organizations (especially investors and developers) are expressing interest in advancing the sector in the province, which bodes well for TES development in the future.

With all of this said, there are some areas where Ontario's energy sector could improve, economically-speaking. The province's thermal network is heavily reliant on natural gas, and this fuel is also used in peak times of electricity consumption to ensure grid supply meets the demand. This, along with the vast majority of vehicles in the province being powered by fossil fuels, means that the energy sector as a whole depends largely on fossil fuels. In fact, in 2015 about $16.8 billion was spent on importing fossil fuels alone (Environmental Commissioner of Ontario, 2019). Although these costs are not directly associated with microgrids, one of the benefits of establishing TESs in Ontario would be the ability to increase electrification across other goods and services, including thermal infrastructure and vehicles.

Other sectors are relevant when considering TES, or more specifically BEM development in Ontario. The information technologies (IT), real estate, and building sectors are of significant importance as well. Blockchain relies heavily on IT expertise, and the development of microgrids consisting of clustered prosumer homes likely requires real estate and building expertise. Therefore, understanding how these sectors are creating jobs in Ontario to attract an influx of expertise is crucial in understanding whether or not the talent necessary for developing a TES project in Ontario can be expected. Of the three sectors mentioned, only the building sector saw a decrease in employment from the second quarter of 2017 to the second quarter of 2018, with the drop being a 0.6% change. The IT sector and real estate sector saw increases in employment over the same time frame of 9.8% and 2.2%, respectively (Ontario Ministry of Finance, 2018).

Environmental impacts

In 2017, Ontario's average GHG intensity of electricity generation was 40 g CO_2/kWh, which is drastically higher than the surrounding Manitoba (3.4 g CO_2/kWh) and Quebec (1.2 g CO_2/kWh). This still placed Ontario in the upper echelons of the bottom half of provinces when ranked in descending order by average GHG intensity of electricity generation. Although Ontario had already phased out all of its coal-fired power plants by that time and had a grid primarily powered by nuclear and hydro, which emit no GHGs during electricity generation (as it still is), this source attributes the higher GHG intensity to lifecycle emissions associated with (de)commissioning generation facilities, building infrastructure, maintenance, and other non-generation activities. (National Energy Board, n.d.). The significance of lifecycle emissions impresses the need for increased energy efficiency with minimal construction, which is a promise that TESs can deliver on by relying on pre-existing distribution networks and using P2P energy transactions to more efficiently distribute and consume electricity.

The importance of energy efficiency can again be demonstrated by two reports from the Environmental Commissioner of Ontario. In her final report before the closing of her position and office, the Environmental Commissioner found that the largest contributor to the provincial carbon footprint is the energy system, responsible for about 75% of the overall emissions (Environmental Commissioner of Ontario, 2019). Granted, the vast majority of these emissions are due to fossil fuels being used for purposes other than electricity generation. In 2016, 75% of energy sources in Ontario were fossil fuels, broken down by use into 37% for transport, 28% NG for heating/industry, 8% other fossil fuels for heating/industry, and 2% natural gas for electricity. In that same year, 6 % of electricity in Ontario was generated using natural gas (Environmental Commissioner of Ontario, 2019), and the energy sector of that year was solely responsible for about 120 Mt CO_2eq of GHG emissions (Environmental Commissioner of Ontario, 2018).

A special report issued in 2018 (before Premier Ford's election and subsequent changes made to energy conservation and carbon emission reduction efforts) by the IESO assessing the GHGs emitted in Ontario by the electricity sector found that 4% of the emissions in 2015 could be attributed to electricity in Ontario (Navigant Consulting Ltd., 2018). This same report found that, although Ontario's shutting down of all of its coal-fired power plants was, and still is the largest and most ambitious GHG reduction effort in North America, progress in further reductions was projected to plateau, if not slightly increase during what is known as the "nuclear bathtub period". This period simply refers to the visual graph of the chance of nuclear power plant failure plotted over time. Nuclear power plants have higher chances of failure at the beginning and end of their lifespans, leading a curve of the chances of failure over time to resemble a bathtub, being curved up at both extremes of the graph. It is during these high-risk periods that other forms of electricity generation will likely be required, leading to increased emissions. Compounding this nuclear bathtub period effect is the fact that during its refurbishment, the Darlington nuclear facility's generators will not all be online, meaning that this lack of capacity will have to be made up from other sources of electricity. The likely candidate to fulfill this role is natural gas, as Ontario currently has the installed capacity for a rapid increase in natural gas-powered electricity generation (see Figure 1: installed capacity in Ontario 2019). However, switching from nuclear to natural gas during the refurbishment period would drastically increase GHG emissions in the province. The Cap and Trade program was offered as a potential counter for the emission increases, but with the program being cancelled by Ontario's current government, emissions can be expected to increase.

Natural Resources Canada broke down energy consumption for the nation by residential and commercial applications, and even further by energy use. This investigation found that, on average, 81% of the energy used for residential applications is used on space and water heating (62% and 19% respectively), and 63% of the energy used for commercial applications is used on space and water heating (55% and 8% respectively). For residential applications, fuel for space heating is supplied by 50% natural gas and 25% electricity, while the same metric for water heating is supplied by 68% natural gas and 29% electricity (Natural Resources Canada; n.d., a). These statistics reveal an opportunity for drastically reducing GHG emissions by electrifying space and water heating.

There is some encouraging data with regards to the energy sector's potential for decreased emissions. Energy intensity in Ontario decreased by 10% from 2007 to 2016, and the amount of energy consumed per dollar of GDP produced decreased by 19% over that same time frame (Environmental Commissioner of Ontario, 2019). These figures indicate that consumers are becoming more energy-efficient, as they also depict a gradual decoupling of energy use from economic prosperity. This decoupling is promising for TES development, as it indicates consumer recognition of and market acceptance of economic growth not being dependent on increased energy consumption, which is the basis of the business case for TESs in Ontario.

Social impacts

Most social issues in the energy sector in Ontario can be boiled down to two major concerns: energy affordability and the concept of “energy poverty”, and energy generation-related emissions leading to healthcare issues. Other, perhaps less prominent but still noteworthy concerns include consumer demand for more renewable energy (Campaign Research, Ontario and Energy, Presentation made to OEA Conference; 2015).

The air pollution from the electricity sector that led to health problems in Ontario was largely eradicated in 2014 when the province closed its final coal-fired power plant. Now, other than the use of natural gas-fired power plants used in times of peak electricity consumption to meet heightened demand, the province’s electricity generation is largely carbon-free. However, as has been stated before in this paper, the opportunity for carbon reductions in the form of electrifying other emission sources still exists. Fossil fuels used for transportation is one of Ontario’s largest sources of air pollution, which leads to significant damages to public health. In 2014, 20% of all hospitalizations and 30% of all premature deaths related to air pollution were attributable to vehicle emissions (Environmental Commissioner of Ontario, 2019). Developing infrastructure that enables EV adoption, such as microgrid deployment throughout the province, would allow for further electrification of the transportation sector, reducing the amount of harmful air pollution in Ontario.

Perhaps more socially impactful than the health concerns related to electricity in Ontario is the issue of energy poverty. According to an article published by the Fraser Institute, roughly 8% of all Canadian homes in 2013 were categorized as living in energy poverty. The organization also identified Ontario as the province with the third most households living in energy poverty (Green, Jackson & Herzog; 2016). Habitat Humanity defines those living in "energy poverty" as households who spend over 10% of their combined income on energy bills. The not-for-profit's studies indicated that Ontario had the fastest-growing electricity rate in Canada in the summer of 2018, leading to around 60,000 low-income homes having their power shut off due to missed payments (Habitat for Humanity, 2018).

Power Advisory LLC, commissioned by Environmental Defence, an environmental rights advocacy group, conducted an investigation into the makeup of the average Ontarian's electricity bill, and found that over 50% of the bill is comprised of costs associated with nuclear generation (24%) and the delivery of electricity to the consumer (31%). Comparatively, the combined share that renewables, including hydro, wind, solar, bioenergy, and energy conservation take of the electricity bill is 22% (7%, 6%, 5%, 1%, and 3% respectively) (Brooks, 2017). Environmental Defence's report accompanied by the article also clarified the makeup of the Global Adjustment (GA) portion of the electricity bill, which makes up a significant portion of some consumers' bills, especially large industrial consumers. The GA was found to be made up of 43% nuclear, 14% natural gas, and the remaining 43% covering all forms of renewables and energy conservation (Environmental Defence Canada, 2017). All of these statistics show that delivery charges, nuclear power, and natural gas are by far the largest sources of costs on Ontarians' electricity bills. This is an important observation because if Ontario wants to aid those living in energy poverty, the most effective method for doing so would be a solution that tackles all three of these factors.

The Ontario Energy Board established the Low-Income Energy Assistance Program – Emergency Financial Assistance (LEAP) to provide a grant to consumers who are at risk of being disconnected from the grid due to missed payments. The program saw an increase of recipients of over 55% from 2013 to 2016, with a decrease from 2016 into 2017 that still constituted an over 25% increase of recipient numbers when compared to 2013. This indicates a growing trend of energy poverty in the province, as more and more Ontarians require emergency financial assistance to make electricity bill payments. It is worth noting that of the 20,554 applicants for the grant in 2017, only 14,330 received it, meaning that 6,224 Ontarian households were potentially living in energy poverty in 2017. Of the top 3 utilities that provided LEAP grants to their customers, 2 were in the GTA, with a nearly 223% difference in recipient numbers between the third-highest LDC on the list, Alectra Utilities Corporation, and the fourth-highest LDC, Hydro Ottawa Limited (Ontario Energy Board, 2019).

The problem of energy poverty in Ontario is a salient one. More and more Ontarians are experiencing hardships due to energy affordability. This, in conjunction with the province's environmental protection and job creation goals, constitutes a problem in the form of the requirement for reform of sorts of Ontario's electricity system. A solution in the form of a transition away from costly nuclear and natural gas generation that includes a reduction in delivery/distribution costs and the promise of creating jobs in the cleantech industry could be precisely what is needed to remedy the energy situation.

International TES & BEM case studies

As was outlined in the Research Methods section of this paper, the selection of the case studies included in this project follows a set of criteria that is summarized in the table below.

Table 2: Case study selection criteria

Case study selection criteria
Presence of transactive mechanisms and/or blockchain technology
Existing technical literature
Varied operational regions
Varied TES/BEM model implementation

Based on these selection criteria, the case studies that are considered in this paper are:

1. LO3 Energy
2. Power Ledger
3. Electrify
4. Electron
5. Opus One Solutions

The criteria used to evaluate the case studies consists primarily of a set of questions that aid in understanding the value brought to each case study from the inclusion of transactive mechanisms and blockchain technology, which in turn aids in determining what components of each case study are applicable, if any at all, to Ontario's context. This results in a primarily qualitative evaluation of the case studies. The evaluative criteria are summarized in the following table:

Table 3: Case study evaluative criteria

<table>
<tr><th>Evaluative criteria</th><th colspan="2">Nested evaluation questions</th></tr>
<tr><td rowspan="4">1. Is blockchain used in the project?</td><td rowspan="2">Yes</td><td>How so?</td></tr>
<tr><td>Value add from blockchain?</td></tr>
<tr><td rowspan="2">No</td><td>Why not?</td></tr>
<tr><td>Untapped value from lack of blockchain?</td></tr>
<tr><td>2. Value proposition from transactive mechanisms</td><td></td><td></td></tr>
</table>

3. Transferable characteristics to Ontario context	Are these characteristics improvements or shortcomings when compared to Ontario?	

The following sections present each of the case studies in alphabetical order. To facilitate navigation within this section of the paper, each case study is presented using the following structure (with the heading given to each subsection in parentheses): a description of the company and the project(s) being assessed (Description), an explicit statement answering the first evaluative criteria and its nested questions (Blockchain's role), and an exploration of the value added to the project by its transactive capabilities (Transactive value-add). The final evaluative criteria, Ontario-transferable characteristics, is explored in the Discussion section of this paper. A table summarizing the results of the case studies is presented at the end of this section.

Electrify (Singapore)

Description

Electrify is an Asian utility that is looking to decentralize and liberalize Asian electricity markets by leveraging blockchain and transactive mechanisms. Electrify has a range of products that are meant to enable consumer choice by: giving prosumers access to demand response (DR) markets, democratizing the energy retail landscape by making tools that were traditionally only available to utilities available to DER owners, reducing *consumer credit risk* for energy providers (a growing issue in Ontario, as seen by the growing energy poverty statistics in the province) by ensuring that all parties involved in energy transactions are financially secure, and stabilizing the appeal in renewable DER adoption by increasing the predictability of energy revenues (surplus electricity generated by RE, for example) (Tam, 2017). The suite of Electrify products includes The Synergy trading platform, the Marketplace 2.0 user interface, the eWallet, and ELEC token, and the PowerPod energy information device.

Synergy is Electrify's trading platform that enables P2P energy transactions (Tam, 2017). It is a 2-tiered system, and is broken down as follows: Tier 1 consists of 1-1 matching between consumers and producers based on agreed-upon contract parameters, and Tier 2 consists of matching excess production and unmet consumption that was not handled in Tier 1 based on price alone, with no effect on Tier 1 contracts (Electrify.Asia; n.d., b). Using this system, consumers, prosumers, and producers can exchange electricity based on contracts or demand. The contracts for all trades are hosted in Marketplace 2.0.

Marketplace 2.0 is the main consumer interface for Electrify's products (Tam, 2017). A prototype of Marketplace 2.0, ELECTRIFY.SG was tested in Singapore in 2018 on commercial and industrial consumers. This test successfully facilitated over 60 GWh of transacted electricity (Electrify.Asia; n.d., a). The difference between Synergy and Marketplace 2.0 can be understood as Synergy being the infrastructure that enables P2P energy transactions, while Marketplace 2.0 is the environment in which participants can set up and execute these trades.

Electrify's eWallet product facilitates contract settlements between energy retailers, prosumers and consumers. The eWallet holds the customer's fiat currency and ELEC tokens (which are explained below). Customers pay for energy transactions in fiat currency and are rewarded for participating in transactions with ELEC tokens, which can be used for a multitude of purposes. This wallet tool enables Electrify to build credit ratings for each consumer based on their transaction history, and it is also used to track the rewarding & expiry of renewable energy certificates (RECs) in a secure manner (Tam, 2017).

The ELEC token is a cryptocurrency of sorts based on the Ehtereum blockchain, meaning that it enables self-executing smart contracts. It was developed by Electrify to: List energy deposits from producers to retailers, pay transaction fees from producers to Electrify, pay network fees for access to the public Ehtereum blockchain, act as a loyalty reward for customers that can be put towards future monthly bills in an effort to incentivize customer retention (Tam, 2017).

The PowerPod is a physical device that logs and stores energy information on the blockchain. This is an IoT device that reads smart meters to provide real-time monitoring of electricity production and consumption to consumers and network operators. All of the information gathered by PowerPod is stored securely on the blockchain. It is designed as a mandatory device for all energy retailers and prosumers, but can also be purchased as an optional device for consumers to monitor their electricity consumption in real-time to adjust their energy consumption accordingly (Tam, 2017).

The combined use of Electrify's products is meant to provide DER owners and consumers with the option of securely, profitably and reliably buying/selling electricity on their terms, without the intervention of a centralized utility. The free-to-use nature of the Marketplace 2.0 product makes transactive energy accessible to the masses, which in turn acts as a catalyst for increased DER and RE adoption in Electrify's operational areas.

From November 2018 to January 2019, Electrify hosted an Alpha test of their Synergy P2P trading platform in Singapore. Singapore was chosen as it had newly liberalized its electricity market, making the socio-political landscape appropriate for a TES project to be tested. The Alpha test ran on 15 participants, including 12 consumers and 3 producers, and was meant as a test of the user interface alone, not a test of the transactive properties of Electrify's products. The test was reported as successful, although no technical details of the project have been made publicly available. Electrify plans to launch a Beta test soon to further improve its interface as well as other products (Electrify.Asia; n.d., b).

Blockchain's role

Electrify leverages blockchain technology to:

- Create the ELEC tokens, which in turn enable
    - Self-executing smart contracts
    - Energy producers, retailers, and distributors to keep an updated inventory of DERs
- Consumer participation in DR markets by giving them access to real-time energy efficiency statistics that can be framed as energy savings to be sold on the DR market
- Confirm the financial stability of energy transactions to reduce consumer credit risk
    - This, in turn, is combined with the tiered matching system to quickly and effectively match DER-produced energy with a viable customer
- Increase the predictability of energy revenues by providing increased access to transparent energy data
- Provide a foundation for the eWallet product, which gives prosumers a new method for building their credit score

Implementing these systems simultaneously without the use of blockchain would be a difficult task, making blockchain integral to Electrify's value proposition. This model makes use of blockchain in some unique ways, including establishing a new credit building mechanism and granting prosumer access to DR markets. Blockchain's secure nature for logging transaction information makes it a crucial component of the credit building mechanism, but it is not necessary for granting consumers access to DR markets. Smart meters are capable of logging real-time production and consumption information that can be used to log energy savings on the DR market. In this case, blockchain simplifies the information collection process by making it automated and immutable, minimizing customer intervention in the process.

Transactive value-add

The added benefits brought on by the transactive component of Electrify's model are:

- Consumers can participate in DR markets without owning distributed generation resources.
- DER owners are given greater autonomy in determining the financial compensation for their excess generation
- Ensuring that all DER-produced energy is sold to a customer by making use of the tiered matching system

Allowing prosumers to participate in DR markets gives them an added source of revenue for their DERs beyond simply selling excess electricity to their neighbours. However, an added benefit comes in the form of granting consumers who do not have their own generative capacity access to these electricity markets as well. Since the Marketplace 2.0 interface is free to use, consumers who cannot generate their own electricity but have access to storage technologies such as a battery system or an EV can purchase electricity from their prosumer neighbours and store this electricity until they decide to put it towards participating in the DR market. This greatly extends the accessibility of DR markets, further democratizing the energy sector by introducing participation at the local and consumer levels.

The second value-add listed above, giving DER owners uninterrupted access to the revenues generated by their resources, is a direct consequence of participating in a TES. Traditionally, DER owners were financially compensated for their generation either by selling excess electricity back to the market at market-price, selling back to the market at a fixed rate determined by a FIT contract, or by participating in a net metering program. All of these options involve long-term agreements made between the DSO and the prosumer that can be inflexible, as is the case with a FIT model, or cannot guarantee attractive financial returns, as is the case with selling electricity at market-price and net metering. Allowing prosumers to determine the terms of their contracts either on a case-by-case basis or by setting up parameters to have the contracts automatically generated gives them increased autonomy and control over the financial aspects of energy transactions.

Ensuring that prosumers will always have a market for their excess energy coincides well with the second value-add. This gives prosumers confidence that their energy will be sold, perhaps not at the rates that they initially wished, but sold nonetheless. Electrify's tiered matching system gives prosumers a buffer when building their Tier 1 contracts – if they set the minimum sale price for their energy too high to attract any consumer interest, their energy will still be sold via Tier 2 matching, likely for a reduced rate, but the prosumer will have the ability to adjust their Tier 1 parameters to attract more consumer interest. This creates a reliable revenue stream for prosumers participating in Electrify's TES, which in turn invites greater DER adoption.

Electron (UK)

Description

Electron is a company based in the UK that looks to use blockchain in the energy sector. Of the cases presented in this paper, Electron is the only company whose platform can be used for both electricity and natural gas. Electron's product is an advanced billing platform that can be used by energy suppliers (Zhang et. al, 2017). Although the company has yet to launch any projects or products, they plan to use blockchain to keep an inventory of energy assets in the form of DER registries and transactive energy contracts, enable flexible P2P energy trading, and promote community energy projects.

The main operations of the company are developing flexible trading platforms using DERs registered on the blockchain. Their goal is to enable the balancing of energy systems by integrating existing energy data sets and allowing them to interact seamlessly with each other and new DER data sets. This will increase the predictability of energy systems, increase contractual visibility and facilitate energy mapping for energy sector developers (Electron, 2019).

Although Electron is a blockchain company in the energy sector, it is not as dedicated to building BEMs as it is to developing the identity and trading infrastructure that will be the foundation for TES systems in the future. To that end, Electron is currently working alongside the United Kingdom Power Network, NationalGridSO, and SPEN in London to develop a prototype blockchain-based registry for DERs – the first of its kind in Great Britain. The project is called RecorDER (NationalGridSO, 2019).

Blockchain's role

Electron uses blockchain to create a secure, transparent, and up-to-date registry of existing DERs. This is the only integration of blockchain into their operations. The value generated by this implementation of the technology is two-fold. Firstly, it allows for increased contractual visibility by logging energy transaction contracts as energy assets on a transparent and secure energy asset registry. Secondly, the use of blockchain technology to create an up-to-date registry of DERs facilitates energy project development by making energy mapping less complicated. Energy mapping, which is the practice of geographically mapping energy resources, is becoming increasingly complex with the rise in popularity of DERs. Having a registry of DERs that is secure for the resource owner's sake, but transparent and current for the developer's sake, is a valuable resource that can facilitate energy project development and greatly cut down on the amount of research time that is usually involved in energy mapping. If the energy project is a public development project, meaning that it is financed by some government department, then this reduced time would directly result in tax savings.

Transactive value-add

Electron's current plan is to have their projects support transactive mechanisms, not necessarily to have their projects be TESs themselves. So, this case does not generate any value for participants due to transactive energy mechanisms in a manner that is unique to Electron. Any value generated by transactive mechanisms in this case study applies to all TES implementations.

LO3 Energy – Brooklyn Microgrid case study (USA)

Description

The Brooklyn Microgrid, developed by LO3 Energy in the USA, is an ongoing project with plans to transition to becoming a transactive system in the form of a BEM in the future, although blockchain capabilities have not been made available to project members as of yet. Currently, Brooklyn Microgrid is not transactive. Instead, its present focus is on expanding the development of microgrids in the Brooklyn area and using their deployed software/hardware to run simulations, some of which including the use of public participants, and gather data on distributed electricity generation and consumption. This is all done to strengthen the design of the soon-to-be-deployed Exergy trading platform (Mengelkamp et. al., 2018). Exergy is also the name of the blockchain token that will enable P2P transactions. Brooklyn Microgrid is developing the Exergy platform to enable self-executing smart contracts that will, in turn, enable permissioned data sharing, localized energy markets, and DSO access to consumer data (LO3 Energy, 2017). Trials have been run with two-member P2P transactions to test the Exergy platform, but the tech has not been applied to all members of the Brooklyn Microgrid project yet (Mengelkamp et. al., 2018).

Blockchain’s role

LO3 plans to use blockchain to:

- Enable the Exergy token, which will be Ethereum-based to allow for self-executing smart contracts
- Provide DSOs with real-time consumer & prosumer data

Most notable of LO3’s Brooklyn Microgrid project is the fact that it is not transactive and does not make use of blockchain as of yet. So, the value-adds due to blockchain and transactive mechanisms are purely speculative. With that being said, the planned roles of blockchain and transactive mechanisms can still be examined.

The Exergy token, in much the same way as the ELEC token in Electrify's case and the Sparkz and POWR tokens in Power Ledger's case (see the Power Ledger case study below), is based on the Ethereum blockchain, meaning that it has self-executing smart contract capabilities. The automated nature of smart contracts allows prosumers to be less involved in the transaction design process, reducing the number of complications that might seem daunting to those considering joining a BEM. Combining smart contracts with automated smart home appliances can further increase the potential for profiting off of energy savings by, for example, having appliances preset to consume minimal energy during peak hours of DER energy production, thus maximizing the amount of energy that can be sold to other members of the BEM. This type of energy sale optimization can occur without the need for the prosumer to initiate the process, because of all the components of the process can be automated.

The Exergy platform also promises to provide DSOs with real-time consumer and prosumer data. This is a necessary value-add for DSOs because the Brooklyn Microgrid operates using existing distribution infrastructure, which is owned by the local DSO. Providing the DSO with access to consumer and prosumer data allows the DSO to gain insights into how they must adapt to increased DER adoption by their existing consumer base. Blockchain not only grants real-time access to this data to the DSO, but it also grants confidence to the consumers and prosumers that their data is secure and immutable. In regions outside of Ontario, a potential conflict could arise because consumers and prosumers might not want a private entity to have access to their personal information. However, as utilities are municipally-owned in Ontario, customer data is closely protected by the Municipal Freedom of Information and Privacy Act. Regardless, this conflict is explored in detail in the Discussion section below.

Transactive value-add

The value added by LO3's planned transactive components are:

- Establishing localized energy markets
- Enabling consumer choice with regards to how their electricity is generated

Again, it must be noted that the Brooklyn Microgrid project is not transactive as of yet. With that said, the transactive mechanisms to be employed in the project are rather straightforward in that this project only seeks to enable P2P energy transactions. LO3 has not announced any innovative or unique transactive mechanisms, examples of which can be seen in Electrify's tiered matching protocol for P2P transactions or in their enabling prosumer participation in DR markets. Thus, the value added to the Brooklyn Microgrid project by transactive components is limited to establishing localized energy markets and enabling consumer choice with regards to how their electricity is generated, which is often interpreted as enabling consumers to opt for RE generation methods as opposed to traditional fossil fuel-dependent generation methods.

Opus One Solutions (Toronto, Ontario, Canada)

Description

Opus One Solutions Energy Corporation (Opus One, for short) is a Toronto-based company that focuses on providing 4 products for their customers: Integrated distribution planning, DER management systems (DERMS), an optimization engine (optimizes geographical asset dispatch, grid reliability, economic optimization, and distribution investments), and transactive energy management (TEM) (Opus One Solutions Energy Corporation; n.d., a). For this paper's purposes, the DERMS and TEM services will be the focal points of Opus One's operations. Although the company is both an energy company and a tech company, it does not specialize in using blockchain technology for energy system applications. Instead, Opus One has developed a software solution, namely the GridOS product, that aims to facilitate DER uptake, transactive energy, and integrated distribution planning, among other things.

GridOS can be used to evaluate DER and TES potential, and it has several iterations. GridOS-Integrated Distribution Planning (GridOS-IDP) evaluates the ability of 'feeders' to accommodate DERs and the impact that integrating these DERs into the electricity system will have. GridOS-DERMS provides several services including oversupply mitigation, volt-VAR optimization/conservation voltage reduction, short-term load forecasting, load adaptation, and coordinated system restoration and dispatch. GridOS-TES creates price signals to incentivize consumer DER adoption by blending traditional utility costs with new costs/benefits brought on by the DERs themselves. Examples of these costs/benefits include the avoided cost of energy purchases, the utility's avoided spending on unnecessary peaking and baseload units, the avoided costs of operations and maintenance, a value given to increased resiliency to weather- and infrastructure-related events, a value given to increased grid reliability (measured as a percentage of hours without outages), and external societal benefits valued by the regulator (Opus One Solutions Energy Corporation, 2018).

Opus One creates a transactive energy environment by attaching a monetary value to the services provided by DERs, thus making these services exchangeable on a market for a price. This method is meant to create a more rewarding prosumer experience. The company recently launched a pilot project in New York with National Grid and Buffalo Niagara Medical Campus as partners as part of the New York Reforming the Energy Vision (NY REV) initiative. The project created time- and location-specific price signals in a TES set up for DER operations within the National Grid jurisdiction. The key differentiator for this project is using the transactive energy concept to create dynamic price signals that accurately reflect the ever-changing grid dynamics, operational costs, and other variables to more effectively incentivize customer adoption of DERs (Opus One Solutions Energy Corporation; n.d., b).

Blockchain’s role

Opus One Solutions has not explicitly identified blockchain as a technology being used by their suite of products. Although this may seem like an untapped resource when it comes to TES technologies, Opus One's suite of products renders blockchain unnecessary. It is important to recall that blockchain's primary source of value is that it establishes trust in the exchange of information between actors who do not necessarily trust each other. Simply put, blockchain is a trust-building technology. Another source of value from blockchain is specific to blockchain-enabled systems based on the Ethereum blockchain, which allows for self-executing smart contracts. Opus One's products are meant to support and encourage TES development and growth, meaning that their products do not necessarily require blockchain.

Transactive value-add

Opus One Solution's approach to enabling transactive mechanisms is unique in that their products seek to build a more attractive TES model by creating dynamic price signals. These signals are meant to be better incentives for consumers to adopt DERs and engage in TESs than traditional market mechanisms such as FIT or net metering programs. This results in a downstream value-add from Opus One Solution's TES concept. Although their technology does not enable P2P transactions itself, it does encourage increased consumer adoption of DERs and participation in TESs, thus spreading the distribution of prosumers benefitting from the values generated by TESs that have been highlighted thus-far in this paper.

Power Ledger (Australia & USA)

Description

Power Ledger is an American company with operations around the world that deals in using blockchain technology to enable P2P energy transactions. The Power Ledger platform operates by making use of two tokens, Sparkz and POWR, both of which are Ethereum-based, and thus are capable of producing smart self-executing contracts (Power Ledger, 2018). Understanding this platform and how it leverages blockchain to create value for its users requires understanding the two tokens and how they are different.

Sparkz is a token that exists only within the Power Ledger platform, and it is equated to 1 unit of fiat currency. This token is responsible for monetizing electricity for Power Ledger members by being the currency that members use to pay for electricity within the Power Ledger platform. The POWR token, on the other hand, is a publicly-traded cryptocurrency that grants users access to the Power Ledger network. So, the POWR token can be understood as the publicly-traded market token, whereas the Sparkz token can be understood as the transactive energy currency token. Both of these tokens are enabled via the blockchain, meaning that they are immutable, secure, and transparent.

Power Ledger offers three main products for different levels of P2P transactions: xGrid, μGrid and Power Port (Power Ledger, 2018). These three products are used for grid-connected transactive energy systems, behind the grid transactive energy systems (such as campuses that operate as islanded microgrids), and EV charging station management, respectively. Each of these applications of Power Ledger technology makes use of blockchain to allow for transparent transaction record storage, which can be more thoroughly understood by 3 use cases from Wyomissing, Santa Clara, and White Gum Valley.

The White Gum Valley project in Australia is an upcoming trial project by Power Ledger at the Evermore apartment development. The project combines rooftop solar PV, energy storage, and the Power Ledger blockchain platform to enable residents to sell excess PV-generated electricity to neighbours during times of peak demand, instead of selling this excess electricity back to the grid (Power Ledger; n.d., b). This is the most straightforward application of a TES model that Power Ledger employs. Also, it is not running yet, so there are no details with regards to which Power Ledger products are set to be deployed with the project or any other technical specifications.

The project in Wyomissing, USA demonstrates Power Ledger's use of its xGrid product. This project encompasses several buildings belonging to the headquarters campus of American PowerNet, which has an existing distribution network that can be taken advantage of. The existing distribution network also means that no additional hardware is required, nor are any additional software or engineering fees incurred because the solar PV resources are already connected to the existing distribution system and there are existing meters that provide the necessary data for the Power Ledger platform to function. This project operates by using the xGrid platform to monitor American PowerNet solar resource generation as well as the buildings' grid consumption. The data gathered via the xGrid platform is stored securely on the blockchain, and it is used to provide energy generation and consumption data to American PowerNet to facilitate invoicing and P2P transactions between the buildings on the campus and external buildings as well (Power Ledger; n.d., c). This project is also not running as of yet.

The Santa Clara, USA project incorporates EVs into the energy system, as well as energy storage capacity. The project, run for Silicon Valley Power, uses EVs, carbon credits, on-site energy storage, and rooftop solar PV all on a 6-story parking garage to create a business benefit for the client. Power Ledger's platform monitors PV generation as well as energy storage use. It then uses all publicly-available data to calculate how many kWhs of EV charging equate to 1 Low Carbon Fuel Standard (LCFS) credit securely and transparently (LCFS is the unit used in the California Air Resource Board's carbon pricing scheme). By combining this calculated data with the measured data from the project site, an environment in which carbon credit trading can occur through the POWR token and EV resources is created. This also gives users the ability to track the carbon credits they have earned due to EV charging in real-time (Power Ledger; n.d., a).

Blockchain’s role

Power Ledger’s various projects use blockchain to:

- Create the Sparkz and POWR tokens, which enable self-executing smart contracts
- Provide DSOs with DER production and consumption data
- Facilitate invoicing for energy billing/crediting
- Transform POWR token accumulation into carbon credit accumulation to enable carbon credit trading

Just as with the ELEC tokens and Exergy tokens, blockchain is used to enable self-executing smart contracts, resulting in the same value-adds that were outlined in the previous case studies. Also similar to the Brooklyn Microgrid project, Power Ledger leverages blockchain to provide DSOs with access to prosumer data. The value brought on by this use of blockchain is outlined in the LO3 case study. Another component of Power Ledger’s operations attributable to blockchain is facilitating invoicing for energy billing and crediting. Although this is inherent to any blockchain-enabled energy transaction because of the transparent logging of transaction information, Power Ledger is the only company of those considered in this paper to explicitly highlight this function as a by-product of their use of blockchain, hence its inclusion in this case study and not in the others.

The only implementation of blockchain that is unique to Power Ledger's case is enabling carbon credit trading. Using blockchain to access and store prosumer information is common among many BEM models, but alternatively using blockchain to access and store carbon pricing information is a new concept. This allows for renewably-generated energy that is being tracked within the BEM to generate credit in whatever form the local carbon pricing scheme, assuming there is one in place, allows. This grants consumers access to carbon credit markets that they had originally not had access to. Granting carbon credit market access to distribution- and sub-distribution-level consumers, in turn, incentivizes their participation in decarbonization, greatly enhancing the reach of any economic incentive decarbonization program which likely would have been designed for high-level consumers in the first place.

Transactive value-add

The transactive mechanisms that Power Ledger employs deliver much of the same value discussed in the previous case studies, including enabling consumer choice, establishing localized energy markets, and providing DER owners with a secure source of financial compensation. What differentiates Power Ledger's model is that blockchain and energy transactions are integrated into more ways than just enabling self-executing smart contracts. As was explored above, Power Ledger also marries these two technologies to grant consumers access to previously inaccessible markets, much in the same way that Electrify's model grants consumers access to DR markets. In Power Ledger's case, consumers who otherwise had no way of generating carbon credits can now accumulate and trade carbon credits as a new form of currency.

Table 4: Summary of blockchain and transactive mechanism value-adds for each case study

Case study	Unique blockchain value-add	Unique transactive mechanism value-add
Electrify	• ELEC tokens to enable self-executing smart contracts and real-time inventory of DERs • Granting consumer access to DR markets • Confirming the financial stability of energy transactions • Ensuring all DER-generated energy is sold to a consumer • Increasing energy revenue predictability • Providing a new method for building one’s credit score	• Granting non-DER-owning consumer access to DR markets • Improving DER owner autonomy with respect to energy transaction financial compensations • Ensuring that all DER-generated energy is sold to a consumer

Electron	• Creating a secure, transparent and up-to-date DER asset registry • Facilitating energy mapping for energy project development	• N/A
LO3	• (Planned) Exergy tokens to enable self-executing smart contracts • (Planned) Enabling consumer/prosumer data accumulation by the DSO	• Establishing localized energy markets • Increasing consumer choice for electricity generation, especially for RE
Opus One Solutions	• No blockchain capabilities	• Creating dynamic price signals in electricity market • Encouraging DER adoption
Power Ledger	• Sparkz and POWR tokens to enable self-executing smart contracts • Enabling consumer/prosumer data accumulation by the DSO • Facilitating energy bill invoicing/crediting • Granting consumer access to carbon credit trading markets	• Increasing consumer choice for electricity generation, especially for RE • Establishing localized energy markets • Improving DER owner autonomy with respect to energy transaction financial compensations • Granting consumer access to carbon credit trading markets

Discussion

Lessons learned from the case studies

The case studies explored in the previous section present many applications of transactive energy mechanisms and integrating blockchain into energy systems. Some of these applications can be projected into Ontario's context, whereas others are less applicable. The table below depicts the components of the case studies believed to have the potential to generate value in Ontario. It also outlines what potential barriers exist to the adoption of these components in the province.

Table 5: Case study components that are applicable to Ontario, with barriers

Company	Project location	Project component of interest to Ontario	Barriers in Ontario
Power Ledger	Santa Clara	EV charging for carbon credits generation & trade	Government is opposed to a carbon price Low EV penetration in Ontario market
Brooklyn Microgrid	Brooklyn	P2P electricity transactions. DSO access to consumer data	Consumer distrust of private organizations' access to data
Electrify	Singapore	Free to use Marketplace 2.0 interface making P2P energy transactions accessible to all	Centralized energy regime. No need for added capacity – ongoing refurbishments mean large portion of provincial capacity will remain nuclear
Electron	UK	Blockchain-based DER registry	None
Opus One Solutions	New York	Grid-responsive dynamic price signals	None

Power Ledger - carbon credit trading

Beginning with the Power Ledger Santa Clara project, the component of interest to Ontario is the capacity to charge EVs using RE, which in turn generates carbon credits that can be tracked and traded between users. This is interesting for Ontario's case because of its potential to seamlessly integrate with a carbon pricing scheme. Although the Santa Clara project uses blockchain to generate and track carbon credits, it is conceivable that the project could be altered to instead track the savings generated by charging an EV using RE. This negates the ability to trade carbon credits, however. The environmental benefits of carbon emissions reductions are inherent to any RE project, but the economic benefits to the consumer are created solely by the blockchain capabilities of this project.

The barriers to this project component that exist in Ontario are the low share of EVs in Ontario's vehicle fleet, which can be partially attributed to EV incentive programs being shut down by the current provincial government, and the provincial government's opposition to a carbon price. The political position of the province is against RE development, EV uptake, and pricing carbon emissions. These are significant barriers that would likely impede the development of a project such as the Power Ledger Santa Clara project in Ontario, if not halt it altogether. However, the carbon price barrier is non-existent at the moment because of the federally-mandated backstop to price carbon at $50/tonne. This means that, despite the provincial government's opposition to pricing GHGs, there is a cost for emitting carbon, and therefore there is the potential for savings to accrue by charging EVs using RE.

LO3 – straightforward TES and data accumulation

The Brooklyn Microgrid project is the most direct interpretation of a TES of the cases that were studied in this paper. The project's use of P2P energy transactions can generate value for energy system operators and consumers for all of the various reasons previously listed, including improving grid resilience and flexibility among other benefits. These benefits make the P2P transactions an interesting component for any jurisdiction seeking to alter its energy system to explore, including Ontario. It is worth noting, however, that this project does not include any blockchain capabilities whatsoever. Instead, the Brooklyn Microgrid project merely has a plan to add blockchain capabilities to their system through the Exergy platform. Most interesting of these added capabilities for Ontario's case is the ability for the DSO to have access to consumer and prosumer data. With utilities across the province acknowledging the growing trend of DER adoption and the growing demand for decentralization, gaining access to consumer/prosumer data would undoubtedly facilitate transitioning DSO business models and infrastructure designs to a decentralized model. However, consumer/prosumer support for this might not be easily obtained if organizations other than the DSO are involved.

Ontario citizens might disagree with the notion of having their personal data collected by a private organization. This is the source of the ongoing controversy surrounding Sidewalk Labs' development of the eastern waterfront in Toronto. Sidewalk Toronto, as the project is named, is an innovative smart city development project that has generated a great deal of support and critique from various stakeholder groups, with the vast majority of the critiques being focused on Sidewalk Labs' accumulation of user data. Sidewalk Toronto differs from the Brooklyn Microgrid in that the former has made no statement with regards to plans to integrate blockchain into its operations as a means for establishing trust between the users and the company, nor would such a statement be helpful when it comes to this particular critique. Sidewalk Labs has already taken several measures to establish trust using technological solutions, and it seems as though the recurring criticism is that Ontarians are distrustful of using technological solutions themselves, as well as of a private organization having access to a wealth of consumer information. It is important to note that blockchain creates trust by ensuring that information is immutable, but it does not promise anonymity to users. If a user joins a BEM that shares consumption/production data with a third party other than the DSO and wants to have their information remain confidential, it is unlikely to happen. Although DSOs are municipally-owned, it is feasible that they would partner with a private firm, such as Opus One Solutions or Peak Power, to help develop a BEM project. If this were to be the case, consumer anonymity could not be guaranteed. What blockchain offers is the inability for any parties to alter the information without the user's consent, but access to this information would likely be made a mandatory clause of the onboarding contract for the user. Another important consideration with regards to participant data accumulation is that although private organizations may claim that they are gathering aggregate data to protect the individual data of participants, it is, in fact, impossible to gather aggregate data. By definition, data accumulation is done at the individual level, with aggregation only occurring after the data has been accumulated. This means that significant opposition to a BEM project could be expected from Ontarians who have already presented themselves as opposed to companies using technology to gather consumer data.

Electrify – necessity of blockchain and increased DER adoption

Electrify's operations depend heavily on the use of blockchain. However, the Singapore Alpha test's component that is most interesting when extrapolated to the Ontario context is the Marketplace 2.0 user interface, and more specifically, its free-to-use nature. Electrify strives to make DERs and transactive energy accessible to the masses, and its free-to-use Marketplace 2.0 interface would do exactly that for DER owners in Ontario. The underlying system infrastructure that relies on Electrify's two blockchain-based tokens, Sparkz and POWR, is not crucial to the successful implementation of a TES. This is because TESs can be established using smart meters (which have already been deployed in Ontario) to measure in- and outflows of energy to a building and traditional financial mechanisms, such as FITs or net metering can be used to provide economic benefits to the prosumer. Blockchain simply adds a layer of security and transparency to the transactive energy model. Introducing an affordable entry point for current DER owners into the energy market stands to be disruptive to the Ontario energy sector regime, and it would also likely entice more Ontarians to invest in DERs.

This disruption could pose as a barrier to this component's adoption as well. Ontario's current energy sector structure is semi-liberalized, with energy utilities acting as monopolies in their respective jurisdictions. If consumers were to suddenly enter the energy market with their own generative capacity in the form of DERs, pushback from utilities would likely follow. This pushback could take the form of lobbying for regulatory intervention to prevent the sudden overwhelming uptake of DERs or restructuring existing utility-consumer contracts to discourage shifting from purchasing energy from utilities to relying on DERs. In addition to this pushback from the private sector, there is the reality that Ontario's current energy supply is sufficient for its demand. The ongoing refurbishments to the Darlington nuclear facility mean that a large portion of the provincial electricity capacity will remain nuclear for the foreseeable future, which abolishes the requirement for added generation in the province. If new generation is not needed in Ontario, then organizations such as the OMENDM, IESO, and OEB could step in to prohibit too many DERs being added to the grid, resulting in a buildup of excess supply with no demand to match it.

Electron & Opus One Solutions – barrier-less projects

Electron and Opus One Solutions present two project components that do not have any explicit barriers present in Ontario at the moment. Of interest from the Electron project in the United Kingdom is the blockchain-based DER registry. Of interest from the Opus One Solutions pilot project with NY REV is the notion of grid-responsive dynamic price signals. The DER registry is a project that holds the potential to ease the transition towards further DER adoption in the

Ontario grid, regardless of when energy sector decision-makers deem it to be appropriate to have this transition. Such a registry could incite public backlash in much the same way that Sidewalk Toronto has incited backlash due to private entities having access to consumer data, but this is entirely dependent on the type of data being collected and how it is being used. Unlike the Sidewalk Toronto case or the Brooklyn Microgrid case, the DER registry does not necessarily need to be used by a private organization for financial gains. Instead, the registry could be envisioned as a government tool for planning energy project/infrastructure development throughout the province, meaning that the information would be housed with the public sector. The grid-responsive dynamic price signals component of the Opus One Solutions project is interesting for Ontario because it is a demonstration of a TES that does not rely on blockchain in any way. This is important because of the various barriers that blockchain technology faces in Ontario in the form of increased project complexity, distrust from Ontarians in overly-technological solutions and the accumulation of consumer data.

Collective lessons

These case studies have collectively shown that a TES does not require blockchain technology to successfully: transact energy between prosumers, deliver financial compensation to prosumers for their excess energy, gather data on TES participants, or encourage DER adoption. Blockchain imparts value to a TES in two ways: enabling buildings already equipped with smart appliances to integrate with self-executing smart contracts; and increased transparency, information immutability, and the capacity for trust-less transacting.

The capacity for P2P energy transactions to be executed without the need for the participants involved to actively initiate the transaction is a common theme among the case studies explored in this paper. This is valuable because consumers can set the parameters under which they wish for their energy to be automatically sold or for neighbour-produced energy to be automatically purchased, freeing up their time. Another key value delivered by automated contracts is that the participants do not need to constantly monitor their energy data to determine when they should initiate an energy trade. Most participants in these projects are not likely to be energy experts with the knowledge required to execute sensible energy transactions. Enabling automated transacting relieves the need for such knowledge on the participant's part, making the TES model much more accessible. This automation value-add is compounded when the participant(s) involved have smart appliances in their building. Smart appliances can provide real-time consumption information to a central system that can then act in sync with the self-executing smart contracts to initiate trades based on a far more accurate set of data. This can generate far more value for the participant by making the entire TES more efficient and more responsive to changes in energy supply and demand.

The other value-add due to blockchain, transparency, and immutability, could turn out to be a benefit that would-be participants do not value. It is important to note transparency and immutability do not necessarily mean anonymity, which is something that Ontarians seem to value at the individual consumer level. And, despite their disappointment in the provincial government to deliver on electricity cost reduction promises for over a decade, Ontarians have demonstrated that they are also distrustful of private organizations, especially those that seek to collect large amounts of highly individualized information. This lack of trust in companies presents itself as a serious barrier to blockchain development for one simple reason: a company must be employed to design and launch a BEM project. This simple fact means that although blockchain is inherently a trust-building tool, a company's central involvement in the project development would likely lead to skepticism from citizens. This, in conjunction with the noted success of the Brooklyn Microgrid and Opus One Solutions to deliver transactive energy solutions without the use of blockchain, means that the blockchain component of a BEM can be considered as unnecessary in Ontario's particular case.

Socio-technical regime impacts

To reiterate the MLP framework levels as they are defined for Ontario's energy sector in this paper: The socio-technical niche is transactive energy systems, now excluding blockchain-enabled microgrids as blockchain is shown to be an unnecessary technology for transactive energy purposes; the socio-technical regime consists of all of Ontario's energy sector actors, being electricity generators, electricity transmitters, electricity retailers, the IESO, the OEB, the OMENDM, and LDCs/utilities, and climate change action commitments made by COP21 and the Pan-Canadian Framework on Clean Growth and Climate Change; and the socio-technical landscape consists of the combined pressures of: the global phenomenon of climate change, the growing trends of electricity system decentralization and DER adoption, Ontario's economic restructuring from heavy industry towards services and knowledge-based activities, and Ontario's centralized grid structure. The lessons learned from identifying these three levels of the MLP framework in conjunction with those learned from the various case studies examined in this paper have unveiled several anticipated impacts on the different actors in Ontario's energy sector regime. These impacts can be grouped into impacts on private sector regimes and impacts on public sector institutions/regimes, both of which are explored in the following sub-sections.

Private sector regime impacts

The regime actors in the private sector include electricity generators, electricity transmitters, electricity retailers, and other businesses that operate in the energy sector. Of these actors, electricity transmitters will likely not be impacted to a great degree by a socio-technical transition in Ontario to a more decentralized electricity system that employs TESs. This is because electricity transmitters solely manage the transmission of electricity from bulk generators to LDCs, which is all upstream from where TESs would operate in Ontario's electricity system. Although, if TESs were adopted with such speed and breadth that they significantly reduced the need for electricity transmission infrastructure, then electricity transmitters could be impacted. However, this is unlikely to happen in the near- or medium-term. Similarly, electricity generators are unlikely to be noticeably impacted by TES deployment in Ontario unless the technology is adopted quickly and broadly. This leaves electricity retailers and other energy sector businesses as the regime actors that are likely to be significantly impacted by TESs.

Retailers and utilities are the most vulnerable to disruption by TESs because they operate at the distribution level of Ontario's electricity system, where TESs would be deployed. Retailers are flexible because they do not own or manage any distribution infrastructure, so they can react to the disruption TESs would cause readily. Utilities, on the other hand, are the sole operators of distribution infrastructure in their respective jurisdictions. Utilities would need to either lobby regulative bodies like the OEB and IESO to limit the spread of TESs within their jurisdictions to prevent too much of a disruption to business as usual, or they would have to adapt to the changing energy regime by embracing the technological niche and steering its development towards a future in which DSOs still have an indispensable role in distribution level electricity system management.

With think tanks and advocacy groups spawning from within the OEB and IESO like the Electricity Transformation Network of Ontario (ETNO) who are declaring that DER adoption is inevitable and that Ontario's electricity system must transform alongside current energy market trends, it is unlikely that these bodies would act to impede the growth of TESs in Ontario. One utility, in particular, Alectra Utilities, has displayed marked willingness to adapt to the changing electricity landscape.

Alectra Utilities, a utility based in south-western Ontario, has recently announced its intentions to deploy blockchain-based developments alongside Sunverge (Sunverge, 2018). The utility has also made plans to launch a blockchain-based transactive energy program. Although none of these projects are active at the time of writing this paper, the utility is the only one in Ontario to be openly pursuing integrating transactive mechanisms into its operations.

The final private sector actor that would likely be significantly impacted by TES deployment in Ontario is the group of other energy sector businesses. This group can be broadly defined as businesses that operate within the energy sector but are not classified as any of the other regime actors listed beforehand. Examples of such businesses are Opus One Solutions and Peak Power. Opus One has already been explored in this paper, and Peak Power is a company that uses AI and machine learning algorithms to predict times of peak consumption for industrial consumers who can then use on-site energy storage resources to offset their consumption at these peak demand times. While Peak Power has been said to be an example of a company advancing transactive energy models, it was not included in the case studies section of this paper because their business model is not centered around supporting or enabling P2P energy transactions, rather it is focused on using energy storage to offset peak demand in order to ‘GA bust'. This is a fairly complex and controversial method for industrial consumers to drastically reduce their electricity bills. Due to its complex nature and irrelevance to the subject matter of this paper, it shall not be explored any further. Opus One and Peak Power are clear examples of the business potential for tech companies to start operations in Ontario, attracting talent to the province in a similar vein to IT companies attracting tech talent to Silicon Valley. These types of companies coincide with the socio-technical landscape pressures of Ontario's transition towards a services- and knowledge-based economy and the growing trend of DER adoption and grid decentralization, meaning that further economic development in the smart energy industry, including TES development, can be expected.

Public sector regime impacts

The public sector regime actors identified in this paper include the Ontario provincial government, the OMENDM, the IESO, the OEB, and LDCs. These actors have high-level interests in mind when considering energy project development in Ontario, such as electricity prices, grid reliability, especially with increasingly common extreme weather events, and providing all Ontarians with unhindered access to electricity.

TESs have great potential to drastically reduce the amount of electricity being purchased from the grid, but this does not necessarily translate to electricity bill savings. TES participants would have to purchase electricity from their neighbours at a cost that is lower than the market price for savings to accrue. On the other hand, prosumers can save on electricity bill costs by drawing from their DERs instead of from the grid and by accessing the P2P energy sale revenue stream. However, only the latter could be attributable to the TES itself, as drawing electricity from DERs does not require a TES.

Another potential method for TESs to affect electricity bill costs could be for the technology to be so widely adopted that it reduces the need for distribution infrastructure. If this occurs, DSOs would not be justified in charging as much as they currently do on monthly electricity bills for distribution infrastructure operation and maintenance (O&M). This is an interesting concept because the savings would be reaped by all consumers living within the borders of that DSO's jurisdiction. However, it is highly unlikely that TESs would reach that level of market penetration in the near future. Early participants in TESs would see the cost savings benefits first, especially if they can disconnect entirely from the grid. Distribution infrastructure O&M is a fixed cost for the utility, though, so as more consumers join TESs and are exempt from certain utility bill costs, the O&M costs and other fixed costs will be redistributed among the remaining utility customers. This could cause tension between TES participants and non-participants. All of this indicates that TESs might not result in large electricity cost savings for Ontarians, which is undoubtedly a central focus for any energy project development that the Ontario government and other public sector regime actors would endorse.

TESs stand to noticeably alter grid dynamics and structures, thus impacting grid reliability. By introducing more responsive DERs into Ontario's electricity system and enabling consumers to dynamically produce and consume their own electricity, TESs can greatly increase the flexibility of Ontario's rather rigid grid. One could argue that a major shortcoming of Ontario's current grid is that historically the province has displayed a lack of foresight when expanding its capacity. The province's grid relies heavily on the extremely long-term electricity resources of nuclear and hydro, which take a long time to build and have very long project lifetimes when compared to RE and DERs. TESs, by encouraging RE and DER adoption in the province, can better prepare the provincial grid for unforeseen complications in electricity system planning. As a hypothetical example of one such complication, perhaps the world might come to realize that global reserves of silicon are nearing depletion, rendering photovoltaics obsolete. Having a large fleet of DERs and transactive consumers available would enable Ontario to react to the sudden decommissioning and transition away from PV quickly.

Grid reliability is becoming an increasingly important component of energy system planning and development as the effects of climate change reveal themselves. The pressure exerted on Ontario’s energy sector regime by physical changes to the province due to climate change, such as ice storms knocking down power lines and intense summer heat leading to elevated cooling energy demand, necessitates a grid that is flexible enough to respond to these occurrences. This pressure also creates a need for the grid’s response to sudden changes in electricity demand to be carbon-free, which is not the case at the moment. Ontario's current solution for managing peak demand is to engage its natural gas generators, which is highly GHG emissive. This paper considers TESs that are based on RE as examples of sustainable energy. This is supported by the definition of ‘sustainable energy' provided in the Technical context section above. RE-based TESs can be designed to be environmentally and socially benign by depending on carbon-free or carbon-neutral energy sources and by democratically providing participants access to energy. And, as was outlined in the previous paragraph, TESs' dependence on DERs makes them highly adaptable to new economic or environmental challenges, satisfying the second characteristic of this paper's definition for ‘sustainable energy'. This type of sustainable deployment of a TES would allow for a fast, carbon-free alternative for Ontario to respond to demand fluxes, satisfying the requirement for grid reliability while also managing the socio-technical landscape pressure exerted by climate change.

A final note about the impact that TESs could have on the public sector regime is its potential to democratize energy access among Ontarians. This concept primarily applies to remote and First Nations communities that exist in locations without access to a distribution or transmission network. These communities often rely on diesel fuel shipments to power generators for their electricity, making supplying electricity both costly and insecure. The energy system design for these communities is often a microgrid with a diesel generator for electricity production and some sort of battery bank for electricity storage. These microgrids would not stand to benefit from adding transactive mechanisms to their design because consumers in these communities likely value electricity as a much more prized commodity than consumers with access to a distribution network. It is unlikely that consumers in such remote regions are looking to generate additional revenue by producing their own electricity using DERs. All of the generation in these regions is done using DERs, albeit usually using fossil fuel-based technologies. Additionally, building a TES would be more expensive due to shipping costs associated with getting all of the materials and personnel required for the project to the job site. This means that TES adoption is best-suited for densely-populated urban areas. It is conceivable that the OMENDM and provincial government could receive negative criticisms from remote community members for favouring energy project development in urban areas where access to reliable electricity is not a pressing issue over providing remote communities with a dependable connection to an electricity source.

Anticipated socio-technical transitional pathway

Socio-technical transition analyses done using the MLP framework culminate in an anticipated transitional pathway that describes how the niche innovation is adopted into the existing regime or to what degree the niche innovation disrupts the existing regime. In the case of TES integration into Ontario's electricity system, two of the four transitional pathways outlined at the beginning of this paper may apply: the technological substitution path and the reconfiguration path. These two pathways are marked by slowly exerted pressures on the existing regime from the landscape level, niche innovation market maturity, and strong regime actors. This fits well with the socio-technical niche, regime, and landscape levels identified in this paper. TESs have been proven to be market-ready, as can be seen in the various case studies presented throughout the paper. The landscape pressures identified in this paper, while strong and unrelenting, are slow. This can be seen in the slow onset of climate change and the changes it inflicts upon Ontario's physical, cultural, and political environment. It can also be seen in the province's transition towards a knowledge- and services-based economy and in its gradual increase in DER adoption (or, at least, in the acknowledgement that DER adoption is inevitable). The final characteristic that is shared by these two transitional pathways is strong regime actors. The centralized structure of Ontario's electricity system demonstrates that its regime actors, most notably the IESO, OEB, OMENDM, LDCs and electricity generators like Ontario Power Generation (OPG) have considerable influence on the direction in which the sector will develop.

This leaves the differentiating factor between the technological substitution and reconfiguration transitional pathways. The former is characterized by resistance to change from regime actors leading to their eventual replacement. The latter is characterized by a willingness to adopt the niche innovation from the regime actors leading to a fundamental change in regime architecture but leaving regime actors intact. As has been identified throughout this paper, many of the prominent regime actors in Ontario have acknowledged the inevitability of DER adoption within the province. Consequently, they have acknowledged the inevitability of fundamental shifts in energy sector institutions such as the electricity market scheme, distribution structures, and the role of prosumers in grid dynamics. Some actors, such as the OEB through the ETNO and the IESO through its Innovation Roadmap (IESO, 2019) have explicitly identified TESs as a technology to be explored for implementation in Ontario. Additionally, Ontario companies such as Opus One Solutions and Alectra Utilities have seized the opportunity that DERs and transactive mechanisms present to form financially successful businesses. This shows that Ontario's energy regime is willing to adopt the TES technological niche innovation.

The main disruption that must be anticipated is the LDC's new role in an Ontario grid with integrated TESs. With prosumers now playing an independent, active role in distribution level grid dynamics, a large portion of the DSO's operations will be turned over to prosumers. The most likely scenario in which the DSO remains an important component of the energy regime is if they shift their business model to becoming distribution infrastructure managers. This would require that the DSOs have access to real-time prosumer data so that they can manage an electricity system that would now be in a constant state of flux due to P2P transactions occurring at the individual consumer level. The DSO would not necessarily need to manage the energy transactions themselves, although this could also be a possibility if they are responsible for the development of the TES, as would be the case with Alectra Utilities. This is a likely outcome of TES adoption in Ontario because the LDCs act as monopolies within their jurisdictions, meaning that competition is essentially non-existent, and they are protected by regulations from the OEB and OMENDM to prevent their disappearance from grid operations. This combined with their municipal ownership positions LDCs well as potential transactive energy market facilitators. Additionally, prosumers are not likely to invest the capital nor navigate the regulatory obstacles required to develop their own distribution infrastructure, so they would likely rely on existing infrastructure, which is owned by the DSO.

Future Research

This section addresses the various research questions relating to TES development in Ontario that exist beyond the boundaries of this research paper. The socio-technical transition evaluation presented in this paper is primarily based on qualitative research, however, many factors contribute to the feasibility of the adoption of new technology into Ontario's energy sector. This evaluation largely neglected quantitative factors, such as project costs to various stakeholders, which would be influential in stakeholder support for a TES project. Another quantitative assessment that would clarify how a TES could be integrated into Ontario's grid is a technical model of a sample project to demonstrate how it would fit into the existing electricity system alongside other energy resources and how it would impact grid dynamics. Several other quantitative evaluations could be conducted to reveal whether or not integrating TESs into Ontario's grid would be beneficial for Ontario based on economic (with particular emphasis on electricity affordability), political, environmental, and social criteria. Beyond the quantitative, further research into qualitative impacts of the research topic could be valuable as well. Such research could explore the social and political impacts of TES development in Ontario, including addressing the question of whether or not TESs could increase community cohesion by establishing a new point of interaction between neighbours.

Conclusion

DERs adoption is accelerating in Ontario at a historic rate, with new technologies and DER-supporting system designs being introduced in the province at an equally rapid rate. One such system design, TESs, has the potential to disrupt the provincial energy paradigm by enabling P2P energy transactions and introducing new players to the electricity market that operate below the distribution level. This raises the question of if and how a socio-technical transition towards integrating TESs into Ontario's electricity system might arise.

This research paper has assessed the factors contributing to TES adoption in the province by employing the MLP framework to identify and understand Ontario's existing socio-technical regime, define and assess the disruptive potential of TESs as a socio-technical niche innovation, and analyze the socio-technical landscapes that exert pressure on the regime. The niche, defined as TESs, has been shown to have breakthrough potential in Ontario's electricity market. The regime, identified as the various energy sector actors and the province's climate change action commitments, is firmly-rooted but willing to adapt to a changing energy context. The landscape, identified as climate change, Ontario's economic restructuring, the province's centralized grid structure, and the growing trend of grid decentralization, has been shown to exert significant pressure on the regime, opening a window of opportunity for the niche to be adopted.

The phenomenon of climate changes has been shown to exert tremendous pressure on Ontario's energy regime, creating a demand for less environmentally-taxing generation methods. By definition, sustainable energy is environmentally benign, so its share of Ontario's generative capacity can be expected to grow alongside the growing demand for sustainable solutions in the energy regime. TESs, fitting the definition of a sustainable energy technology, are a viable option for integrating sustainable solutions in the form of RE into the grid.

The MLP framework identifies four transitional pathways that a technology can follow to either disrupt or not disrupt the socio-technical regime. Of the four pathways available, TESs are likely to follow the reconfiguration pathway to be adopted by the regime due to willing regime actors, the fact that TESs are a market-ready niche innovation, and significant yet slow landscape pressures. This paper finds that TESs are an unavoidable outcome of Ontario's ongoing energy sector development because of the province's collective accelerating DER awareness and support, the rise of new opportunities for business development surrounding transactive energy, a growing demand for consumer choice and autonomy with regards to energy, and the rapidly expanding understanding of climate change as a pressing threat that requires immediate action.

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