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Advancing a New Generation of Sustainability-Based Assessments for Electrical Energy Systems: Ontario as an Illustrative Application—A Review

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Abstract: Negative social and ecological trends are putting essential life-support systems at risk. Necessary responses include sustainability transformations in diverse sectors to enhance the planetary capacity to deliver more positive effects to all. Sustainability-based assessment frameworks are tools to guide the evaluation of initiatives in different human sectors and promote decisions that enhance overall social and ecological well-being. However, advancing sustainability remains difficult, in part because it must be pursued in a world of complex interactions and must respect the specifics of each case and context. This paper reports the process of building a sustainability-based assessment framework for electrical energy systems carried out by Aguilar. This work further specified the framework for electrical energy systems for application in the case and context of the electrical energy system in the Canadian province of Ontario. The illustrative application revealed that Ontario's electrical energy system has made some progress towards contributions to sustainability but requires improved efforts to be on a path to adequate transformation. The research found that the sustainability-based assessment framework for electrical energy systems is promising and well-suited for further application to particular electricity-related initiatives. However, more applications are needed to further test the utility of the framework and refine the proposed criteria.

Keywords: sustainability assessment; sustainability transformations; electrical energy systems

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1. Introduction

Electrical energy systems are relevant venues for sustainability applications since they play a key role in attaining widely accepted sustainability goals. For instance, electrical energy systems are expected to make important contributions to tackling poverty, meeting climate change commitments, and alleviating the long-term effects of the COVID-19 pandemic [1]. However, while they provide many essential services for human well-being, electrical energy systems need to better address the serious negative impacts that they contribute to social and ecological contexts—e.g., significant contributions to climate change [2], deepening inequities [3], poor air quality and health risks [4], and severe impacts to natural systems [5].

This paper is based on Aguilar's [6] doctoral thesis dissertation research on "Transforming electrical energy systems towards sustainability in a complex world: the cases of Ontario and Costa Rica". This work reviewed the literature on sustainability in complexity, electrical energy systems and sustainability, and directing transformations towards sustainability. It then synthesized the key learnings into a framework of sustainability-based assessment criteria specified for designing and evaluating electrical energy systems in the complex context of climate change and other pressing social and ecological issues that demand transformative responses. The resulting framework was further specified and applied to the context of two different jurisdictions with electrical energy systems in need of transformation with the aim to identify key learnings about barriers to and opportunities for transforming the electrical energy systems of the two jurisdictions. Full documentation of the research approach and findings is available in the published dissertation [6].

The discussion here focuses on the process of further specifying and applying the generic sustainability-based assessment framework for electrical energy systems to the case and context of Ontario. This process was useful as an illustrative application that was an initial test of the proposed framework's utility in identifying and evaluating key characteristics that are relevant to the specific context of Ontario. At the same time, applying the framework specified to Ontario contributed to an iterative process to further hone the specified criteria. The application revealed that the decision-makers responsible for Ontario's electrical energy system have made some progress in advancing initiatives that support sustainability efforts (e.g., coal phase-out, the incorporation of some renewable energies, advancements in the use of demand management tools). However, the province requires improved efforts to take transitioning steps towards designing electrical energy systems that make more significant contributions to attaining sustainability objectives. The research found that Ontario lacks effective long-term planning and needs greater efforts to promote more democratic and participatory governance as well as inter- and intra-generational equity. Additionally, cost-related issues have contributed to consistent increases in electricity prices and have hindered the capacity for attaining public approval of new design options.

This paper is structured as follows. First, it reviews the studies that are foundational for building the sustainability-based assessment framework proposed in this work. In particular, it considers approaches to sustainability that have been historically relevant, contributions of complex systems thinking that are essential to sustainability, next-generation sustainability-based assessment, and electrical energy systems as venues for sustainability applications. Second, this paper sets out the steps taken for building the sustainability-based assessment framework for electrical energy systems. The process consisted of adopting Gibson and colleagues' [7] generic sustainability requirements, specifying the basic requirements into a set of evaluation criteria that are applicable to the review of any electrical energy system, and further specifying the criteria to the context of Ontario. The data collection methods used included literature reviews, document research, and semi-structured interviews. Third, this paper introduces the illustrative application by describing the Ontario case context, including electrical energy system planning rules in Canada, the provincial energy system's structural characteristics and electricity mix, its management model, and the key actors involved. The fourth component is a presentation of the sustainability-based assessment framework specified for Ontario's electrical energy system, followed by a summary of the key system characteristics in light of the framework criteria and a summary of key findings from the Ontario case application. The final section discusses the significance of the findings and offers concluding insights from the elaboration and application of the framework. The proposed overarching electrical energy system evaluation criteria proved to be well-suited to further specification to recognize Ontario's main contextual considerations and are likely to be usefulin future applications in different cases and contexts.

2. Relevant Approaches to Sustainability

Sustainability is a concept that has been embraced by different cultures for most of human history to protect and restore valuable resources that are essential to the continuity of societies [8]. Sustainability efforts in recent history have focused on redirecting negative social, ecological, and economic trends to stay within the limits of what the planet can safely tolerate [9] while providing universal basic needs for social well-being [10]. However, human activities have continued to accumulate adverse effects on life-support systems and human security [6,11]. Consequently, the transition to sustainability-enhancing practices is increasingly relevant in local and global efforts to tackle pressing social and environmental crises.

Approaches to progress towards sustainability have been depicted in many different ways. The Brundtland Commission's ground-breaking work emphasized the interdependence of poverty reduction and environmental protection in development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" [12] (p. 15). The triple bottom line approach [13] focused on the combined importance of economic, environmental, and social factors as the pillars of sustainability efforts, in contrast to prevailing narrowly economic priorities. Gibson and colleagues' [7] sustainability assessment approach centred on basic requirements for moving towards sustainability and specifying them as criteria for application in different contexts with attention to interconnections and the avoidance of trade-offs. The planetary boundaries approach [9] stressed remaining within the finite capacity of natural systems to tolerate human-induced damage, to which Raworth [10] added concurrent efforts to build the basic social foundations for positive and just interactions between societies and the environment. The widely accepted Sustainable Development Goals [14] established a set of 17 interconnected global targets to be met by 2030 through unifying global efforts to reverse deepening severe risks to the planetary capabilities of providing prosperous futures for humanity and the ecological context.

While these different approaches have advanced our understanding of sustainability and how to pursue it, the sustainability agenda remains challenging, in part because it must be pursued in a world of complex interactions. Section 3 examines key insights from complexity thinking that should be considered in any effort to pursue sustainability in the context of complex social and ecological systems.

3. The Nexus of Sustainability and Complexity

Understanding the nexus between sustainability and complexity can be key to better attempts to transform human practices that endanger essential planetary systems and social prosperity [15]. Building on contributions from the fields of biology, psychology, and ecology in the study of living systems [16,17], complexity thinking recognizes the characteristics, dynamics, and interactions in and among social and ecological systems. In a complex world, sustainability cannot be attained in social, ecological, and economic silos. This is because complex systems are interlinked and influence each other through non-linear interactions that can have powerful but minimally predictable positive and adverse effects at multiple system scales [18–20].

Official long-term planning efforts to support sustainability objectives must be prepared for dealing with unexpected outcomes in different spatial and time scales. Complex systems are self-organizing and ever-changing and unfold uncertain and unpredictable system dynamics at multiple levels [17]. In this context, searching for solutions to current sustainability-associated issues by recreating past system dynamics and predicting future ones in the present (e.g., forecasting and modelling) is only partly effective [21,22].

Sustainability objectives must be fair, broad, and mutually reinforcing. In complex systems, the over-assertion of one main component over the others can debilitate the whole system, putting it at risk of irreparable consequences, including the collapse of life-support systems that are vital for human and environmental well-being [23–25]. In this context, fair representation of future generations, as well as the needs of different actors in different systems, are essential in overall sustainability efforts.

Complex systems have the capacity to transform into systems with new dynamics and key characteristics [26–28]. For sustainability purposes, this means that systems that have rooted dynamics that are risky to social and ecological well-being can be transformed towards more desirable behaviours. In complex systems, a transformation usually happens as an accumulation of transitioning effects, resulting from diverse multi-scale transition dynamics that push systems across thresholds to new functions and structures [15,26,29].

While transformation in complex systems can happen as a result of the dynamic qualities and effects of system interactions, it can also be influenced by human intent. Human-induced transformation is driven by human dynamics that emerge in response to and with the contributions of those experiencing the social and ecological environment [30–32]. When systems are delivering negative effects, human intent can intervene and push change in entrenched system dynamics to accumulate more positive effects. One key consideration is seeking multiple and mutually reinforcing sustainability-contributing packages that feed systems with positive effects stimulating change towards more desirable system behaviours [33–35].

Complex systems have the capacity for resilience. They can retain vital functions in the face of disturbances by adapting and transforming if they are not too debilitated to reorganize [36–38]. Complex systems' capacity for resilience is key to transforming systems to deliver more positive sustainability-associated effects while maintaining already desirable characteristics. When entrenched dynamics accumulate detrimental effects on social and ecological behaviours, transformation is needed to redirect systems to deliver more positive effects [29,39,40]. In such cases, building resilience at multiple system scales can provide a large-scale context for disrupting smaller-scale components that pose risks to the resilience of the larger system, without compromising the whole [38,41].

While it is possible to direct desirable changes, sustainability efforts must consider that system transformations are very difficult to manage. In complex systems, change cannot be fully controlled since changes usually happen abruptly, unexpectedly, and unpredictably [42–44]. Therefore, changes must be implemented with precaution. For sustainability purposes, system interactions can be managed to create favourable conditions for retaining the system's desirable functions and enhancing the positive effects they can provide to all [18,42,45]. However, different agents of change may perceive differently what is desirable for the system. Therefore, while system agents can have positive effects, they also have the capacity to resist transformation if it threatens their favourable individual states [46–48].

Finally, sustainability in a context of complexity does not have an ultimate end form. Social and ecological systems usually sustain themselves by changing their components indefinitely, without a preferred state [49–51]. Additionally, the dynamics between system components vary with their social and environmental context [7,52,53]. In a complex world, sustainability is an ever-moving target, rather than a fixed one, which requires consideration of the specific characteristics of different venues of application.

Section 4 highlights the need to move towards the next generation of explicitly sustainability-based assessments that are better suited than first-generation environmental assessment approaches to deal with the complex interactions of our world addressed above.

4. Sustainability-Based Next-Generation Assessments

Sustainability-based assessment frameworks are tools to guide the evaluation of initiatives in different human sectors and promote decisions that enhance overall social and ecological well-being [54]. First-generation assessment approaches focused mostly on identifying the less environmentally harmful options for particular projects [7] (Ch. 2). While the best initial practices have provided important benefits (e.g., identifying the need, purpose, alternatives, and potential cumulative effects of individual undertakings) [55], first-generation assessments have suffered from limited scope in a context of complexity and insufficient ambition in the context of unsustainable trajectories.

Next-generation assessment is a package of linked components that combines responses to common deficiencies of first-generation approaches and attention to emerging demands in a world of recognized complexity and needs for transition to sustainability [56]. Among the package's substantive and procedural considerations for designing and implementing updated assessment regimes, the most important components for this discussion here are sustainability objectives, precautionary respect for complexity and uncertainty, broad engagement and transparency, inter-jurisdictional collaboration, independent administration, and emphasis on mutually-supporting assessments at the strategic level of policies, plans, and programs, and the level of individual projects. With a sustainability agenda and open process, this integrated, multi-level approach is meant to facilitate a more farsighted, efficient, credible, defensible, and consistent delivery of lasting benefits from applications, including the review and re-consideration of electrical energy systems.

One key consideration for next-generation efforts is the need to specify assessment criteria for application in the particular contexts of different socio-economic and jurisdictional sectors. Section 5 suggests main objectives that should be incorporated in next-generation sustainability-based assessment frameworks with criteria specified for the evaluation of electrical energy system-related initiatives.

5. Electrical Energy Systems as Venues for Sustainability Applications

As mentioned above, sustainability assessment requires specification to the context of application in different social–ecological systems. Electrical energy systems are relevant venues for sustainability applications since they are key to attaining overall sustainability goals [57]. The literature review carried out in this research work synthesized seven desirable sustainability objectives for electrical energy system design. This section uses the identified objectives to illustrate and undertake a specified sustainability-based assessment of electrical energy systems, recognizing key options, possibilities, and needs to make broader contributions to sustainability. The following list provides only a broad picture of the seven main topics discussed in the literature. More detailed considerations are discussed below.

5.1. Providing Accessible, Reliable, and Affordable Electrical Energy Services for All

Today, electricity services are essential to basic human aspirations. Sustainability applications must seek to enhance electrical energy systems' capability to ensure accessible, reliable, and affordable electricity for all. For instance, the main sectors that require maximized contributions to meeting the Sustainable Development Goals—e.g., health, food, and transportation—are highly reliant on access to reliable electricity [57]. The supply of reliable electricity is also essential for energy security, including self-sufficiency and the capacity to respond to threats and unexpected events—e.g., geopolitical, economic, political, and technological [58,59]. Additionally, reliable electricity services are key contributors to nations' economic revenue and the provision of jobs [60].

5.2. Reducing and Reversing Greenhouse Gas Emissions and Climate Change

Since energy-associated operations have been major contributors to climate change, sustainability applications in electrical energy systems must emphasize the reduction in harmful emissions to the atmosphere. Roughly two-thirds of global greenhouse gases (GHGs) have been emitted by energy system activities [61]. In the last decade, energy-related GHG emission increases averaged 1.5% yearly, setting a historic record of 55.3 GtCO2e in total emissions in 2018 [62]. While the temporary decrease in energy consumption caused by the COVID-19 pandemic contributed to a 6% decrease in energy-related CO2 emissions in 2020, electricity and heating were still responsible for 40% of global emissions [61].

5.3. Protecting Social–Ecological Integrity

The high demand for natural resources for energy system purposes (e.g., metals, non-metallic minerals, fossil fuels, biomass, water, land) has resulted in detrimental effects on social–ecological systems. Energy systems' operations for resource extraction have been key to global increases in the average material demand per capita—from 7.4 tonnes per capita in 1970 to 12.2 tonnes per capita in 2017 [63]. As a result, associated damages to ecosystems and releases of harmful substances to the environment have contributed to severe irreversible impacts—e.g., poor air quality has caused millions of deaths [5], and roughly one million flora and fauna species face extinction [6].

5.4. Increasing the Systems' Capacity for the Development, Deployment, and Integration of Diverse Renewable-Sourced Energy

Renewable energy has gained attention as an electrical energy system design option that can make significant contributions to tackling climate change and reducing electricity costs. Renewable energy is reportedly now the cheapest form of energy, and investments in renewable energy can save countries billions of dollars [64]. Also, renewable energy and electrification can reduce energy-related GHG emissions by 75% [65]. Since political influence can be a key barrier to the wider adoption of renewable energy, some works have focused on understanding and proposing options for removing political barriers to maximizing the potential benefits of renewable energy [66–68]. The remaining concerns about renewable energy-based systems are related to inter- and intra-generational affordability, vulnerability to price volatility, and compatibility with market incorporation models [69,70]. Additionally, some works have paid attention to the best means of managing the unpredictable and intermittent nature of renewable energy resources [71,72].

5.5. Maximizing the System's Efficiency, Cost-Effectiveness, and Conservation and Demand Response Capacity

Energy efficiency has been identified as key to reducing costs, as well as harmful emissions to the atmosphere and waste [73]. Energy storage as a design option has gained attention due to its multiple applications and its potential to address the problem of renewable energy intermittency and improve end-user management [74,75]. Some authors have stressed, however, that energy storage advocates need to further address the potential adverse impacts of mainstream use (e.g., toxic waste and extraction of materials) [76,77]. In this context, conservation and demand management have also been promoted as technical components and policy options to diminish resource use, waste, and consequent costs [78,79].

5.6. Enhancing Capacity for Democratic and Participatory Governance Processes

For sustainability purposes, it is important that globally pressing issues are tackled through more evenly distributed, democratic, and just forms of energy governance [80,81]. Effective governance of energy-related initiatives requires seeking public approval through the appropriate consultation, assessment, and consideration of societal and environmental impacts [82]. These aspects are key to facilitating collective action and knowledge integration necessary for better understanding and tackling energy-related and broader sustainability issues [83,84]. This includes promoting energy justice in its different dimensions—distributional [85], recognition [86], and procedural [87]. Ignoring democratic processes to favour vested interests can hinder energy sovereignty and citizenship, gender and race equality, and sufficiency for all [88,89].

5.7. Supporting Design Options That Minimize Vulnerability and Maximize Capacity to Recover from Potential Threats

Broadly, enhancing system capacity for resilience is needed to deal with possible disturbances and threats to the reliability of the system [90,91]. Modularity and flexibility have been identified as desirable system characteristics to minimize vulnerability and maximize recovery capacity. The development and use of modular technologies can greatly enhance prospects for the integration of electricity obtained from diverse sources in a safe, effective, and efficient manner [92,93]. Modular designs can also significantly lessen the severity of consequences of natural disasters, accidents, and other threats to system integrity [94,95].

Section 6 explains the steps taken in this work to incorporate the sustainability objectives discussed above into a set of sustainability assessment criteria and introduces the resulting sustainability-based assessment framework specified for application to electrical energy systems.

6. Sustainability-Based Assessment Framework for Electrical Energy Systems

One main outcome of the research was the elaboration of a sustainability-based assessment framework specified for electrical energy systems. This framework was designed as a tool for evaluating electricity-related policy- and decision-making, long-term energy plans, and project proposals in any jurisdiction. Further specification of the framework for application to a particular case and context will follow in Section 7.

The frameworks discussed here and in Section 7 do not represent the only possible approach to assessing electrical energy systems. Academics and practitioners have published a diversity of research findings and analyses that incorporate important sustainability factors in planning and evaluating electrical energy systems, e.g., [96–100]. These works have advanced understanding of many relevant concerns and opportunities and have facilitated more attention to sustainability factors in or along with the usual suite of electrical energy system design priorities (efficiency, reliability, accessibility, etc.). However, these contributions have typically focused on limited sets of sustainability issues and response options. In contrast, the approach summarized and illustrated here has begun with the full sustainability and complexity agenda—a comprehensive set of requirements for progress to sustainability, recognition of the complex dynamics of multi-scale systems, and respect for the differences among particular cases and contexts. It offers both criteria broadly applicable to all electrical energy systems and means of specification of these criteria for application in the diversity of individual jurisdictions in which electrical energy systems are designed and managed. Given this approach, the frameworks presented here depart from, but also complement, the more focused work that prevails in the literature. The process for building the broad framework for assessing electrical energy systems started by adopting Gibson et al.'s (revised and updated from [7]) requirements for progress towards sustainability as a generic set of objectives that should be addressed in, and specified to the context of, any major undertaking that aims to maximize contributions to sustainability (Table 1). The utility of the set of requirements is supported by different applications, including in energy-related undertakings, at strategic and project levels [1,33,101]. However, the sustainability requirements are only the basic elements that need to be considered, and significant contributions need to be made in each of them, depending on context.

Table 1. Gibson et al.'s [7] requirements for progress towards sustainability.

Socio-ecological system integrity
Build human–ecological relations that establish and maintain the long-term integrity of socio-biophysical systems and protect the irreplaceable life-support functions upon which human and ecological well-being depend.
Livelihood sufficiency and opportunity
Ensure that everyone and every community has enough for a decent life and opportunities to seek improvements in ways that do not compromise future generations' possibilities for sufficiency and opportunity.
Intragenerational equity
Ensure that sufficiency and effective choices for all are pursued in ways that reduce dangerous gaps in sufficiency and opportunity (and health, security, social recognition, political influence, etc.) between the rich and the poor.
Intergenerational equity
Favour present options and actions that are most likely to preserve or enhance the opportunities and capabilities of future generations to live sustainably.
Resource maintenance and efficiency
Provide a larger base for ensuring sustainable livelihoods for all while reducing threats to the long-term integrity of socio-ecological systems by reducing extractive damage, avoiding waste, and cutting overall material and energy use per unit of benefit.
Social–ecological civility and democratic governance
Build the capacity, motivation, and habitual inclination of individuals, communities, and other collective decision-making bodies to apply sustainability principles through more open and better-informed deliberations, greater attention to fostering reciprocal awareness and collective responsibility, and the more integrated use of administrative, market, customary, collective, and personal decision-making practices.
Precaution and adaptation
Respect uncertainty, avoid even poorly understood risks of serious or irreversible damage to the foundations for sustainability, plan to learn, design for surprise, and manage for adaptation.
Immediate and long-term integration
Attempt to meet all requirements for sustainability together as a set of interdependent parts, seeking mutually supportive benefits.

The next step was specifying the basic requirements into a set of evaluation criteria that are applicable to the review of any electrical energy system and that should not be overlooked in any related endeavour. For this purpose, the research identified specification factors for the design of electrical energy systems that aim to make broader positive contributions to sustainability. The specification factors included key characteristics and issues of electrical energy systems, key themes in recent energy paths discussions, system design options that should advance progress towards overall sustainability goals, and desirable objectives for designing electrical energy systems. Contributions from previous works that applied Gibson and colleagues' approach to energy-related initiatives were also considered in the selection of the criteria set comprising the initial framework.

The literature on transformations towards sustainability provided the concepts and approaches that informed key considerations for designing and assessing transformational proposals and initiatives. These considerations were specified into a novel criteria category that considers the comprehensive sustainability agenda as interdependent with the sustainability and transformation goals more specific to electrical energy systems in response to sustainability-associated challenges. The criteria category incorporates and is applicable to the eight generic sustainability requirements for progress towards sustainability and provides a transformative lens for the proposed specified criteria categories. The resulting framework, shown in Table 2, is made of six criteria categories, each with a set of mutually reinforcing sub-criteria specified for application to electrical energy systems in any jurisdiction.

Table 2. Sustainability-based assessment framework broadly specified for electrical energy systems.

Climate safety and social–ecological integrity
• Reducing and reversing harmful GHG emissions and damages to carbon and sinks that aggravate global warming • Mitigating and adapting to already unavoidable adverse social and ecological effects associated with climate change • Enhancing human health by maximizing air quality, reducing toxic waste, and ensuring safe management in all life-cycle processes • Minimizing threats to biodiversity and ecological integrity, including toxic substances, resource depletion, animal and plant species extinction, and pollution, in all life-cycle processes • Preserving main system characteristics that contribute to lasting socio-economic well-being and generate positive social–ecological system dynamics and effects
Intra- and inter-generational equity, accessibility, reliability, and affordability
• Favouring direct and indirect employment opportunities that are well-paid, long-lasting, conveniently located, and otherwise accessible, fulfilling/challenging, etc. • Promoting distributional justice related to the benefits and risks of electrical energy system operations, addressing energy poverty by avoiding the creation of negative effects, and ensuring the fair provision of positive effects among present and future generations across regions, gender, race, Indigenous/non-Indigenous people, poor and rich, and marginalized groups • Favouring technical and policy options that maximize system capacity to provide electricity access and power essential human services for poor and remote areas • Ensuring technical viability (e.g., reliability, resilience, safety, adaptive capacity, ease of repair, etc.) • Ensuring economic viability (e.g., capital and operating costs and risks in the short and long term in comparison with other design options available)
Cost-effectiveness, resource efficiency, and conservation
• Increasing capacity for the development and integration of reliable and affordable renewable-sourced energies that reduce negative climate change effects • Decreasing reliance on fossil fuels • Enhancing technical demand management capacity to match electricity quality and quantity to end-user needs (e.g., storage, smart grid technologies, demand response options) • Preserving and enhancing natural (and other meaningful) resources that are essential for community well-being • Minimizing provision costs and socio-ecological costs, which are predominantly caused by life-cycle losses in generation and delivery activities

Table 2. *Cont.*

Democratic and participatory governance
• Maximizing the capacity for democratic and participatory deliberation that facilitates public consultation and acceptance through explicit and transparent processes • Building favourable conditions for open and informed discussion with the integration of experts, stakeholders, vulnerable groups, and local knowledge, and ensuring particular attention to the adequate representation of Indigenous peoples' rights and interests in decision-making • Recognizing and addressing political barriers embedded in electrical energy systems that undermine democratic and participatory governance (e.g., powerful political and economic interests) • Enhancing understanding and other capacities for just transitioning, opening windows of opportunity, and mobilizing key actors' influence for positive change • Favouring a policymaking design that clarifies the implications of attaining climate and associated social–ecological objectives
Precaution, modularity, and resiliency
• Favouring prudent and precautionary decision-making in consideration of unpredictability and incomplete understanding of complex dynamics • Supporting design options that minimize vulnerability and maximize recovery capacity to potential threats (e.g., natural disasters, accidents, system malfunctions, terrorist attacks, etc.) • Favouring technology with high adaptive capacity for modifications over time, as well as design options for greater system compatibility • Minimizing social, economic, and biophysical risks in planning and decision-making for the electrical energy systems of the future • Avoiding planning and decision-making that increase path dependency (e.g., capital-intensive, massive long-term projects with low capacity for modifications over time)
Transformation, integration of multiple positive effects, and minimization of adverse effects
• Accumulating positive sustainability-oriented effects for desirable change while avoiding trade-off scenarios that pose risks to already disadvantaged groups through the implementation of multiple and mutually reinforcing sustainability-contributing packages of initiatives • Enhancing the capacity for addressing governance challenges of transforming towards sustainability by incorporating governance design options that facilitate transformations (e.g., collaboration and multi-scale alignment, self-examination and clarification of political dynamics, adaptive capacity in policy- and decision-making for long-term considerations, specification to context) • Supporting just transitions to ensure that transformation planning and practice build the resilience of what is valuable and pay special attention to the interests of the most vulnerable • Developing pathways to sustainability that address combinations of policy and technical options, deliberative processes, and strategic approaches that aim to identify how specific desirable targets can be reached, instead of aligning decision-making to predictions based on current technical and economic trends • Facilitating the complementarity of different approaches to transformation by taking diverse knowledge seriously, accepting a plurality of pathways to sustainability, and embracing the political nature of transformations

After the initial sustainability-based assessment framework was specified for application to electrical energy systems, the next step was further specifying the framework to the jurisdictional context of Ontario. This step involved applying the sustainability-based assessment framework to identify key characteristics and conducting an initial assessment of jurisdictional electrical energy system planning and associated decision-making in recent years. The findings from this exercise were used to identify contextual characteristics to further hone the framework. The specification process followed Gibson's [33] steps of criteria specification but was iterative and adjusted as needed to provide criteria categories with the same level of importance. For this task, the collected data were a primary resource to inform specification and application.

Data Collection

The research adopted three case study methods for data collection: literature review, document research, and semi-structured interviews.

The literature review included an analysis and synthesis of three encompassing areas of knowledge: sustainability in complexity, electrical energy systems and sustainability, and directing transformations towards sustainability. The key learnings drawn from the literature provided a theoretical understanding of best designing sustainability-based assessment frameworks for electrical energy systems that can be further specified to different jurisdictional contexts.

Document research was key to identifying jurisdictional historical and political contexts, conventional planning perceptions, efforts to change, and related issues. This involved an extensive review of official publications by government and non-government organizations, private sector reports, legislative pieces, press coverage, and academic articles. Overall, the document research provided a better understanding of contextual issues and official responses reflected in government announcements, energy plans released, approval of bills, and press coverage of electrical energy system-related events.

The semi-structured interviews were essential to supporting the literature review and document research and refining the specified framework criteria. Eight interviews were conducted with participants with deep knowledge, familiarity, and involvement in Ontario's electricity sector. The interviewees represented five different sectors of experience: government (one), industry (one), utility companies (three), academia (one), and social community representatives (two). The interviews were guided by a questionnaire consisting of five open-ended questions and some additional follow-up questions that aimed to evoke and collect insights that can be interpreted and analyzed under the framework criteria. The contributions from the interviewees were incorporated into the analysis in a manner that emphasizes the comments more than the particular sources. However, the incorporation of the contributions to the analysis aims to provide a context according to the area of expertise and the insights provided by each of the interviewees.

Figure 1 illustrates the process used for building the broad assessment framework for application to electrical energy systems generally and for further specification of this framework to the context of Ontario. Insights from the literature review on the main areas of knowledge informing the theoretical foundations were synthesized to establish the broadly applicable sustainability-based assessment framework for assessing electrical energy systems. Then, the data were collected from the document research and interviews and supported the process for further specification and application to the context of electrical energy system planning in Ontario, the selected case study jurisdiction.

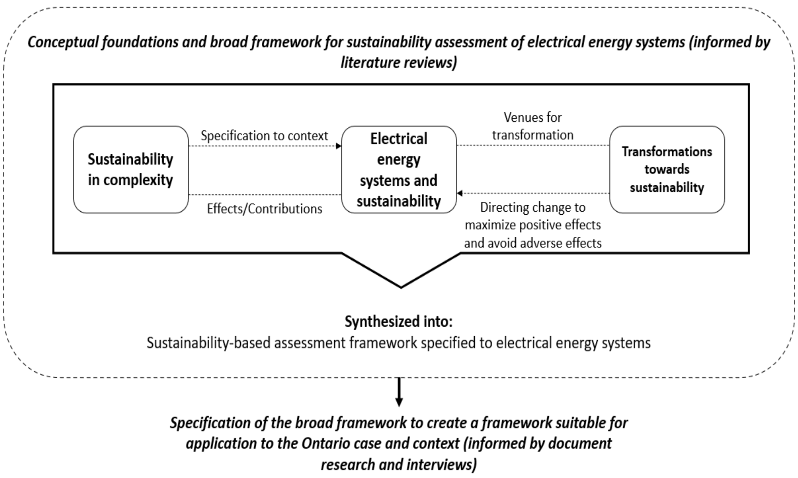

Figure 1. The process for building and specifying the sustainability-based assessment framework for electrical energy systems and the associated data collection methods.

Section 7 presents a condensed account of the Ontario case study carried out as a part of Aguilar's [6] research. The section reviews Ontario's electrical energy system as a specific venue for applying the proposed sustainability-based assessment framework for electrical energy systems. It also presents the sustainability-based assessment framework specified to the jurisdictional context of Ontario and a summarized version of key case findings from Aguilar's work.

7. Illustrative Application: Ontario's Electrical Energy System

As mentioned above, the proposed sustainability-based assessment framework for electrical energy systems was specified and applied to the jurisdictional context of Ontario for illustrating and preliminary testing the utility of the framework. This section provides a description of Ontario's contextual characteristics that are relevant to the jurisdictional electrical energy system and that require consideration in the specified framework. These include electrical energy system planning rules in Canada, provincial structural characteristics and electricity mix, management models, and key actors involved. Afterwards, the sustainability-based assessment framework specified for Ontario's electrical energy system is presented. The section also includes a description of relevant characteristics that were identified from and are relevant to the specification and application of the framework criteria.

7.1. The Ontario Context

Canada's Constitution allows every province a high degree of autonomy for decision-making in their electrical energy systems. Each province, for example, has the responsibility to plan its own "development, conservation and management of sites and facilities in the province for the generation and production of electrical energy" [102].

Ontario has roughly 120 generating stations [103], with a rough transmission-connected capacity of 38,214 megawatts [104], and a rough distribution-connected capacity of 3559 megawatts [105]. Provincial electricity is generated from six different fuel sources—nuclear, hydro, natural gas, wind, solar, and biofuel. In 2022, Ontario generated roughly 146.85 terawatt-hours of electricity, with nuclear power having the highest share in this mix at 53.7%, followed by hydro at 25.9%, natural gas at 10.4%, and wind at 9.4% [106]. Notably, Ontario completed the process of closing coal-fired power plants in 2015, motivated by severe public health issues related to poor air quality [107].

Ontario's electrical energy system is managed as a hybrid operational model. That is, the government defines overall system planning and the components of long-term projects and contracting, but the market is free for private actors to compete for contracts [108,109]. This process is carried out by a cluster of provincially created entities assigned to oversee different aspects of the sector's operations. Since the different regions in Ontario have their own contextual electricity needs, the provincial government coordinates electricity planning at the local, regional, and provincial scales [110]. These have as their main goals the coordination of multi-regional planning, the engagement of citizens, and the integration of design options [110].

7.2. Key Actors in Ontario's Electrical Energy System

Most of Ontario's electricity is generated by Ontario Power Generation, a Crown corporation owned by the province [111] and, provincial-scale transmission activities are mostly run by Hydro One, which is majorly government-owned [112]. Meanwhile, the local electricity supply is managed by local distribution companies [111]. The Independent Electricity System Operator (IESO), another Crown corporation, is a key actor in managing the provincial electrical energy system. The operations of the IESO, which are subject to the requirements of the Ministry of Energy, Northern Development and Mines, and the Ontario Energy Board, include overseeing electricity grid operations in real-time, directing overall electrical energy system planning, and managing the involvement of participants in the electricity market [113]. The Ministry of Energy, Northern Development and Mines develops the policy and legislative frameworks that guide the provincial system operations [114]. The same Ministry is responsible for advancing the economic development of the northern portion of the province and for regulating the mining sector [114]. The Ontario Energy

Board is a government agency that regulates the provincial electricity sector and enforces the laws set in the legislation [115]. The Ontario Energy Board's key responsibilities include setting electricity rates and reviewing proposals for electricity-related projects, initiatives, and long-term planning [115]. Other key actors outside the governmental sphere have a major influence on electricity policy and decision-making. For instance, major power consumers, Indigenous peoples, communities, and private generators can influence the success or failure of proposed plans [116,117].

7.3. Ontario-Specific Framework

Table 3 presents the result of an exercise that took the broad framework of sustainability-based assessment criteria for electrical energy systems and specified them for application to the Ontario context. This framework incorporates the findings from the Ontario case study by Aguilar [6], which evaluated Ontario's electrical energy system and associated planning in recent years. This exercise was used to further hone the broadly specified framework and develop sub-criteria based on relevant themes that appeared in the Ontario context and that were supported by the contributions from the interviewees. The framework is meant to work as a tool for application in future evaluations of electrical energy system-related efforts, such as provincial plans, projects, and initiatives in the province.

Table 3. Proposed sustainability-based assessment framework specified for application to Ontario's electrical energy system.

1. Climate safety and social–ecological integrity
1.1. Reducing and reversing GHG emissions to the atmosphere and damages to carbon sinks that aggravate climate change, as well as adapting to and mitigating associated adverse effects ○ Minimizing GHG emissions and protecting carbon sinks in all life-cycle processes of the electrical energy system's operations—e.g., generation, distribution, and transmission ○ Maximizing the share of renewable energy sources by facilitating promising options in the overall electricity mix ○ Enhancing the development and implementation of smart grid tools that are promising to efficiency and GHG emission reductions—e.g., smart meters and energy storage. 1.2. Preserving citizen's health and community well-being ○ Maintaining safe air, water, and soil quality levels through the minimization of toxic waste emissions and the promotion of safe management in all life-cycle processes ○ Avoiding design options that pose risks of significant adverse effects to human well-being and the environment if the system fails unexpectedly—e.g., system malfunction, extreme weather conditions, accidents, and releasing harmful substances to the environment 1.3. Maintaining life-support systems that contribute to socio-economic benefits, such as long-lasting jobs and livelihood sufficiency ○ Minimizing electricity project-related impacts on soil quality and agricultural land, as well as fisheries and forest areas 1.4. Preserving biodiversity populations and natural habitats to enhance the potential for positive social–ecological dynamics and effects ○ Supporting technology and policy options that avoid threats to animal species and negative impacts on habitats ○ Favouring electricity generation and delivery projects that minimize risks of harmful impacts to biodiversity in all life-cycle processes—e.g., material procurement, construction, operation, and waste disposal

Table 3. *Cont.*

2. Intra- and inter-generational equity, accessibility, reliability, and affordability

2.1. Providing equity in opportunity for present and future generations, including decent and long-lasting jobs, livelihood sufficiency, and improvement to Indigenous peoples and disadvantaged groups

- Ensuring that consultation obligations and appropriate compensation when necessary to Indigenous peoples and rural communities are respected
- Supporting policymaking and electrical energy system projects that enable community-oriented benefits that avoid risks to present and future generations
- Favouring project proposals that can create direct and indirect employment opportunities that are well-paid, long-lasting, conveniently located, and otherwise accessible, fulfilling/challenging, etc.

2.2. Favouring system design options that are easy to understand, operate, and adjust over others that require higher levels of specialization and technical expertise

2.3. Ensuring affordable electricity for all citizens, including Indigenous peoples and rural communities, as well as major power consumers that provide essential services for socio-economic well-being

- Promoting cost-effective and efficient options in electricity projects and programs to reduce global adjustment and other operation costs
- Supporting pricing tools and smart technologies that help to better align electricity supply and demand and promote off-peak consumption—e.g., advanced metering infrastructure, smart meters, and self-healing grids
- Avoiding long- and short-term economic risks in project approval—e.g., long-term commitments to high capital and operation cost projects

2.4. Ensuring technical reliability and viability for all citizens, including Indigenous peoples and rural communities, in the face of unexpected events (e.g., extreme weather, blackouts, and system malfunction)

- Supporting the development and implementation of technology options that can increase the modularity, reliability, resiliency, and safety of the electrical energy system—e.g., smart grid and self-healing grid tools

3. Cost-effectiveness, resource efficiency, and conservation

3.1. Minimizing provision costs and social–ecological costs

- Enhancing the capacity for public approval of proposals that are cost-effective in terms of provision costs (e.g., costs related to construction, operation, and distribution) and social–ecological costs (e.g., costs related to poor air and water quality and the impacts on human health)
- Minimizing electricity losses in all life-cycle processes of generation and delivery activities

3.2. Minimizing the consumption of natural and community-valued resources

- Enhancing electrical energy systems' efficiency and matching electricity quality and quantity to end-user needs
- Maximizing the approval of options for new energy infrastructure and retrofitting that minimize electricity losses in all life cycles of existing and proposed projects

3.3. Building policy and technology pathways that enable the development and implementation of efficiency tools such as energy storage, smart grid technologies, and demand response options

- Increasing the capacity of industries and major power consumers for off-peak consumption—e.g., smart grid tools
- Enhancing aligned multi-jurisdictional efforts for the widespread adoption of community engagement in energy efficiency and conservation programs
- Enabling the further development of current technologies and implementation stages for conservation and demand management tools

3.4. Building capacity to avoid reliance on the extraction and consumption of fossil fuels

- Enhancing technical capacity for increasing the share of renewable energy in the electricity mix reliably and at affordable costs
- Maximizing public acceptance, technological development, and policy pathway creation for the widespread adoption of affordable and reliable renewable energies

Table 3. *Cont.*

4. Democratic and participatory governance

4.1. Ensuring democratic and participatory deliberation that promotes consultation with experts, stakeholders, Indigenous peoples, vulnerable groups, and community leaders, and attains public acceptance through explicit and transparent processes

- Avoiding the streamlining of official processes for faster approval of electrical energy system projects, as well as decision-making that is based only on technical and economic considerations
- Ensuring that decision-making considers community needs—e.g., addressing citizens' health and safety (and other) concerns, finding effective means for the equitable distribution of financial benefits, promoting community participation, and respecting cultural heritage landscapes

4.2. Enhancing capacities for innovation and knowledge integration from the citizens, Indigenous peoples, key actors, and communities in the province

- Enhancing reflexivity to recognize political pressures in governance processes (e.g., agency, vested interests, power dynamics)
- Increasing citizen engagement for the adoption of renewable energy and demand response technologies
- Maximizing the alignment of policy development efforts between multiple jurisdictions (e.g., federal, provincial, municipal)

4.3. Favouring policymaking design and planning that clarifies the implications of attaining climate and associated social–ecological objectives

- Promoting the incorporation of tools for policy pathway development that are better suited for breaking negative trends—e.g., backcasting and scenario planning

5. Precaution, modularity, and resiliency

5.1. Supporting prudent and precautionary policy- and decision-making in consideration of unpredictability and incomplete understanding of complex social–ecological dynamics

- Favouring design options that avoid risks of severe socio-economic crises and irreversible damage to vital life-support systems
- Increasing the system's adaptive capacity for modifications over time as well as greater system compatibility for the integration of diverse sources to the grid
- Avoiding project proposals that increase path dependency and pose socio-economic and environmental risks (e.g., capital-intensive, massive, and wasteful long-term projects with a low capacity for modifications over time)

5.2. Supporting design options that minimize vulnerability to system failure and maximize recovery capacity to potential threats (e.g., extreme weather events, blackouts, system malfunctions, release of toxic waste, etc.)

- Building policy pathways for the development and deployment of technologies that increase the modularity, flexibility, and resilience of the electrical energy system—e.g., energy storage, demand/supply monitoring, smart grids, microgrids, self-healing grids, etc.
- Increasing the widespread adoption and public approval of smart grid tools and initiatives for community engagement

Table 3. *Cont.*

6. Transformation, integration of multiple positive effects, and minimization of adverse effects
6.1. Accumulating positive sustainability-oriented effects for desirable change while avoiding trade-off scenarios that pose risks to already disadvantaged groups through the implementation of multiple and mutually reinforcing sustainability-contributing packages of initiatives ○ Implementing official energy plans with sets of goals and criteria oriented to accumulate benefits that are compatible and mutually supportive among sectors (e.g., electricity, transportation, buildings, residential, etc.) 6.2. Enhancing capacities for addressing governance challenges that hinder the accumulation of positive effects by incorporating effective governance design options ○ Advancing knowledge and practical capacities for more effective collaboration and multi-scale alignment, self-examination and clarification of political dynamics, adaptive capacity in policy- and decision-making for long-term considerations, and specification to context 6.3. Supporting just transitions to ensure that electrical energy system planning and operations build the resilience of what is valuable and pay special attention to the interests of the most vulnerable ○ Respecting consultation obligations with those most affected by system operations ○ Avoiding decision-making and trade-offs that prioritize economic and political interests by creating intra- and inter-generational burdens to vulnerable groups, citizens, and the environment ○ Providing more effective targeted relief to those that are more affected by ongoing and unavoidable changes (e.g., climate change, price increases, and COVID-19 pandemic effects) 6.4. Developing pathways to sustainability that address combinations of policy and technical options, deliberative processes, and strategic approaches that aim to identify how specific desirable targets can be reached, instead of aligning decision-making to predictions based on current technical and economic trends ○ Promoting backcasting, scenario planning, and other visioning and negative trend-breaking approaches identified for policy design and planning 6.5. Facilitating the complementarity of different approaches to transformation by taking diverse knowledge seriously, accepting a plurality of pathways to sustainability, and embracing the political nature of transformations ○ Promoting effective and meaningful engagement with key actors in the electrical energy system to strengthen the complementarity of diverse approaches for knowledge co-production and innovation

7.4. Strengths and Limitations of the Ontario Electrical Energy System Revealed through Application of the Case-Specified Sustainability-Based Criteria

The Ontario-specific framework set out in Table 3 was applied to the Ontario case as informed by the document research, and the insights provided by key informant interviews. Table 4 presents the main findings, identifying strengths and weaknesses of the system as considered in light of the case-specified criteria. Recognition of these strengths and weaknesses should be useful for further developing sustainability-based assessment frameworks and for future applications; in particular, electricity system-related projects and initiatives in Ontario.

Table 4. Key strengths and limitations of Ontario's electrical energy system.

Climate safety and social–ecological integrity
• Provincial authorities have paid insufficient attention to climate change goals and federal commitments to attain net-zero emissions (1.1) • Poor air quality and health issues motivated the closure of coal-fired power plants [107] (1.2) • The IESO [108] has reported that GHG emissions by the electricity sector are expected to increase to over 10 mega-tonnes of CO2e by 2028 (1.1, 6.3) • The province has removed requirements for an integrated strategic plan that clarifies how the climate and related socio-ecological targets will be met [118] (1.1, 1.2, 4.3, 6.1) • Public approval of and financial support to climate change-related initiatives has been stifled by cost-related challenges (e.g., increasing electricity prices) (1.1, 3.1)

Table 4. *Cont.*

Intra- and inter-generational equity, accessibility, reliability, and affordability
• Canada provides access to reliable electricity to 100% of the population [119] (2.1, 2.4) • In addition to longer-term planning, Ontario maintains and reports on in-place resource and transmission capacity to continue providing reliable electricity to all for many months [104] (2.4) • A long history of cost-related issues has undermined the system's capacity to provide affordable electricity for all (2.3, 3.1) • Subsidy programs to help maintain affordable electricity are expected to cost the province hundreds of billions of dollars, posing risks of continuing price increases in the next two decades [120] (2.3, 3.1, 6.3) • New system components (e.g., energy storage, distributed generation, renewable energies) and emerging characteristics (e.g., more distributed systems with the addition of many moving parts and with electricity flowing multi-directionally, instead of the conventional linear supply flow) require innovative and adequate policy options and technological developments to ensure system reliability (2.4, 3.3, 5.2) • Indigenous peoples' and local communities' needs and benefits (e.g., long-term and more equal opportunities for livelihood) require greater attention in provincial electricity-related initiatives (1.3, 2.1, 4.1, 6.3)
Cost-effectiveness, resource efficiency, and conservation
• The provincial system can reduce costs and provide associated benefits through available options for efficiency and conservation [73] (2.2, 3.1, 3.3) • Some progress has been made in the adoption of cost-effective options [121] and efficiency and conservation programs [122], but changing political contexts can undermine the continuity of such efforts (3.1, 3.2, 3.3, 4.2, 6.2) • The province has made relevant decisions towards maintaining a nuclear-based electrical energy system [123] and away from promoting a renewables-based one [124] (1.2, 1.4, 2.2, 2.3, 3.4, 5.1) • Costly options have been favoured in recent provincial decisions—e.g., the approval of refurbishments in Bruce, Darlington, and Pickering nuclear generating stations (estimated at CAD 25 billion) [125] (2.3, 3.1, 5.1) • The province has made relevant advancements in smart grid and demand management tools compared to other provinces in Canada [109] (3.2, 3.3, 5.1) • Further advancement of smart grid and demand management tools can be supported by policy and strategic development focused on attaining broader social acceptance, meeting community needs, and ensuring technical reliability [126] (2.4, 3.3, 4.2, 5.2, 6.5)
Democratic and participatory governance
• Electrical energy system management has faced challenges related to ineffective planning, lack of transparency, ignored legislated milestones, and questionable stakeholder consultation processes [82] (4.1, 6.1, 6.3) • Planning processes need better alignment with the multiple jurisdictional scales and the dynamics between and among them [127] (3.3, 4.2, 6.2) • Failure to establish effective planning and public engagement processes has sometimes resulted in negative long-term effects—e.g., the cancellation of costly projects (2.3, 3.1, 4.1, 6.5) • Consultation efforts need to be strengthened and supported by policy- and law-making to better include Indigenous peoples and local communities' interests in electricity-related initiatives (2.1, 4.1, 6.3) • Engagement with provincial communities, local utilities, and distribution companies is key for attaining broader social acceptance of system design options, projects, and initiatives [108] (3.4, 4.2, 5.2, 6.5)
Precaution, modularity, and resiliency
• Enhanced capacity for developing and deploying technological advancements and scientific innovations is a key focus for the broader adoption of promising alternatives for attaining climate goals (1.1, 5.2, 6.5) • The development and deployment of technological advancements and policy innovations can help to safely add promising alternatives for attaining climate goals to the system (1.1, 2.4, 3.4, 4.3, 5.1, 6.4) • A larger role for energy storage can support decentralized generation, diversification of sources, further deployment of electric vehicles, and resource conservation and efficiency [128] (2.3, 3.3, 3.4, 5.2) • Provincial interest in efficiency and conservation options has created an advanced potential for the further implementation of emerging options [73] (2.3, 3.2, 5.2) • Nuclear-based electricity generation poses long-term risks related to environmental degradation, high costs, low flexibility, and intergenerational inequities [123] (1.2, 1.4, 2.3, 3.1, 5.1, 6.3)

Table 4. *Cont.*

Transformation, integration of multiple positive effects, and minimization of adverse effects
• Planning processes or frameworks with officially approved and published criteria, requirements, or objectives are necessary for accumulating positive effects, minimizing trade-offs, and building policy pathways towards sustainability-related goals (4.3, 6.1) • Forward-looking electricity-related decision-making needs to ensure just transitions to protect and increase the resilience capacity of the most vulnerable and valuable social–ecological system components (1.2, 1.3, 1.4, 2.1, 4.1, 6.3) • Immediate political considerations and current technical and economic trends have been often prioritized [124] over establishing sets of desirable goals and clarifying the actions needed to attain them (e.g., backcasting and scenario-based planning) (4.1, 5.1, 6.4) • Capacities for ensuring the complementarity of diverse approaches, innovation, and knowledge co-production can be strengthened by more effective consultation and engagement with key actors [129,130] (4.2, 5.2, 6.2, 6.5) • Precautionary decision-making that avoids highly costly financial, social, and ecological risks can be supported by assessment approaches that focus on maximizing contributions to positive sustainability-associated effects (1.4, 2.1, 2.3, 3.1, 5.1, 6.1)

The application of the criteria in Table 3 to the electrical energy system and its context in Ontario led to the identification of the key strengths and limitations presented in Table 4. At the same time, the findings from the application of the framework informed a further honing of the sustainability-based criteria with considerations that are important in the specific provincial context. The main criteria have been numbered in Table 3 and referenced in Table 4 (as numbers in round brackets) to illustrate how the key strengths and limitations presented were identified in light of the application of the sustainability-based criteria to the Ontario context. This exercise shows that the criteria are interlinked and often overlap through different categories. A more extensive version of the main findings from this exercise can be found in Aguilar's study [6].

The strengths and limitations statements provided in Table 4 combine findings from the document research and semi-structured interviews. The interviews were meant to complement the findings from the document research, but they also provided more nuanced insights according to the participants' experience in the electrical energy system. Some of the statements in Table 4 are based on insights that different interviewees agreed upon as key strengths or limitations of the provincial electrical energy system. Others were built from contributions made by individual participants, drawing on their particular areas of expertise. The statements in Table 4 that are not supported by references show key aspects that were not necessarily made explicit in the document research but were corroborated by the interviewees' comments. More detailed evidence of this process can be consulted in the Ontario case study chapter in Aguilar's work [6].

7.5. Summary of Key Findings from the Ontario Case Application

Ontario's electrical energy system evolved significantly but also erratically under the influence of economic, social, and environmental pressures, technological changes, and shifting politics and policies [6]. The latter have been particularly significant. Provincial electricity system objectives have oscillated considerably, depending on the political party and leadership that forms government. For instance, current provincial authorities have removed the previous government's official requirements for long-term energy planning towards attaining climate change-related goals. Such changes undermine capacities even for the forward-looking management of complex energy systems. They present a more serious barrier to effective preparation and implementation of transformative steps towards sustainability, which depend on understanding the cumulative effects of past and recent events anticipating future needs, problems, and opportunities, and selecting among alternative pathways.

The province also faces cost-related issues that have contributed to increases in electricity prices and have hindered the capacity for attaining public approval of new system design options. Key energy system actors in Ontario have disagreed on the main causes of current cost concerns and appropriate responses. However, the application of the framework showed that paying attention to the possible interacting effects among the sustainability-based assessment considerations helped to identify the most salient issues and ways to reconcile divergent views.

In the past, some events related to severe health risks, poor air and water quality, and social pressures pushed Ontario to make some progress towards sustainability-based goals. These included the closure of coal-fired power plants, incorporating some renewable energy options, and advancements in conservation and demand management technologies and programs. However, the electrical energy system has not yet been designed to be compatible with emerging technical options in the global context or build capacity-directed change and flexible adaptation over time. Furthermore, the current provincial government has decided not to follow national net-zero GHG goals and has demonstrated limited interest in pursuing climate change goals.

Ontario also needs to improve efforts to address key sustainability requirements, such as democratic and participatory governance, as well as inter- and intra-generational equity. Particularly, provincial electrical energy system management has overlooked Indigenous peoples' and local communities' rights to be consulted and to have their interests recognized in the creation of long-lasting jobs and protecting land and other socially valuable sites.

7.6. Suggested Directions for Next Steps for the Transformation of Ontario's Electrical Energy System

As noted above, shifts in Ontario's political context have expanded and limited sustainability-related initiatives for the electrical energy system. One key recommendation is that electrical energy system governance re-design should favour structures able to deliver more consistently far-sighted electrical energy system planning and management in the lasting public interest. This can help energy systems to make more positive contributions to climate safety and social–ecological integrity and promote intra- and intergenerational equity, accessibility, and affordability. For instance, options would include the establishment of more independent system planning authorities, subject to transparency requirements and public accountability but somewhat insulated from immediate political temptations to avoid open planning and ignore climate change mitigation imperatives. Strengthening planning and public approval processes would also help to avoid economic risks that, as suggested in Table 4, can undermine cost-effectiveness, resource efficiency, and conservation.

The application of criteria relevant to democratic and participatory governance revealed that establishing effective processes for attaining broad public approval in electrical energy system projects and initiatives has been a key challenge in the province. In this regard, new electrical energy system planning efforts need to respect consultation obligations and public approval requirements in ways that build public understanding and capacities for informed engagement. Particularly, projects and initiatives must be better designed to deliver broader positive effects to Indigenous peoples and communities. By strengthening electrical energy system planning processes and attaining broad public approval for electrical energy system design options, policymaking can, at the same time, take a step forward in advancing new technical options for efficiency, conservation, and demand management. In this way, positive contributions can also be made in the precaution, modularity, and resiliency criteria category. For example, policymaking could promote greater flexibility for changes over time to incorporate emerging renewable, efficient, and lower-cost system options. Such engagement in an open, comprehensive, and integrated sustainability-based approach to electrical energy systems should have greater success in delivering multiple, mutually reinforcing gains for the lasting public interest.

Addressing political considerations in Ontario would be key to promoting sustainability-based criteria relevant to transformation, the integration of multiple positive effects, and the minimization of adverse effects. As in many other jurisdictions, Ontario's electrical energy system has faced political challenges linked to the apparent attractions of right-wing populism and post-truth politics, which have dismissed climate change evidence, ignored sustainability imperatives, and generally made positive transformations more difficult [131]. In this context, provincial efforts may benefit from a focus on targeted interventions for system innovation centred on leverage points where it may be possible to demonstrate attractive alternatives to currently entrenched practices and deliver visibly positive contributions that can be scaled out and up to the provincial and multi-jurisdictional context [30]. For instance, different works have highlighted strategies to create niches for innovation as protected spaces for policy development, experimentation, and eventual implementation as desirable tools to advance climate and other sustainability-related policies more effectively [132,133].

8. Conclusions

Electrical energy systems inevitably require transformations to diminish the negative impacts that they have posed to life-support systems and human well-being and maximize the positive contributions to widely accepted sustainability objectives locally and globally. For instance, stopping and reversing risky climate change effects entails making changes that are sufficiently disruptive to break current harmful trends and redirect electrical energy system operations to interact more positively with their social and ecological contexts. This work has suggested that next-generation sustainability-based assessments can be key tools for designing and evaluating electrical energy system projects and initiatives that make more positive contributions to tackle social and environmental crises.

Key conclusions from this work can inform the further adoption of sustainability-based assessment approaches for application to electrical energy systems. The processes of specification and application of the framework shed light on key contextual characteristics that can be unique to each venue and jurisdiction of application. The identified characteristics are foundational to building a set of sustainability criteria to guide more comprehensive and accountable consideration of key issues, specific needs, and available options to steer positive change. As demonstrated in this illustrative Ontario case study, specifying and applying the framework in particular cases can provide key insights related to the full suite of generic criteria and electrical energy system strengths and limitations.

There are, however, additional implications for advancing next-generation sustainability-based assessments in official electrical energy system planning processes. One key aspect is that new sustainability assessment efforts will need to acknowledge the complexity of social–ecological systems, including the complex dynamics that unfold in electrical energy systems. The main factors that will require particular attention are uncertainty and unpredictability, interlinked effects between and among system components, sectorial and jurisdictional multi-scale interactions, the capacity to constantly transform and resist change, human influence, precautionary approaches, and specification to context.

Next-generation approaches must address emerging needs in the context of complexity and urgency for rapid and safe transitions to tackle ongoing crises. The adoption of specified criteria that can be further specified to the context of the application is an essential component. Designing frameworks of specified sustainability-based criteria as packages of mutually supportive effects can help promote the accumulation and alignment of positive effects compatible with adjacent projects and initiatives in the electrical energy system and other sectors in the same jurisdictional context [33]. Positive cumulative effects can, for example, stimulate contributions in different sectors towards achieving net-zero GHG emissions and providing broader social benefits.

The explicit consideration of trade-off scenarios is also required in next-generation sustainability-based assessments to avoid unnecessary adverse effects resulting from interactions among the different components, vested interests, and other provincial actors in the electrical energy system [133]. Considering this, sustainability-based assessments are likely to play a relevant role in advancing new approaches to electricity planning, policymaking, and project assessment that consider the interlinked effects and identify more effective ways of addressing them. However, more research into the possible cumulative effects and trade-offs of past and ongoing initiatives is essential to better understand the upcoming challenges and design electrical energy systems that can anticipate the evolving needs and options of the coming decades [15].

Adverse political scenarios in the particular contexts of application will also require attention in efforts to advance next-generation sustainability-based assessments for electrical energy systems. Emerging trends of right-wing populism and post-truth politics in the global energy landscape, for instance, can create barriers to making broader contributions to attaining sustainability goals [131,134,135]. Broad public engagement, transparency, collaboration, open review processes, and independent administration are needed to ensure continuity and public acceptance in the face of changing political contexts.

Positive aspects were identified in the application of the sustainability-based assessment framework to the Ontario context. For instance, the proposed broad criteria for electrical energy system applications were overarching, well-suited to the main provincial contextualities, and appropriate as a foundation for further specification for application in the Ontario case. Incorporating complexity thinking provided a lens for considering a broad suite of possible interacting effects among the criteria and recognizing diverging and conflicting views in Ontario's electrical energy system landscape. Also, knowledge of complex systems' transformations informed the examination of Ontario's recent contextual capacity to induce electrical energy system transformations. Particularly, the criteria category on transformation, the integration of multiple positive effects, and the minimization of adverse effects were especially helpful in illuminating elements that can increase opportunities for positive change.

However, the illustrative application also revealed openings for improving the proposed framework in future applications.

More contributions to knowledge relevant to the evolving needs of the provincial electrical energy system are needed to further test and hone the criteria in all the categories. For instance, efforts to ensure better representation of Indigenous communities, industry actors, local utilities, and distribution companies would be helpful.

The framework is also likely to be enriched by findings from more applications in different electricity-related efforts (plans, projects, etc.). As suggested above, the framework needs to facilitate attention to more specific initiatives and promising alternatives that are relevant to sustainability progress and have interacting effects in each of the criteria categories. At the same time, further application of the proposed framework will be useful for testing the utility of the framework in additional specific applications.

Future applications can help to hone the framework by identifying the strengths and weaknesses of the current structure and criteria. As new system options emerge, electricity markets change and current promising options move forward—e.g., further technological development and the adoption of energy storage, renewable energy alternatives, and smart grid tools—the framework will require modification to reflect more recent knowledge on energy scenarios and their implications. It will also be important for future applications to focus on identifying possible steps needed to move away from adverse political trends to more evidence- and criteria-based systems of planning and decision-making.

Further applications could help to improve the framework by exploring how to ensure the application of the full suite of criteria and to find ways to combine the divergent interests of participants with commitment to meeting sustainability requirements. One key aspect, for instance, would be the widespread experimentation with means to pursue sustainability as mutually supportive goals and cumulative gains beginning in the earliest stages of sustainability-based assessment efforts.

The proposed framework could also be improved with the application of approaches to human-induced change that seek transitional steps that have positive influences at multiple scales, identify places or leverage points in the system to intervene and foster desirable change (e.g., niches for policy and technological development, experimentation, and innovation), as well as initiatives that can emerge from bottom-up and be supported by top-down scales, instead of relying mainly on technocentric, large-scale top-down full system change [30,132].

Finally, future applications could help to identify, assess, and celebrate particular initiatives that have succeeded in delivering broader contributions to positive sustainability-related effects through effectively implementing transitioning and transforming efforts. This would advance knowledge on the implications for directing transitions and transformations in electrical energy systems to contribute more positively to sustainability. At the same time, future works could develop and specify sustainability-based assessment frameworks for application to other energy-related initiatives and other sectors to advance our understanding of the implications for transitioning and transforming towards attaining broader sustainability objectives.

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