

**Planning for Climate Change in Seattle:
Exploring Energy Infrastructure through Scenario Planning**

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Abstract

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Climate change impacts continue to unfold, intensify, and consequently, endanger the fundamental aspects of life by threatening health, livelihood, and community. Climate research indicates that while all sectors contribute to climate change, the energy sector in particular is one of the major contributors. The energy sector involves all aspects of the industry which generates, transmits, distributes and sells energy. Moreover, since infrastructure is interconnected, disruptions to the energy system will lead to disruptions in other systems such as telecommunications, transportation, security, and healthcare. Therefore, understanding climate change impacts on electrical infrastructure will be crucial for preparing and planning for climate change. This is particularly important for Seattle City Light (SCL), Seattle's public power utility, as it serves over 400,000 consumers; as a vertically-integrated utility, all components of SCL infrastructure will experience some climate-related threats and hazards. Warmer temperatures have the potential to decrease snowpack and lead to seasonal timing changes of streamflow, which will impact hydropower generation in the Puget Sound region and change the dynamic of energy supply in the region. Further, the increased intensity and frequency of climate-related hazards such as heavy precipitation, wind storms, flooding, wildfires, and storm surges can damage transmission and distribution lines, which can cause disruptions and delays to service. With climate change impacts impending, there is an increased urgency to develop a response that would ensure the utility's ability to provide energy service to their customers as well as protect

their existing infrastructure. However, maintaining infrastructure is a very capital-intensive endeavor, which is further complicated by climate change. This thesis explores alternative futures facing SCL to identify robust strategies to adapt to climate change.

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Chapter 1 Introduction

Climate change is an issue that is becoming more difficult to ignore as extreme weather events increase in frequency and intensity. Additionally, the impacts of climate change, such as intense flooding, declining snowpack, and warmer temperatures are more apparent. Climate change endangers the fundamental aspects of life by threatening health, livelihood, and community. It is important to note that the effects of climate change vary based on location, income, and racial/ethnic identities. Therefore, the affects will be vast and on a multi-scale level.

Climate change is the culmination of decades of greenhouse gas emissions that reflect the changing patterns of fossil fuel consumption and development and land use changes as it relates to population growth.¹ The current impacts of climate change reflects the already released emissions that have remained in the atmosphere for decades. The results will continue to unfold throughout the century and the trajectory of impacts beyond 2050 will become clearer as humans live out the first half of the century.² The actions and decisions made presently are crucial as it will determine exactly how climate change will affect the health and livelihoods of communities across the globe.

Climate research indicate that while all sectors contribute to climate change, the energy sector in particular is one of the major contributors. The energy sector involves all aspects of the industry which generates, transmits, distributes and sells energy. The infrastructure involved in this process will likely be impacted by climate change. Warmer temperatures are expected to increase the electricity demand for cooling purposes, which will add additional stress on the system. Further, warmer temperatures can decrease the capacity of transmission lines, which will impact the system's reliability. Extreme weather events, such as wildfires, flooding, and heavy precipitation, can lead to system downtimes due to impacting infrastructure directly or impacting

¹ Intergovernmental Panel on Climate Change, *Climate Change 2014: Synthesis Report Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, 56, http://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_FINAL_full_wcover.pdf [<https://perma.cc/W6GR-RHSN> (Geneva, Switzerland, 2014) [*hereinafter* IPCC, *Climate Change 2014: Synthesis Report*].

² Guillaume S. Mauger et al., *State of Knowledge: Climate Change in Puget Sound* (Seattle: University of Washington, 2015) 2-5, <https://doi.org/10.7915/CIG93777D>.

the surrounding environment causing delays in service. Generation can be impacted by seasonal timing changes, soil erosion and crop yield, which will impact energy output and supply.³

Climate change impacts on energy infrastructure is an important issue to focus on, especially for Seattle City Light (SCL), which provides electricity to over 400,000 customers within Seattle and the neighboring areas directly north and south of the city. SCL is a vertically-integrated utility, which means it owns each component of the power system, from generation to distribution. Therefore, climate change has the potential to damage several hydroelectric generation facilities, thousands of miles of transmission and distribution lines, and over 15 substations. Collectively, SCL's assets are valued at \$45 billion.⁴ Damages and disruptions to the energy infrastructure will cause delays in service, which impacts the primary function of SCL. Consequently, the research conducted in this thesis specifically asks:

What potential changes does Seattle City Light (SCL), the city's public power utility company, need to undergo in the next 30 years as a response to climate change?

This investigation explores the administrative, operational, and financial aspects of providing a crucial service to consumers.

To begin to understand the focal issue, the thesis begins with a review of literature in *Chapter 2*. The literature review covers key concepts that lays the foundations for approaching the research question; this includes an overview of climate change, infrastructure, SCL, and scenario planning. *Chapter 3* sets up the scenario planning framework that helps structure the problem-solving approach, one that attempts to anticipate the plausible futures and potential challenges. Scenario planning is a useful tool for understanding the potential and plausible impacts that could occur in the future, particularly with complex issues that contain an element of uncertainty.⁵ Scenarios can help to visualize the “plausible trajectories of different aspects of the future that are constructed to investigate the potential consequences” that result from climate

³ Thomas J. Wilbanks et al., *Climate Change and Energy Supply and Use: Technical Report for the U.S. Department of Energy in Support of the National Climate Assessment* (Washington, DC: Island Press, 2013), 5-6.

⁴ Seattle City Light, “Lighting the Path - 2017 Annual Report Financial Information, 2017.”

⁵ Marina Alberti, *Cities That Think like Planets* (Seattle: University of Washington Press, 2016), 206; Peter Schwartz, *The Art of the Long View Planning for the Future in an Uncertain World* (New York: Doubleday, 1991), 37-49.

change.⁶ Additionally, through the scenario planning process, practitioners are more able to articulate choices and make robust decisions about the future.⁷ In *Chapter 4*, the scenario planning process lead to the creation of four scenarios that reflect the major drivers which have the potential to influence the outcomes. The four scenarios presented in this chapter illustrate the challenges and opportunities present in grappling with climate change and energy consumption/density. While the four scenarios illustrate different potential futures, the scenarios overall reveal an emphasis on service reliability, which is tied to infrastructure maintenance and operations. Maintaining infrastructure is a very capital-intensive endeavor, which is further complicated by climate change. Under the traditional cost of service model, which is dependent on levels of energy consumption, SCL will not be able to keep up with climate change impacts. *Chapter 5* offers a discussion regarding modifications to the traditional cost of service model. Specifically, the chapter advocates for consideration of a performance-based regulatory model as a mechanism to separate revenue generation and energy consumption levels.

Ultimately, the thesis illustrates that to respond to climate change SCL can: change the physical infrastructure to respond to climate-related hazards; change the method for energy generation; change the mechanism for transmitting and distributing energy supply; and/or change infrastructure investment. However, infrastructure is expensive and climate change impacts have financial consequences. The strategies to harden, relocate, and design climate-responsive or climate-resilient infrastructure will require capital. Further, diversifying energy generation requires investing in new infrastructure to increase access to resources such as solar and wind; again, this requires capital. Therefore, focusing on mechanisms for revenue generation and financing infrastructure is the biggest opportunity to respond to SCL's future.

⁶ "Scenarios Background Information – Scenario Process for AR5," Intergovernmental Panel on Climate Change, last modified March 5, 2019, http://sedac.ipcc-data.org/ddc/ar5_scenario_process/scenario_background.html.

⁷ Alberti, *Cities That Think like Planets*, 206; Schwartz, *The Art of the Long View*, 37-49.

Chapter 2 Literature Review

To begin this research topic, a review of key concepts is needed to structure our understanding of the research question:

What potential changes does Seattle City Light (SCL), the city’s public power utility company, need to undergo in the next 30 years as a response to climate change?

The question asks for considerations regarding the problem-solving process as it relates to decision-making; additionally, the question requires an understanding of energy systems, energy infrastructure, and SCL, as a utility. Further, the issue of climate change must be reviewed to give a basic understanding of the challenges facing SCL. Therefore, this literature review includes a discussion regarding rational planning, scenario planning, resilience, transformations, robustness analysis, climate change research, and infrastructure.

The literature review is organized into three sections. The first section will cover scenario planning and rational planning; an understanding of these theories aids our approach in dealing with issues of uncertainty and complexity. To understand the potential outcomes and consequences that result from the decision-making process, the section will provide an overview on the concept of resilience, transformations, and robustness; each concept helps to develop an approach for evaluating decisions. Collectively, the concepts and theories presented in this section help to contextualize the methodology—scenario planning—used for the analysis.

The second section of the literature review focuses on climate change; specifically, the section provides background information to understand the potential threats and challenges unfolding due to climate change. Further, the section will provide climate research specific to the Pacific Northwest and Seattle, which helps to clarify the threats and risks facing the region.

Additionally, the section covers the topics of infrastructure and energy infrastructure, as these topics are central to the research question. The information provided in this section allow for a more meaningful conversation about potential changes to the system.

The final section specifically covers SCL; the section will provide information about the utility and the challenges it faces due to climate change. As this thesis focuses on SCL and the potential

changes facing the utility, the information presented in this section lays the foundation for understanding the presented issue.

Overall, the literature review helps to frame our understanding and approach of the central question; the information briefed in this chapter paves the way for the analysis and discussion that will occur in *Chapter 4* and *Chapter 5*.

2.1 Scenario Planning

Scenario planning emerged as a formal practice in the 1960's after WWII through Herman Khan's work with the RAND Corporation.⁸ Initially, scenario planning served as a form of military planning, but it evolved into a "tool for business prognostication" through the Stanford Research Institute and the Shell Oil Company.⁹ Practitioners of scenario planning explain it as a tool that systematically thinks about complex and uncertain futures.¹⁰ Scenario planning should not be confused with forecasting, projections, or predictions despite the commonalities between those respective tools and scenario planning. Scenario planning is unique because it explores all possible and plausible futures rather than focusing on a singular vision of the future.¹¹ However, it is important to note that scenario planning does not solely focus on understanding what the future may look like; instead, scenario planning attempts to position users to observe and evaluate changes at a systems level, question their respective ways of understanding the world and their "established patterns of assessing situations and planning actions".¹² Ultimately, scenario planning equips users with the ability for strategic decision-making given an understanding of how choices may unfold into the future.

⁸ Thomas J. Chermack and Susan A. Lynham, "Definitions and Outcome Variables of Scenario Planning," *Human Resource Development Review* 1, no. 3 (2002): 367; Garry D. Peterson, Graeme S. Cumming, and Stephen R. Carpenter, "Scenario Planning: A Tool for Conservation in an Uncertain World," *Conservation Biology* 17, no. 2 (2003): 360, <https://doi.org/10.1046/j.1523-1739.2003.01491.x>.

⁹ Schwartz, *The Art of the Long View*, 7.

¹⁰ A. Khakee, "Scenario Construction for Urban Planning" *Omega* 19, no. 5 (1991), 461, [https://doi.org/10.1016/0305-0483\(91\)90062-X](https://doi.org/10.1016/0305-0483(91)90062-X); Peterson, Cumming, and Carpenter, "Scenario Planning: A Tool for Conservation in an Uncertain World," 359; Schwartz, *The Art of the Long View*, 3.

¹¹ Ahti A. Salo and Derek W. Bunn, "Forecasting with Scenarios," *European Journal of Operational Research* 68 (1992): 292; Schwartz, *The Art of the Long View*, 3-6.

¹² Eva Wollenberg, David Edmunds, and Louise Buck, "Using Scenarios to Make Decisions about the Future: Anticipatory Learning for the Adaptive Co-Management of Community Forests," *Landscape and Urban Planning* 47, no. 1-2 (1999): 65-77, [https://doi.org/10.1016/S0169-2046\(99\)00071-7](https://doi.org/10.1016/S0169-2046(99)00071-7); Salo and Bunn, "Forecasting with Scenarios," 292; Schwartz, *The Art of the Long View*, 4.

For the purposes of this thesis, scenario planning is the chosen methodology to explore the given research question due to the complexity of the issue, as the impacts of climate change are vast and on a multi-scale level. *Chapter 3* explores the specific elements of scenario planning and outlines how it will be used for analysis. It is important to note that even though climate change leaves a level of uncertainty and complexity, it does not mean it is impossible to understand potential impacts. In fact, scenario planning is a useful tool for understanding the potential and plausible impacts of climate change that could occur in the future. Scenario planning overall is an iterative process that works through complexity and uncertainty to help articulate choices and make robust decisions about the future.¹³

2.1.1 Plausibility vs. Possibility

Scenario planning theoretically deals with all plausible and possible futures; as a tool, scenario planning attempts to frame the problem-solving approach to consider the many outcomes that could result or unfold due to the uncertain nature of our world. The Oxford Dictionary defines ‘plausible’ as something that can seem reasonable or probable whereas it defines ‘possible’ as something that can be done or achieved.¹⁴ Usually in planning, the process attempts to establish a singular path to a singular imagined future based on information that presumes actions can lead to an achievable future; however, while the focus is on the most possible future, circumstances can easily change and create an environment that allows for another, different future—one that is not out of the realm of reasonability—to emerge. Consequently, scenario planning attempts to expand our approach to envisioning our future and broaden our perspective on challenges, risks, and opportunities; this is particularly important when thinking about the potential changes or the futures that could unfold for SCL as the utility responds to climate change.

2.1.2 Resilience

Resilience, first introduced in the 1970’s by scholar C.S. Holling, is commonly understood from an ecological perspective; the term describes the persistence of the natural system to "absorb change and disturbances while maintaining the same relationships between populations or

¹³ Alberti, *Cities That Think like Planets*, 206; Schwartz, *The Art of the Long View*, 37-49.

¹⁴ Oxford Dictionaries, s.v. “possible,” accessed May 28, 2019, <https://en.oxforddictionaries.com/definition/possible>; Oxford Dictionaries, s.v. “plausible,” accessed May 28, 2019, <https://en.oxforddictionaries.com/definition/plausible>.

variables”.¹⁵ The natural system will experience various fluctuations or oscillations, which can cause changes to the system; however, the system’s ability to maintain the fundamental dynamic of predator to prey regardless of changes to the environment allows for species to persevere. Scholar Lance H. Gunderson explains this phenomenon as an ability to withstand disturbances “without changing self-organizing processes and structures”,¹⁶ which is illustrated in Figure 2-1, specifically in environment A and B where the system can manage fluctuations and move between the oscillations—an action defined as ‘adaptive capacity’.¹⁷

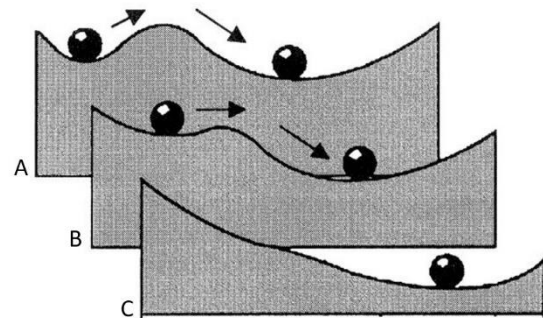


Figure 2-1 Resilience of a system

Source: Lance Gunderson, “Ecological Resilience,” 427.

Adaptive capacity is a key element for understanding resilience outside of the context of ecology as the concept adapts to various fields.¹⁸ It underpins resilience not only as the ability to absorb disturbances, but also as having the capacity to learn and adapt, which continues the basic functions of a system and demonstrates flexibility.¹⁹ However, resilience assumes that every system has adaptive capacity, which may not be the case; therefore, how resilience is assessed and cultivated will be an important consideration. It is also important to note that resilience can be described as good or bad, but it is dependent, again, on how resilience is assessed and whether the perpetuation of the system in question is seen as valuable.

This issue emerges when thinking about the resilience of infrastructure. Infrastructure—generally defined as hard, physical structures—is “designed to tolerate a limited set of disturbances [and] when stressed beyond those limits, [the] structures are subject to degradation

¹⁵ C. S. Holling, “Resilience and Stability of Ecological Systems,” *Annu.Rev.Ecol.Syst.* 4 (1973): 1–23, <https://doi.org/10.1146/annurev.es.04.110173.000245>.

¹⁶ Lance Gunderson, “Ecological Resilience - In Theory and Application,” *Annual Review of Ecology and Systematics* 31 (2000): 415–39.

¹⁷ Gunderson, “Ecological Resilience”.

¹⁸ Michael J. Pratt and Karen Van Peurse, “Towards a Conceptual Framework for Resilience Engineering,” *IEEE Systems Journal* 3, no. 2 (2009): 11–32, <https://doi.org/10.1080/09639289300000002>.

¹⁹ Timothy McDaniels et al., “Fostering Resilience to Extreme Events within Infrastructure Systems: Characterizing Decision Contexts for Mitigation and Adaptation,” *Global Environmental Change* 18, no. 2 (2008): 310–18, <https://doi.org/10.1016/j.gloenvcha.2008.03.001>; Gunderson, “Ecological Resilience”.

and collapse”.²⁰ While the behaviors surrounding infrastructure, that is service provision and consumption, are also a component of the infrastructure system, it is important to note that the resilience of infrastructure is the focus of this discussion.

Resilience, while not a traditional element of the scenario planning process, will be added to the methodology for this thesis because the assessment helps to shape our approach in thinking about the future. Specifically, the assessment attempts to address and define the system, threats, purpose, and timeframe.²¹ A resilience assessment provides a framework for understanding the potential changes and disturbances that will unfold and impact the system in question; in the case of this thesis, the focus is on the electrical infrastructure of SCL. Since scenario planning will explore multiple futures and the potential challenges, risks, and opportunities across several futures, a resilience assessment will further the investigation of potential changes facing SCL.

2.1.3 Transformations

As scenario planning explores the plausible and possible futures, transformations, “big, mostly irreversible, radical departures from the status quo”,²² are important elements to consider in this process. Practitioners of scenario planning generally organize futures that are considered in the process as strategic or adaptive scenarios. Strategic scenarios extrapolate for a future that illustrates strategies under current system conditions, that is strategies that work within the parameters of the existing system.²³ For example, the framework of capitalism influences the types of strategies that institutions would implement to address carbon emissions. Users may be satisfied with the future illustrated in strategic scenarios depending on the focal issue. Moreover, according to how resilience is defined, users may believe that strategic scenarios demonstrate a resilient system. Adaptive scenarios analyze strategic scenarios for desirability and acceptability; subsequently, strategic scenarios are modified to consider the changing dynamics of the system.

²⁰ J Whittington and S Young, “Resilience through Transaction Cost Economic Evaluation: Recognizing the Cost-Effectiveness of Sustainable Development,” *S.a.P.I.En.S* 6, no. July 2014 (2013): online, <http://sapiens.revues.org/1639>.

²¹ Marina Alberti, “Assessment of Resilience: Theories and Models,” (lecture, University of Washington, Seattle WA, April 24, 2018).

²² David M Iwaniec et al., “The Framing of Urban Sustainability Transformations,” *Sustainability* 11, no. 3 (2019): 1–10, <https://doi.org/10.3390/su11030573>.

²³ David M Iwaniec, Elizabeth M. Cook, and Marta Berbés-Blázquez, “Scenario Planning and Transformative Futures,” (Urban Ecology Research Lab discussion, University of Washington, Seattle WA, May 9, 2019).

Therefore, the observations and lessons learned from strategic scenarios lay the foundations for developing adaptive scenarios. However, in considering all the plausible and possible futures, the scenario typography expands to consider the likelihood of a future that exists completely outside of the current system. A transformative scenario describes the process in which the system enters a fundamentally new state, otherwise described as a regime shift.²⁴

Transformations can be unintentional or deliberate, as decisions can lead to unexpected and/or strategic consequences. Further, transformations can occur at multiple scales, where transformative changes at lower scales can facilitate eventual large-scale changes.²⁵ The system experiences a reconfiguration and challenges the assumptions that constructed both strategic and adaptive scenarios.²⁶

Transformative scenarios describe desirable and plausible futures and the path to achieve them whereas strategic and adaptive scenarios describe the range of possible futures that may occur. However, with the unpredictability, uncertainty, and hazards that climate change poses, transformative changes further challenge our approach to thinking about the future; with a crisis like climate change, bold ways of thinking about the future and the strategies for addressing climate change are arguably necessary.²⁷ Considering transformations in the scenario planning process helps to strengthen the framework for identifying and exploring challenges, risks, and opportunities. Moreover, as the thesis investigates the potential changes SCL will undergo, the concept of transformation will help facilitate discussions regarding the plausibility and possibility of the various futures and evaluate the desirability of those futures. Specifically, transformations will ask questions regarding the desirability of the system, that is whether the end state is desired and whether it reflects the actions and strategies needed to respond to climate change.

2.2 Rational Planning

²⁴ Carl Folke et al., “Resilience Thinking: Integrating Resilience, Adaptability and Transformability,” *Ecology and Society* 15, no. 4 (2010); Per Olsson, Victor Galaz, and Wiebren Boonstra, “Sustainability Transformations: A Resilience Perspective,” *Ecology and Society* 19, no. 4 (2014).

²⁵ Olsson, Victor Galaz, and Wiebren Boonstra, “Sustainability Transformations: A Resilience Perspective;” Iwaniec et al., “The Framing of Urban Sustainability Transformations.”

²⁶ Iwaniec et al., “The Framing of Urban Sustainability Transformations.”

²⁷ Robert W. Kates, William R. Travis, and Thomas J. Wilbanks, “Transformational Adaptation When Incremental Adaptations to Climate Change Are Insufficient,” *Proceedings of the National Academy of Sciences of the United States of America* 109, no. 19 (2012): 7156–61, <https://doi.org/10.1073/pnas.1115521109>.

Rational planning developed throughout the 1960's and 70's through the Chicago School, an educational program created in response to the Great Depression, the New Deal, and WWII. The program used "methods and tools of science towards social ends in order to ensure that public decision-making was based on facts rather than hunch".²⁸ The emergence of the Chicago School coincided with the new perspectives surrounding planning, one that involved more advocacy and societal management. Therefore, to make the best decisions regarding projects and policies that impact society, the planning process needed a methodology that helped to discern information and navigate the presented problems.

To think about problems and develop a course of action, scholar Ernest Alexander explains that in decision-making, an understanding of rationality is important, namely because it helps to frame our problem-solving approach. The core of rationality explores the relationship between goals or values and means, that is, rationality "requires people using it to consider what they ought to do in the light of what it is they want to accomplish".²⁹ Therefore, in decision-making, rationality helps to systematically collect, organize, and evaluate information through a consistent logic; the subsequent choices are informed by this process.³⁰

Rational planning is a common model in planning due to its systematic framework, which assists in the decision-making process, especially when dealing with complex issues. Specifically, rational planning involves:³¹

1. Problem identification, in which an understanding of the problem is made clear
2. Formulation of goals and objectives, in which a vision or ideal outcome is developed
3. Information gathering, in which relevant information is collected to help identify constraints and opportunities
4. Design of alternatives, in which different strategies and scenarios are explored to consider the full pathways for achieving the established vision

²⁸ Philip Allmendinger, *Planning Theory* (Basingstoke: Palgrave Macmillan, 2009), 41-67.

²⁹ Ernest R. Alexander, *Approaches to Planning Introducing Current Planning Theories, Concepts, and Issues* (New York: Gordon and Breach Science Publishers, 1986), 11.

³⁰ Alexander, *Approaches to Planning*, 12.

³¹ Andreas Faludi, *Planning Theory* (Oxford: Pergamon Press, 1973), 35-52; Edward Kaiser, David Godschalk, and F. Stuart Chapin Jr., *Urban Land Use Planning* (Urbana: University of Illinois Press, 1995), 38; Alexander, *Approaches to Planning*, 20.

5. Evaluation of actions, in which the alternative scenarios are assessed based on likelihood and a cost/benefit analysis
6. Establish choice, in which a course of action is agreed upon based on the vetted information
7. Implementation, in which the established choice is enacted
8. Monitor progress and outcomes, in which the course of action is evaluated to see if it achieves the established goals and objectives
9. Revision, in which the established vision and course of action are re-visited and re-evaluated to ensure that they remain relevant

As a tool, rational planning presents itself as the ideal procedure for planning because of its ability to analyze information in a systematic manner. Additionally, rational planning provides the clarity needed in determining the best course of action when presented with complex issues.

Scenario planning draws elements from the rational planning procedure. Similarly, scenario planning sets out systematic steps for engaging with a problem. Scenario planning also involves investigating and comparing different alternative outcomes to determine the best course of action. Moreover, the set of procedural requirements prescribed by the scenario planning process, comparable to the rational planning process, assumes practitioners have collected and analyzed all information relevant to the potential outcomes.

While both scenario planning and rational planning share a similar approach, the difference between the two methods are found in what the methods choose to emphasize. Rational planning is ultimately concerned with the decision or the action that results from the procedure. When using rational planning as a tool, planners are hoping to establish a course of action or strategy to fulfill an objective. Even though the process involves exploring alternative scenarios and evaluating costs and benefits, the process is meant to lead planners to a choice in which action can be taken; the important element for rational planning is implementation, the ability to act. Scenario planning, on the other hand, places more emphasis on the alternatives, that is, the exploration and understanding of the plausible and possible futures. Scenario planning attempts to take a meaningful consideration of the ends; this is apparent in the scenario planning process because of the structure of the process, which concerns itself on identifying the trends, key

factors, and drivers that may create various futures. Scenario planning is also concerned about action, but the process is rooted in a desire to understand the likelihood of alternative futures.

Since this thesis focuses on scenario planning, it is important to understand the concept in relation to other methods to avoid any confusion, especially with the similarities shared between rational planning and scenario planning. However, it is the differences that serve this thesis. Scenario planning is the main methodology used to understand the research question in this thesis because as a tool, scenario planning helps to envision all the potential futures facing SCL as climate change impacts unfold. Rational planning's emphasis on implementation helps to move the conversation forward to focus on action by thinking about strategies for responding to climate change impacts and the type of world that may exist in the future.

2.3 Robustness Analysis

The concept of 'robustness', understood as a measure of flexibility of decisions under uncertain conditions, was introduced in the 1970's by scholars Jonathan Rosenhead, Martin Elton, and Shiv Gupta.³² Robustness speak directly to plans and planners regarding the decision-making process; while planners work to create certainty in response to the complex and uncertain dynamics of societal management, the structure for understanding and approaching problem-solving create inflexibility.

Rosenhead explicitly states that creating a plan and implementing a plan are two starkly different activities. Rosenhead explains that the action of planning sets up the decision-making process, however it is not binding, and plans can be revised or discarded at any point. Moreover, the assumptions during the planning process and the circumstances when decisions and commitments are made can be different.³³ Rosenhead argues that rational planning fails to acknowledge and anticipate the continual role uncertainty plays in decision-making as uncertainty exists in establishing goals or values, in the social-political dynamic, and in the

³² Jonathan Rosenhead, Martin Elton, and Shiv K. Gupta, "Robustness and Optimality as Criteria for Strategic Decisions," *Operational Research Quarterly* 23, no. 4 (1972): 413–31.

³³ Jonathan Rosenhead, "Robustness analysis: keeping your options open," in *Rational Analysis for a Problematic World*, ed. Jonathan Rosenhead (Chichester: Wiley & Sons, 1989), 193-218.

actions of decision-makers.³⁴ As a result, flexibility becomes an important element of consideration because it creates the capacity to respond to uncertainty.³⁵ Consequently, Rosenhead advocates for incorporating a robustness analysis to the planning process.

The robustness analysis involves identifying the following:³⁶

- Systems and the environment, where the system describes the elements that form the focal issue and the environment defines the conditions of the system
- Decision and implementation periods, where decision periods detail the timeframe in which decisions must be made and implementation periods outline the timeframe for instigating actions
- Commitment, where the term describes a single action that can create specific changes to the system
- Commitment sets, where multiple decisions or a combination of decisions are defined
- Configurations, where the combination of decisions are arranged according to the system
- Perspectives, where the assumptions and world views of the group who will be affected by the decisions are described
- Future scenarios, where a future beyond the implementation period is considered
- Desirable configuration, where the most optimal set of decisions are decided upon

The robustness analysis essentially observes the interplay between the initial decisions, otherwise known as commitments, with the future scenarios and desirable configurations. Initial commitments create commitment sets, or intermediate decisions, which describe a configuration that leads to an end state, or a plausible future condition of the system; the end states are extrapolated to describe multiple potential futures. The future scenarios are evaluated as desirable, acceptable, undesirable, catastrophic, or questionable;³⁷ based on this evaluation, the desired configurations are established.

³⁴ Jonathan Rosenhead, "Planning Under Uncertainty: I. The Inflexibility of Methodologies," *Journal of the Operational Research Society* 31, no. 3 (1980): 209–16; Jonathan Rosenhead, "Planning Under Uncertainty: II. A Methodology for Robustness Analysis," *Journal of Operational Research Society* 31, no. 4 (1980): 331–41.

³⁵ H. Y. Wong and J. Rosenhead, "A Rigorous Definition of Robustness Analysis," *Journal of the Operational Research Society* 51, no. 2 (2000): 176–82, <https://doi.org/10.1057/palgrave.jors.2600868>.

³⁶ Wong and Rosenhead, "A Rigorous Definition".

³⁷ Rosenhead, "Robustness analysis: keeping your options open."

The element of flexibility is apparent in the desired configurations. One intermediate decision can lead to different end states and various futures. Therefore, when selecting the desired configurations, several intermediate decisions can be considered acceptable actions to implement; these decisions can lead to multiple desirable futures. Since the various decisions can exist under different circumstances and still produce a desirable future, the process has the flexibility to respond if the environment changes.

Ultimately, the idea of robustness and the process of a robustness analysis changes the dynamic of decision-making. Similar to scenario planning, robustness anchors itself in uncertainty and explores alternative futures based on the various choices or decisions in consideration. By considering the different possible futures, not only is the element of uncertainty accounted for, but flexibility is reintroduced into the process, which strengthens the system and environment.

The robustness analysis provides tools for evaluating different futures in terms of desirable, acceptable, undesirable, catastrophic, or questionable. This differs from scenario planning, where the methodology uses the driving forces to define the potential futures. While the robustness analysis explores multiple futures, it frames the decision-making process towards desirability, that is, the analysis attempts to reveal the various decisions that lead to various desirable futures. Scenario planning takes a more pragmatic approach by analyzing the likelihood of the potential futures based on the driving forces and key factors found in the system and environment. Scenario planning does not concern itself with desirability, rather it addresses the threats and risks facing a system and environment and works to strategically address the focal issue.

However, the robustness analysis calls our attention to the fact that circumstances change constantly, which means uncertainty remains. Despite efforts to deal with uncertainty, the idea of robustness calls into question how futures are evaluated and compared. Even when the most desirable outcome or most likely future is determined, it does not negate the fact that there is a possibility another, different future may emerge; this coupled with transformations, allows for a more critical analysis of the potential changes that could unfold due to climate change.

Summary

Due to the unpredictability, uncertainty, and complexity of climate change, scenario planning helps to envision different futures for SCL and develop strategies to respond to climate change impacts. While the scenario planning process focuses our attention on cultivating an understanding of the various futures, rational planning helps to facilitate the conversation about implementation, that is what actions need to be considered and enacted to respond to climate change impacts. The additional elements of resilience, transformations, and robustness creates a bridge between scenario planning and rational planning. Collectively, these concepts help to understand the process of envisioning futures and evaluating decisions from different perspectives. Specifically, the concepts help to create a more critical and meaningful analysis about the assumptions that construct the futures in consideration for SCL. They call for intentional evaluation of SCL's electrical infrastructure (the system) to not only identify the threats and risks, but also to consider the larger context of the system as it relates to the future end state of SCL. Robustness expands our approach to constructing and assessing decisions and strategies while transformations challenge our approach to thinking about SCL's future, asking questions of whether the potential actions and strategies are bold and radical enough to fully address the climate crisis.

To understand the potential futures of SCL, an understanding of the problem needs to be established, that is, the research question asks how SCL will change due to climate change impacts. Therefore, a consideration of *what* changes could occur to the system and the circumstances that define the system will be explored in the following section, which provides background information on climate change and infrastructure.

2.4 Climate Change

Warming of the planet has always occurred; this is proven through the existence of the greenhouse effect, which describes the process of the Earth absorbing, retaining, and re-emitting solar radiation. The amount of energy absorbed and re-emitted, and the subsequent effect on surface temperatures, depends on several factors; one factor is the concentration levels of natural and human-made greenhouse gases such as carbon dioxide (CO₂), nitrous oxide (N₂O), methane

(CH₄), chlorofluorocarbons (CFCs), and ozone (O₃).³⁸ It is important to note that many greenhouse gases remain in the atmosphere for long periods of time; for greenhouse gases like CO₂ and N₂O, they can last for decades, even centuries.³⁹

Despite climate change being a common phenomenon of the Earth, the current trajectory of climate change is distinctly different from past cycles. Scientists reporting for the Intergovernmental Panel on Climate Change (IPCC) illustrate (Figure 2-2) in the Fifth Assessment the complex relationship between anthropogenic emissions, greenhouse gas concentrations, and their impacts on the planet. As greenhouse gas concentrations have increased in the last 60 years, scientists have also observed global surface temperatures increase, rising sea levels, ice sheets shrinking and glaciers retreating.⁴⁰ Scientists are “95 percent certain that human are the main cause of current global warming”.⁴¹ Human activities related to development and economic growth such as land-use changes and increased fossil-fuel use have caused the concentration of greenhouse gasses in the Earth’s atmosphere to swell. Despite mitigation efforts, anthropogenic greenhouse gas emissions between 2000 and 2010 increased; CO₂ concentrations accounts for about 78 percent of the total greenhouse gas emissions that increased between 2000 and 2010. By sector, the energy sector contributed the highest amount of annual anthropogenic greenhouse gas emissions with 47 percent; followed by the industry sector with 30 percent.⁴²

³⁸ Intergovernmental Panel on Climate Change, *Climate Change: The IPCC Scientific Assessment (Working Group I)*, xiv-xx, (Cambridge University Press, 1990) [*hereinafter IPCC, Climate Change: The IPCC Scientific Assessment*].

³⁹ IPCC, *Climate Change: The IPCC Scientific Assessment* supra note 39; Intergovernmental Panel on Climate Change, *IPCC Second Assessment Climate Change 1995*, 21, (1995) [*hereinafter IPCC, Second Assessment*].

⁴⁰ “Climate Change: How Do We Know?,” NASA, last updated April 29, 2019, <https://climate.nasa.gov/evidence/>.

⁴¹ IPCC, *Climate Change 2014: Synthesis Report*, supra note 1

⁴² *Ibid.*, 46.

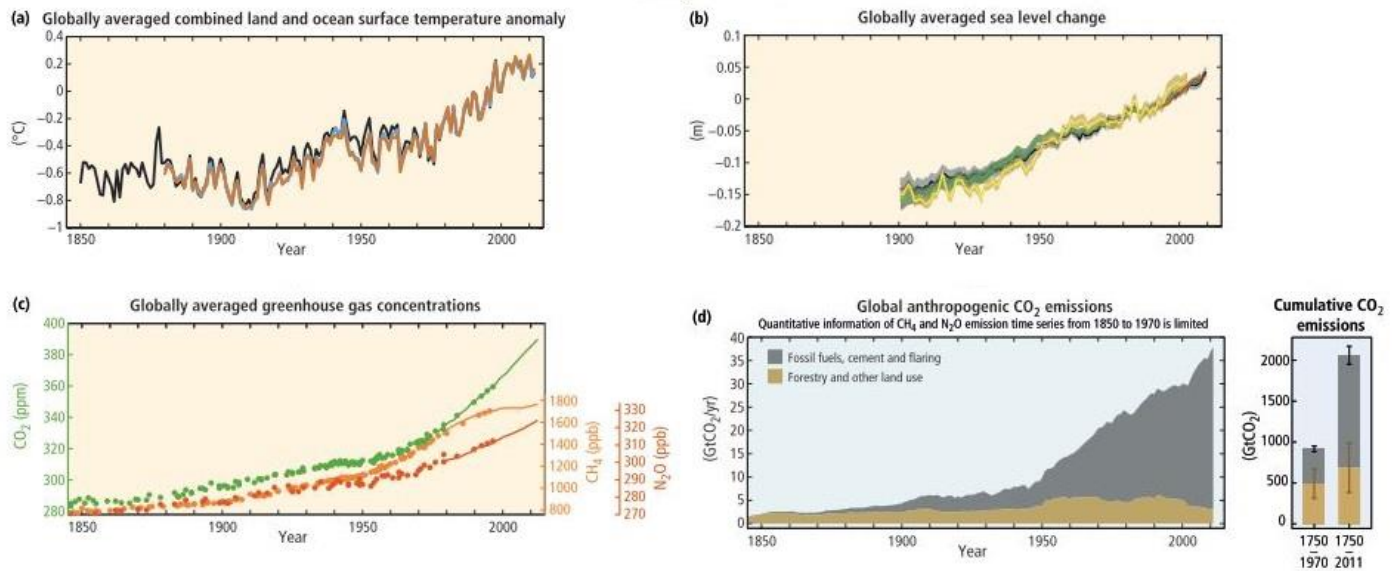


Figure 2-2. Graphs a-d illustrate over time changes in global land and ocean surface temperatures and sea level change along side the accumulation of greenhouse gas emission and CO₂ emission.
 Source: IPCC, *Climate Change 2014: Synthesis Report*, supra note 1, 3

The gravity of impacts due to climate change varies regionally, however, changes in the global temperature can affect multiple systems, that is, nearly all aspects of life will be affected by climate change as systems are interconnected. Climate change has the potential to “amplify existing risks and create new risks for natural and human systems”.⁴³ Scientists report with medium to high confidence that continued high emissions will lead to losses in biodiversity and ecosystem goods, functions and services, species extinction, and ocean acidification. Additionally, climate change will lead to resource scarcity, that is, difficulties in production, access, use, and price stability of resources.⁴⁴ Moreover, climate change will increase the risk of disease outbreak and displacement of people as well as “indirectly increase risk of violent conflict by amplifying well-documented drivers of these conflicts, such as poverty and economic shocks”.⁴⁵ Therefore, climate change is a critical issue and poses real challenges that must be addressed.

In the 2018 IPCC Special Report, *Global Warming of 1.5°C*, scientists outline an urgency for climate action as scientists explain the differences in severity of impacts in temperature increases

⁴³ Ibid., 64.
⁴⁴ Ibid., 65 - 69.
⁴⁵ Ibid., 73.

between 1.5 to 2°C (2.7 to 3.6°F). As human activity has caused global temperatures to rise 1°C (1.8°F) above pre-industrial levels, scientists report with high confidence that global temperatures will likely reach 1.5°C (2.7°F) between 2030 and 2050 if the rate of increase remains the same.⁴⁶ While climate-related risks and threats exist at 1.5°C (2.7°F), the risks and threats at 2°C (3.6°F) are higher and cause further irreversible damage to natural and human systems.⁴⁷ Scientists report increased threats and challenges to the planet’s oceans, land, and biodiversity. There will be further impacts to “health, livelihoods, food security, water supply, human security, and economic growth”.⁴⁸ However, with the presented information, scientists stress limiting global temperature rise to 1.5°C (2.7°F), as the stresses and impacts are more manageable—compared to the damages at 2°C (3.6°F) and dependent on the mitigation and adaptation actions employed presently.

To limit global temperature increases to 1.5°C (2.7°F), global CO₂ emissions need to start to decline well before 2030; specifically, CO₂ emissions will need to decline globally by 24 percent by 2030, reaching net zero by 2050. Achieving this will require “rapid and far-reaching transitions in energy, land, urban and infrastructure (including transport and buildings), and industrial systems”.⁴⁹ Transformations will depend on national, regional, and local circumstances and the influences of economic, institutional, and socio-cultural factors,⁵⁰ moreover, governmental policies and financial investments will influence the success of these transformations.⁵¹ It is important to note that efforts towards adaptation may also result in mal-adaptations or adverse impacts depending on the circumstances surrounding intent, design, and implementation of policies and projects.⁵² This is an important consideration as disadvantaged and vulnerable populations such as low-income communities, indigenous populations, and communities of color will have difficulties responding to climate-related impacts due to lasting and systematic discrimination and racism, which limits access to resources and the capacity of

⁴⁶ IPCC, “Summary for Policymakers,” in *Global Warming of 1.5°C: An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change*, 2018, 4.

⁴⁷ IPCC, “Summary for Policymakers.”

⁴⁸ IPCC “Summary for Policymakers,” 9.

⁴⁹ IPCC, “Summary for Policymakers,” 15.

⁵⁰ IPCC, “Summary for Policymakers,” 16.

⁵¹ IPCC, “Summary for Policymakers,” 22.

⁵² IPCC, “Summary for Policymakers,” 19.

these respective communities. Therefore, when discussing transformative changes, the element of equity should be at the forefront of policies and investment.

2.4.1 Representative Concentration Pathways (RCPs)

Using scenarios in climate research is common practice; scenarios help visualize the “plausible trajectories of different aspects of the future that are constructed to investigate the potential consequences of anthropogenic climate change”.⁵³ For decades, scientists have created and ran many models to understand how the climate itself is changing and how humans are changing the climate.

Five types of scenarios are used in climate research: emissions scenarios, climate scenarios, environmental scenarios, vulnerability scenarios, and narrative scenarios. Emissions scenarios use information regarding greenhouse gases, pollutants, land use and land cover. Climate scenarios focus on climate conditions such as temperature and precipitation. Environmental scenarios work in tandem with climate scenarios by investigating environmental conditions such as water availability and air quality. Vulnerability scenarios explore the socioeconomic, demographic, cultural, political, and institutional influences that impact climate change. Finally, narrative scenarios use similar data as vulnerability scenarios; however, narrative scenarios investigate the data qualitatively instead of quantitatively. Each scenario investigates different aspects of climate change that aids in the understanding of the varied outcomes and uncertainties that exist within the issue.⁵⁴

Presently, climate models and projections are anchored in the information modeled in the Representative Concentration Pathways (RCPs), the most recent climate change scenarios approved by the IPCC. The four RCPs scenarios are based on the concentration levels of greenhouse gas emissions and total radiative forcing (Figure 2-3), which “include a stringent mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0), and one scenario with very high GHG emissions (RCP8.5)”.⁵⁵

⁵³ “Scenarios Background Information – Scenario Process for AR5,” Intergovernmental Panel on Climate Change, last modified March 5, 2019, http://sedac.ipcc-data.org/ddc/ar5_scenario_process/scenario_background.html.

⁵⁴ Ibid.

⁵⁵ IPCC, *Climate Change 2014: Synthesis Report*, supra note 1, 57.

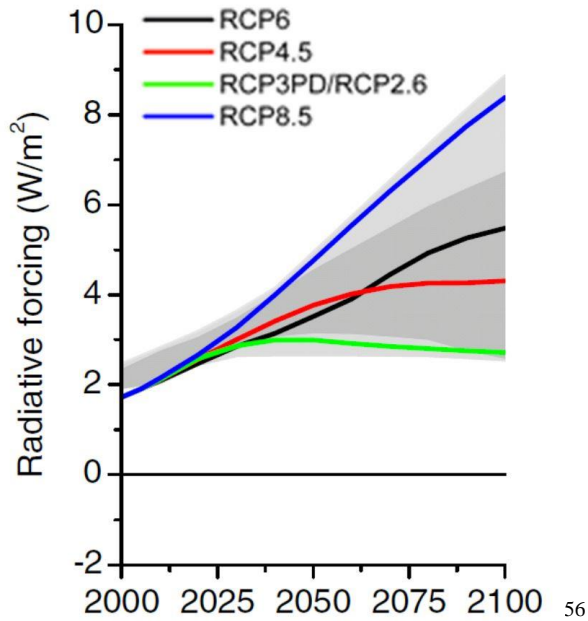


Figure 2-3. Radiative forcing of the Representative Concentration Pathways (RCP) used by the IPCC in developing scenarios for climate change impacts. The light grey area captures 98% of the range in previous IAM scenarios, and dark grey represents 90% of the range.

Original source: van Vuuren et al (2011) *The Representative Concentration Pathways: An Overview. Climatic Change*, 109 (1-2), 5-31.

Each RCP is based on different sets of socioeconomic, cultural, technological, demographic, and political assumptions, which reflects the variability in human behavior that may change the trajectory of each pathway.⁵⁷ The RCPs are used to illustrate a variety of outcomes, which are anchored in the respective assumptions that each RCP contains. Usually the RCPs, and other climate change scenarios, are structured to be presented together, as seen in Figure 2-4.

⁵⁶ “Representative Concentration Pathways – Scenario Process for AR5,” Intergovernmental Panel on Climate Change, last modified March 5, 2019, http://sedac.ipcc-data.org/ddc/ar5_scenario_process/RCPs.html.

⁵⁷ Ibid.

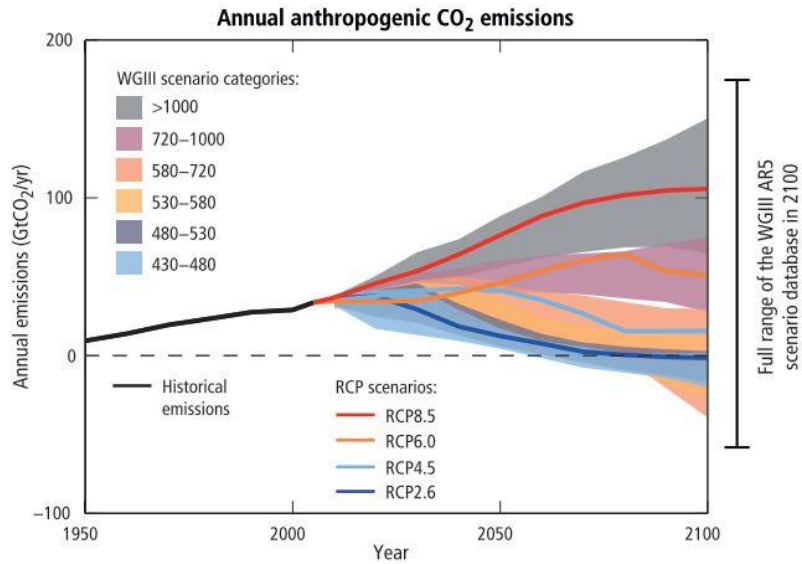
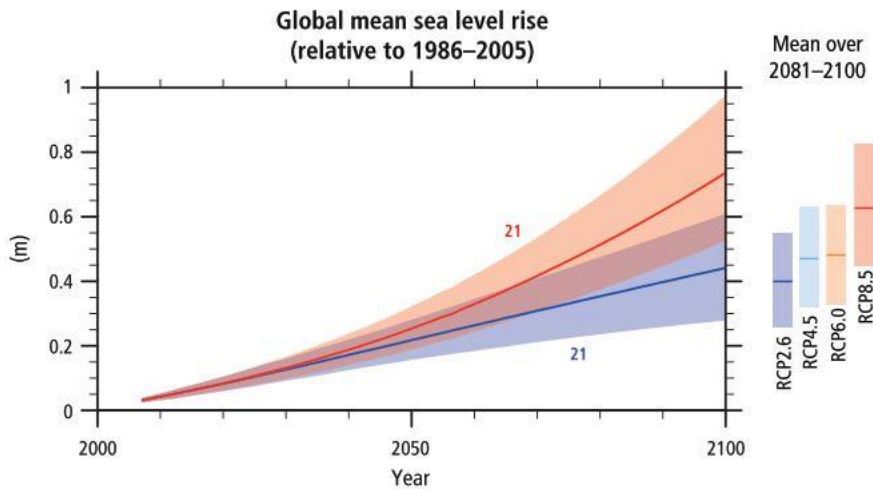
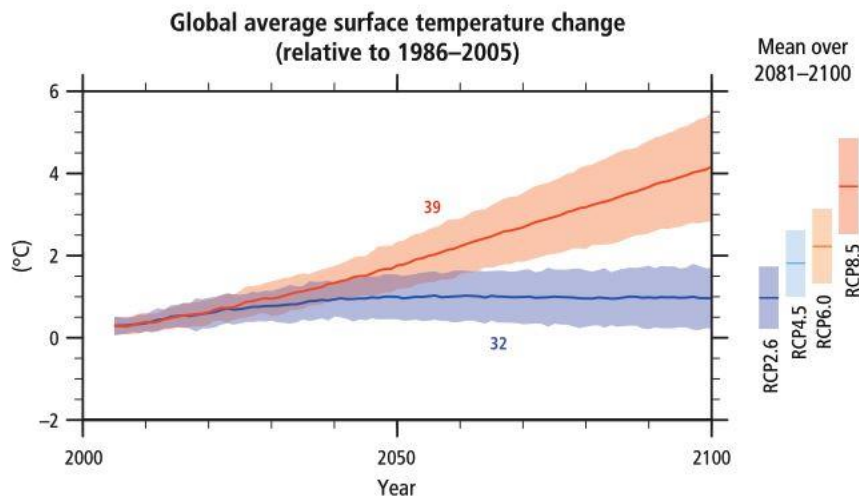


Figure 2-4. The three graphs illustrate the IPCC’s use of the RCPs in construction scenarios regarding emissions, surface temperature, and sea level rise. The scenarios outline potential outcomes from present day until the end of the century.

Source: IPCC, *Climate Change 2014: Synthesis Report*, supra note 1, 9-11.



2.4.2 Climate Change in the Pacific Northwest

Scientists reporting for the *Fourth National Climate Assessment, Volume II* and for the *State of Knowledge: Climate Change in Puget Sound* indicate that in all climate model projections, the Northwest region of the continental United States (Figure 2-5), which encompasses the Puget Sound region (Figure 2-6), will continue to warm. Data specifically illustrates that the Puget Sound region warmed by about 1.3°F from the 1890s to 2014, which is comparable to the overall two degree warming in the Northwest.⁵⁸

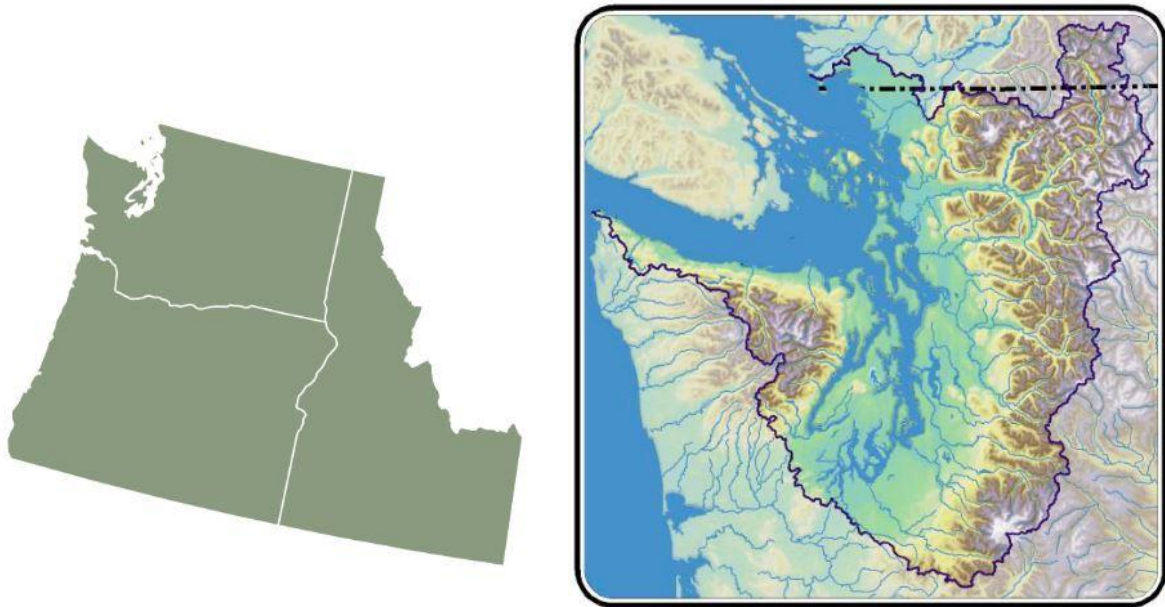


Figure 2-5. (left) The Northwest geographically consists: Washington, Oregon, and Idaho.
Source: U.S. Global Change Research Program, *Fourth National Climate Assessment*, 1038

Figure 2-6. (right) The Puget Sound Region as defined in the *State of Knowledge: Climate Change in Puget Sound* report.

According to scientists, climate change impacts on the natural environment in the region will be extensive, ranging from changes in snowpack and streamflow, timing of biological/seasonal events, and flooding to species distributions, forest growth and productivity, and agriculture.⁵⁹ Consequently, the projected changes will impact the region's natural resource economy and built infrastructure as well as threaten the health and livelihoods of all residents.⁶⁰ For example, within

⁵⁸ Mauger et al., *State of Knowledge*, 2-5; U.S. Global Change Research Program, *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*, (2018): 1041, <https://doi.org/10.1016/j.pbb.2008.09.016>.

⁵⁹ Mauger et al., *State of Knowledge*, ES3-6.

⁶⁰ U.S. Global Change Research Program, *Fourth National Climate Assessment*, 1043.

the agriculture, forestry, and fisheries sectors, over 700,000 jobs will be impacted and over \$139 billion (in 2015 dollars) are at risk due to climate change; further, within the outdoor recreation industry, over 450,000 jobs will be impacted and \$51 billion (in 2017 dollars) will be at risk.⁶¹

In addition to climate change impacts on the local economy, climate change will also impact health outcomes of residents within the region. Higher frequency of wildfires will create respiratory and cardiovascular health challenges; moreover, warmer climates can lead to increased exposure to infectious diseases and pathogens.⁶² Further, extreme weather and climate events will likely disrupt transportation, water, and energy services, which will cause delays in access and delivery of services. Therefore, there will be challenges to accessing food, healthcare, and other social services.⁶³

It is important to note that the impacts of climate change will not be felt equally based on location, income, access to resources, and racial/ethnic identity. Residents living on the coast will likely experience the effects of climate change differently compared to residents living in mountainous areas as events of sea level rise and wildfires are location specific; further, “indigenous communities that rely heavily on the natural environment for their culture and heritage” will be among the first group of people to experience the impacts of climate change.⁶⁴

The presented climate research provides the context for understanding the challenges facing SCL and why it will likely need to change. Specifically, the information provided on climate change helps to understand how the issue is a driving force that will influence the future of SCL. Globally, climate change impacts will have lasting effects on all natural and human systems; therefore, making the ramifications far-reaching as well as cascading. Climate research specific to the Pacific Northwest echo the information presented through the various IPCC reports. The challenges, threats, and risks of climate change will cause direct impacts to SCL’s capacity to

⁶¹ Ibid.

⁶² Mauger et al., *State of Knowledge*, 13-7.

⁶³ U.S. Global Change Research Program, *Fourth National Climate Assessment*, 1053-1054; Mauger et al., *State of Knowledge*, 12-1-8.

⁶⁴ U.S. Global Change Research Program, *Fourth National Climate Assessment*, 1048.

provide energy to its customers. SCL describes potential impacts to the physical infrastructure as well as to water resources, as hydroelectric generation is SCL's main fuel source.⁶⁵

The remainder of this section examines infrastructure and SCL as a utility to understand further the gravity of the issue. Since climate change will impact SCL's physical infrastructure, it will be important to review our understanding of infrastructure, specifically energy infrastructure to contextualize the potential changes SCL will undergo. Additionally, as the central element for this thesis, an overview of SCL is necessary to anchor the primary investigation.

2.5 Infrastructure

Infrastructure is typically defined as the physical structures, facilities, and networks that provide products and services necessary to support human activities.⁶⁶ Various mechanisms impact how infrastructure systems evolve and operate; economics, public policy, technology and security as well as cultural concerns shape the dynamics of infrastructure.⁶⁷ While many different elements can influence infrastructure systems, they are generally "centrally managed, standardized in design, and governed with relatively broad concern for the public interest".⁶⁸ Additionally, infrastructure is designed and constructed to have long lifespans.⁶⁹ Overall, the design, construction, operations, and maintenance of infrastructure is an expensive activity. Therefore, infrastructure decisions have lasting implications, specifically in terms of development patterns.⁷⁰

⁶⁵ "Power Mix – How Our Electricity is Generated," Seattle City Light, accessed April 26th, 2019. <http://www.seattle.gov/light/FuelMix/>; Crystal Raymond, *Seattle City Light Climate Change Vulnerability Assessment and Adaptation Plan*, 2017.

⁶⁶ Steven M. Rinaldi, James P. Peerenboom, and Terrence K. Kelly, "Identifying, Understanding, and Analyzing Critical Infrastructure Interdependencies," *IEEE Control Systems Magazine* 21, no. 6 (2001): 11–25, <https://doi.org/10.1109/37.969131>; Whittington and Young, "Resilience through Transaction Cost Economic Evaluation: Recognizing the Cost-Effectiveness of Sustainable Development"; Robert K. McNally et al., "Learning the Critical Infrastructure Interdependencies through an Ontology-Based Information System," *Environment and Planning B: Planning and Design* 34, no. 6 (2007): 1103–24, <https://doi.org/10.1068/b32078>; Thomas J. Wilbanks and Steven J. Fernandez, *Climate Change and Infrastructure, Urban Systems, and Vulnerabilities: Technical Report for the U.S. Department of Energy in Support of the National Climate Assessment* (Washington, DC: Island Press, 2013), 4.

⁶⁷ Rinaldi, Peerenboom, and Kelly, "Identifying, Understanding, and Analyzing Critical Infrastructure Interdependencies."

⁶⁸ Whittington and Young, "Resilience through Transaction Cost Economic Evaluation: Recognizing the Cost-Effectiveness of Sustainable Development."

⁶⁹ *Ibid.*

⁷⁰ Jan Whittington and Catherine Lynch, "Climate-Informed Decisions The Capital Investment Plan as a Mechanism for Lowering Carbon Emissions," *Policy Research Working Paper Series* no. WPS 7381 (2015).

Infrastructure is highly connected and interacts at various scales, that is, systems, to varying degrees, impact each other in operations. Consequently, the interdependencies of infrastructure is described as bidirectional since the state of each infrastructure can influence the other.⁷¹ Therefore, when discussing one infrastructure system such as energy infrastructure, it is important to consider how the system interacts and impacts other infrastructure such as telecommunications or transportation. Due to the interdependencies of infrastructure systems, “disruption of services in one infrastructure will almost always result in disruptions in one or more other infrastructure”.⁷²

Climate change poses real threats to infrastructure systems. Sea level rise, flooding, heavy precipitation, and extreme weather events such as wildfires and heat waves threaten the capacity of infrastructure systems to deliver its products and services.⁷³ Therefore, it is likely that climate change impacts will have cascading impacts as disruptions to one infrastructure system will lead to disruptions in other systems. However, as development and the operations of infrastructure has contributed to climate change, transformations in decisions-making can change the dynamic of infrastructure and its role in climate change.⁷⁴

The physical components of infrastructure systems, along with the products and services it provides, and its long lifecycle introduces rigidity to infrastructure. Reliable service is an important criterion for infrastructure, which requires the design of infrastructure to remain relatively static. Therefore, in thinking about the future of infrastructure and its role in responding to the climate crisis, these characteristics are important considerations, especially when investigating potential changes or transformations SCL will undergo. Later chapters will explore exactly how to think about SCL’s system and resilience of its infrastructure as different futures are constructed and considered.

⁷¹ Rinaldi, Peerenboom, and Kelly, “Identifying, Understanding, and Analyzing Critical Infrastructure Interdependencies”; McNally et al., “Learning the Critical Infrastructure Interdependencies through an Ontology-Based Information System.”

⁷² Wilbanks and Fernandez, *Climate Change and Infrastructure, Urban Systems, and Vulnerabilities*.

⁷³ IPCC, *Climate Change 2014: Synthesis Report*, supra note 1.

⁷⁴ IPCC, *Climate Change 2014: Synthesis Report*, supra note 1.

2.5.1 Energy Infrastructure

Since this thesis focuses on climate change impact to energy infrastructure, specifically investigating impacts on SCL's infrastructure, the following will give a brief overview of the electrical system.

Energy infrastructure involves all components that generate, transmit, and distribute energy or power; this consists of generators, transformers, power lines, and loads. Generators produce the electrical energy that is distributed in the power system. Multiple generators operate simultaneously; this allows for the power system to respond to large consumer loads, increase service reliability, and to create operational resilience.⁷⁵ Generators are driven by a prime mover, a mechanism that converts mechanical energy. Prime movers include diesel engines, steam, gas, water, and wind turbines.

The energy that is generated must be converted to a voltage level that is safe to use.

Transformers aid in this conversion process; specifically, transformers convert the energy in alternating current (AC) circuits at one voltage level to another lower voltage level. Unit transformers receive and convert the energy produced by the generators so that energy can be transmitted over long distances from the source to the user. The energy will encounter two other transformers on its way to the user: the substation transformer and the distribution transformer. At the substation, the traveled energy is received and is, again, converted to a lower voltage level. This energy travels a shorter distance to be distributed to consumers; however, prior to reaching consumers, the energy is converted for a final time by distribution transformers, which permit the safe consumption of energy.⁷⁶

Power lines serve as the mechanism that transmits the energy produced and connects it to the users; it connects the generators to the loads, essentially the devices that use energy. There are two types of power lines: transmission and distribution. Transmission lines take the bulk of the power from the generators and carries it over long distances. Energy that travels through

⁷⁵ Stephen J. Chapman, *Electrical Machinery and Power System Fundamentals* (Boston: McGraw-Hill, 2002).

⁷⁶ James L. Kirtley, *Electric Power Principles, Electric Power Principles* (Chichester: Wiley & Sons, 2010), <https://doi.org/10.1002/9781119994404>.

transmission lines are transmitted at high levels to reduce losses.⁷⁷ As energy comes closer to the locality where it will be used, the energy carried by transmission lines will be converted at substations for distribution lines to transmit the energy over short distances—relative to the distance transmission lines cover—to users.

Climate change has the potential to impact nearly all parts of the power system and energy infrastructure. Resources for energy generation will likely experience changes due to climate change.⁷⁸ For example, warming temperatures will impact regional snowpack in the Pacific Northwest, and it will likely cause a shift in the seasonal timing of snowmelt and streamflow,⁷⁹ which will impact hydropower generation in the Puget Sound region and change the dynamic of energy supply; this will subsequently impact SCL's operations. Further, the increased intensity and frequency of climate-related hazards such as heavy precipitation, wind storms, flooding, wildfires, and storm surges can damage transmission and distribution lines, which can cause disruptions and delays to service.⁸⁰ Additionally, warming temperatures will influence behavioral changes in consumers, that is warmer summers will increase demand for cooling while warmer winters will decrease demand for heating. The changes in demands will impact how utilities will conduct their operations and cause them to review the capacity of their system to monitor the potential changes in the energy supply.⁸¹ Further, many utilities generate revenue based on volumetric sales—this includes SCL; therefore, fluctuations in demand will have financial consequences.

Summary

Climate research illustrates that the planet will continue to warm; the increased temperatures will have lasting and detrimental effects to all natural and human systems. Due to the interconnectedness and interdependencies between infrastructure systems, disruptions caused by climate change will lead to cascading consequences, as disruptions in one system will lead to disturbances in one or more systems. Therefore, when considering climate change impacts,

⁷⁷ Kirtley; Chapman.

⁷⁸ Jane Ebinger and Walter Vergara, *Climate Impacts on Energy Systems Key Issues for Energy Sector Adaptation*, (Washington DC: The World Bank, 2011), 26-35.

⁷⁹ Raymond, *Seattle City Light Climate Change Vulnerability Assessment and Adaptation Plan*, 59, 84.

⁸⁰ Ebinger and Vergara, *Climate Impacts on Energy Systems Key Issues for Energy Sector Adaptation*, 35-37.

⁸¹ Ebinger and Vergara, 37-41.

understanding the consequences as it relates to infrastructure will be important since infrastructure defines and facilitates human activities.

As the research questions asks: **What potential changes does Seattle City Light (SCL), the city’s public power utility company, need to undergo in the next 30 years as a response to climate change**, the provided information on climate change helps to frame our understanding of the world in 2019 and assists in thinking about the future of SCL as climate change impacts unfold. Additionally, the information helps to further contextualize the gravity of the climate crisis and the challenges it will bring to utility infrastructure. Climate change will not only cause disruptions to the energy system, but the interdependencies between systems such as telecommunications, transportation, security, and healthcare will also be impacted if electrical infrastructure is damaged or experiences changes to its system.

To understand the specific challenges and threats facing SCL because of climate change, the following section provides background information on the utility. Since the research question specifically asks how the utility will change, information is needed to understand the current conditions of SCL and its infrastructure.

2.6 Seattle City Light (SCL)

Seattle City Light (SCL) is a not-for-profit utility company that has a long history of serving the public dating back to 1902 when Seattle voters first approved the development of a hydroelectric facility. As a not-for-profit utility, SCL is govern by Seattle City Council, regulated by the Washington Utility and Transportation Commission (UTC), and guided by public interest. SCL, as a utility, is committed to providing reliable, affordable, and quality service to its consumers.⁸² This remains at the core of its operations and is reflected in the priorities for the next six years [2019-2024] as detailed in their current 2019 Strategic Plan:⁸³

- Customer service, where customer needs and expectations guide the evolution of service

⁸² “Public Power: A Tradition,” Seattle City Light, accessed June 7, 2019, <https://www.seattle.gov/light/history/publicpower.asp>; Seattle City Light, “Lighting the Path - 2017 Annual Report Financial Information”.

⁸³ Seattle City Light, “2019-2014 Proposed Capital Improvement Program,” 2019; Seattle City Light, *We Power Seattle: Strategic Plan 2019-2024*.

- Affordability, where the costs to consumers are fair and reasonable
- Clean energy, where efficient use of clean energy and continued commitment to protect the environment is promoted
- Core utility business, where continued investment in infrastructure and workforce ensures the ability to provide reliable service

SCL owns and operates the generation, transmission, and distribution components necessary to providing energy service to over 400,000 consumers within Seattle and the neighboring areas directly north and south of the city (Figure 2-8).⁸⁴ There are over three thousand miles of transmission and distribution lines, many of which pass through rural and forested areas found in Western Washington due to the location of the utility’s hydroelectric generation facilities (Figure 2-7).⁸⁵ Additionally, SCL operates and maintains 15 substations, which connect the transmission and distributions lines to their customers.⁸⁶

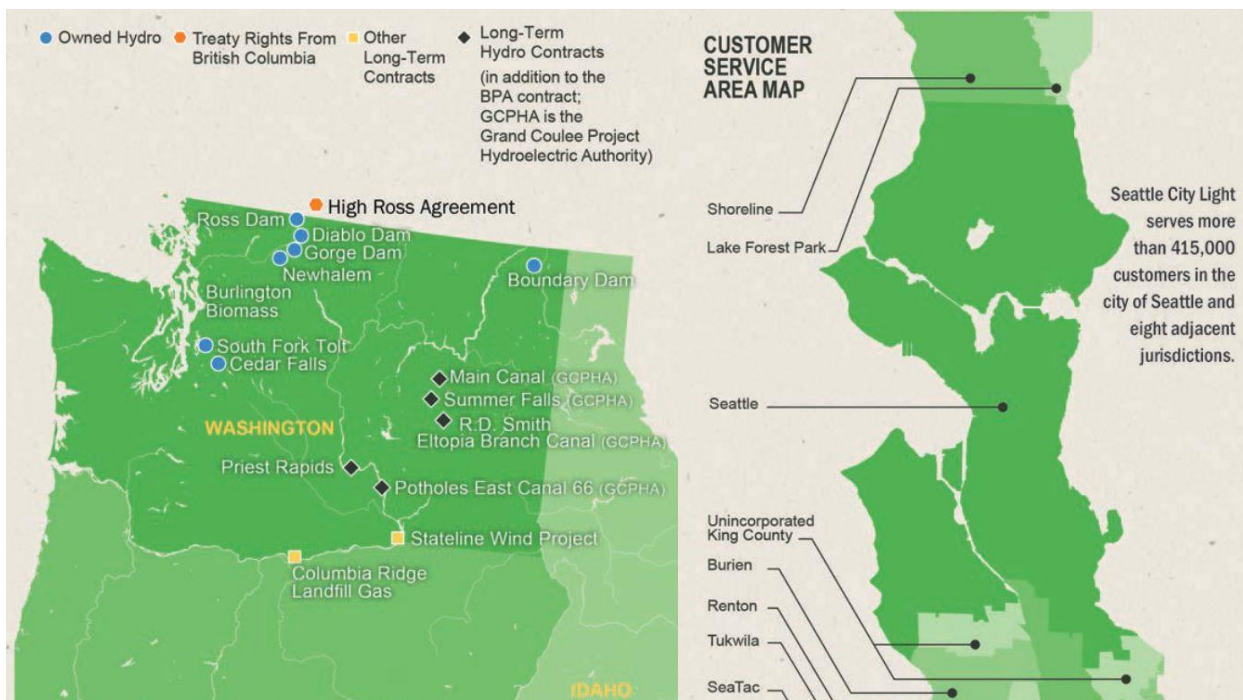


Figure 2-7. (left) Locations of SCL’s hydropower facilities.
Source: SCL, *Fingertip Facts Information Guide*, 13

Figure 2-8. (right) SCL’s customer service area map, which includes the communities directly north and south of Seattle
Source: SCL, *Fingertip Facts Information Guide*, 14

⁸⁴ Raymond, *Seattle City Light Climate Change Vulnerability Assessment and Adaptation Plan*, 29.

⁸⁵ Raymond, 8.

⁸⁶ Seattle City Light, “2019-2014 Proposed Capital Improvement Program,” 431.

SCL's Capital Improvement Program (CIP) works to repair, upgrade, and expand the utility's infrastructure as well as respond to various safety and licensing requirements. Its goal is "to ensure that the facilities required to serve [SCL]'s customers with low-cost, reliable power, are in place".⁸⁷ The overall CIP budget for 2017 was over \$400 million for projects regarding power supply, transmission, distribution, central utility, and external obligations.⁸⁸

In 2017, SCL's operating expenses was \$850 million. Operational activities include maintenance to the generation, transmission, and distribution facilities and equipment as well as labor and contracting, customer service, taxes, and general administrative tasks.⁸⁹ The total adopted budget for 2017 was \$1.3 billion.⁹⁰

In 2017, SCL was able to generate 6.3 million megawatt-hours (MWh) of energy. Most of SCL's electricity is generated primarily through hydropower facilities (Figure 4-2).⁹¹ Revenue is generated through volumetric sales to customers, wholesale energy transactions, investment income, and nonexchanges transactions. Non-residential consumers accounted for over 62 percent of electric energy sales while residential consumers accounted for 37 percent of electric energy sales during 2017.⁹²

2.6.1 Seattle City Light Assets

SCL manages and operates the major components of the power system, from generation and transmission to distribution within its area of service.⁹³ According to SCL's 2017 annual financial report, SCL's assets are valued at \$45 billion.⁹⁴ SCL defines assets as "any physical item or piece of equipment that enables services to be provided to consumers".⁹⁵ SCL organizes

⁸⁷ Seattle City Light, "2019-2014 Proposed Capital Improvement Program," 431.

⁸⁸ <http://www.seattle.gov/financedepartment/17proposedbudget/documents/2017-2018ProposedBudgetBook.pdf>

⁸⁹ Seattle City Light, "Lighting the Path - 2017 Annual Report Financial Information".

⁹⁰ <http://www.seattle.gov/financedepartment/17proposedbudget/documents/2017-2018ProposedBudgetBook.pdf>;

⁹¹ "Power Mix – How Our Electricity is Generated," Seattle City Light, accessed April 26, 2019,

<http://www.seattle.gov/light/FuelMix/>.

⁹² Seattle City Light, "Lighting the Path - 2017 Annual Report Financial Information".

⁹³ "2019-2024 Seattle City Light Proposed Capital Improvement Program," Seattle City Light, accessed May 28, 2019, <http://www.seattle.gov/financedepartment/1924proposedcip/documents/SCLCAP.pdf>.

⁹⁴ Seattle City Light, "Lighting the Path - 2017 Annual Report Financial Information."

⁹⁵ Seattle City Light, "Asset Management 101," Video File, 2011, Accessed May 28, 2019, <https://vimeo.com/24101615>.

its assets into four categories: generation, transmission, distribution, and general plant. Generation assets would include the seven hydroelectric facilities, dams, circuit breakers, and turbines. Transmission assets involve transmission towers, power poles, transformers, relays, vaults, overhead lines and underground cables. Distribution assets include substations, lines, and meters. General Plant assets involve vehicle fleet and general building facilities.⁹⁶

2.6.2 Seattle City Light Climate Change Vulnerability Assessment

SCL's *Climate Change Vulnerability Assessment and Adaptation Plan* set out to understand the impacts of climate change on continued operation and capacity of the utility and to develop strategies to minimize impacts, protect assets, and continue reliable service to customers.⁹⁷ As summarized in Figure 2-9, the vulnerability assessment indicates that eight primary changes—sea level rise and storm surge, warmer temperatures and heat waves, extreme weather, wildfires, landslides, reduced snowpack, higher peak streamflows, and lower summer streamflows—will impact the operation and capacity of the utility. It is important to note that there is variability to the projected impacts, that is some impacts will have a higher chance of occurrence and subsequently, have a more meaningful impact. Additionally, there will be variability in impact for each component of the energy system; this variability is caused by location, existing age, and maintenance of the infrastructure as well as progress of resilience strategies deployed by SCL.

⁹⁶ Ibid.

⁹⁷ Raymond, 1.

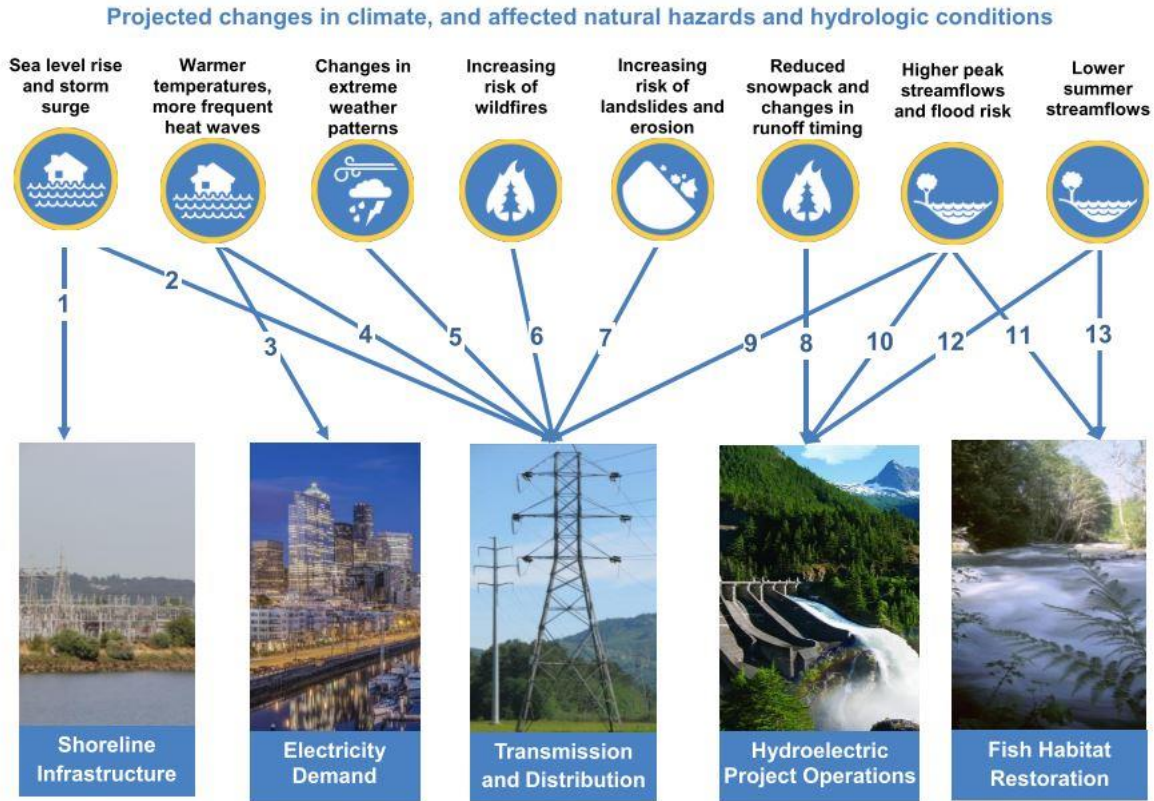


Figure 2-9. Components of SCL’s infrastructure and operations and the projected climate change impacts facing the utility.

Source: *Seattle City Light Climate Change Vulnerability Assessment and Adaptation Plan, 15*

Transmission and distribution of energy will experience the most threats due to projected climate change impacts; these impacts include:⁹⁸

- Reduction of life expectancy of equipment
- Reduced capacity of transmission lines
- Damage and failure of underground cables
- Increase frequency of outages
- Slow outage restoration times
- Interruptions to hydroelectric generation
- Delays in repairs and maintenance

Climate change poses real threats and challenges to SCL’s infrastructure; consequently, the utility has introduced strategies to help mitigate potential damages and protect its assets. For

⁹⁸ Raymond, 8.

example, most of the transmission and distribution equipment are located at elevations that will not be exposed to sea level rise. Moreover, both transmission and distribution equipment are designed to be water tight, therefore protecting most of the transmission and distribution equipment from sea level rise, flooding, and heavy precipitation. However, heavy rain storms, high winds, or flooding would likely cause damage that may lead to outages and cause challenges to access and restoration.⁹⁹

Warming temperatures can decrease the capacity of transmission lines and it can impact the operating capacity of transformers. Moreover, warmer temperatures can reduce the life expectancy of the equipment when it operates at or near the temperature limits set by system ratings; the greatest concern for system operation will be during the summertime when summer peak loads will coincide with higher air temperatures.¹⁰⁰

Wildfires will pose a greater risk over time to the utility's transmission and hydroelectric generation equipment. All of SCL's hydroelectric generation facilities and thousands of miles of transmission lines are located in forested areas, which will experience higher wildfire risk as the forests change due to climate variability. It is projected that the wildfire season in the Pacific Northwest will lengthen, and the area burned by wildfires will dramatically increase by 2050. The event of wildfires "can damage equipment, interrupt electricity transmission and generation, and put the safety of employees at risk".¹⁰¹

Decreasing snowpack and changes in seasonal timing of snowmelt and streamflow will have the greatest impact on hydropower generation. This is particularly important to note because most of SCL's electricity is generated primarily through hydropower.¹⁰² Total streamflow determines hydropower generation; as winter streamflows are expected to increase and summer streamflows will decrease, the timing of power generation will follow the seasonal timing changes.¹⁰³ Less water during the summertime has the potential of decreasing power generation, which can be

⁹⁹ Raymond, 18, 43.

¹⁰⁰ Raymond, 34-37.

¹⁰¹ Raymond, 47.

¹⁰² "Power Mix – How Our Electricity is Generated," Seattle City Light, accessed April 26, 2019, <http://www.seattle.gov/light/FuelMix/>.

¹⁰³ Raymond, 59, 84.

problematic as electricity demand for cooling is expected to increase. Overall, the changes in seasonal timing will likely impact hydropower generation and change the dynamic of energy supply in the region.

SCL recognizes that in an era of climate change, providing energy service that is reliable, affordable, and environmentally responsible remains important to their customers. As temperatures are expected to increase, there is an assumption that demand for electricity overall will also increase and cause additional stress to the electrical infrastructure. Altogether, the system's capacity to provide reliable service to consumers will be affected. SCL has set out four guiding strategies—enhancing capacity to adapt, hardening infrastructure, increasing resilience, and retreating from exposed locations and resources¹⁰⁴—to address climate change impacts, which will affect the reliability and affordability of energy services.

Summary

The literature review was organized into three parts. The first section focused on theoretical concepts that establish an understanding for the scenario planning methodology, which will be explained in full detail in *Chapter 3* and enacted in *Chapter 4*. The second section provided background information about climate change and infrastructure, which help frame our understanding of the research question. Finally, the third section presented information on SCL. Collectively, the material covered in the literature review helps to contextualize the research question: **What potential changes does Seattle City Light (SCL), the city's public power utility company, need to undergo in the next 30 years as a response to climate change?**

¹⁰⁴ Raymond, 3.

Chapter 3 Methodology

As *Chapter 2* provided an overview of the main elements most relevant and important for understanding the research question of this thesis:

What potential changes does Seattle City Light (SCL), the city’s public power utility company, need to undergo in the next 30 years as a response to climate change?

Chapter 3 describes the scenario planning methodology used to investigate the research question.

Scenario planning is the chosen methodology for this thesis because to understand the potential changes facing SCL, the question requires an exploration and consideration of the potential and plausible futures for SCL. Consequently, the framework provided by the scenario planning procedure helps to examine the potential and plausible impacts that could occur in the future, particularly with the complex and uncertain issues presented by climate change.¹⁰⁵ Through the scenario planning process, practitioners explore the driving forces and key factors that influence the future, which then help to articulate choices and make robust decisions about the future.¹⁰⁶

While the scenario planning methodology that is detailed here in *Chapter 3* establishes a clear understanding of the scenario planning methodology, the information provided in *Chapter 2*, specifically regarding climate-related threats and challenges found in the Pacific Northwest and those respective impacts on SCL, its infrastructure, and operations, anchors the construction and consideration of the potential futures of SCL.

This chapter covers the general scenario planning framework. Additional elements are introduced to the framework to allow for a more complete analysis of the research question. These elements focus on establishing an understanding of the system itself and it introduces a resilience assessment to the analysis.

¹⁰⁵ Alberti, *Cities That Think like Planets*, 206; Schwartz, *The Art of the Long View*, 37-49.

¹⁰⁶ Ibid.

3.1 General Scenario Planning Framework

There are slight variations in how to conduct and facilitate scenario planning. However, the following framework reflects the core components of scenario planning that commonly emerged when reviewing the literature:¹⁰⁷

1. *Focal Issue*

To construct the scenarios, the focal issue frames the investigation; it identifies the problem to which decisions must be made about.

2. *Key Factors*

A key factor is any factor or phenomena that influences the success or failure of the focal issue.

3. *Driving Forces*

The driving force will impact the key factors. A driving force can be identified as any factor or phenomena that can significantly change the future trajectory.

4. *Ranked Driving Forces*

Once the driving forces are identified, they must be ranked. The ranking process arranges the driving forces based on importance and uncertainty. Importance addresses the magnitude of the force, that is, what will have the greatest impact. Uncertainty addresses the unpredictability of the force. The forces that are listed as the most important and most uncertain become the boundaries or end points for the scenarios.

5. *Scenario Plot*

A scenario plot describes the mechanism that organizes the most important and most uncertain driving forces. The plot helps to develop the different scenarios (futures) that may result based on the focal issue; the scenario plots give more structure for imagining the plausible and possible futures, which can be endless. The scenario plot is organized to present four scenarios. Within each scenario is an exploration of characteristics, outcomes, and actions that may occur within that particular future; each scenario attempts to identify challenges and opportunities that may be found given the circumstances. The use of a scenario plot helps to avoid the creation of scenarios that represent two opposite

¹⁰⁷ Salo and Bunn, "Forecasting with Scenarios," 293-294; Peterson, Cumming, and Carpenter, "Scenario Planning: A Tool for Conservation in an Uncertain World," 360-362; Alberti, *Cities That Think like Planets*, 199-206; Schwartz, *The Art of the Long View*, 241-248.

extremes and a middle ground; in fact, it is likely that the presented scenarios will overlap in certain aspects. The overlap is a positive aspect of the scenario process as the four scenarios will share similar elements of the driving forces and key factors, which structure the different scenarios.

It is important to note that scenarios created through this process will not become the exact imagined future. In exploring the possible and plausible futures, users are asked to reflect upon their understanding of the world and analyze their approach to problem-solving. Scenarios are meant to call attention to potential challenges, risks, threats, and opportunities that may otherwise be missed due to various cultural and institutional factors that lead to fragmented and dispersed knowledge. Ultimately, scenario planning enables learning, reflection, and a level of agility that strengthens the resilience of organizations, businesses, and communities alike,¹⁰⁸ especially when a robustness analysis and resilience assessment is included in the process. The strategies and actions developed because of the scenarios created in this process reflect a decision-making process which organizes its decisions to have the flexibility to exist in multiple scenarios; as noted, there will likely be overlap in the produced scenarios due to the shared elements of the driving forces and key factors. When creating strategies for responding to the focal issue, several sets of decisions can be considered acceptable actions to implement; these different sets of decisions can lead to multiple desirable futures. Since the various decisions can exist under different circumstances and still produce a desirable future, the strategies and actions allow for flexibility as circumstances change.

6. *Indicators*

Even though the imagined futures described in the scenario planning process will not completely come true, indicators are still an essential component to include in the process. Indicators help monitor how the future unfolds. They continue to assist users with reflection on their decision-making and problem-solving process. By monitoring how the future develops, users can determine whether decisions made due to the scenario planning process were correct or if decisions need to change course.

¹⁰⁸ Chermack and Lynham, "Definitions and Outcome Variables of Scenario Planning," 373; Schwartz, *The Art of the Long View*, 204.

For the purposes of this thesis, the six components listed above will be employed to explore the given research question; however, the framework will be expanded upon. To establish a more complete analysis, an examination of the system structure and a resilience assessment will be added.

3.2 System Structure

Establishing the system structure is important because it gives clarity to the boundaries of the analysis. Moreover, discussing the system structure gives an indication of the dynamics that exist within the system.

3.3 Resilience Assessment

The term “resilience” refers to the capacity of a system to experience disturbances while maintaining system functions.¹⁰⁹ To determine a system’s resilience, the following components need to be defined:¹¹⁰

- Resilience of what system, where the system’s conditions and environment are defined to provide background information on the status quo
- Resilience against what threats, where the potential pressures that can change the system is identified
- Resilience for what and whom, where the system’s functions are evaluated to determine what needs to be preserved; this detail directly impacts those who interact with the system
- Resilience over what timeframe, where the timeframe considered for assessment is established

In establishing these components, the resilience assessment aids our understanding of the condition of the system. Further, the assessment provides a foundation of knowledge regarding the potential challenges and risks as well as the opportunities that may be on the horizon. Moreover, the resilience assessment serves, to a degree, as a feedback mechanism; the elements

¹⁰⁹ Steve Carpenter et al., “From Metaphor to Measurement: Resilience of What to What?,” *Ecosystems* 4, no. 8 (2001): 765–81, <https://doi.org/10.1007/s10021-001-0045-9>; Holling, “Resilience and Stability of Ecological Systems.

¹¹⁰ Alberti, “Assessment of Resilience: Theories and Models” (lecture, University of Washington, Seattle WA, April 24, 2018).

that define a resilient system can be used to determine whether the choices made because of the scenario planning process increase, maintain, or decrease the system's resilience.

How resilience is assessed and cultivated will be an important consideration, as resilience can be described as good or bad; it is dependent, again, on how resilience is assessed and whether the perpetuation of the system in question is seen as valuable.

3.4 Limitations of Scenario Planning

There are several limitations to the scenario planning process conducted in this thesis. For starters, the time constraint in producing the thesis limited the author's ability to gather information and engage with stakeholders. Information gathering is one of the more crucial components of the scenario planning process; it is also the component that takes the most amount of work. The information gathered is meant to be broad and extensive, that is, the information covers multiple topics such as technology, science, and politics, and the information is carefully analyzed for the most relevant trends. However, this speaks to the larger issue within the scenario planning process (and rational planning), which attempts to gather all the unbiased information to deal with the uncertainty presented by the focal issue. However, it is impossible to have completely unbiased information and it is a challenge to be able to gather *all* the necessary information, especially when the scenario planning process is conducted within a given timeframe. The information used in this thesis, from the IPCC reports to SCL's *Climate Change Vulnerability Assessment and Adaptation Plan* are the most up-to-date and relevant information available at the time of production.

Further, the scenario planning process also gathers multiple stakeholders/experts to discuss the focal issue. The process provides an environment for the stakeholders to share their knowledge regarding the issue; the sharing of knowledge is meant to break down silos and allow for users to make the best decision given the presented knowledge. However, the scenario planning process conducted in this thesis did not involve other stakeholders in the process.

Another limitation emerges when considering the effectiveness of the scenario planning process. While the process includes indicators to assist in evaluating the robustness of the process,

measuring the overall effectiveness of the scenario planning process is difficult. The objective of the process is to help make decisions regarding complex and uncertain issues; therefore, to understand whether the scenario planning process worked, it is contingent on how behaviors change as a result of the decisions made. However, actions and responses can be unpredictable and require time to observe to fully understand the reaction. Additionally, the measures put into place to evaluate decisions or actions are vague, which creates another layer of difficulty for understanding how behavior and patterns of decision-making change.

Summary

In this chapter, the general framework for scenario planning is outlined and detailed with two additional elements incorporated into the process: a system identification and a resilience assessment. The structure for the scenario planning procedure is described in the following image (Figure 3-1):

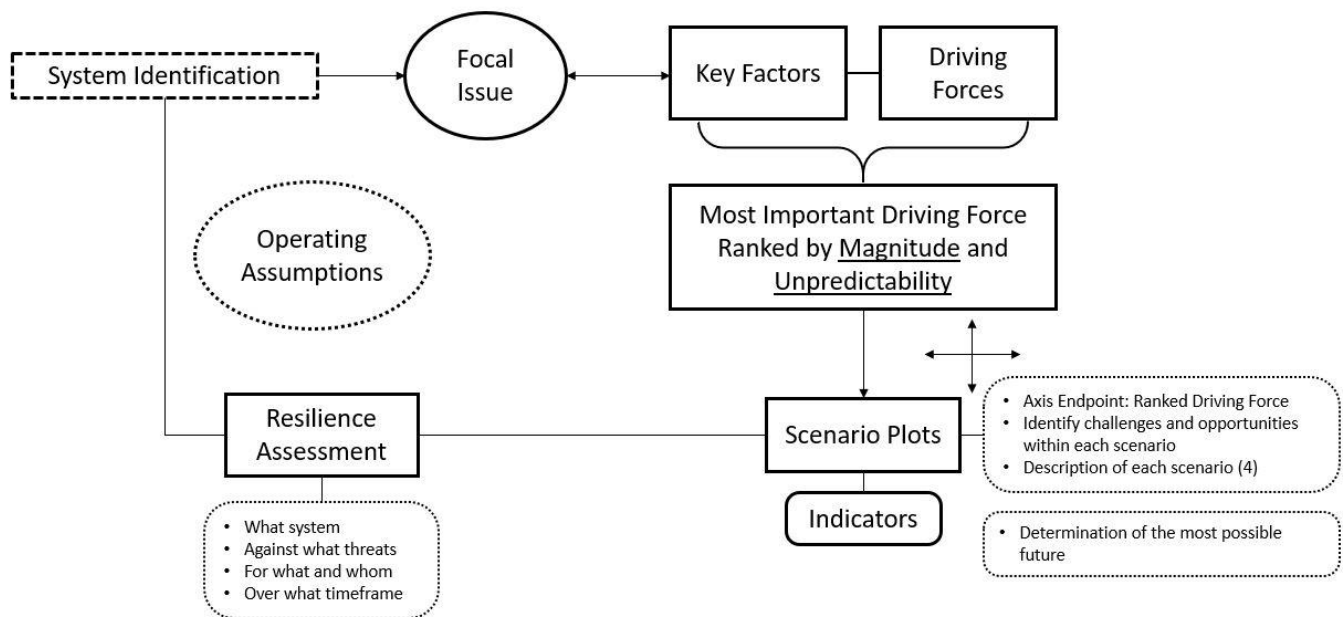


Figure 3-1. An illustration of the scenario planning process, which shows not only the different components of the process, but also demonstrates the iterative nature of the process.

Source: Author

The framework presented in this chapter will be applied officially in the following chapter, where the research question: **What potential changes does Seattle City Light (SCL), the city’s public power utility company, need to undergo in the next 30 years as a response to climate**

change? will be explored. *Chapter 4* will not only use the scenario planning framework as detailed in this chapter, but the chapter will also incorporate information provided in *Chapter 2* from the literature review. The climate research and the information provided about SCL as a utility and its infrastructure will anchor and guide the analysis found in the following chapter.

Chapter 4 Application of Scenario Planning

As mentioned in *Chapter 1*, the objective of this thesis is to address the central question:

What potential changes does Seattle City Light (SCL), the city’s public power utility company, need to undergo in the next 30 years as a response to climate change?

Due to the complexity of climate change, scenario planning is the chosen methodology to explore the given research question; scenario planning provides the opportunity to think critically about plausible outcomes that may affect Seattle residents and SCL. The scenario planning process outlined in *Chapter 3* structures the analysis that will take place in this chapter and will provide the information needed for discussion in *Chapter 5*. It should be noted that SCL is governed by Seattle City Council and regulated through the Washington Utility and Transportation Commission (UTC); therefore, any major regulatory change considered by SCL will need approval by multiple entities.

4.1 System Identification

The scale of analysis for this scenario planning process is Western Washington because most of SCL’s infrastructure is located throughout this area (Figure 4-1). However, since SCL provides services to Seattle and the neighboring areas directly north and south of the city, there will be additional emphasis placed on the city of Seattle.¹¹¹

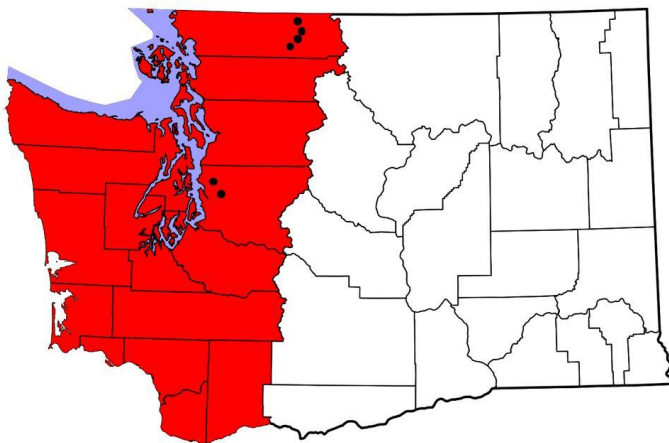


Figure 4-1. Western Washington is highlighted to illustrate the geographic scope of the scenario planning process.

Source: The base image was retrieved through public domain from Wikipedia; the black dots, which illustrate the location of the generation facilities, were added based on SCL information, see Figure 2-7

Geographically, the distinction between Western and Eastern Washington is established through the Cascade Mountains. West of the Cascade Mountains exists 19 counties, the Puget Sound

¹¹¹ Raymond, *Climate Change Vulnerability Assessment and Adaptation Plan*, 29.

Lowlands, San Juan Islands, Skagit Valley and several peninsulas.¹¹² According to the 2010 Census, over five million people live in Western Washington.¹¹³ Moreover, since Western Washington covers a large portion of the state, it is expected that the region is economically, politically, culturally, and demographically diverse.

In terms of infrastructure, SCL operates seven generation facilities; six facilities—the Ross Dam, Diablo Dam, Gorge Dam, Cedar Falls, South Fork Tolt, and Newhalem Dam—are located in Western Washington, while one—the Boundary Dam—is located in Eastern Washington (Figure 2-7).¹¹⁴ Due to the location of the utility’s generation facilities, there are over three thousand miles of transmission and distribution lines passing through rural and forested areas found in Western Washington.¹¹⁵ The service area size for SCL is over 130 square miles and provides energy service to over 400,000 consumers.¹¹⁶

4.2 Operating Assumptions

An important aspect of scenario planning involves reflecting upon one’s understanding of the world; this helps to frame how we make decisions and explains how we arrive at an outcome. For the purposes of this exercise, the operation assumptions regarding how the world works reflects the information presented in the literature review.

Assumption #1: Climate change is the result of human activity; therefore, to change the trajectory of climate change, it depends on changes made in human activity and in the subsequent behaviors.

Assumption #2: Human activity and behaviors today will determine the severity of climate change impacts that will unfold in this century. To limit the increased warming to 1.5°C (2.7°F), actions to dramatically reduce CO₂ emissions must begin well before 2030. Therefore, there is a sense of urgency and need for dramatic, transformative changes to take place.

¹¹² “Western Washington,” Wikipedia, accessed April 17, 2019, https://en.wikipedia.org/wiki/Western_Washington.

¹¹³ “Washington Counties Census 2010,” United States Census American Fact Finder, accessed April 17, 2019, <https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src=CF>

¹¹⁴ Raymond, *Climate Change Vulnerability Assessment and Adaptation Plan*, 10.

¹¹⁵ Raymond, 8.

¹¹⁶ Raymond, 29; Seattle City Light, *Fingertip Facts Information Guide*, 2018, 3.

Assumption #3: Climate change is not going to stop; the damages to the planet’s natural systems are irreversible. Therefore, the focus is on the pace, that is how quickly will temperatures warm and how quickly will the climate-related impacts unfold.

Assumption #4: The impacts of climate change will not be felt equally based on location, income, access to resources, and racial/ethnic identity.

Assumption #5: The energy sector is a key industry because of its strong and multiple cross-sector relationships. Energy infrastructure and services have the potential to impact other sectors and it has the potential to be affected by other sectors; therefore, making the sector both sensitive to climate change impacts, but also powerful in influence.¹¹⁷

Assumption #6: Service is the ultimate focus for infrastructure. Reliable service is the goal of operation and maintaining infrastructure; therefore, pressure from consumers, who want reliable and affordable service, may have more influence in changing the utility than climate change.

Assumption #7: SCL is a public utility that is govern by Seattle City Council and regulated through the Washington Utility and Transportation Commission (UTC). As a public utility, any changes considered by SCL will need approval by multiple entities including Seattle City Council and the UTC.

4.3 Resilience Assessment

The resilience assessment serves as a mechanism for understanding how the potential disturbances will affect the system. The assessment clearly defines the system in question and focuses our attention on what primary function to preserve, that is the function that remains despite the disturbances.

This assessment of resilience investigates how the electrical infrastructure of SCL develops and maintains resilience against warmer temperatures over the next 30 years; the goal of a more resilient system works to ensure service reliability, which is an important priority for SCL. Therefore, the two specific areas of interest when discussing resilience of energy systems is the physical infrastructure and the service. It should be noted that the physical infrastructure that provides energy to consumers is designed to be relatively static. The infrastructure can withstand a certain amount of stress and change over a given timeframe, but “when stressed beyond those

¹¹⁷ Wilbanks and Fernandez, *Climate Change and Infrastructure, Urban Systems, and Vulnerabilities*, 21-22.

limits, [the] structures are subject to degradation and collapse”.¹¹⁸ However, the ultimate goal in discussing resilience of infrastructure is to understand how to maintain the system’s function, that is how to continue to provide energy as a service despite the disturbances to the system. The resilience assessment will help to confirm our understanding of the threats and challenges facing SCL; additionally, it will lead the discussion in evaluating the anticipated futures that will be explored in the scenario planning process. To examine the resilience of SCL, this section will look at:¹¹⁹

- the system’s conditions and environment that define its status
- the potential threats that can change the system is identified
- the system’s function is determined to give an indication of what needs to be preserved; this detail directly impacts those who interact with the system
- the timeframe considered for assessment is established

4.3.1 Resilience of what system

The system in question is the energy system, which specifically explores SCL. The system’s infrastructure for generation, transmission, and distribution consists of seven hydroelectric generation facilities, over three thousand miles of transmission and distribution lines, and over 15 substations. SCL is vertically-integrated, that is the utility owns each component of the power system, from generation to distribution. Additionally, SCL provides energy service to over 400,000 consumers.¹²⁰

4.3.2 Resilience against what threats

As described in *Chapter 2*, climate change has the potential to impact all aspects of the power system. SCL’s *Climate Change Vulnerability Assessment and Adaptation Plan* indicates that eight primary changes—sea level rise and storm surge, warmer temperatures and heat waves, extreme weather, wildfires, landslides, reduced snowpack, higher peak streamflows, and lower

¹¹⁸ Whittington and Young, “Resilience through Transaction Cost Economic Evaluation: Recognizing the Cost-Effectiveness of Sustainable Development.”

¹¹⁹ Alberti, “Assessment of Resilience: Theories and Models” (lecture, University of Washington, Seattle WA, April 24, 2018).

¹²⁰ Raymond, *Seattle City Light Climate Change Vulnerability Assessment and Adaptation Plan*, 29; Seattle City Light, *Fingertip Facts Information Guide*, 2018, 3.

summer streamflows—will impact the operation and capacity of the utility.¹²¹ While protecting the physical infrastructure is important, resources for energy generation is also a crucial focus.

Based on 2017 information (Figure 4-2), SCL’s electricity is generated primarily through hydropower facilities.¹²² Warmer temperatures have the potential to decrease snowpack and lead to seasonal timing changes of streamflow, which will impact hydropower generation in the Puget Sound region and change the dynamic of energy supply in the region.

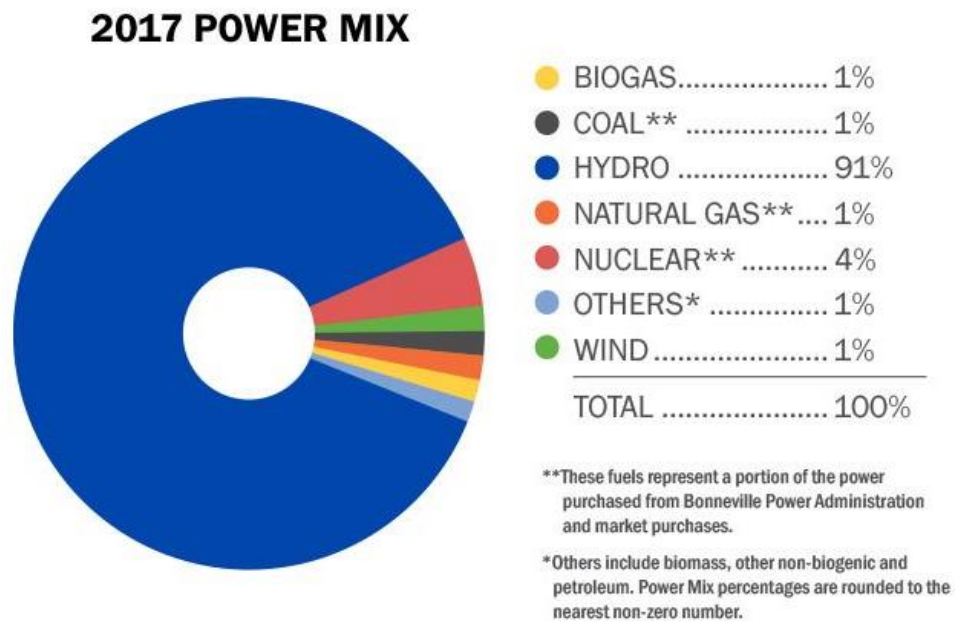


Figure 4-2. The figure illustrates SCL’s energy mix.
Source: SCL

A more diverse renewable energy mix will likely increase the overall resilience of the system. Diversifying energy generation can occur not only at the larger utility system level, but also through the consumer level through technologies like solar and geothermal, which can function separately from the main grid; this would increase the ability to access and use electricity.¹²³

Further threats to SCL’s infrastructure and its capacity to provide service include the increased intensity and frequency of climate-related hazards such as heavy precipitation, wind storms,

¹²¹ Raymond, *Seattle City Light Climate Change Vulnerability Assessment and Adaptation Plan*.

¹²² “Power Mix – How Our Electricity is Generated,” Seattle City Light, accessed April 26, 2019, <http://www.seattle.gov/light/FuelMix/>.

¹²³ World Energy Council, *World Energy Perspective The Road to Resilience - Managing and Financing Extreme Weather Risks*, 2015, 27.

flooding, wildfires, and storm surges; these threats can damage transmission and distribution lines, which can cause disruptions and delays to service.¹²⁴

In SCL's *Climate Change Vulnerability Assessment and Adaptation Plan*, the utility set out four guiding strategies to respond to climate change impacts; one of the strategies involves hardening infrastructure, which include initiatives to retrofit and upgrade the structure.¹²⁵

Examples of hardening include installing submersible saltwater-resistant equipment, elevating infrastructure, or building flood barriers around substations to protect against sea level rise and storm water flooding. In wildfire prone areas, utilities are hardening by converting from wood to steel poles.¹²⁶

The process of hardening infrastructure depends on the location and specific threats challenging infrastructure; therefore, the process will introduce a diversity of material into the physical system, which will increase the system's ability to remain responsive during extreme weather events and through climate variability.

4.3.3 Resilience for what and whom

Providing energy as a service is the primary task of SCL; fulfilling consumer demands—in addition to providing affordable service, the use of clean energy, and continual infrastructure investment—remains a top priority for SCL.¹²⁷ Any change can occur to the mechanisms for generation, transmission, and distribution of energy so long as consumers continue to have access to energy. It is also important to mention that the ability for the system to function overall will be tied to the utility's access to capital and its ability to use capital to operate and maintain the system.

4.3.4 Resilience over what timeframe

A system that is resilient can withstand any disturbances over various time periods and maintain the system's primary function. As climate change impacts unfold and become tangible, it will be

¹²⁴ Ebinger and Vergara, *Climate Impacts on Energy Systems Key Issues for Energy Sector Adaptation*, 35-37.

¹²⁵ Raymond, *Seattle City Light Climate Change Vulnerability Assessment and Adaptation Plan*, 3; Office of Energy Policy and Systems Analysis US Department of Energy, *Climate Change and the Electricity Sector: Guide for Assessing Vulnerabilities and Developing Resilience Solutions to Sea Level Rise*, 2016, 39.

¹²⁶ Raymond, 7.

¹²⁷ Seattle City Light, *We Power Seattle*.

crucial to ensure that the energy system can continue to perform its primary function; the mechanisms for how the system will provide energy to consumers may change as it works to respond to the climate-related challenges and threats.

This assessment specifically focuses on a 30-year timeframe, essentially until 2050. In the 2018 IPCC Special Report, *Global Warming of 1.5°C*, scientists report with high confidence that global temperatures will likely reach 1.5°C (2.7°F) above pre-industrial levels between 2030 and 2050 if the rate of increase in global temperatures remains the same.¹²⁸ To limit temperature increase to 1.5°C (2.7°F), implementation of actions will need to occur as soon as possible. Climate change impacts will continue to unfold throughout the next 30 years; therefore, concerns regarding climate-related threats to generation, transmission, and distribution of the energy supply remain. Within the next 30 years, the potential changes, fluctuations, and disturbances—created by climate change—will test the resilience of the energy system.

4.4 Focal Issue

The central themes of climate change impacts and energy infrastructure frames the research conducted in this thesis, which specifically asks:

What potential changes does Seattle City Light (SCL), the city’s public power utility company, need to undergo in the next 30 years as a response to climate change?

This investigation explores the administrative, operational, and financial aspects of providing a crucial service to consumers.

4.5 Key Factors

Many different factors can spur changes in operations, management, and finances; oftentimes, it is the combination of factors that foster a dynamic that creates positive or negative changes. Generally, the dynamic of the energy system depends on: the physical infrastructure, the operation and management of the infrastructure, the service it provides, and the exchange between consumers and the utility. Physical infrastructure includes the location, the lifecycle, and the replacement schedule of the infrastructure. Operation and management of the physical infrastructure involves the equipment and technology for operation and maintenance, the labor or

¹²⁸ IPCC, “Summary for Policymakers,” 4.

workforce, and the material for replacement or upgrades. Service includes the generation output, the transmission and distribution of the supply, and reliability of the service. Finally, the exchange between consumers and the utility involves consumer demand, revenue generation, and rate fees.

The key factors that have the potential to lead to both positive and negative changes for SCL are found within the operation and management of the utility's infrastructure and the influence of consumers. Changes in available technology and material could make operations and management of infrastructure more cost efficient; however, new technology and infrastructure equipment also has the potential to create more challenges for overseeing infrastructure operations. Additionally, customers have great capacity to influence changes in the utility such as the introduction of green or sustainability focused programs. SCL claim in their 2019 Strategic Plan that consumers have responded to the introduction of energy efficient technology and energy conservation efforts; consequently, SCL reports consumer behaviors changing, and they believe it may lead to the rate of energy consumption to decline.¹²⁹ Moreover, customers continue to expect SCL "to lead the charge to source renewable energy, reduce carbon emissions, and remove contaminants from [the] system."¹³⁰ Therefore, both consumer behaviors and expectations can pressure the utility to make changes.

4.6 Driving Forces

Driving forces are phenomenon that are difficult to predict and have the potential to leave lasting impacts; these forces influence the key factors that operate within the framework of the focal issue. To identify the driving forces, the different elements that can create positive and negative changes in the key factors were investigated.

In terms of operation and management of infrastructure, climate change, technology, policy, capital expenses, population growth, and energy consumption levels are all driving forces.

¹²⁹ Raymond, *Climate Change Vulnerability Assessment and Adaptation Plan*, 28; Seattle City Light, *We Power Seattle*, 12-17.

¹³⁰ Seattle City Light, *We Power Seattle*, 9.

Similarly, the driving forces that impact consumers are climate change, cost of service, technology, and policy.

Climate change impacts operations and maintenance procedure through damaging equipment and facilitating upgrades and/or relocation of infrastructure due to extreme events such as flooding, wildfires, and sea level rise. SCL's *Climate Change Vulnerability Assessment and Adaptation Plan* anticipates climate change to impact the life expectancy of their equipment, increased frequency of outages, interruptions to hydroelectric generation, and delays in repairs.¹³¹ Consequently, climate change impacts can delay service, which could lead to a re-evaluation of current repair and recovery procedures or the creation of new procedures. Further, delays in service also jeopardizes reliability of the service, which impacts consumers. The cascading effects of climate change has the potential to change the interactions between consumers and the utility.

The introduction of new technology and/or the incorporation of technology such as smart metering will influence how operation and maintenance will be conducted; overtime, this can change the dynamics of operational procedures. Moreover, new technology such as energy efficient appliances and smart metering impact customer behavior as they work to conserve energy. Further, electric-power transportation is on the rise, which will also contribute to the changing energy consumption patterns. Additionally, with solar panels and battery technology, customers are expressing their interest in generation and storing of their own energy. SCL has noted that the emerging technology is influencing consumer behaviors.¹³² As consumer behaviors and expectations change, SCL will need to determine how they navigate these changes.

Legal mandates can change the rules and regulations associated with operation and maintenance of infrastructure. While policies can have a variety of impact on operations, policies will have substantial impacts on how utilities will perform. Changes in policies and/or regulations may give utilities more agency to raise rates or may impose more financial burdens because of new

¹³¹ Raymond, *Seattle City Light Climate Change Vulnerability Assessment and Adaptation Plan*, 8.

¹³² Seattle City Light, *We Power Seattle*.

requirements. For example, the recent Washington State Senate Bill 5116 (SB5116) lays out plans for 100 percent carbon-neutral electricity supply by 2030, and 100 percent carbon-free electricity supply by 2045. To achieve these goals, SB5116 requires that all electric utility companies within the state to “eliminate coal-fired resources from its allocation of electricity”.¹³³ The consequences of SB5116 will have significant impacts on how SCL will generate and operate its infrastructure. While most of SCL’s energy is generated through hydroelectric facilities, SCL’s power mix still includes coal.¹³⁴ Therefore, to eliminate coal from its power mix, SCL will need to determine how to continue to diversify its energy mix. This may lead to more opportunities to increase other renewables such as wind and solar, which could increase the overall resilience of the system. Nevertheless, the consequences of changing the power mix will have financial implications because it may lead to new capital projects and could change existing purchasing agreements and contracts. SCL will need to determine its role and response to changes in policies. SCL has the opportunity to respond to changes by using policies as a positive springboard to be at the forefront of those changes.

Maintaining infrastructure overall is a very capital-intensive process. Utilities are paying for labor and material in addition to responding to requirements regarding safety, security, and fulfilling legal mandates.¹³⁵ Therefore, utilities are closely watching their capital expenses and likely trying to align operation and maintenance of infrastructure to decrease capital expenses. Further, capital expenses for operations and maintenance also spurs conversation regarding financing arrangements. Cost of service will be an important consideration to consumers, which is set through a variety of mechanisms to cover the cost of operation, maintenance, and service provision.

Demand for electricity, also referred to as energy density, is “sensitive to the drivers of economic development and population growth”.¹³⁶ Generally, levels of energy consumption is linked to population, that is, as a population grows, its use of energy also increases. However, as

¹³³ S. 5116, 66th Leg., Reg. Sess. (Wash. 2019), 1.

¹³⁴ “Power Mix – How Our Electricity is Generated,” Seattle City Light, accessed April 26, 2019, <http://www.seattle.gov/light/FuelMix/>.

¹³⁵ Seattle City Light, *We Power Seattle*, 17-18.

¹³⁶ Raymond, *Seattle City Light Climate Change Vulnerability Assessment and Adaptation Plan*, 28.

previously mentioned, the incorporation of new technology and the accessibility of technology—in terms of availability and cost—also influences the demand for electricity. The rise of electric-powered vehicles, interest in solar generation and battery storage, and the increased prevalence of energy efficient appliances are all changing consumption patterns. Further, warmer temperatures can also influence demand for electricity; during summer months, the increased temperatures could increase energy demand for cooling. The changing consumption patterns will impact how SCL will operate and manage its infrastructure. Responding to customer needs and expectations are a top priority for SCL; how SCL will respond to customers will be reflected in the changing consumption patterns of consumers.

4.7 Ranking Driving Forces

To understand how the driving forces affect the focal issue, the forces need to be assessed based on importance and uncertainty. Importance addresses the magnitude or impact of the force. Uncertainty addresses the unpredictability of the force. Both importance and uncertainty speak to the force's ability to spur the most change.

The following list (Table 4-1) ranks the driving forces in order of importance and uncertainty. The scale ranges from one to six. In terms of importance, one represents the force that has the greatest impact and six represents the smallest impact. For uncertainty, one represents the force that is the most unpredictable and six represents the least predictable. The rankings of the individual drivers are relative to the other drivers. Table 4-1 reflects this process of comparing drivers and ranking their effect on SCL. It should be noted that all the listed drivers have the potential to influence the focal issue; the rankings help to organize which drivers have the most impact.

To rank each driving force, the drivers are evaluated based on its ability to cause SCL to adopt or make changes to their operations. The criteria used to determine importance and uncertainty involved assessing whether the force directly or indirectly impacted SCL; at what scale the impacts occur; the level of control SCL have in determining outcomes; and whether there were identifiable trends.

Drivers	Importance	Uncertainty
Climate Change	1	1
Technology	4	4
Energy Density	2	2
Policy	3	5
Cost/Capital	6	6
Population Growth	5	3

Table 4-1 Ranking drivers separately on importance and uncertainty.

In terms of importance or magnitude of impact, climate change is listed as the driving force that has the potential to have the highest impact because climate change will affect both human and natural systems. Additionally, climate change impacts will be far-reaching and irreversible; therefore, impacts will unfold at multiple scales. SCL is able to act proactively to mitigate the severity of climate change impacts, but climate-related hazards and events such as sea level rise and wildfires will continue regardless of SCL’s actions. In terms of unpredictability, climate change is the most unpredictable force. Climate research detail how the environment is changing, and it provides a mechanism for understanding the different outcomes. However, the severity of impacts also depends on human activity; therefore, there is an element of unpredictability in how climate change impacts will unfold.

Energy density ranks second in terms of magnitude of impact. The level of consumption has the potential to impact SCL directly in their operations and through their finances. SCL’s revenue largely depends on consumption levels; the volumetric sales are used to continue investment and maintenance of infrastructure. Due to the dependency on volumetric sales, decreased demand would cause SCL to evaluate their operations. However, increases in demand would also call for an evaluation of system capacity. In both cases, changes in demand calls into question whether SCL can provide reliable service and keep up with changing consumer behaviors and expectations. Its relationship with customers serves as a large force that dictate the actions of SCL, which is reflected in the priorities established in SCL’s 2019 Strategic Plan. In terms of unpredictability, there are many factors that can influence level of consumption; those factors include emerging technology and population growth. While trends can be identified for energy

density as well as factors such as technology and population growth, energy density is not as unpredictable as climate change; however, because level of energy consumption is impacted by multiple factors, the dynamic of energy density is relatively unpredictable.

Policy follows energy density in ranking in terms of magnitude of impact because of its ability to influence how SCL will perform its tasks as a utility company. Policy has the potential of forcing changes onto SCL either directly or indirectly, which will then influence operations such as the type of infrastructure investment or how to structure their financial arrangements. However, how SCL decides to respond to policies is flexible. For example, SCL can do the bare minimum to respond to policy changes or it can leverage policy changes to make substantial changes to its operations. Due to this flexibility, policy has less impacts compared to climate change and energy density. In terms of unpredictability, it ranks relatively low, that is policy is predictable. The development of policy and the potential impact of such policy are usually publicly discussed and publicized, or at minimum policy proposals are accessible to the public. As a public utility company, SCL needs to be attune to potential changes in rules and regulations proposed by various political institutions such as Seattle City Council, UTC, or the Washington State Legislator so that the utility can anticipate impending impacts. Therefore, the passage of policies, when it impacts the utility, does not come as a surprise.

Technology ranks fourth in terms of magnitude of impact. While technology can directly and indirectly influence how SCL operates, SCL can decide what types of technology to adopt. Technology that is adopted by consumers will impact demand, which then affect SCL's operations. As previously mentioned, the incorporation of new technology and the accessibility of technology can change consumption patterns; due to SCL's relationship with customers, energy density serves as a more important driver than technology. In terms of unpredictability, technology ranks fourth because the type of technology that would impact consumers and the utility does not enter the market overnight. Accessibility and cost of technology determines how quickly new technology is adopted and incorporated; therefore, technology's ability to influence change in SCL is relatively predictable.

Population growth ranks fifth in terms of magnitude. Population growth has the potential to influence levels of energy consumption, which results in impacting SCL's volumetric sales. However, as previously detailed, levels of consumption/energy density are comparably more influential than simply population growth alone. In terms of unpredictability, population growth ranks third because many factors can influence the pace of growth such as changing economies or migration due to disasters. Consequently, predicting population growth is more difficult than predicting policies or technologies.

Cost/capital ranks last in terms of magnitude and in terms of unpredictability. Infrastructure is expensive. Due to its capital intensity, SCL is conscious of the capital needed to operate and maintain its assets. SCL's ability to provide reliable service is dependent on operations and maintenance of its infrastructure, which is affected by capital. Insufficient capital jeopardizes SCL's ability to provide energy to its consumers. However, SCL has historical data that helps to inform their financial decisions, which gives the utility relative control in mitigating the impacts of the cost to operations and management. Further, since SCL has historical data, the utility is able to plan for operational expenses and develop plans for responding to costs, which makes cost/capital relatively predictable.

4.7.1 Determining the most important and uncertain drivers

Based on the rankings of the driving forces in the previous section, it is determined that the most important and uncertain drivers are climate change and energy density. It should be noted that all of the considered drivers have the potential to spur change to the operations and management of SCL's infrastructure. However, for the purposes of constructing specific scenarios to consider as likely futures for SCL, the most important and uncertain drivers need to be identified; these drivers are further outlined in this section.

Climate Change

Climate change is the most important and most uncertain driver. As scientists reporting for the IPCC reports have illustrated, climate change will likely have lasting and multi-scale impacts by affecting every system connected to the health and livelihoods of humans. Climate research investigates the vast impacts of climate change and scientists have modeled the likelihood of

impacts; however, a level of unpredictability remains as the trajectory of climate change impacts through the end of the century depends on human activity presently.

Key dimensions of climate change:

- Temperatures will continue to increase. Scientists reporting for the *Fourth National Climate Assessment, Volume II* and for the *State of Knowledge: Climate Change in Puget Sound* indicate that in all climate model projections the Northwest will continue to warm. Under the high RCP scenario (8.5), scientists consider an average annual increase of over 10°F by the end of the century; while under the low RCP scenario (4.5), scientists predict an average annual increase of over 5°F by 2100.¹³⁷ It should be noted that the projected temperature increases do not indicate how many extremely hot days (days above 90°F) that may occur during a single year.
- Temperature increase will impact hydrology. According to the *State of Knowledge* report, the region will continue to experience a decline in snowpack, shift in snow to rainfall, and earlier streamflow timing. Scientists predict snowpack to decline between 20 to 50 percent by the end of the century. Increasingly warmer winters translates to less snow accumulation and quicker spring melt; “most models project an increase in winter streamflow [and] all scenarios project a decrease in summer streamflow”.¹³⁸ Moreover, declining snowpack, intensifying heavy rainfall, and rising seas lead to increased flood risks.¹³⁹
- Temperature rise will create drier conditions. This element is specifically important to consider as wildfires in the Puget Sound region become more common and intensify. Researchers estimate that area burned will double by the end of the century.¹⁴⁰

Endpoints: For climate change, the scenarios will be created within the bounds of **temperature rise from 2 to 10°F**. Data specifically illustrates that the Puget Sound region warmed by about 1.3°F from the 1890s to 2014, which is comparable to the overall two degree warming in the Pacific Northwest. In all climate model projections, the Pacific Northwest is expected to

¹³⁷ Mauger et al., *State of Knowledge*, ES-3.

¹³⁸ Mauger et al., 3-17.

¹³⁹ Mauger et al., 3-1-24.

¹⁴⁰ Mauger et. al, 9-5-6.

continue to warm anywhere from 5 to 10°F by 2100.¹⁴¹ As temperature is expected to rise, the uncertain detail is the rate of increase, that is whether the temperature will rise quickly or if the temperature will rise slowly. To be clear, there is no consideration of static temperatures because all climate models indicate some rate of increase. Further, it is clear that any amount of change will have lasting impacts on the health and livelihoods of communities in the Pacific Northwest.

Energy Density

Energy density is the second most important and unpredictable driver. It describes the level of energy consumption, which is influenced by many factors including technology and population growth. It may be noted that technology and population growth was listed separately as individual driver. However, in the ranking process, it was determined that separately, technology and population growth does not compare to the level of impact and unpredictability presented by energy density. It became clear in the driver identification and ranking process that technology and population growth are factors that greatly influence energy consumption levels instead. The incorporation of new technology and the accessibility of technology have the potential to change consumption patterns. For example, SCL has noted that the energy efficient technology is influencing consumer behaviors; specifically, SCL has observed a decline in energy consumption.¹⁴² Additionally, as technology can influence energy density, population growth can also determine energy consumption. Growth influences development patterns, which affects demand on infrastructure and services. Generally, when populations grow, there is likely an increase in energy use. Level of energy consumption has a major financial impact to SCL, which depends on volumetric sales to generate revenue to continue the core businesses of the utility.

Key dimension of energy density:

- Population growth will impact demand on infrastructure and services. “Since 2010, the [Puget Sound] region has gained more than 440,000 new residents”.¹⁴³ With new growth, it is expected that built infrastructure will attempt to keep up and respond to the new

¹⁴¹ Mauger et al., *State of Knowledge*, 2-5; U.S. Global Change Research Program, *Fourth National Climate Assessment*, 1041.

¹⁴² Seattle City Light, *We Power Seattle*.

¹⁴³“Regional Population Trends,” Puget Sound Regional Council, accessed April 23, 2019, <https://www.psrc.org/sites/default/files/trend-population-201808.pdf>.

demands. Housing, transportation, water and electricity will be sensitive to changes in population. Level of consumption will be partly influenced by the amount of people within the region; generally, levels of energy consumption is linked to population, that is, as a population grows, its use of energy also increases.

- Technology will impact consumption patterns. As new technology become more accessible and available, how people use electricity will change. “More efficient buildings, appliances and lighting mean households and businesses use less electricity”,¹⁴⁴ SCL has noted the changing dynamics in energy consumption due to the incorporation and adoption of energy efficient technologies. Further, consumption patterns are also changing due to the rise of electric-power transportation.

Endpoints: For energy density, the chosen parameters for the resulting scenarios are **low and high density**. Energy density describes level of energy consumption. Depending on various factors such as technology, population growth, and climate change, the use of energy can fluctuate. To be clear, there is no consideration for zero energy use; due to the interdependencies between infrastructure systems, there will be some demand for electricity to perform and support human activities.

4.8 Scenario Plots

Based on the identified drivers, four scenarios were developed (Figure 4-3):

- The first scenario is called “**Critical Condition**”, which describes the situation at the intersection of rapid temperature rise and high energy density. Both elements foster an environment where the electrical system receives pressures from environmental challenges and consumers. As temperatures rise, the electrical infrastructure will see threats to the generation, transmission, and distribution of energy; specifically, there may be disruption to hydroelectric generation, reduced capacity of transmission lines, and increased frequency of outages.¹⁴⁵ Further, a rapid temperature rise will likely increase electricity use for cooling purposes in the summertime, which will increase demand. High energy density refers to high levels of energy consumption. Pressures from

¹⁴⁴ Seattle City Light, *We Power Seattle*.

¹⁴⁵ Raymond, *Seattle City Light Climate Change Vulnerability Assessment and Adaptation Plan*, 8.

consumers to ensure reliable service and the increased threats to the electrical infrastructure will likely lead to a dramatic transformation or an extreme regime shift in terms of changes to administrative and/or operations and maintenance procedures. Further, this scenario will require immediate action because the circumstances instills an element of urgency.

- The second scenario is called “**Climate-Driven Pressure**”, where energy density is low, but the temperature continues to rise rapidly. With rapid temperature rise, the anticipated impacts will continue to affect generation, transmission, and distribution of the energy supply. In this scenario, climate change impacts will be the primary threat to operations and management of infrastructure. Consequently, it is likely that mitigation and adaptation strategies will be closely monitored and modified as needed. Energy consumption levels are low, which will have financial impacts on SCL since it is dependent on volumetric sales to continue operations, maintenance, and investment in infrastructure. If climate-related threats reach a level where the reliability of service becomes uncertain, this scenario could evolve to share similar outcomes as the “Critical Condition” scenario. Specifically, consumers may pressure and influence the actions of SCL to ensure service provision.
- The third scenario is called “**Consumer-Driven Pressure**”, which describes the scenario of high energy density and slowed temperature rise. In this scenario, increased consumer demand creates more pressure on the system than climate change impacts. Climate change impacts will still be present; therefore, concerns regarding climate-related threats to infrastructure remain. However, service reliability is the clear priority in this scenario. High energy consumption potentially increases revenue generation for SCL; however, high levels of energy use could stress the system’s capacity to supply energy. Therefore, SCL will need to evaluate whether current operations are able to keep up with changing consumer behaviors and expectations. Since service provision is the primary task of infrastructure and a top priority for SCL to ensure the needs of their customers are met, it is likely that the pressures from customers will impact how SCL will operate and maintain its infrastructure.
- The last scenario is called “**Proactive Mitigation**”, where energy density is low and the pace of temperature rise has slowed. Despite slowed temperature increases, climate

To respond to these conditions, SCL can: change the physical infrastructure to respond to climate-related hazards; change the method for energy generation; change the mechanism for transmitting and distributing energy supply; and/or change infrastructure investment.

While these are potential opportunities for SCL to respond to climate change, it becomes clear that the circumstances of high or low energy demand/use and slow or rapid temperature rise has direct and indirect financial consequences to SCL. Overall, operating and maintaining infrastructure is expensive. The added consideration of climate change impacts and the requirement to respond to customer needs and expectations increases the cost to operate and manage infrastructure. This is further complicated because of the traditional cost of service model which SCL presently uses as its financial model. SCL's revenue largely depends on consumption levels; the volumetric sales are used to continue investment and maintenance of infrastructure. Due to the dependency on volumetric sales, decreased demand would cause SCL to evaluate their operations. However, increases in demand would also call for an evaluation of system capacity. In both cases, changes in demand calls into question whether SCL can provide reliable service and keep up with changing consumer behaviors and expectations. Ultimately to be able to provide reliable service and to be prepared to respond to climate change, developing strategies for approaching revenue generation and financial investment will be crucial.

It should be noted that SCL can pursue any of the listed opportunities and develop corresponding strategies. However, strategies to harden, relocate, and design climate-responsive or climate-resilient infrastructure will require capital. Further, diversifying energy generation requires investing in new infrastructure to increase access to resources such as solar and wind; again, this requires capital. Therefore, focusing on mechanisms for revenue generation and financing infrastructure is the biggest opportunity to respond to SCL's future.

The fluidity between the scenarios are important to note, as it is the reason why the thesis does not focus on one singular scenario, but rather the commonalities shared among the four scenarios. Depending on the circumstances, it is possible for one scenario to become another scenario. For example, the "Climate-Driven" scenario can change trajectory and become the

“Critical Conditions” scenario if consumer behaviors and expectations change. Through this fluidity, the strategies and actions enacted can exist in multiple scenarios or multiple futures.

4.9 Indicators

Indicators help to monitor how the future unfolds. To monitor the pace of temperature rise and the levels of energy density, the following serve as indicators:

- **Housing Development.** The pace of housing development in the Puget Sound region will give an indication as to whether the population growth occurs at a rapid or slowed pace. As more people move to the region, it will likely translate to more demand for housing, which will lead to demands on other infrastructure such as energy. The amount and percentage of housing units added over the course of a few years will indicate potential changes in energy consumption levels.
- **Electric Vehicle Sales.** Electric-powered transportation is increasing. As these vehicles become more accessible in terms of cost and availability, the dynamic of energy use will likely change. Specifically, increasing energy use would indicate high energy density.
- **Wildfires.** Historically, wildfires are rare in the Puget Sound region; however, intensity and frequency of wildfires are increasing. “Increasing air temperatures and drier conditions are the primary mechanisms leading to projected increases in area burned”.¹⁴⁶ Therefore, monitoring the wildfire season for intensity and area burned over the course of a few years will illustrate the pace of temperature rise.

Summary

In this chapter, the research question: **What potential changes does Seattle City Light (SCL), the city’s public power utility company, need to undergo in the next 30 years as a response to climate change?** was examined using the scenario planning process, which was first detailed in *Chapter 3*. Through the scenario planning process, the major drivers that will influence change was established: climate change and energy density; the two drivers were determined to have the most impact and were the most unpredictable.

¹⁴⁶ Mauger et al., *State of Knowledge*, 9-5.

As the impacts of warmer temperatures unfold, the biggest challenge facing SCL will be finances. The urgency for action to address climate change impacts will require more capital for labor and materials to ensure smooth operations and management of the infrastructure; this could potentially lead to changes in infrastructure financing and investment. The traditional cost of service model may not be able to keep up with cost to operate and maintain SCL's energy infrastructure as climate change impacts unfold; therefore, the development and incorporation of new models can help create more financial stability for the utility, so that it may continue to provide reliable energy service to its customers.

Service reliability is an important component that anchors the conversation regarding the resilience of SCL's system. Specifically, the main priority for SCL under the circumstance of climate change is to have the capacity to deliver energy to its consumers. To do so, potential changes to the mechanisms for generation, transmission, and distribution can occur and/or changes in infrastructure finance and investment will aid in how the system will maintain its primary function.

To monitor how the future will unfold, the following indicators will help signal how the future will develop:

- **Housing Development**, where the pace of housing development in the Puget Sound region will give an indication as to whether the population growth occurs at a rapid or slowed pace; this will then signal a potential change in energy density.
- **Electric Vehicle Sales**, where the increase in sales will signal that the dynamic of energy use will likely change.
- **Wildfires**, where the intensity of the wildfire season and the area burned describe the combination of increases in air temperatures and dry conditions.

The analysis conducted in this chapter paves the way for an extended conversation in *Chapter 5* regarding the potential changes SCL can instigate as a result of climate change.

Chapter 5 Discussion

The following chapter aims to take the information presented in *Chapter 4* through the scenario planning process and further explore the implications of modifying the traditional cost of service model. To begin, the thesis set out to address the central issue of:

What potential changes does Seattle City Light (SCL), the city's public power utility company, need to undergo in the next 30 years as a response to climate change?

In working to answer this question, it became clear that regardless of climate change impacts and consumer demands, the cost to operate and maintain infrastructure is expensive. Climate change impacts and consumer behaviors contribute additional concerns to service provision and increases cost of operation and maintenance. In addition to climate-related threats and hazards impacting the cost of infrastructure operation and maintenance, new safety and security requirements, state mandates, and the overall inflation of cost for labor and materials increase each year for the utility.¹⁴⁷ Climate change has the potential of damaging various equipment needed for the generation, transmission, and distribution of energy; therefore, to repair, replace, and harden infrastructure as a response to already existing impacts or impending impacts requires capital. Consequently, to have the capacity to respond to climate change, SCL will need to address the issue of capital; therefore, capital remains at the crux of the issue.

The scenario planning process reveal opportunities to modify SCL's relationship with capital. As mentioned, SCL's primary method for collecting revenue is through volumetric sales, the traditional cost of service model. One mechanism to consider in exploring potential changes to the financial model is the introduction of a services-driven and/or value-driven regulatory model. As previously mentioned, SCL is govern by Seattle City Council and regulated through the Washington Utility and Transportation Commission (UTC); therefore, any major regulatory change considered by SCL will need approval by multiple entities including the UTC. This can pose as a challenge to the utility because it does not have the power to make the needed transformative change on its own.

¹⁴⁷ Seattle City Light, *We Power Seattle*, 17-18.

The backbone of an energy utility company like SCL is to provide a service—electricity—to consumers, whom pay for the ability to access and use the good. However, utilities in the 21st century are not simply expected to provide reliable service; SCL consumers expect affordable service, clean energy sources, as well as a customer-oriented utility. Therefore, the challenge becomes how to balance the maintenance and operations of energy infrastructure with the new expectations of utilities. A services-driven and/or values-driven utility is a mechanism that can help bridge the gap between maintenance and operations of infrastructure with the new expectations of utilities.

In an age of rapid technological development consumers expect services to follow suit. Indeed, new technology has quickened information processing and allowed for easy communication, yet these developments come as a cost to the utility. Therefore, a services-driven utility commodifies the additional services provided by the utility.¹⁴⁸ The goal of creating language around a services-driven utility is to establish clear expectations of service provision. The idea parallels the current setup for revenue collection; if consumers already pay a base rate by volume to access and use electricity, then there should be a similar approach for other added services provided by the utility. Further, a services-driven utility would be able to separate volumetric sales from overall profit and potentially gain more flexibility in creating the needed capital for operations and maintenance of infrastructure.

A values-driven utility is a performance-based regulatory model. The utility's revenue is based on its performance, that is its ability to reach targets and fulfill goals. This approach is more ideal in a state like Washington because there is already a culture of establishing targets or goals to address climate change and other environmental issues. Similar to the services-driven approach, the values-driven method focuses on the actions that the utility takes and establishes clear expectations for service. Further, the performance-based model realigns the branding of utility and its role in the climate crisis. The approach can serve as an accountability measure for the utility as the demand to be environmentally conscious continues to serve as a priority. Again, similar to a services-driven approach, a performance-based model separates revenue from volumetric sales.

¹⁴⁸ Satchwell et al., *A Framework for Organizing*, 23.

Understandably, there will be consumer pushback in changing the traditional cost of service model. Customers have become normalized to the added services utilities provide. Moreover, as times change, customers expect utility companies to adapt as well. Therefore, consumers will likely protest the proposed changes to their monthly bills. However, the introduction of a services-driven or performance-based model provides an opportunity to both the utility and consumers to find new ways of understanding and navigating utility services during an era of climate change. Researchers for the Ernest Orlando Lawrence Berkeley National Laboratory argue that a combination of the traditional cost of service method along with the services-driven and performance-based model can create a balance to lead to more stability for utility companies as they navigate climate change impacts and the operations and maintenance of infrastructure. Additionally, these new approaches provide a better opportunity for utility companies to align with energy efficient policies and initiatives rather than pit utilities against conservation efforts. It is important to note that any change to the traditional cost of service model will likely lead to changes in the interaction between consumers and utility providers; the task is to decide what the relationship moving forward will look like.

It should be noted that during the production of this thesis, the Washington State Legislature passed Senate Bill 5116 (SB5116), otherwise known as the “100 Percent Clean Energy Bill” on April 22, 2019. SB5116 outlines a pathway to support and transition the State of Washington towards a cleaner, more affordable, and resilient energy future. One of the more important elements introduced in SB5116 that will play a crucial role in this transition is through the Legislature granting UTC the power to implement a performance and incentive-based regulatory model.¹⁴⁹ To be clear, SB5116 does not outline how UTC will implement a performance and incentive-based regulatory model nor does the bill explain the changes associated with the transition. Technically, SB5116 gives UTC the flexibility to explore various mechanisms, which include performance and incentive-based regulation, to find the most suitable method that achieves the establishment of “fair, just, reasonable and sufficient rates” that align with the public’s interest.¹⁵⁰ Therefore, UTC could implement other ratemaking models that are not performance or incentive-based. Ultimately, the current traditional cost of service regulatory

¹⁴⁹ S. 5116, 66th Leg., Reg. Sess. (Wash. 2019), 2.

¹⁵⁰ *Ibid.*

model is not sufficient for the needs of the 21st century and it is insufficient to respond to climate change impacts.

The challenge of performance and incentive-based regulation will be defining the parameters that clearly establish the goals and the mechanism that decides how financing occurs. SB5116 has laid the foundation for certain clean energy goals such as requiring that electric utilities remove coal-fired resource from the production of electricity by 2025.¹⁵¹ However, the bill gives UTC the responsibility to review and approve goals established through individual utility implementation plans; therefore, SCL will have a voice in establishing goals and incentives that align with the utility's priorities and the concerns of their consumers. While performance and incentive-based regulation helps to align the objectives and interests of environmentally conscious consumers, there are challenges to monitoring and evaluating goals. Utility implementation plans, and the goals stated within them, will stand as incomplete contracts between UTC and the utility because there remains a level of risk and uncertainty within the market.

A further challenge results from the introduction of modifications to the traditional cost of service. Any modification requires an evaluation of the market structure and asset ownership, that is whether the role of the utility will continue to provide its service as a monopoly or competitively and whether to restructure the utility's asset from vertical integration—generation, transmission, and distribution—to a distribution-only operation. These considerations will also lead to questions regarding the role of the utility in administration and operation of the service.¹⁵²

Another challenge in this transition will be ensuring that the results provide service equitably. Infrastructure systems are the product of human interactions and are susceptible to the biases that humans hold. Inequities in infrastructure manifest in a variety of ways from who has access to the service and one's ability to pay for the service to representation in the decision-making process and access to information. Under the traditional cost of service model, equity issues come into consideration when thinking about who has access to energy efficient technologies

¹⁵¹ Ibid, 10.

¹⁵² Satchwell et al., *A Framework for Organizing*, 34-35.

that decrease consumption; low-income households may pay more in their bill and subsequently are burdened with paying more for maintaining and operation the infrastructure to respond to climate change impact. SB5116 places a large emphasis on equitable distribution of energy costs and benefits to ensure that through the transition towards carbon-free electricity supply, vulnerable populations, low-income communities, and indigenous tribes are included in the conversation; further, SB5116 wants to ensure assistance to these respective communities as the energy sector changes. Under a performance and incentive-based model, the utility can set service affordability as a top priority and measure of performance. While there are complicated ways of defining “affordability”—in terms of affordability varies across different incomes—the ability to have the element of affordability as measure of performance would incentivize the utility to work toward such goal; if the utility fails to reach such goal, the utility would be penalized under the performance and incentive-based model. Additionally, it can be argued that because a performance and incentive-based regulatory model separates utility profits from consumption and focuses on other financing mechanism, this change alleviates some burdens from low-income communities. Since the performance and incentive-based regulatory model is relatively new, it will need to include an equity focus in its implementation and evaluation process to ensure an equitable distribution of energy costs and benefits.

5.1 Generalizability

Climate change will affect all human and natural systems; therefore, it is expected that infrastructure systems will experience damages, disruptions, and delays. The interdependencies between infrastructure systems further extends the potential disruptions climate change will cause. The focus on electricity and the power system attempts to emphasize and acknowledge the severity of climate change impacts to the daily operations of cities, businesses, and communities.

There are approximately 2,000 public power utility companies, including SCL, in the United States.¹⁵³ As a not-for-profit utility company, the goals of providing affordable and reliable energy service to consumers are shared among the 2,000 utility companies. Further, as a public utility company, there is an emphasis placed on the public’s interest, that is, responding to

¹⁵³ “Our Members,” American Public Power Association, accessed June 9, 2019, <https://www.publicpower.org/our-members>.

customer needs and expectations are important priorities to public utility companies.¹⁵⁴ These goals are reflected in SCL’s four priorities—customer service, affordability, clean energy, and core utility business—defined in their 2019 Strategic Plan.¹⁵⁵ Climate change, therefore, poses real threats to public utility companies in their ability to provide affordable and reliable service. Further, energy use patterns are also evolving with new technology and a growing climate-conscious culture. Therefore, the challenges and opportunities discussed in this thesis are likely similar challenges and opportunities shared among other public utility companies. Specifically, this thesis discusses the financial challenges presented by the traditional cost of service model and the difficulties it may lead to responding to climate change impact. However, the thesis suggests transitioning the traditional cost of service model to a performance-based incentive model, which allows for more flexibility in revenue generation. The conversation regarding financial challenges are common for utility companies because the overall operation and maintenance of infrastructure is expensive; therefore, the lessons learned through this thesis can be shared among other public utility companies.

5.2 Reflections on the scenario planning procedure

While the components of the scenario planning process are straight-forward, the execution of the process is more complex. Since scenario planning as a tool is meant to explore all the plausible and possible futures of complex and uncertain issues, it should not be a surprise that the process itself reflects the complex, unpredictable, and subjective nature of our world. When constructing the various futures or scenarios for SCL, assumptions about how the world functions were operationalized; however, establishing these assumptions can be a challenge, especially when scenario planning is used in practice with community organizations, businesses, and/or public agencies. Being able to work together, among different perspectives and through different power dynamics is part of the process in establishing a vision of a desired future but it is not without issues.

¹⁵⁴ “Public Power,” American Public Power Association, accessed June 9, 2019, <https://www.publicpower.org/public-power>.

¹⁵⁵ Seattle City Light, *We Power Seattle*.

Further, when discussing the plausible and possible futures, the element of transformation is an important consideration. As mentioned in *Chapter 2*, transformations describe futures that depart from the status quo. In considering the future of SCL and the complex, unpredictable nature of climate change, do the constructed scenarios and the subsequent actions and strategies surrounding those scenarios establish a future outside of the current system? Specifically, with the issue of climate change, should the actions and strategies developed in the scenario planning process lead to transformative futures? To take the climate crisis seriously and properly respond to the matter, it can be argued that the imagined futures should be radically different from our present circumstances. In the 2018 IPCC report, this approach is implied as scientists report with high confidence that to limit global temperature increases to 1.5°C (2.7°F) above pre-industrial levels, sweeping changes will need to be made across all sectors, including the energy sector.¹⁵⁶ Therefore, given the scenarios constructed in this thesis, are the actions and strategies of modifying the traditional cost of service transformative? The biggest challenge will be identifying when actions and strategies lead to transformative change.

However, it is important to note that transformative change can occur on multiple scales. In the case of infrastructure, it might be more meaningful for transformative changes to occur on a lower scale due to the static nature of infrastructure. Since infrastructure's primary goal is to provide a service, it is unlikely that departing from this function is beneficial to its user. Nevertheless, how infrastructure evolves and how it is operated and managed can experience changes that depart from the current mechanisms of operation and management and create beneficial outcomes.

Summary

Climate-related threats and hazards would increase the urgency to protect the utility's infrastructure and ensure their ability to continue to meet consumer demands. Infrastructure is a capital-intensive endeavor and the additional pressure created by climate change will likely increase cost to SCL for operating and maintaining its infrastructure. As a response to these conditions, changes would need to occur to their financial mechanisms.

¹⁵⁶ IPCC, "Summary for Policymakers," 15.

This chapter further discusses the circumstances of modifying the traditional cost of service model to a services-driven and/or a performance-based model. The traditional cost of service model relies on volumetric sales of energy, that is revenue generation depends on how much users consume. A services-driven and performance-based model both separates revenue from volumetric sales. Ultimately, the current traditional cost of service regulatory model is not sufficient for the needs of the 21st century and it is insufficient to respond to climate change impacts.

It should be noted that during the production of this thesis, the Washington State Legislature passed Senate Bill 5116 (SB5116), otherwise known as the “100 Percent Clean Energy Bill” on April 22, 2019. In SB5116 the Legislature grants UTC the power to explore and implement various mechanisms, which include performance and incentive-based regulation, to find the most suitable method that achieves the establishment of “fair, just, reasonable and sufficient rates” that align with the public’s interest.¹⁵⁷ Therefore, there is a possibility in the near future, SCL’s financial mechanism will change.

¹⁵⁷ S. 5116, 66th Leg., Reg. Sess. (Wash. 2019), 2.

Chapter 6 Conclusion

The thesis illustrates how climate change impacts may dramatically impair and disrupt systems. Further with more interconnected systems, the cascading effects of such impacts threatens the health and livelihoods of communities everywhere. The thesis focuses on the energy sector specifically because it is a key industry that has strong cross-sector relationships; this makes the energy sector not only powerful as it can influence other sectors, but also sensitive to changes in other sectors. Disruptions to the energy system can lead to disruptions in communications, transportation, and healthcare. Additionally, the energy sector has historically contributed the highest amount of annual anthropogenic greenhouse gas emissions than any other sector.¹⁵⁸ Consequently, the interaction between climate change and energy infrastructure is an important element to consider in the next 30 years This thesis addresses the following question:

What potential changes does Seattle City Light (SCL), the city’s public power utility company, need to undergo in the next 30 years as a response to climate change?

To answer this question, this thesis is grounded in a scenario planning approach to understand the complex relationship between climate change and energy infrastructure and their respective influence on how cities and communities plan and respond for climate change.

The scenario planning process helped to frame the problem where climate change impacts intersected with consumer behavior. Exploring the combined effects of warmer temperatures and pace of population growth revealed that regardless of climate change impacts and consumer demands, capital will be the biggest challenge to SCL. To have the capacity to respond to climate change impacts and consumer demands, SCL needs to have the financial capacity to operate and manage the infrastructure. With climate change impacts impending, there is an increased urgency to develop a response that would ensure the utility’s ability to provide energy service to their customers as well as protect their existing infrastructure.

The traditional cost of service model is based on volumetric sales, that is, revenue is generated through user consumption levels. However, in the last few years, SCL has reported a decline in energy consumption despite the rapid population growth in Seattle. While revenue is not a major

¹⁵⁸ IPCC, Climate Change 2014: Synthesis Report, supra note 1, 46.

issue presently, in the near future, if changes are not made, SCL will likely have a challenge in revenue generation. Therefore, this thesis suggests that changes in SCL's financial model require the development of a services-driven and/or performance-based model. The introduction of a services-driven and/or performance-based regulatory model will help separate the dependency on customer consumption from profit. However, changing how SCL operates financially requires the approval of multiple entities including Seattle City Council and Washington Utility and Transportation Commission (UTC), which respectively, govern and regulate SCL's operations.

The services-driven approach redefines the terms of service. As utilities offer many value-added services such as energy efficiency programs, green power options, and energy usage information, the added services increase costs to the utility. While it is understandable that the utility will need to adapt as technology becomes available and with climate change impacts posing serious threats to operations, the utility cannot bear the burden of cost in adaptation alone. Therefore, the services-driven approach suggests transferring the cost for the added services to consumers. This approach will likely be the more challenging approach to advocate for due to already established consumer expectations.

The values-driven approach is a performance and incentive-based regulation where the utility's revenue is tied to the performance of the utility, that is its ability to reach targets and fulfill goals. This approach is more ideal in a state like Washington because there is already a culture of establishing targets or goals to address climate change and other environmental issues. During the production of this thesis, the Washington State Legislature passed Senate Bill 5116 (SB5116) on April 22, 2019, which grants UTC the power to implement a performance and incentive-based regulatory model or any other financial mechanism so long as the UTC finds the most suitable method that achieves the establishment of "fair, just, reasonable and sufficient rates" that align with the public's interest.¹⁵⁹ Therefore, it is possible that in the near future the traditional cost of service model will change; consequently, giving SCL the power to change their financial model, which needs to happen to ensure the utility's ability to respond to climate change impacts and consumer demands. Ultimately, the current traditional cost of service regulatory model is not sufficient for the needs of the 21st century and it is insufficient to respond to climate change

¹⁵⁹ S. 5116, 66th Leg., Reg. Sess. (Wash. 2019), 2.

impacts. A performance-based regulation makes the most sense as its framework aligns with the objectives of SB5116 since the bill already outlines goals and targets to move Washington's energy future towards a cleaner, more affordable, and resilient energy system.

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