Future Pathways to U.S. Decarbonization Through Nuclear and Other Energy Systems

Submitted in partial fulfillment of the requirements for the degree of
Doctor of Philosophy in
Department of Engineering and Public Policy

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December 2020

Acknowledgements

Funding for this work was supported by the Alfred P. Sloan Foundation (grant 2016-7281) and the Center for Climate and Energy Decision Making (CEDM) through a cooperative agreement between the National Science Foundation and Carnegie Mellon University (SES-1463492). I was also supported by the U.S. Department of Education's Graduate Assistance in Areas of National Need (GAANN) fund.

I am sincerely grateful for my invaluable mentors during my time at Carnegie Mellon. I would like to thank Dr. M. Granger Morgan (committee chair) for bringing me to Carnegie Mellon, supporting me throughout the PhD program, and supporting my growth as a researcher. Second only to my mother, no one has been more patient with me then Granger. I am also grateful for the support and guidance of Dr. Ahmed Abdulla (co-chair), who has also supported my growth as a researcher over a substantial portion of my PhD. Ahmed’s guidance has helped me focus my work and turned my pondering directionless questions into a research agenda. I would like to thank Dr. Jared Cohon, who exposed me to, and mentored me in, multi-criteria decision making. Despite his busy schedule, Jerry always found time to discuss my favorite topic, food, in our research meetings, and I thank him for being a committee member. Thank you to Dr. Michael Ford for serving as a committee member. Michael was the first student I met in EPP, and I am thankful that he has stayed by my side till the very end.

Without the help of Patti Steranchack, my paper would not have been published, my research meetings would not be on time, and every aspect of my CMU experience would have been disorganized, thank you for your help and hard work Patti. Additionally, I would like to thank Debbie Kuntz, Adam Loucks, and Vicki Finney for making me feel welcome at EPP. Thank you to the EPP administrative staff, my classmates, and friends who have supported me during the

PhD program.

Thank you to Logan Warberg and Daniel Gingrich for always finding the time to get breakfast with me every week, and for sharing your small-town stories. Thank you to the many restaurants in Pittsburgh that fed me for free when my Phd stipend was not enough to cover my large appetite: Kelly O's Diner, Bitter Ends Luncheonette, and Spirit. Thank you to my friends in NYC for always being there for me and keeping my head on straight. I do not know where I would be without Greyson, Andy, Mike, Kristo and my longest friend Scott. They always had words of encouragement, and a couch for me to sleep on.

Lastly, thank you to my family; Antoinette Rath, Jeffrey Rath, Elizabeth and Domenic DePascale, my nieces Juliana and Lucia, my seemingly hundreds of Petrillo family members, and my grandparents Jerry and Barbra Blum for your unconditional encouragement, love, and support.

Abstract

This thesis examines the hurdles involved in converting the U.S. energy system to one that emits little or no carbon dioxide into the atmosphere. The first part of this thesis looks at nuclear energy in the U.S., while the second part examines the pursuit of decarbonization through decentralized micro-grids.

The thesis begins by examining the possibility of a U.S. domestic market for factory-manufactured small modular nuclear reactors (SMRs) being developed through the use of hybrid water-energy systems. This work found that the use of the proposed hybrid system will not likely lead to the mass market needed to facilitate the mass manufacturing of SMRs. On the electricity side, these hybrid systems powered by SMRs are not cost competitive in the U.S. against similar low carbon technologies like natural gas equipped with carbon capture and sequestration (NGCCS). On the water side, I conclude that the need for water desalination over the next several decades in the U.S. will not be large enough to support the mass SMR market I was searching for. However, there might exist substantial markets in arid countries where natural gas prices exceed 12 $/mscf and where there is a strong desire to adopt nuclear power.

Chapter 3 investigates the perceptions of nuclear power as supported by existing theories on differing nuclear perspectives. Our survey participants held significantly less favorable views about nuclear energy if they cited Chernobyl and Fukushima as noteworthy events that shaped their perception. I found that Chernobyl has the most negative impact on participants, even for those who were not alive for the event. There was also a significant increase in negative views of nuclear energy in participants who would have been between the ages of 20 to 30 years old during Chernobyl, but these results do not extend to other events like Fukushima. The survey results also suggested that participants who are both non-white and non-male held significantly

less favorable views compared to white males.

Chapter 4 examines the trade-offs between decentralization and decarbonization in microgrid planning. A trade-off curve is produced by using a previously developed mixed-integer program (DER-CAM) in a multiobjective programming framework. The results include a range of microgrid designs with different technology mixes or typologies. As the weight on greenhouse gas emissions increases the associated costs rise; at the design that minimizes emissions, the levelized cost of energy (LCOE) of the micro-grid rises to approximately 7x the current cost of electricity in southern California. Changes in natural gas (NG) prices do not change the micro-grid's typology, but rather forces a quicker transition to low-carbon typologies. Every micro-grid developed in this chapter contained some amount of dispatchable distributed energy resource (DER), leading to an examination as to why a PV + storage only micro-grid would be unlikely. With the apparent need for micro-grids to contain some amount of distributable generation, a relatively small social cost of carbon of $50 per ton of CO_2 ensures that every micro-grid would consist of primarily low-no emission DERs.

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CHAPTER 1: Introduction

1.1: Research context

Many studies argue that the United States must begin to convert its energy system to one that emits little or no carbon dioxide into the atmosphere [1-3]. However, making such a transition poses a variety of scientific, engineering, and policy challenges, as this transition involves juggling many different and conflicting criteria. This thesis examines these hurdles in two parts. Chapters 2 and 3 investigates nuclear energy, regarding its potential expansion and public perception in the U.S., while Chapter 4 examines the pursuit of decarbonization through decentralized microgrids.

For many energy investors, new nuclear is a non-starter because the upfront capital costs are far greater than the cost of other forms of generation, like coal and natural gas [4,5]. Capital costs of new nuclear are often underestimated, as recent nuclear developments have exceeded budgets by 4 – 12 times the initial capital cost estimates [6,7]. Cost overruns are expected to continue if only large light water nuclear plants are pursued. In addition to high nuclear costs, since the late 1970s there have been three highly publicized nuclear accidents: Three Mile Island in 1979, Chernobyl in 1986, and Fukushima Daiichi in 2011. Though the number of nuclear accident events that have occurred in the past 50 years is significantly fewer than the number of coal or natural gas accident events [8], these nuclear events are heavily publicized. Such events have villainized nuclear energy and led to a "not in my back yard" response from laypeople to any proposed development of nuclear power. Despite these setbacks, nuclear technology continues to draw interest for its potential role in deeply decarbonizing the U.S. energy system. Further, the U.S. grid depends on nuclear energy as a baseload generating source, as approximately 20% of U.S. electricity generation has come from nuclear power over the past three decades. Accordingly, nuclear energy is the largest form of zero-emission energy generation in the U.S. [9].

The second part of this thesis assesses a path towards decarbonization through micro-grid development. Interest in decentralized micro-grids is increasing. This interest is creating an opportunity for future decarbonization developments through small distributed energy resources (DERs), rather than through more conventional large power stations. One key benefit to micro-grids is their contribution to more resilient energy system; micro-grids have the capacity to "island" themselves and operate separately from the larger grid. As such, micro-grids can supply the energy demanded by their operators when the bulk electric power system suffers disruptions. This capability, among others, has elevated interest in the development of micro-grids among organizations that are keen to improve the reliability and resilience of their electric power supply. However, there is no singular reason for investing in a micro-grid. Even in the case of an islanded micro-grid, which provides the most resilience against blackouts, many other factors are considered before investing. Recent surveys of micro-grids in the U.S. show that many facility operators invest in micro-grids for their potential cost savings and emission reductions, along with their resilience.

With micro-grid development still relatively new, policy makers have time to understand and shift the policy incentives in order to push facility operators to invest in low to no carbon based DERs. However, such incentives are based on the delicate balance of decentralization and their willingness for decarbonization. Currently, decentralization is primarily powered through fossil fuels [10,11], which are cheaper than most low to no carbon emitting forms of generation. As micro-grids continue to proliferate, the dominance currently seen in fossil fuels will be called into question, especially if there continues to be a societal push towards deep decarbonization.

1.2: Dissertation Overview

The goal of the first part of this thesis (Chapters 2 and 3) is to examine the hurdles of converting the U.S. energy system to one that emits little or no carbon dioxide through the promotion of nuclear power, such as the move away from large-light-water nuclear reactors to factory-manufactured small modular reactors (SMR), and the public perception of nuclear power. The second part of this thesis (Chapter 4) explores the potential for, and implications associated with decarbonization through the use of decentralized micro-grids.

The first study examines two ways to back up intermittent wind using a hybrid power desalination system. This is done by comparing small modular reactors to natural gas power plants outfitted with carbon capture and sequestration. These hybrid systems will use the electricity from the SMR or gas plant to desalinate water (which can be relatively easily stored) when the wind is blowing and provide power to the grid when it is not. This chapter examines the possibility that a U.S. domestic market for factory-manufactured small modular nuclear reactors (SMRs) might be developed to use the constant output of an SMR to perform water desalination. The evaluation includes considerations of conditions when wind or solar power were producing at high output and the uneven water supply situation across the U.S. My model results indicate that other than a few local markets, the U.S. will not need mass desalination over the next several decades. Further, the commercial risks and siting difficulties that are likely to accompany SMRs would likely preclude their wide adoption in the U.S. over the next few decades. While it is unlikely such a system will spur mass manufacturing of SMRs in the U.S., the potential for global markets remains. However, in the face of aggressive Chinese, and Russian programs of reactor exports, U.S. nuclear policy will need substantial changes in order to compete in these markets.

The second study examines whether the era in which people grew up and experienced different events involving nuclear power might shape their perceptions of choice of nuclear as a low-carbon energy source. It is likely that learning about nuclear accidents can strengthen negative associations with nuclear weapons, fear of nuclear waste, and other negative attributes. The nuclear industry and its allies have struggled with largely ineffective public engagement strategies to defuse the public's sense of dread associated with the use of nuclear energy. The element of dread may result in as much as a 40% lower willingness to adopt nuclear power as part of a strategy to decarbonize the energy system [12]. These negative perceptions of nuclear power may in part be explained by the theory that the attitudes that people form during particularly intense experiences occurring in their formative years tend to stick with them and be intensified by confirmation bias [13]. We performed an exploratory analysis to investigate whether past nuclear accident events have created a lasting impact on people's perception of nuclear energy. We do this by exploring the relationship between nuclear accident event occurrence during survey participants' formative years and their perception of nuclear energy, hypothesizing that if a nuclear accident occurred during participants' formative years, they would be more likely to oppose nuclear energy. This hypothesis was further supported by Berntsen et. al [14], who noted that "many studies suggest that negative events cause greater physiological and affective reaction and more cognitive processing…which would enhance memory…[and] cause an immediate mobilization, which may lead to long-term distress if not dampened down." At the same time, the intensity of people's reactions may have been modulated by the fact that social media played a much greater role in publicizing the Fukushima Daiichi event [8].

The third study examines the roles that micro-grids might play in developing a more resilient low carbon future energy system. Current environmental policy around energy production regulates the emissions of the large utilities, which does not include micro-grids, but the majority of micro-grids are powered by fossil fuels, such as diesel. If the current practice of only optimizing on cost continues as micro-grids proliferate, it is possible that the U.S. will regress on its goal to reduce their CO_2 emissions [2]. As micro-grids become a popular option for energy resilience, it is necessary to evaluate their environmental impacts as well. With a push towards deep decarbonization of the U.S. energy system, many facility operators are being placed in tough positions in which they face the tradeoff between minimizing cost and minimizing emissions—two objectives that usually conflict. With the possibility of being regulated and the growing push towards increased resilience, micro-grids are an attractive approach to emission reductions while, hopefully, allowing those who invest in and maintain micro-grids to cut costs. With this possibility, previous literature has looked at the role of economic and policy levers in changing the mix of distributed energy resources used in a micro-grid from predominantly fossil-backed resources to low-carbon ones [15]. Instead, we look to explore the relationship between the weights (i.e., the relative importance) ascribed to costs and emissions by [facility operators] and the final mix of various iconic micro-grid types.

The goal of this work is to determine the extent to which decentralization and decarbonization are competing or orthogonal goals, and to elaborate the nature of the transition as carbon constraints on a micro-grid tighten. Our approach will yield a more robust and comprehensive assessment of the likely trajectory of micro-grid adoption than existing models currently offer

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CHAPTER 2: Assessment of a Hybrid System that Uses Small Modular Reactors (SMRs) to Back Up Intermittent Renewables and Desalinate Water[1]

2.1: Abstract

Because water is easier to store in substantial quantity than electricity, this paper examines the possibility that a U.S. domestic market for factory-manufactured small modular nuclear reactors (SMRs) might be developed to use the constant output of an SMR to perform water desalination when wind or solar power plants are producing high output and generate electricity for the grid when wind or solar power output is low. In the first part of the paper, we compare powering desalination systems with electricity from SMRs and from natural gas plants that are equipped with a system that performs carbon capture and geological sequestration (NG CCS). We show that mass-produced SMRs could have costs that are comparable to, but probably somewhat higher than those of systems based on NG CCS. We find that the cost of CO_2 emissions would have to rise to roughly 200 $/ton for the SMR solution to be clearly dominant. In the second part of the paper, we examine the uneven water supply situation across the U.S., focusing on the southwestern and western regions, and conclude that over the next several decades serious shortages are likely to develop only in a few local markets, such as West Texas and the Monterey Peninsula in California. Even if factory mass production of SMR's were more successful in reducing costs than experts have estimated, and costs could be reduced to that of NG CCS systems, the commercial risks and siting difficulties likely to accompany SMRs would probably preclude their wide adoption in the U.S. over the next few decades. Globally there are regions where a significant market for desalination supported by

[1] This chapter is based on a paper co-authored with Prof. M. Granger Morgan. It can be found at Michael Rath and M. Granger Morgan. (2020). "Assessment of a Hybrid System that Uses Small Modular Reactors (SMRs) to Back Up Intermittent Renewables and Desalinate Water", *Progress in Nuclear Energy*, 122 103269.

nuclear power might develop. Aggressive changes in U.S. regulatory and export policy will be needed if U.S. SMR manufacturers are to play a role in those markets in the face of aggressive Chinese, South Korean, and Russian programs of reactor exports.

2.2: Introduction

For the past three decades roughly 20% of electricity generated in the U.S. has come from nuclear power [1]. Many estimates of how to optimally decarbonize the U.S. energy system include adding a significant amount of additional nuclear power [2]. However, given the recent history of delays, and cost overruns, it is unlikely that the U.S. will build any more large light water nuclear reactors [3]. It also appears that no U.S. advanced reactors will become commercially available before mid-century at the earliest [4,5]. Thus, if nuclear power is going to play a role, in addition to the one it is already playing, in decarbonizing the U.S. energy system in the next three or four decades, it will probably have to be through the use of factory-manufactured, light-water small modular reactors (SMRs). This cannot happen at a low enough cost, or in high enough quantities to make a difference, unless some significant domestic market can be identified to justify the heavy front-end investment involved in getting U.S.-based factory mass production off the ground.

Unlike electricity, which is difficult and expensive to store, especially in large quantities and for extended periods, it is relatively easy to store water. Motivated by the frequent talk about future water shortages [6,7] and the "water-energy nexus" [8], we examine the feasibility of creating a large enough market to jump-start the mass manufacturing of SMRs through the use of hybrid systems that use the constant output of an SMR to supply electricity to the grid when the wind is not blowing, or the sun is not shining and to perform water desalination when the wind is blowing, or the sun is shining. Such a system would allow SMRs to operate with a high-capacity factor and avoid having to ramp up and down if they were only used to fill the gaps in wind and solar generation. The feasibility of using desalination systems to operate flexibly in tandem with intermittent sources of renewable energy has been demonstrated by Kim et al., whose results show that such a configuration can respond and settle quickly and maintain loads long enough to respond to large and fast changing variable generation sources [9].

One of the obvious advantages of using an SMR for this hybrid system is that it produces no carbon dioxide in operation. A similar system could be built using any other base-load low-carbon energy source such as hydro power or fossil plants using carbon capture and geological sequestration (CCS). Because it is unlikely that the U.S. will be able to add much additional hydro capacity[reference?], we compare the SMR-based system to a system that uses a natural gas plant fitted with CCS (NG CCS). While the NG CCS plant could of course be cycled[2], to make the comparison as fair as possible we operate it in the same manner as the SMR. If an SMR is not cost competitive with NG CCS, it is unlikely that the proposed hybrid systems could contribute to the creation of a mass U.S. market for factory-manufactured SMRs.

2.3: Methods

The hybrid power and desalination system we examine here is different from the cogeneration systems that have been assessed by IAEA, or NEA/OCED. As Al-Othman et al. [10] reports in a recent review, these systems use waste heat from SMRs to drive thermal desalination. For example, Al Rezaei, et al. [11] compares a nuclear-powered desalination plant to a desalination plant powered by fossil fuels for a thermal multi-effect distillation-desalination plant and Bazedi et al. [12] perform cost calculations for a multi-stage flash desalination system coupled with a reverse osmosis process and an SMR. The system we examine assumes that electricity is used to run a plant based on reverse osmosis. In addition, there have been studies on hybrid power and electrical desalination systems which utilize waste heat either to help or completely power the desalination systems; our system only uses the electricity generated by the nuclear plant to power the desalination plant [13,14]. When comparing the hybrid system powered by NG CCS or SMR, it is assumed that the desalination plant in both cases is the same. When comparing the two

[2] Cycling natural gas is when the waste heat from a gas turbine is used to make steam to generate additional electricity via a steam turbine.

systems using the same desalination plant, the costs associated with the plant would also be the same, which allows us to ignore them in the analysis.

The hybrid design we examine allows the SMR to run as efficiently as possible, sending electricity to the grid to back up intermittent and variable wind and solar, or to desalination plants powered by electricity when wind and solar back up generation is not needed [15]. For this initial scoping study, it is assumed that the electricity created by the SMR will never go to both the grid and the desalination plant at the same time.

We adopt estimates of overnight capital costs (OCC) for SMRs from expert elicitations conducted by Abdulla et al. [16]. That study conducted detailed interviews with 16 nuclear experts who were asked to assess probability distributions for the likely future cost of an N^{th} of a kind $45MW_e$ ($165MW_{th}$)[3] SMR based on descriptions from NuScale [17]. Sixteen experts estimated that the OCC for a single $45MW_e$ SMR would be between 4,000-16,300 $\$/kW_e$. Eleven of the 16 assessed a narrower range of 4,000-7,700 $\$/kW_e$. We adopt this narrower range because, based on recent events, nuclear reactors with an OCC in the upper portion of the broader range would have great difficulty making it past a first of a kind production, let alone making it to N^{th} of a kind [18,19]. The estimates from Abdulla et al. are for a single reactor similar in design to the ones being developed by NuScale. These reactors are modular and can be combined for greater electricity output [20]. The elicitations in Abdulla et al. suggest that adding more reactors at a site would lower the OCC. However, our model suggests that this cost decrease in OCC would have a minimal impact on the levelized cost of electricity (LCOE), which we use to compare the cost of NG CCS and SMR.

We break the operation and maintenance costs (O&M) into fixed and variable components. Those for the SMR are adopted from studies done by the Nuclear Energy Institute and the Nuclear Energy Agency [21,22]. While there is discussion in the literature of the possibility of reducing fixed O&M costs through the use of more modest security staffing and smaller emergency exclusions zones [23], in this analysis we

[3] Both MW_e and MW_{th} are unit of power, measuring the output of a SMR in megawatts. However, MW_e measures the electrical output and MW_{th} measures its thermal output.

assume that these costs are comparable for all nuclear reactors independent of size. Variable O&M costs, such as the cost of fuel, change only slightly with changes in the size of the reactor. For this reason, these costs have not been adjusted from values in the literature. We use the net present value of the lifetime O&M cost for both systems using a discount rate of 7%. All costs are reported in 2012 dollars so as to align with the costs presented in Abdulla et al.

The Integrated Environmental Control Model (IECM) developed at Carnegie Mellon University provides models of a variety of different power plants which can be tailored to a user's needs and assessed using stochastic simulation to produce results in the form of probability distributions [24]. We used IECM to estimate the OCC and O&M for a NG CCS system using a GE 7Fb natural gas turbine. Two common approaches to performing CCS use ammonia and amine-based systems. While ammonia systems have some advantages when compared to amine systems [25], we chose the monoethanolamine-based CCS system because it has been more widely used and has lower energy requirements, while still providing high levels of CO_2 capture [26,27]. IECM allows the user to modify the system, including, but limited to, changes I the systems operation and financing. We made all financing assumptions the same for both the NG CCS and SMR.

As with SMRs, CCS costs are also uncertain [28]. Accordingly, we developed a range of possible OCC and O&M costs which allows us to compare those values to the ranges predicted for SMRs. Using the sensitivity analysis capability that is part of the IECM, we explored how the rising cost of an amine CCS system would affect the total cost of a NG CCS plant. We adopted a CCS cost range similar to what is seen in past CCS projects, such as the Boundary Dam and Kemper power plants[29,30]. We used this range to fit an asymmetric triangular distribution when estimating the total cost of a system based on an N^{th} of a kind SMR and an N^{th} of a kind NG CCS plant.

We estimate the LCOE using the simplified LCOE calculation used by the DOE. [31]

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \qquad \forall\ t = 1 \ldots n \tag{1}$$

Where:

I_t is the investment expenditures in year t (including financing)

M_t is the operation and maintenance costs in year t.

F_t is the cost of fuel in year t.

E_t is the amount of electricity generation in MWh in year t, assuming constant output.

r is the discount factor for year t (reflecting payments to capital).

n is the lifetime of the system in years.

The subscript t represents time in years, ranging from the start of construction through the final dismantling of the plant. The amount of electricity generated by each technology is based on a capacity factor of 90% for the SMR [20] and the IECM default capacity factor of 75% for NG CCS. Based on what is included in our O&M costs, we report LCOE in terms of net present value of the annual OCC and O&M costs, divided by the amount of electricity generated per year, using a 7% discount factor.

Because we assume that both the SMR, and the CCS system that is attached to the NG plant are N^{th} of a kind systems, we use the same discount factor (r) for both. We assume a plant lifetime of 35±10 yr for the NG CCS plant and 60±20 yr for the SMR [32,33].

CCS systems can typically only capture between 80% and 90% of CO_2 emissions. Initially, we ignore the cost of those carbon emissions but later assess the cost implications using a cost of carbon that ranges from 25 to 200 \$/ton CO_2. Decommissioning costs are included in the O&M costs for SMRs and are also factored in when reporting the O&M costs for NG CCS.

Stochastic simulation models of the costs of both the SMR and NG CCS systems were constructed in Analytica® in order to compare the LCOE of the two. We assume that each plant is using electricity to power the same type of desalination plant and therefore all costs associated with the desalination plant are the same and we devote less attention to refining those costs than to characterizing the costs of the generation systems.

To estimate a range of costs for desalination, we used data published by the Pacific Institute and by Gao et al. [34,35] and used reports by the Pacific Institute and the Energy Information Administration to estimate how the cost of desalinated water depends on the cost of electricity [34,36]. At a price of 0.10 $/kW_eh$ electricity accounts for about 35% of the total cost of desalination. We scale the annualized capital cost of the desalination plant [34,36] by the average annual capacity factor of U.S. wind farms (33.5%) over the period 2013-2017 [37], to account for the fact that the desalination plant will only be operating with wind power when the wind is blowing. We use this information to adjust the total cost of desalination using the cost of electricity when the power source being used is NG CCS or SMR operated for their average lifetimes. For a rough point of calibration, we compare the cost of desalination with publicly available prices for water transaction in California between 1980 and 2015 [38]. These values are similar to others that we have observed in proprietary data sets.

The identification of potential markets for the hybrid system is assessed by examining communities that may face significant future water shortages. These we have identified through a review of the literature that focused on the future outlook of water demand in the U.S. and through discussions with several water experts [45-58]. Given the uneven water supply situation across regions and communities, it does not make sense to examine the U.S. water market as a whole; rather, we consider different local markets. Communities that could potentially benefit from the proposed hybrid system are defined by those at risk of severe water shortages in the next 30-40 years. Communities are then classified as representing a potential market if, through a review of literature and discussions with water experts local to the area, we find that the community has at one time considered desalination to lower their risk of water shortages.

2.4: Results

2.4.1: Levelized Cost of Electricity

Our probabilistic estimates of the OCC for a NG CCS and a SMR, indicate that for all but the very lower end of the distributions, overnight costs for NG CCS are stochastically dominant (i.e., lower cost at all levels of probability) compared to those for the SMR. The lifetime O&M costs for the best estimates for the expected plant lifetimes for both SMRs and NG CCS are similar. If the lifetime O&M costs are converted to yearly O&M costs, the costs associated with NG CCS would be larger than those associated with SMRs because the SMR has a longer expected lifetime.

We assume that the two results are not correlated and stochastically combine overnight capital costs and O&M, along with the electricity generated by the plant, using equation 1, to obtain estimates of the LCOE. The results are presented in Figure 2.1. For all but a comparison of the shortest SMR lifetime with longest NG CCS lifetime the cost of the NG CCS plant is stochastically dominant. These results indicate that NG CCS can be expected to have a lower LCOE cost than a SMR.

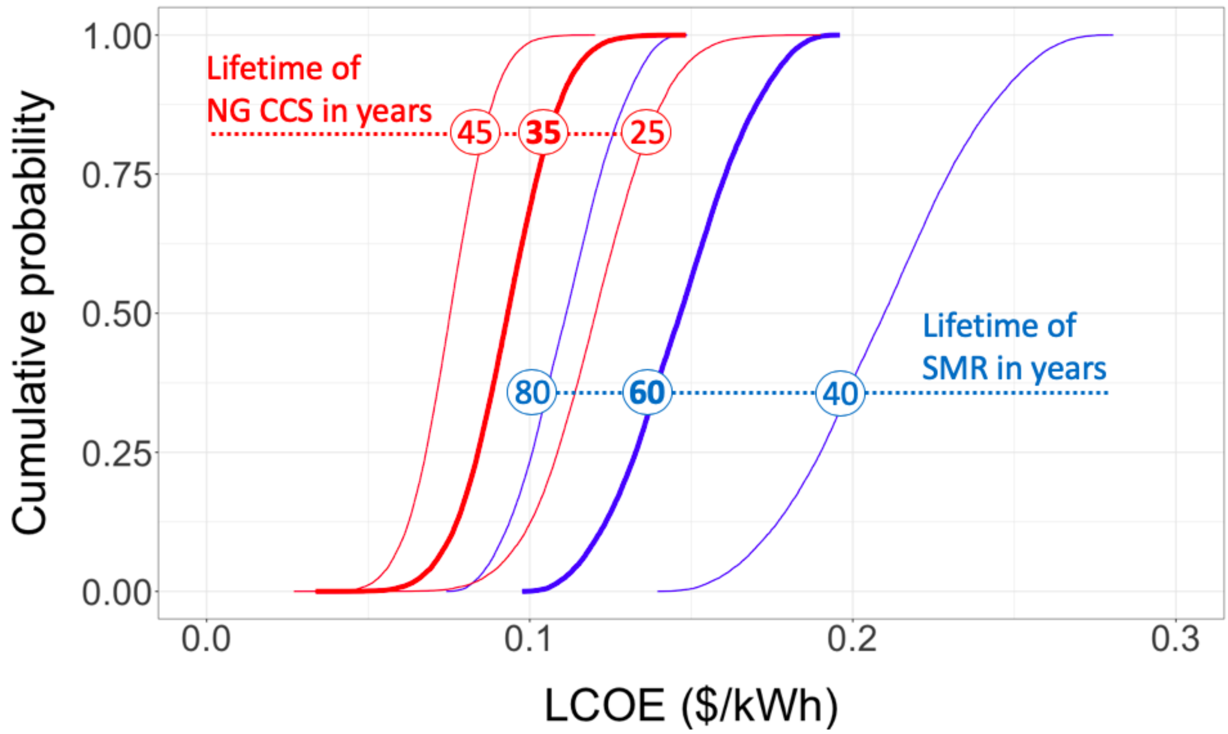

Figure 2.1: LCOE as a function of plant lifetimes for a 45MW$_e$ SMR (blue curves with labels on the right) and a natural gas plant with an amine CCS system (red curves with labels on the left). Results for the best estimate of plant lifetimes are in bold.

The LCOE calculations presented in Figure 2.1 use the IECM's default predicted future price of natural gas, which is 7.49 $/mscf. The present wellhead price of natural gas is 3.42 $/mscf, and the highest price reported in EIA's time series, which occurred in 2008, was 10.79 $/mscf [35]. Across this range the NG CCS system remains stochastically dominant. An average annual natural gas price of 12.00 $/mscf is required to make the SMR price dominant at 50% probability, given the expected lifetimes of the two systems. The wellhead natural gas price in the U.S. has never been greater than or equal to 12.00 $/mscf [39].

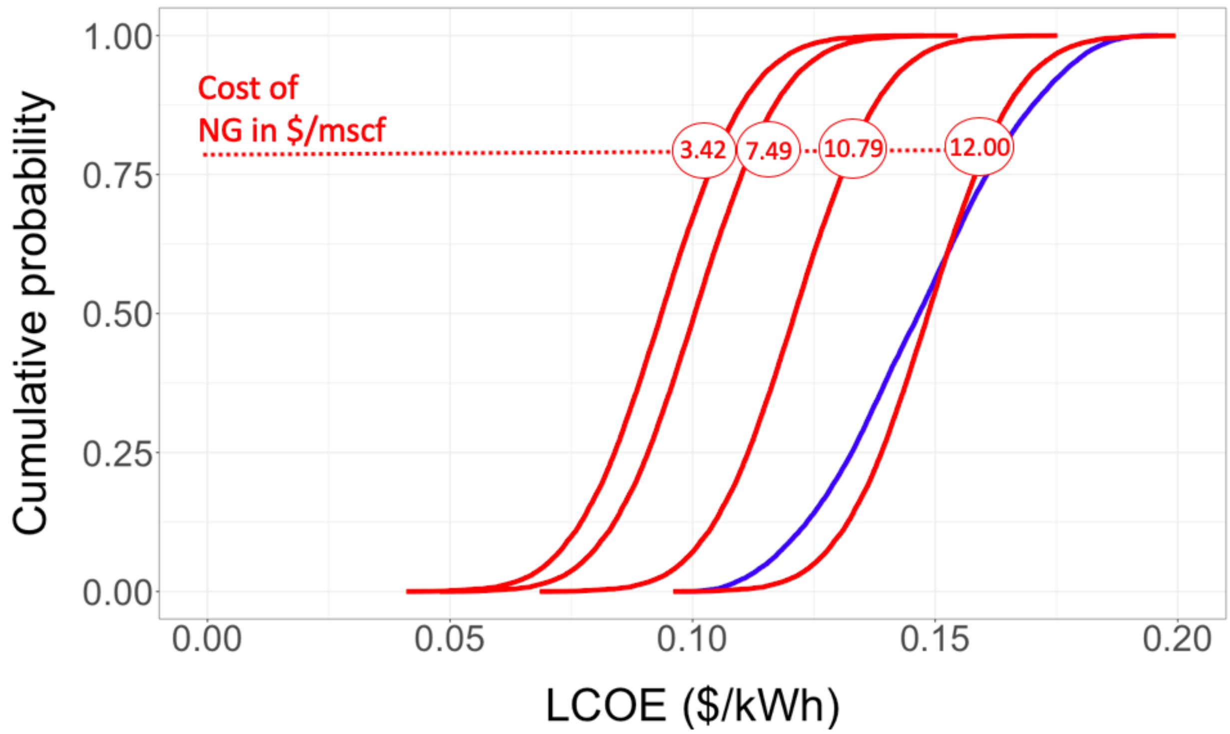

Figure 2.2: Comparison of the LCOE for the 45MW$_e$ SMR (blue curve) with that of a natural gas plant with an amine CCS system (red curves) as a functon of the range of possible future prices of natrual gas.

When modeling the LCOE (Figure 2.1), our calculations do not include an estimate of the social cost of carbon (SCC) or of the amount of cooling water used by the two plants. We first address the issue of SCC.

Amine CCS systems achieve an expected reduction in CO2 emissions of approximately 80%-90%. If we price CO_2 emissions, we find that NG CCS continues to dominate SMRs at CO_2 prices up to about 100 $/ton. We find that the solution does not change between 100 and 200 $/ton and that the cost of CO_2 emissions would have to rise to roughly 200 $/ton for the SMR solution to be clearly dominant at the expected lifetimes.

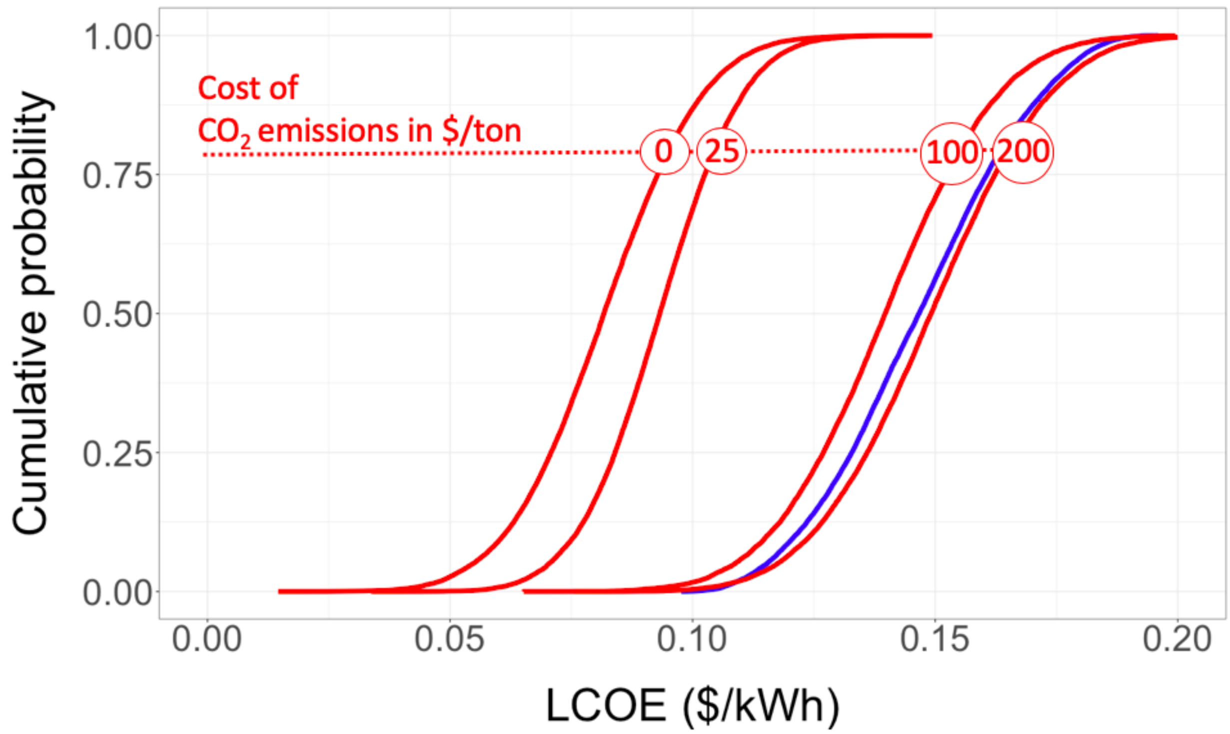

Figure 2.3: LCOE for a 45MW$_e$ NuScale SMR (blue curve) and a natural gas plant with an amine CCS system (red curves) with uncertainty in the cost of CO_2 emissions.

The SMR assessed by experts in Abdulla et al was similar to reactors under development by NuScale at the time of the elicitation. Given recent announcements by that company, some of our initial assumptions are different from that company's future plans [40,20]. NuScale has begun marketing a 60MW$_e$ SMR [20]. If we assume that the OCC (in $/kW$_e$) for the 45MW and 60MW reactors are the same, LCOE for the 60MW reactor would be lower compared to the 45MW reactors, but still higher than the NG CCS (Appendix 1.2). NuScale has also argued that their reactors would have lower O&M costs than those we have assumed [40]. To see if these lower values would impact the LCOE enough to make SMR the dominant solution at the expected lifetimes we calculated the LCOE with the O&M costs reduced by 75%, 50%, 25%, and 0% of the original O&M costs used in the analysis reported in Figure 2.1. These results are shown in Figure 2.4. For SMRs to be the dominant solution in terms of LCOE, O&M costs would have to drop by 35-45%; however, if a 60MW reactor was used, the O&M costs would only have to drop by 20-25% (Appendix 1.2).

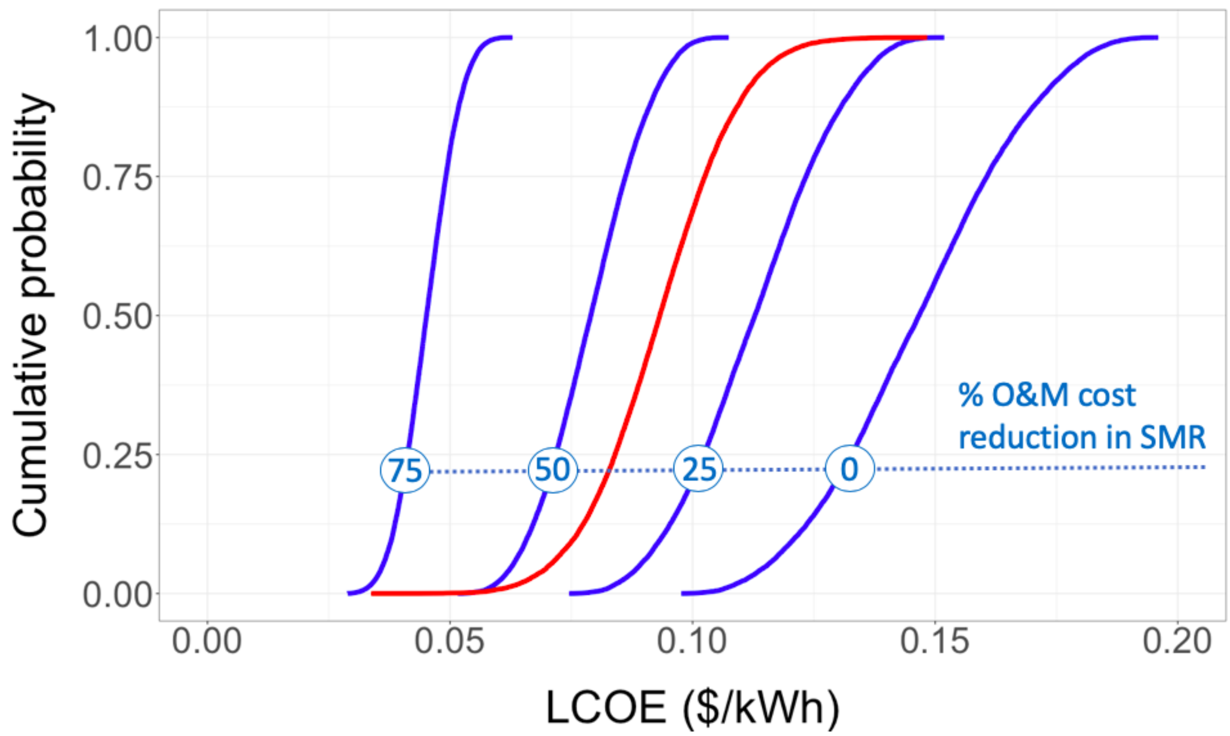

Figure 2.4: LCOE for a 45MW$_e$ SMR (blue curves) and a natural gas plant with an amine CCS system (red curves) with uncertainty in the expected O&M cost for the SMR.

The IECM model estimates that the NG CCS plant with a wet cooling tower system would withdraw 570 gals/MWh and consume 430 gals/MWh. If the NG CCS plant uses a once through cooling system instead, it would only consume 55 gals/MWh but would require withdrawing over 1,500 gals/MWh. In comparison, NuScale's published numbers state that their 45 MW reactors, using wet cooling, withdraw an average of 1,150 gals/MWh with a peak of 1,450 gals/MWh and consume an average of 780 gals/MWh with a peak of 980 gals/MWh [41,42]. Of course, the option of dry cooling is available for both NG CCS and SMRs at a cost between 0.025 and 0.7 $/MWh [43].

2.4.2: Estimating the Price of Water

Unlike many commodities that are traded in markets, it is very difficult to determine the cost of water in the more arid parts of the U.S. because supplies have been heavily subsidized by government-funded dams, aqueducts and other infrastructure. In addition, complex water laws often allocate significant amounts of water to lower-value uses such as agriculture [35].

There is some history of transactions in which urban areas in the west have arranged to purchase water from entities that own water rights. We have constructed a CDF of water transactions based on a triangular distribution using publicly available data from water transactions in California between 1980 to 2015 [37]. The range of values is similar to others we have observed in proprietary data sets. In Figure 2.5, we compare this distribution with distributions of water desalination costs for the NG CCS and SMR systems. The prices paid in these transactions lie well below the costs of desalination with either of the low-carbon electricity sources we have considered (median estimate ~20% of the cost of the NG CCS system).

For two reasons this comparison should be viewed with caution. Because our focus is on comparing the two sources of electricity, we have not modeled the cost of desalination with the same detail as the cost of the SMR and NG CCS systems. The other is that the costs of the desalination systems are likely to be dependent on factors such as plant location and the quality of the input water. In addition, as the impacts of climate change become more severe, the price at which those holding water rights will be prepared to sell can be expected to rise considerably.

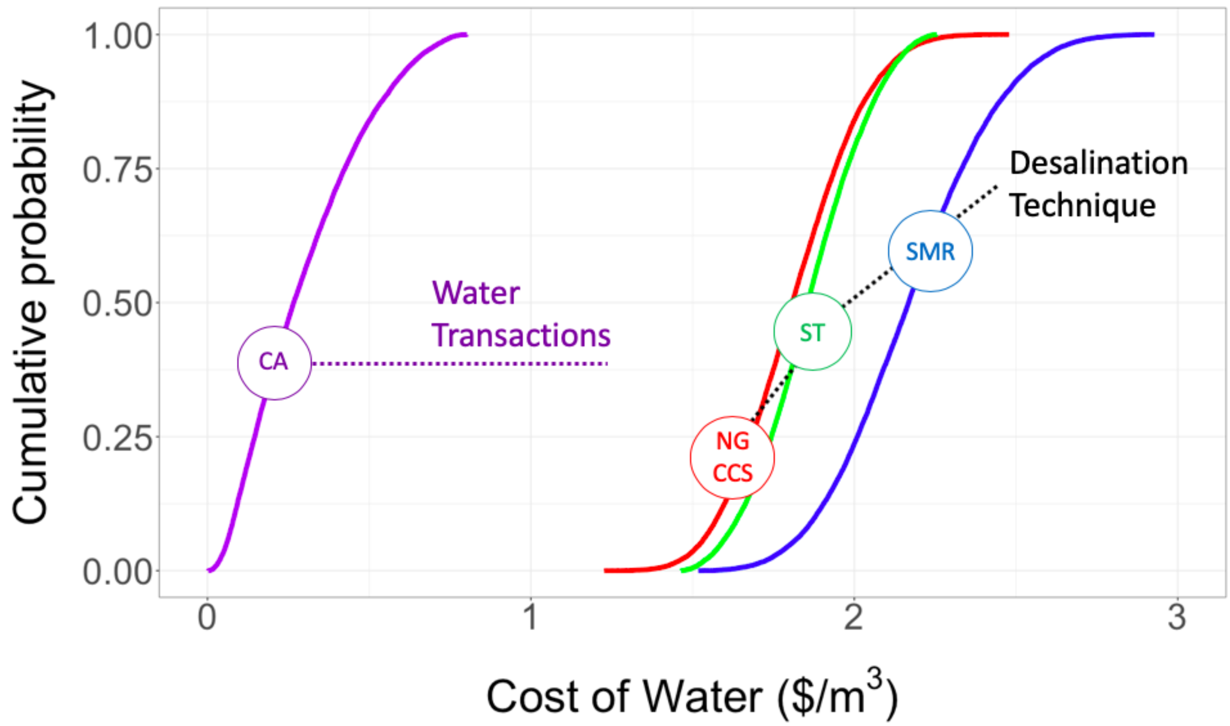

Figure 2.5: Distribution of amounts paid in water transactions between1980 and 2015 in California from publicly available records [38] (purple, CA) compared with distributions for conventional baseline desalination plant powered using electricity at 0.1$/kWh (ST) [33,44] (green), NG CCS (red), and SMR (blue). This comparison should be viewed with caution since future water scarcity may dramatically increase the price at which those holding water rights may be prepared to sell.

Given the results shown in Figure 2.5 an obvious question is "Why would *any* U.S. community engage in desalination?" The literature on such decisions is limited. Discussions we have held with several experts in the field, supported by the literature, suggests that cost is sometimes not the deciding factor in such decisions [45]. Community leaders are often very risk averse, seeking a strategy that will assure that current and future water demand will be met with high confidence.

San Diego's decision to construct the Claude "Bud" Lewis Carlsbad Desalination Plant illustrates this point. The cost of water from that plant is more than twice what the region was paying for imported water ($830 to $942 per acre foot versus $2,131 per acre foot for desalinated water). The price increase gave rise to opposition from San Diego taxpayers, and resulted in more than 14 legal challenges [46,47]. However, area decision makers are concerned about the long-term reliability of imported water and a number of other municipalities in the region are also considering desalination investments [48].

If the U.S. continues to be water conscious, employs smart irrigation techniques and water efficient technology, and makes greater use of markets, the country should have little difficulty meeting its water demand for the next several decades in all but a few local markets [49-51]. These local markets include West Texas, various parts of Arizona and New Mexico, and California's Monterey Peninsula [52-58]. However, the uncertainty associated with climate change makes it difficult to quantify future water resources accurately [59,60]. While something will have to be done to address the needs of those local areas, taken together they clearly do not provide a large enough market to make much of a contribution to jump-starting a domestic SMR industry.

2.4.3: International Markets

Around the world, several regions have used desalination plants as insurance. For example, in 2010, London successfully framed such a strategy as "drought insurance," explaining that the desalination plant may be used infrequently. This strategy probably contributed to better public acceptance than in San Diego. South Australia has had a similar experience. A decade ago, in the face of dwindling flows in the River Murray, the state of South Australia committed to building a desalination plant [61]. Again, this investment was justified as "insurance." More recent years have seen higher flow rates in the River Murray, resulting in some public discourse about the wisdom of making the investment in desalination.

There is considerable interest in desalination across the Middle East and North Africa. For example, with the rapid growth of the UAE, local industrial activities have begun to threaten their water resources with pollution, and the growth in population has caused the remaining groundwater resource to shrink faster than it is being replenished [62]. This situation led the UAE to build the largest desalination plant in the world with plans to build more [63]. UAE's decision to increase desalination to meet water demand is partly based on the success Israel has had with desalination where contributions from desalination have helped Israel to make more fresh water than it uses [63]. While these are massive projects, there is good reason to believe that many other arid regions would find the smaller-scale desalination opportunity offered by an SMR-driven hybrid system to be attractive. Morgan et al. have shown that there is potentially a substantial market for LW-SMRs around the world and based on our model, U.S.-based SMRs could be an option if the cost of natural gas in international markets is high enough [3].

However, in the face of aggressive reactor export plans by China, Russia and South Korea, if a U.S. SMR industry has any hope of playing a competitive role in such markets, the U.S. government will need to make a number of aggressive policy changes. These include: financial support to kick-start the industry; strategies that streamline and accelerate the process of obtaining licensing for factory-manufactured SMRs; and perhaps most importantly, significant changes and streamlining to reduce the obstacles presented by export control - while continuing to guard against nuclear material diversion.

2.5: Discussion

This study was motivated by the urgent need to decarbonize the energy system, with the hope that factory-manufactured SMRs might play a role in that process. With the widespread discussion of problems posed by the "energy-water nexus," including the growing possibility of future water shortages brought on by climate change and growing populations in arid regions of the U.S., our focus was on SMRs used to support water desalination as a way to jumpstart SMR factory-manufacturing. While potable water in the United States is plentiful, it is unevenly distributed. Certain areas in the U.S., such as the Southwest and High Plains, have little rainfall and high levels of water demand [65], and given climate change, the variability and severity of meeting water demand, which is dependent on location, is likely to increase but is highly uncertain[66]. Our hypothesis was that these trends might result in a significant market for factory-manufactured SMRs that desalinate water when the wind is blowing, or the sun is shining, and produce electricity when there is no wind or sun. Our analysis suggests that, with the exception of a few possible local markets, there is not much prospect of significant domestic demand for such systems. Further, our estimate of the cost of such a system is dominated by the cost of a similar system that uses NG CCS. Our estimates assume that an NG CCS plant and an SMR plant could both be sited with limited difficulty. In actually, siting an SMR would likely raise challenges for any community decision maker considering such a system. The infrastructure necessary to operate either system (pipelines plus storage capacity for carbon dioxide, regulatory issues for an SM) creates added obstacles which for this first-order analysis we assume could be overcome.

Even if factory mass production of SMR's were more successful in reducing costs than experts have assumed in the work of Abdulla et al. [16] and cost could be reduced to that of NG CCS systems, and natural gas prices rise much faster than presently anticipated, the commercial risks and siting difficulties likely to accompany SMRs might preclude their wide adoption.

Globally there are regions where a significant market for desalination supported by nuclear power might develop. However, even if such a market were to develop, in the face of aggressive Chinese, South Korean, and Russian programs of reactor exports, it is unlikely that such a market could contribute significantly to the development of a U.S. domestic program of factory-manufactured SMRs. Often when communities make the decision to adjust their water supply, such as the choice to utilize desalination, demand is of more importance than cost. It may stand to reason that the increase in desalination cost due to using SMR as an electricity source is justifiable, if there is a reason and legitimate argument as to how and why powering a desalination plant with a SMR would help with reliability in meeting water demand.

2.6: Conclusion

We draw three conclusions from this analysis.

First, we have been unable to make the case that the use of a hybrid system that uses an SMR to back up wind by providing electricity to desalinate water (while selling electricity to the grid when the wind is not blowing) is likely to be cost competitive in the U.S. when compared with a similar system that uses a natural gas plant combined with carbon capture and geological sequestration. Further, while not assessed in this paper, if the cost of bulk electricity storage continues to fall, storage solutions could come to dominate either of the hybrid systems we analyzed. [67]

Second, while there is considerable talk about a "water energy nexus," and about water shortages in the U.S. arising from future climate change, we conclude that the size of a U.S. market for water desalination over the next several decades is modest and highly localized. Thus, even if SMR costs could be reduced below the levels we have estimated, a hybrid system of the sort we have analyzed would be unlikely to contribute significantly to creating a large U.S. domestic market for SMRs.

Third, there may be some international market for the type of system we have analyzed, especially in countries where natural gas prices exceed 12 $/mscf and there is a strong geopolitical desire to adopt nuclear power. However, given aggressive marketing of SMRs by China, Russia and Korea, we find it difficult to believe that selling to these markets will offer much prospect of contributing to jump-starting the U.S. domestic SMR industry.

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Chapter 3: Variations in Public Perception of Nuclear Energy by Generation and Other Demographic Variables

3.1: Abstract

Nuclear accidents are rare, but they engender much dread in people. There are many reasons for this dread, including the catastrophic disaster potential that accompanies nuclear accidents, the technology's association with nuclear weapons, and the fear of nuclear waste, among others. The nuclear industry and its allies have attempted to defuse this dread through various public engagement strategies. However, their efforts have proved quite ineffective overall. Prior studies have struggled to diagnose the underlying roots of people's dread of nuclear power, which is the subject of this survey-based research. Two highly charged issues motivate this analysis. First, there is research showing that attitudes formed during particularly intense periods tend to stick with subjects. Second, there are a number of monumental events that have dominated the conversation over nuclear power. This research investigates whether these monumental events create a lasting impact on people's perception of nuclear energy. This was done by exploring whether a relationship exists between the underlying reasons behind people's opposition to nuclear energy and these monumental events that have occurred once a generation. I used a survey to ask participants various questions about nuclear energy, followed by a series of demographic questions. Survey responses are then compared to respondents' demographics, including age, location, and gender. I found that participants held significantly less favorable views about nuclear energy if they cited Chernobyl and Fukushima as noteworthy events that shaped their perception. The survey also suggests that participants who are both non-white and non-male hold significantly less favorable views of nuclear energy compared to white males.

3.2: Introduction

Nuclear accidents are rare, but they engender dread because they have the potential to cause catastrophic damage. It is likely that learning about nuclear accidents can strengthen people's negative associations with nuclear weapons, fear of nuclear waste, and other negative attributes. The nuclear industry and its have attempted to defuse this dread through various public engagement strategies. However, these efforts have often proven ineffective. The element of dread may result in as much as a 40% lower willingness to adopt nuclear power as part of a strategy to decarbonize the energy system [1-3]. Attitudes that people form during particularly intense experiences during their formative years tend to stick with them and be intensified by confirmation bias [4].

Since the late 1970s there have been a number of highly publicized nuclear accident events, one occurring virtually every decade (Three Mile Island in 1979, Chernobyl in 1986, and Fukushima Daiichi in 2011). We performed an exploratory analysis to investigate whether these accident events have created a lasting impact on people’s perception of nuclear energy. We do this by exploring whether or not a relationship exists between whether the event occurred during people's formative years and their opposition to nuclear energy. Further, Berntsen et. al, [5] note that "many studies suggest that negative events cause greater physiological and affective reaction and more cognitive processing…which would enhance memory…[and] cause an immediate mobilization, which may lead to long-term distress if not dampened down." At the same time, the intensity of peoples' reactions may have been modulated by the fact that social media played a much greater role in publicizing the Fukushima Daiichi event [6].

3.3: Methods

We conducted a study to explore whether and how these major nuclear events may have shaped public perceptions of nuclear power as a function of when they occurred in the course of an individual's life trajectory. We developed an on-line survey, hosted by Prolific Academic, that could be completed in 1 to 3 minutes. Each participant was paid $0.20 for their participation. A sample of 1036 participants was recruited through advertisements posted by Prolific Academic on the date of June 5, 2020. There was no guarantee that the sample was representative of the population at large [7, 8]. However, we anticipate that with the fairly large sample size, the results are appropriate for this initial scoping study.

We are assuming that one's formative years coincide with their adolescence, (i.e., 11 to 19 years old) [9]. We chose to focus on finding the impacts of two of three major nuclear events: Chernobyl and Fukushima. We expected to find a statistically significant decrease in the favorability of the participant's view on nuclear energy if their formative years, as identified through their age cohort, were during 1986 and 2011. We chose to exclude Three-Mile Island because our sample did not include enough participants who were in their formative years during that event [7, 8].

The survey asked participants to respond to questions that consisted of one word-association, two multiple-choice questions, and one open-ended question about nuclear energy, followed by several demographic questions. These responses to demographic questions are used to group the survey participants into age cohorts, further differentiated by age, gender, ethnicity, and income. Because of IRB privacy requirements, all demographic information was self-reported by the survey participants.

After determining eligibility (age ≥18), the survey began with a word association question. The participants were asked to indicate which one of 12 words they most associate with nuclear energy: Safe; Unsafe, Cheap; Expensive, Low Carbon emissions; High Carbon emissions; Dirty; Clean; Weapons; Accidents; Other. If the participants selected other, they were asked to type the word they identify most with nuclear energy.

Next participants completed two seven-point Likert scales [10] that read "Nuclear energy should be developed further in order to meet the U.S.'s energy needs" and "In general, how safe are nuclear power stations?" Response options for the first ran from "strongly agree" (coded as 1) to "strongly disagree" (coded as 7). Response options for the second ran from "extremely safe" (coded as 1) to " extremely unsafe " (coded as 7). From these responses we computed a score, which will be referred to as the *participant score*, as the average Likert code of the response to these two questions. This score was used to determine whether a participant has a positive or negative view on nuclear energy; the higher a participant score is, the less favorable the individual's views are toward nuclear energy, and vice versa.

Finally, before a set of standard demographic questions (age, gender, ethnicity, education, approximate income), we asked the participants to enter a free-form response to the question, "What event(s), if any, shaped your view of nuclear energy?" The open-ended responses were compared to the survey participant's demographics. These responses are analyzed to find if the major nuclear events, in this case the nuclear disasters Chernobyl and Fukushima, have created a lasting impact on public perception of nuclear energy. With the focus on the nuclear disaster of Chernobyl and Fukushima, the analysis will be specifically looking for words like *Chernobyl* and *Fukushima* or both *Chernobyl* and *Fukushima*.

We compare the survey responses to the participant's self-reported demographics in order to look for a relationship between each demographic and nuclear views. The *participant scores* of each participant are averaged to obtain a *cohort score*. Then, using a t-test, we compare the cohort score of each demographic to examine whether there are any significant differences between different cohorts' views of nuclear energy. If a significant difference does exist, the cohort was further examined to determine whether their formative years matched up with Chernobyl and Fukushima, as well as if they listed either or both of those events as having shaped their view on nuclear energy in their open-ended response.

3.4: Results

We sorted the open-ended responses into 5 categories: Chernobyl; Fukushima; Both Chernobyl & Fukushima (Both); No event noted (None); and events other than Chernobyl or Fukushima (Other). Only 3 survey participants mentioned Three Mile Island as their formative event. After Chernobyl and Fukushima, various events associated with World War 2 were the most frequently mentioned. These events included the dropping of the atomic bombs, the Manhattan Project, and references to the Japanese cities Hiroshima & Nagasaki.

The numbers of participants who mentioned each event are listed in Table 3.1, along with the cohort score for each event together with its standard deviation. Table 3.1 also lists the results of a t-test (P-values) examining whether noting the events resulted in significantly different views. The result of the t-test shows that there is no significant difference in views between those who cited Fukushima, Chernobyl, or both. However, there is a significant difference between those who cited Fukushima or Chernobyl and those that did not cite any event as playing a role in shaping their views toward nuclear energy.

Table 3.14: The responses to the open-ended survey question about which major event shaped each participant's view on nuclear energy are sorted into 5 categories: Chernobyl; Fukushima; Both; None; Other. The number of participants who were sorted into each cohort along with the cohort score and its corresponding standard deviation are seen below. The table also displays the results of a t-test, as P-values, to determine if the differences between the cohort scores are statistically significant.

Major Event	# of Participants	Cohort Score	S.D.	Chernobyl	Fukushima	Both	None	Other
Chernobyl	444	3.81	1.72		0.7263	0.1736	0.0011 (**)	0.0430 (*)
Fukushima	49	3.90	1.58			0.2069	0.0200 (*)	0.1777
Both	114	3.57	1.50				0.1535	0.8725
None	158	3.30	1.56					0.1533
Other	271	3.54	1.74					

(*) = P < 0.05, (**) = P < 0.01, (***) = P < 0.001

Out of the 4 demographic variables examined (*age*, *gender*, *ethnicity*, and *income*), we see no differences for income, while age and gender show the differences between cohorts. The t-tests performed on the data shown in Table 3.2, finds a significant difference between how men and women view nuclear energy, with women having a significantly less favorable view even when the gender cohorts are further subdivided into age cohorts. These significant differences are expected as they have been reported in previous studies [11].

Table 3.15: Grouping of the participants into cohorts based on their self-identified gender. The table displays the results of a t-test, as P-values, to determine if the differences between the age cohort scores are statistically significant, with the only significant difference being between males and females.

Gender Cohort	# of Participants	Average Score	Standard Deviation	Male	Female	Other
Male	630	3.24	1.58		0.0001 (***)	0.9602
Female	399	4.27	1.50			0.0815
Other	7	3.27	1.62			

(*) = $P < 0.05$, (**) = $P < 0.01$, (***) = $P < 0.001$

Figure 3.1 shows the breakdown of the number of survey participants in each age cohort together with the nuclear event(s) cited.

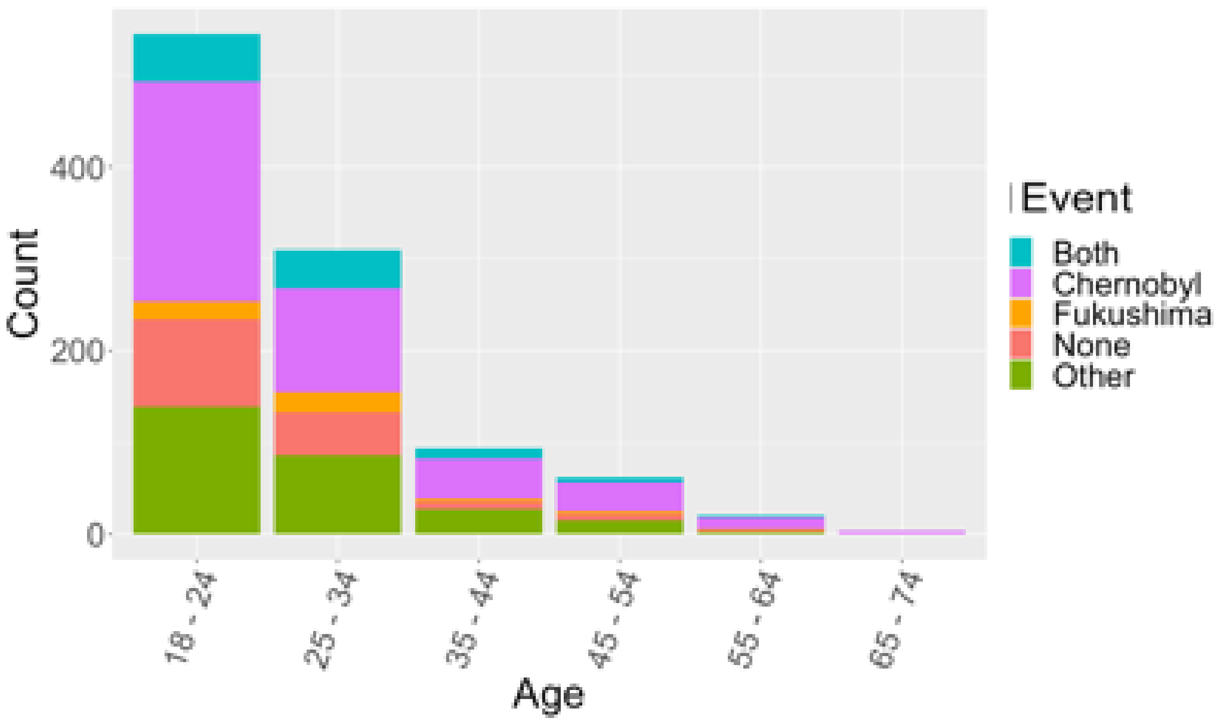

Figure 3.3: The number of participants in each age cohort out of the 1036 responses, which is heavily skewed towards younger age groups. Each bar is filled in accordance with the number of participants in each age cohort and their responses to the open-ended question which asks about what major event most shaped their views on nuclear energy.

The survey participants are heavily skewed towards people ages 18 through 34. Within the age cohort of 18 to 24 and 25 to 34, the majority of participants cited Chernobyl as being the event that most shaped their views on nuclear energy. This result came as a surprise since the 1986 Chernobyl event happened before most of these participants were born. However, some of the participants in these age cohorts explained their response by saying it was not the 1986 Chernobyl event itself that shaped their views, but rather the recent HBO TV series about it. While unclear, it is possible that this is the case for most of the participants in these age cohorts.

The differences between the age cohorts' views on nuclear energy, as shown in Figure 3.2, begin to support the argument that the experience of different generations have had with news about nuclear accidents shaped their perceptions of nuclear energy rather their ethnicity or income. Figure 3.2 shows how age relates to participants views on nuclear energy, using the cohort score of each age cohort. The cohort score and its standard deviation are shown in Table 3.3, along with the number of participants in each age cohort and the results of a t-test used to see if the differences between each cohort's average score is statistically significant.

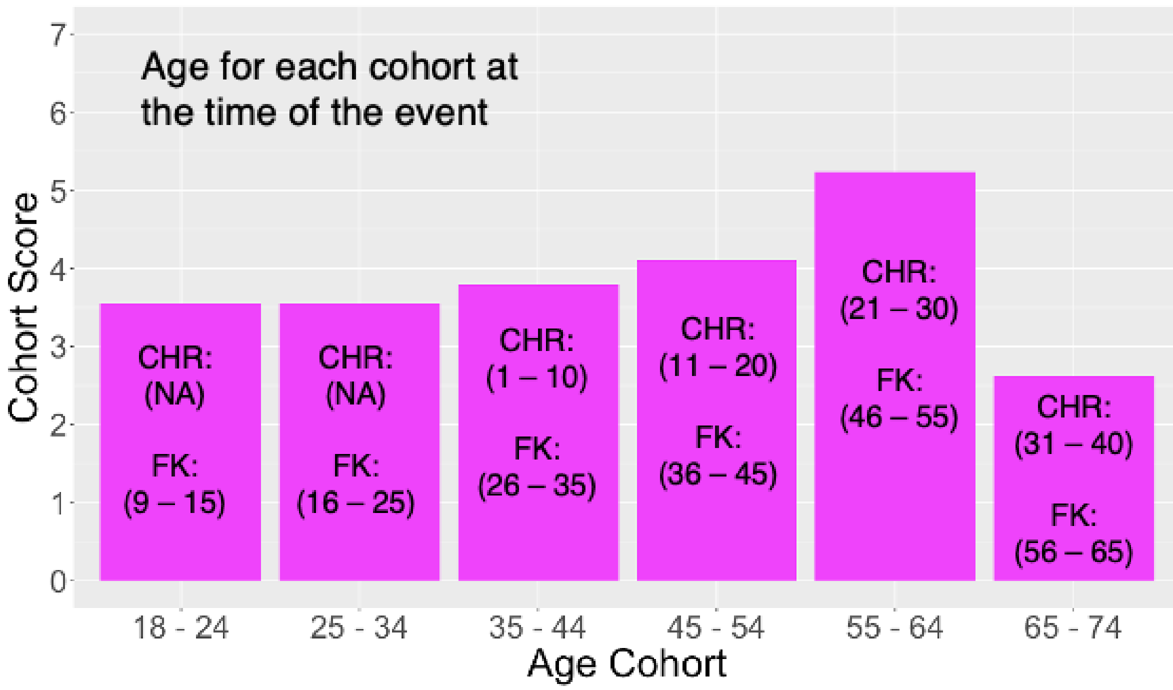

Figure 3.4: The cohort score used to gauge positive or negative views toward nuclear energy for each of the age cohorts asked about in the survey. Each of the age cohorts seen on the x-axis has a cohort score which is an average of the participant scores taken from each individual participant that make up the cohort. Each bar is labeled with the age range of the cohort at the time of the event, CHR represents Chernobyl (1986), and FK represents Fukushima (2011).

Table 3.3: Grouping of the participants into cohorts based on their self-identified age. Displayed is the number of participants who were sorted into each cohort along with the cohort score and its corresponding standard deviation. The table also displays the results of a t-test, as P-values, to determine if the differences between the age cohort scores are statistically significant.

Age Cohort	# of Participants	Average Score	S.D.	18 - 24	25 - 34	35 - 44	45 - 54	55 - 64	65 - 74
18 - 24	545	3.55	1.58		0.9296	0.1826	0.0103 (**)	0.0001 (***)	0.2403
25 - 34	310	3.56	1.61			0.2374	0.0175 (*)	0.0001 (***)	0.0004 (***)
35 - 44	94	3.79	1.78				0.2813	0.0007 (***)	0.85
45 - 54	62	4.10	1.71					0.0078 (**)	0.0916
54 - 64	21	5.24	1.48						0.0023 (**)
65 - 74	4	2.62	0.63						

(*) = P < 0.05, (**) = P < 0.01, (***) = P < 0.001

The data show that participants within the age cohort of 55 to 64 years old have a significantly less favorable view of nuclear energy. Participants within the age cohort of 45 to 54 also have a significantly higher dislike of nuclear energy than the participants whose ages are between 18 to 34.

This trend does not continue for those over 65. Participants in the over 65 age cohorts seem to have a higher approval of nuclear energy, which in some cases are significantly higher. However, it is difficult to infer much from this trend given the small sample for this age cohort.

The 55 to 64 years old age cohort is quite uniform in their demographic make-up. Within the age cohorts, the majority of the demographic diversity seen in the study comes from the younger age cohorts. Every participant in the 55 to 64 age cohort identified as white, with approximately 80% of the participants identifying as female. This trend of uniformity continues with the 45 to 54 age cohort, with approximately 97% of participants identifying as white and a majority (58%) identifying as female. This is compared to the entire sample with 630 identifying as male, 399 (63%) as female, and 7 as other.

3.5: Discussion

Participants hold significantly less favorable views toward nuclear energy if they cited *Chernobyl* and *Fukushima* in their open-ended response. However, there was no significant difference between those that cited either *Chernobyl*, *Fukushima*, or *Both*, suggesting that there are no compounding effects on the negative views caused by nuclear disasters.

The data also show a correlation between a participants age and their perception of nuclear energy, for those who lived through Chernobyl. The participants who were between the ages of 10 and 20 years-old during Chernobyl (45 to 54 age cohort) tended to have less favorable views toward nuclear energy compared to those that did not live through Chernobyl. However, the participant's whose formative years of adolescence (10 to 20 years old) were during nuclear disasters did not show the most negative views toward nuclear energy. Among all cohorts, those between the ages of 20 and 30 years-old during Chernobyl (55 to 64 age cohort) had the most negative views towards nuclear energy.

A possible reason as to why those who were adolescents during a nuclear disaster tend to have less negative views towards nuclear energy, compared to those in their 20s at the time of the event, is that at age 10 to 20 years most people's political views are the same as their parents. The most formative years in developing an individual's political views, independent from one's parents – who were past their formative years during the nuclear event in question – are approximately 20 to 30 years old [12], and there is evidence that perception toward nuclear energy is political [13]. This is supported by our findings, since the 55 to 64 age cohort, who were between the ages of 20 and 30 years old during the Chernobyl disaster, do hold significantly less favorable views towards nuclear energy compared to other age cohorts.

If the 55 to 64 age cohort was between the ages of 20 and 30 years-old during Chernobyl, then they were between the ages of 13 to 23 years-old for the Three-Mile Island disaster. It is possible that Three-Mile Island, which happened during their adolescence, also had a lasting impact on their views toward nuclear energy. However, because the participants did not list Three-Mile Island as the event that most shaped their views in their open-ended response, it is unlikely that it had the impact needed to support this possibility.

Despite participants who cited *Chernobyl* and *Fukushima* both having significantly less favorable views toward nuclear energy, the corresponding significant differences between an age cohorts' formative years and the occurrence of a nuclear disaster, is only seen in those who cited *Chernobyl*. If a relationship existed between the occurrence of a nuclear disaster during a participant's formative years and their opposition to nuclear energy, a significant difference would be expected for all major nuclear events. Despite the largest number of participants being in their formative years during Fukushima, Chernobyl is the only event that seems to suggest this relationship exists. Fukushima did not correlate with significantly higher negative views with participants whose formative years overlap with 2011. In fact, the survey participants cited Chernobyl the most when responding to the open-ended question that asked which event most shaped their views on nuclear energy. This is contrary to our initial assumption, since the majority of survey participants' formative years overlapped with Fukushima, and they were not alive during Chernobyl.

The significant difference in perception of nuclear energy based on gender has been heavily studied previously [11; 14]. Many theories have been advanced to explain these results, but none has been proven without opposition. The most promising theory is, "…white males see less risk in the world because they create and manage, control, and benefit from so much of it." [15], which is an argument that has been studied and supported since [16]. While this argument is intended for general risk perception, our data supports this specific risk perception case, i.e., views towards nuclear energy. Suggesting that the gender differences seen are not between males and females, but between white males and non-white & non-males, a theory which our data supports. Table 3.4 shows the number of participants who are white males vs every other participant, along with their average score and standard deviation. A simple t-test shows that there is a highly significant difference ($P < 0.001$) between the cohorts' average scores, with non-white and non-male participants having a less favorable view toward nuclear energy.

Table 3.4: The grouping of the participants into cohorts of *White Males* and *Non-White and Non-Males* based on their self-identified gender and ethnicity can be seen below. Displayed is the number of participants who were sorted into each cohort along with the cohort score and its corresponding standard deviation.

Ethnicity & Gender Cohort	# of Participants	Average Score	Standard Deviation
White Males	487	3.18	1.57
Non-White and Non-Males	549	4.04	1.57

In the 55 to 64-year-old age cohort, 17 of the 21 participants identified as female. This is the only cohort with a ratio of females to males this high, the next being the 45 to 54-year-old age cohort. Based on our data it is not possible to say whether the significant differences in nuclear views seen in the survey responses are because of age or gender.

3.6: Policy Implications

It is unlikely that the US will build any new nuclear plants in the near future [17]. However, both in the U.S., and elsewhere around the world, there are many nuclear reactors currently in use, and therefore the possibility of a nuclear disaster remains. Some of our respondents cited both Fukushima and Chernobyl as the event which led to their holding an unfavorable view of nuclear energy. However, far more participants cited Chernobyl then Fukushima, despite the fact that many of them were not alive during the event, and an event they lived through, Fukushima, was not cited as much as shaping their view.

Examining the differences between Fukushima and Chernobyl is an active area of research [18 -20]. Our results suggest that the differences between the events led to differences in how the public views them, most likely due to the handling of the situation and the resulting media coverage [21]. In an article in the *Bulletin of the Atomic Scientists*, Sharon Friedman walks through the similarities and differences between the media coverage of the two events [6]. The biggest difference was the amount of available information reported. In the case of Chernobyl, the Soviet Union hid most of the important information like casualties and radiation information. Much of the reporting on Chernobyl, in places like the U.S. and U.K., was based more on speculation than fact. With Fukushima, the internet not only allowed for data and information to be public, but also interactive. Metrics, like website visits, have provided media outlets with data on the public's interest on nuclear events. As Friedman notes " Although heavy print and broadcast coverage also followed the Three Mile Island and Chernobyl accidents in 1979 and 1986, respectively, coverage did not grow as quickly or become as vast as what occurred for Fukushima. The extensive Fukushima coverage has altered, perhaps for years to come, the way the public obtains information about major nuclear plant accidents, their effects, and their ramifications." She goes on the argue that "From a new-media perspective, Fukushima has become iconic because of the massive outpouring of global information and interest, and its coverage in both the traditional and social media will be a standard against which future reporting, particularly of radiation, will be measured."[6] Perhaps this wider and more immediate coverage, combined with a lower level of ambiguity explains some of the difference in the responses we saw, but it is clearly not possible to draws firm conclusions from just these two cases.

3.7: Conclusion

We developed an exploratory analysis to investigate how monumental nuclear events, such as nuclear disasters, create a lasting impact on people's perception of nuclear energy. This was done with a survey which collected responses from 1036 participants. The data show that participants hold significantly less favorable views about nuclear energy if they cited Chernobyl and Fukushima as noteworthy events. There was also a significant increase in negative views of nuclear energy in participants in the age cohort of 55 to 64, or those who would have been between the ages of 20 to 30 years old during Chernobyl. However, it is difficult to tell if the cohort whose formative years overlapped the time of the Chernobyl accident had their views on nuclear energy negatively impacted by that even, since this trend did not continue with other nuclear events like Fukushima. This age cohort was also ~80% female and our data suggest that participants who are both non-white and non-male, hold significantly less favorable views compared to white males, making it harder to discern if timing of the disaster has any impact on the participants views.

The data from the survey suggest that either the Chernobyl accident itself, or the subsequent television reenactment, may have had a much greater impact on shaping participants views on nuclear energy as compared to Fukushima, even for participants whose formative years where during the 2011 Fukushima disaster.

3.8: References

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Chapter 4: Balancing decentralization and decarbonization in microgrid investments

4.1: Abstract

While microgrid planning models are becoming increasingly sophisticated, they do not consider many of the criteria investors use to evaluate the decision to build these systems. They have focused on optimizing microgrid investments by minimizing total system costs given a set of technical and economic constraints. This work develops a novel decision framework—combining empirical data analysis, stakeholder preference, and classical optimization—to illustrate how microgrid typology changes as carbon constraints tighten. I used DER-CAM, a mixed-integer program developed by Berkeley National Lab, in a multi-objective optimization framework that included cost and greenhouse gas emissions for a completely islanded microgrid that could incorporate a range of fossil-fuel based and zero-carbon generating technologies. Using a combination of weighting and constraints, motivated by the non-convexity of the problem, I generated 21 non-dominated solutions for 3 different iconic loads (Large Commercial, Critical Asset and Campus) to evaluate the trade-offs between decentralization and decarbonization. My approach yields a more robust and comprehensive assessment of plausible microgrid topologies than existing models, one that is underpinned by both empirical data and the presumed mental models of the facility operators who choose to build these systems. This work found that the different weighting schemes across cost and emissions-which can only find solutions on the convex hull of the feasible region--produced 3 - 4 different micro-grids with three to four distinct generation technology mixes which are not changed by a range of plausible natural gas prices. In contrast, our gap point analysis, which found solutions inside the convex hull--showed a gradual change in generation technology mix as higher costs are traded off for lower emissions. I also found that because of constraints on available space for solar generation, and high costs, the model does not choose to deploy micro-grids that consist of PV + storage. I also found that a relatively small social cost of carbon produces micro-grids that deploy primarily zero carbon energy

resources. The multiobjective approach and DER-CAM offer an effective methodology for delineating the range of generating technology choice and the tradeoffs involved in micro-grid planning.

4.2: Introduction

The global microgrid market is expanding rapidly and is anticipated to grow 24%, and surpass $25 billion in revenue, by year 2026 [1]. Investors choose to develop microgrids for a variety of reasons. Among these is a desire to switch to low-carbon distributed energy resources (DER) like solar PV and electrochemical energy storage; indeed, recent policy efforts have focused on developing "renewable microgrids" exclusively [2]. Communities might pursue microgrids in order to reduce or, in the most extreme case, eliminate their reliance on utilities. Large industrial consumers might invest in microgrids to ensure certain levels of power quality are maintained. Industrial and commercial customers might exploit microgrids to lower the costs of energy delivery, by shifting consumption in order to avoid expensive demand charges. Finally, investors opt for microgrids in order to enhance the reliability and resilience of energy service, including in the face of potentially long-duration power outages. This last reason is becoming especially salient as the bulk power grid simultaneously ages, undergoes a radical transformation in topology, and becomes more vulnerable to cyber-physical disruption.

Currently, investing in microgrids is primarily driven by the last reason; microgrids represent a reliability proposition, despite their broader range of benefits [3].The ultimate scenario ensuring reliability is one in which microgrids "island" themselves and operate separately from the larger grid, continuing to supply the energy their operators require when the bulk electric power system is disrupted. Recent surveys of existing microgrids in the U.S. show that the majority of microgrids rely on traditional fossil-fuels, like natural gas (NG) and diesel [3,4]. Fossil-fueled distributed energy resources are relatively cheap and mature technologies that can be reliably dispatched by operators to meet load.

Ironically, many developers who use fossil-fueled microgrids nonetheless advertise their systems' green credentials, even though it has been established that these systems can, at best, accomplish only shallow decarbonization if they rely on natural gas [3-5]. There is yet another fundamental challenge:

because many microgrids are deployed by organizations with more limited resources than electric power utilities, investments in diesel or natural gas generators are likely to be long-lived. Organizations opting for fossil-fueled microgrids in a carbon-constrained world are thus acquiring new point sources of carbon pollution that they can probably only afford to replace once their debt has been serviced. Even then, replacement depends on the financial health of their owners. As a result of this tension, one important and outstanding question about microgrids is the extent to which decentralization and decarbonization are complementary or orthogonal, and how we might push them towards complementarity.

There exists a large literature on microgrid investment planning. Much of this literature considers carbon emissions, and some specifically focuses on constraining those emissions in order to produce microgrids with low CO_2 emissions. This literature also investigates the role of economic and policy levers in transforming a microgrid's optimal DER mix from fossil-fuels to low-carbon alternatives [5,6]. However, both have largely focused on optimizing microgrid investments by minimizing total system costs (or emissions) given a set of technical and economic constraints. Here, we explore the tradeoffs between costs and emissions by using an existing DER optimization model in a multi-objective programming framework. By explicitly considering the criteria that investors use to evaluate decisions around microgrid investment, we can estimate how changes in the relative importance of the criteria impact microgrid development, thus helping to illuminate the extent to which decentralization and decarbonization are complementary or orthogonal goals. We also examine how microgrid typologies are likely to evolve as carbon constraints are tightened, providing a technology development pathway to investors, vendors, and policy makers.

We show the nondominated set of microgrid technologies so that any investor, no matter their preferences, can see their range of choice and the tradeoffs involved—a range that is wider than the cost-minimization approach. Our analysis yields a more systematic assessment of the likely pathway of microgrid adoption than existing literature offers, because it explicitly represents how trade-offs regarding cost and emissions affect microgrid deployment.

We ensure that the transition pathway we develop is robust by conducting extensive uncertainty analysis that accounts for various uncertainties in the energy transition. Once a microgrid has been built, its DER typology can be difficult to change (for financial reasons, rather than technical ones). We provide an assessment of how facility operators could future-proof their microgrid development given the likely role of carbon constraints, volatile energy prices, and the evolving trade-off in weights that investors assign to cost and emissions. Our assessment helps facility operators make robust decisions about optimal microgrid investment in light of both evolving CO_2 tightening regulations and the temporal evolution of the wider energy system. We focus on fluctuating commercial natural gas prices, energy storage prices, prescriptive policies that mandate a complete "natural gas exit", and the social cost of carbon.

4.3: Methods

Our focus is on approximating a nondominated set of solutions: a set of microgrids, chosen on the basis of their cost and CO_2 emissions, for which there are no other feasible microgrids that would cost less without producing higher emissions (or that would produce lower emissions without costing more.). This nondominated set shows the range of choice and the tradeoffs between the criteria.

We designed these islanded microgrids using DER-CAM, which is the Distributed Energy Resources Customer Adoption Model [7]. DER-CAM was built and is maintained by Lawrence Berkeley National Laboratory as a DER and is a microgrid investment planning model for investors and analysts. DER-CAM is a mixed integer program (MIP) that we use to produce an approximation of a nondominated set of solutions, first through a weighting method approach [8-10], and then through the exploration of gap points [10, 11]. There are many resources available that describe DER-CAM in detail [12]; what follows is a high-level overview of the software, and a discussion of how we manipulated the DER-CAM objective function to address our research question.

DER-CAM is a mixed integer program which includes, as alternative DERs, generators whose size is discrete and others whose size can be continuously varied. These generators are subject to thousands of constraints that make their operation more applicable to real-world dispatch. These include reliability and efficiency constraints, maximum operating hours, and ramping rates. The discrete generators are restricted to distinct cost and capacity increments and consist of traditional DERs, like those fueled by diesel or natural gas (NG); this category also includes NG-fueled combined heat and power (CHP) plants as well as fuel cells, which are DER-CAM's only zero-emission dispatchable DERs. Each generator at each discrete size has an associated cost.

As mentioned earlier, we chose islanded micro-grid configurations to replicate the ultimate scenario of ensuring reliability. Such a configuration dictates that there will be no "outside help" from the larger utility and no selling excess electricity back to it. Thus, each microgrid in the nondominated set must be able to meet demand on its own. With resilience being the most highly cited reason for micro-grid development [3], we are assuming these micro-grids are completely independent from larger utilities. With complete independence, these micro-grids are entirely resilient against larger grid blackouts and power disruptions. Since in most cases such micro-grids would be connected to, and able to sell to and buy power from the main power grid, our results can be viewed as setting an upper bound on costs.

DER-CAM can generate optimal micro-grid configurations that minimize cost, minimize emissions, or minimize a combination of the two. We adopt this latter formulation to implement the weighting method of multiobjective programming to produce an approximation of the nondominated set [8-10

To use DER-CAM to implement the weighting method, we minimize a weighted objective function, the simplified version of which is shown in equation 1.

$$\text{minimize } Z = \frac{w_{cost} cost}{scale\_cost} + \frac{w_{CO_2} emissions}{scale\_em} \qquad (1)$$

where:

Objectives:

Z	weighted objective function

Criteria:

$cost$	total annual cost of the microgrid ($)

$emissions$ annual tonnes of CO_2 emitted from operating the microgrid (tonnes of CO_2)

Parameters:

w_{cost} unitless weight between 0 to 1 that is applied to the cost criterion

w_{CO_2} unitless weight between 0 to 1 that is applied to the emissions criterion

$scale\_cost$ normalization factor used to make the *cost* dimensionless ($)

$scale\_em$ normalization factor used to make the *emissions* dimensionless (tonnes of CO_2)

The parameters are discussed below, after an explanation of the cost and emissions criteria.

The *cost* attribute encompasses an amortization of the capital costs involved in purchasing the micro-grid's DERs and their respective operations and maintenance (O&M) costs, which is converted to a levelized cost of electricity (LCOE). Since the resulting micro-grid is designed for islanding, there is no integration with the bulk grid and therefore no cost or revenue stream to consider that involves the local utility. As for *emissions*, DER-CAM only provides information on CO_2 emissions that result from operating the micro-grid.

As noted earlier, the model considers DERs that come in discrete sizes and others which are continuous. Thus, the two criteria are comprised of the sum of two components, one for discrete DERs and one for continuous. The cost and emission functions for the discrete DERS are:

$$cost^d = \sum_i \sum_j \sum_t CC_i\, x_i + OC_i d_{ijt} \tag{2}$$

$$emissions^d = \sum_i \sum_j \sum_t E_i\, d_{ijt} \tag{3}$$

where:

Sets:

i	indexes discrete DER types
j	indexes built DERs of type *i*
t	indexes discrete timepoints in the model's horizon

Objectives:

$cost^d$	total cost of discrete generation ($)
$emissions^d$	total annual emissions from discrete generation (tonnes CO_2)

Decision Variables:

x_i	number of built generators of type *i* (integer)
d_{ijt}	dispatch of generator *j* of type *i* during time *t* (MWh)

Parameters:

CC_i	amortized capital cost of DER *i* ($/kW or $/MW)
OC_i	annual operating cost of DER of type *i* ($/MWh)
E_i	emissions rate of DER of type *i* (tonnes CO_2/MWh)

x_i is an integer variable representing the number of DERs of type *i* used in building the micro-grid. This number is then scaled by its corresponding cost .The capital cost of generation is only dependent on the amount of generation being purchased, while its O&M cost depends on the type, and amount of time, each generator is being used. The annualized capital cost and its annual O&M cost are then summed together to equal the total annual cost of discrete generation. The emissions resulting from discrete generation is calculated based on how often each generator is being dispatched, similar to solving for the O&M costs. DER-COM includes the appropriate capacity constraints that relate the continuous variable d_{ijt} to the integer variable x_i, requiring the number of generators of type *i* necessary to support the amount of dispatched energy.

We exclude wind generators, the only non-dispatched discrete generator in DER-CAM. Although wind has been deployed in several micro-grids, it entails serious space constraints that make it infeasible to deploy in our southern California settings, as described later, with the possible exception being a few military bases.

Generators which can take on any size (i.e. continuous generation) include solar photovoltaic (PV) systems and electricity (mainly electrochemical, or battery) storage and have a continuously scalable capacity ($/kW or $/kWh). This method gives a good approximation of the costs of these technologies but does not address the cost discrepancies between small-scale and grid-scale systems, as described in detail elsewhere [16].

$$cost^c = \sum_k y_k F_k + V_k c_k \tag{4}$$

where:

Sets:

k indexes continuous DER types

Objective

$cost^c$ total cost of continuous generation ($)

Decision variables:

c_k capacity of DER *k* (MW or MWh)

y_k is a binary integer variable that corresponds with selecting generator *k*, so that the costs are only incurred when generator *k* is selected

Parameters:

V_k variable cost of DER *k*

F_k fixed instillation cost of DER k

All of the continuous generators are zero-carbon emitting forms of generation and therefore there is no need to calculate their emissions, i.e. $emissions^c = 0$. Their costs consist of a fixed installation cost of each form of generation, F_k, and a $/kW or $/kWh value, V_k, based on their capacity, c_k. Unlike with discrete generators, c_k is not an integer. Instead, it is a continuous variable that represents the capacity of generation k, which could be PV or storage. As in the discrete case, DER-CAM includes constraints that enforce the appropriate relationship between y_k and c_k, i.e.generator k can have a non-zero capacity only if $y_k = 1$

A full list of the DERs included can be found in the Appendix 3.2.

Returning to the parameters of equation (1), *scale_cost* and *scale_emissions* are two normalization factors used to make the *cost* and *emissions* criteria dimensionless and are obtained by running a no-DER reference case in DER-CAM. The two normalization parameters together produce, in effect, a cost of carbon [13]. We also consider a social cost of carbon of $50 [13, 14] and $1 [15].

The weights applied to the two criteria, w_{cost} and w_{CO_2}, are chosen so that they sum to one. They are parameters of the weighting method and are varied in value to explore the nondominated set. Although they do not represent preferences, they can be interpreted as the hypothetical relative importance of the criteria to an investor or facility operator.

We varied the weight on emissions from 0 to 1 in increments of 0.05 (and, correspondingly on cost from 1 to 0 in the same increments), obtaining for each set of weights an optimal solution of the weighted problem which, from MOP theory, is known to be a nondominated solution [10] of the two-objective problem (except in special circumstances discussed below.). This allows us to investigate how the decarbonization of micro-grids might progress as a micro-grid investor places greater relative importance on carbon emissions (whether due to individual or organizational preferences; increasing social pressures; or policy or regulatory prescriptions).

There are two complications of the weighting method which must be dealt with. MOP theory tells us that if at least one of the weights in the weighted problem is zero, a non-unique optimal solution may be dominated. In a two-objective problem, such as ours, this means that if there are alternate optima for an individual objective, such as minimize emissions, then the solution we obtained from DER-CAM may be dominated (i.e. there may be another solution that gives us the same minimum emissions but with lower costs.)

We confirm the non-dominance of the solution or obtain a new solution that dominates the current one by solving a new problem:

$$\text{minimize } cost \tag{5}$$

Subject to the new constraint

$$emissions = e^*$$

where $e*$ is the minimum emissions obtained from the previous solution.

The optimal solution of this problem will be a non-dominated individual optimum for minimum emissions.

The other complication occurs when the weighting method is applied to mixed-integer programs, as in our case. The weighting method can only identify solutions on the convex hull of the feasible region of an MIP. We know, however, that there may be nondominated "gap points" or "unsupported" solutions [10, 11] which are not on the convex hull. Finding the gap points may add considerably to our understanding of the nondominated set, as it does in this case study. We find these solutions by adding constraints to DER-CAM that will allow us to get into the gaps.

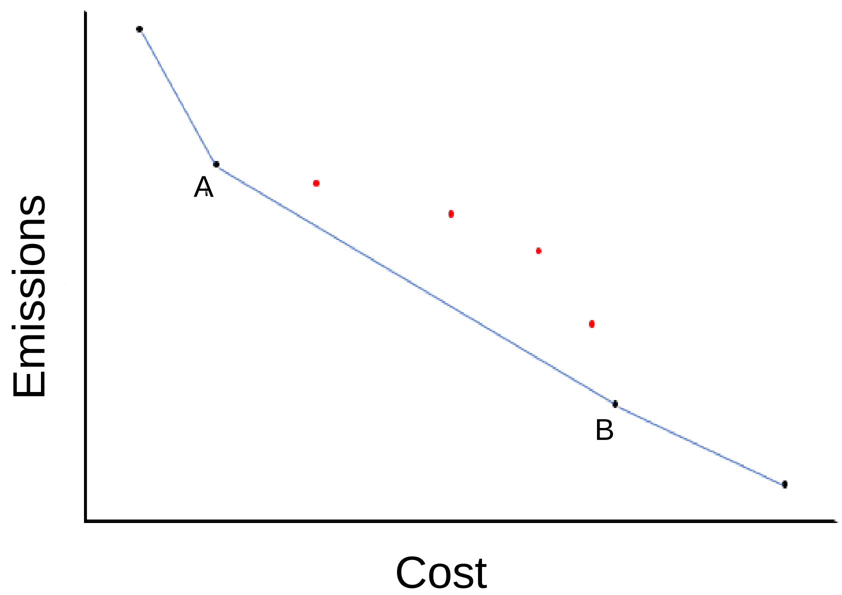

Figure 4.1: A hypothetical MOP in objective space, where the blue line represents the convex hull. The nondominated solutions to the MOP that fall on the convex hull, which can be found using the weighting method, are in black. The red points represent nondominated solutions not on the convex hull—gap points—which cannot be found with the weighting method.

Consider the hypothetical example in Figure 4.1. Suppose we have previously found points A and B using the weighting method; thus, the points are known to be on the convex hull. In order to get into the gap between A and B, we solve the problem:

$$\text{minimize } cost \tag{6}$$

Subject to

$$cost \geq cost_a + \varepsilon$$

$$emissions \geq emissions_b + \varepsilon$$

Where ε is a small positive constant. By making the previously found solutions infeasible, we force

DER-CAM to search the gap between points A and B. Note that we chose to minimize cost in this example but minimizing emissions or a weighted sum would also work in this formulation.

A primary constraint in DER-CAM is that the energy demand of an inputted load must always be met. We examine three “iconic loads,” each of which serves a qualitatively different mission, as elaborated in existing literature [5]. We design islanded microgrids to meet the service demands of each of these: a large commercial facility (LC), a critical asset (CA), and a commercial/residential campus community (CM). The first of these can be mapped to a medium office building [17]. The demand of the LC microgrid is predominantly electric, is larger on weekdays than weekends, and peaks at approximately 0.25 MW_e. The CA iconic load is designed to emulate the aggregated demands of a hospital facility, consisting of a hospital, quick-serve restaurant, and outpatient facility in accordance with DOE reference buildings [17], and peaks at approximately 2.5 MW_e. The final—and largest—iconic load we examine is the CM, which peaks at approximately 12 MW_e. The CM microgrid consists of 21 buildings: one small office building, one medium office building, two large office buildings, three stand-alone retail centers, three supermarkets, four midrise apartments, two primary schools, two secondary schools, a strip mall, a quick- serve restaurant, and a full-serve restaurant [17].

These three iconic systems require electric, cooling, space heating, water heating, and natural gas loads—all of which we consider. Detailed load profiles are included in Appendix 3.2. As a consequence of "exclusive service territory rules”, current U.S. state laws stipulate that, while micro-grids can power multiple buildings or assets, those loads must be owned by a single facility operator [18]. We therefore simulate these iconic loads—even ones that contain multiple buildings—as a single entity by aggregating their needs.

We assume that all three of these micro-grids are located in the San Diego region of southern California in order to compare our results with those of prior studies. Locating these micro-grids in southern California dictates several factors such as fuel prices, tariff structures and peak months of the iconic loads. The space constraints of southern California are also accounted for. Southern California, with the possible of exception of military bases, does not have the land needed to build large wind farms, especially for larger loads like the Campus, and we therefore exclude them from our available DERs. DER-CAM also has the ability to constrain the amount of space available to build solar PV, which would also be dictated by the land constraints of southern California. We adopted the same amount of space used for each iconic load [5], in order to remain consistent with both previous literature and DOE's assessments of these entities. For LC, the maximum land allotted to solar PV was 4,050 m^2; for CA, the figure was 8,100 m^2; and for CM, the maximum space was 20,250 m^2 [5]. Crucially, we removed this constraint when optimizing micro-grids that rely exclusively on PV plus storage in order to compare them to the more realistic space-constrained ones.

4.4: Results

We applied the weighting method to find the nondominated solutions presented in Figure 4.2 which shows the mix of DERs that make up the micro-grids of each iconic load across all criteria weights. Figure 4.3 which shows the approximation of the nondominated set in objective space. Starting from the right side of each panel, where $w_{cost} = 1$ and $w_{CO_2} = 0$, we obtain least cost grids which are primarily powered by natural gas. As emissions begin to be weighted more heavily, we move along the nondominated set to solutions with lower emissions and higher costs. The technology mix changes accordingly, first by increasing efficiency before shifting away from natural gas as the relative weight on w_{CO_2} is further increased.

We observe more dispatchable DERs in larger microgrids than in the smaller ones. For the LC iconic load, there is one dominant dispatchable DER for each unique typology, whether it is NG (when the cost weight is between 1 and 0.45), CHP (when the cost weight is between 0.50 and 0.30) or fuel cells (when the cost weight is between 0.23 and 0.00). As microgrid capacity increases a combination of NG + CHP or CHP+ fuel cell microgrids is adopted because dispatchable DERs are discrete technologies. This can be seen in the CA iconic load, when the weights applied to cost and emissions are roughly even, i.e. when the cost weight is .50 or .45. Instead of purchasing two 2.5MW NG turbines and over building the system, DER-CAM selects a much smaller microgrid that uses one 2.5 MW NG turbine with a smaller CHP DER.

CHP DERs are much more expensive than NG, and when the weights are roughly equal DER-CAM will only incorporate CHP sparingly. However, when emissions are more important than costs, DER-CAM then chooses efficiency over cost, causing it to over-build with two 2.5 MW CHP DERS.

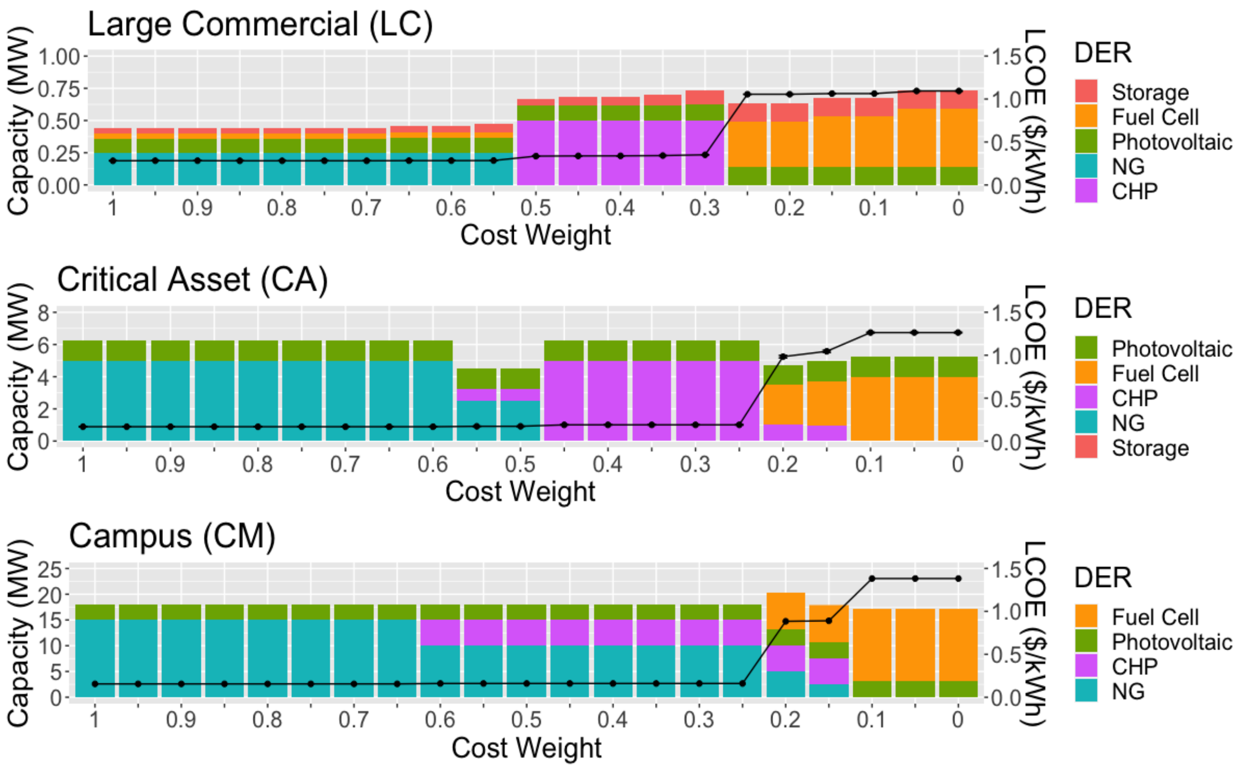

Figure 4.2: The mix of DERs in the three microgrids as a function of the relative weight assigned to cost. The vertical axis on the right shows the nameplate capacity of each microgrid, while the horizontal axis shows the weight applied to the cost criterion in the objective function. (The weight on emissions is 1- $\boldsymbol{w_{cost}}$.) The vertical axis on the left shows the LCOE of the microgrid as indicated by the black curve.

Figure 4.3 shows that the nondominated microgrids cluster together, essentially yielding only a few configurations (from NG to CHP, and then from CHP to fuel cells). The result is large discrete changes in both cost and emissions. Put another way, several sets of weights produce the same or similar solutions as indicated in Figure 4.2. As indicated in Figure 4.3, NG prices determines when the transition takes place between the 3 or 4 unique micro-grids (for the weighted method) varies with the size of the micro-grid. As the size of the iconic loads increases, the weight on emissions must be higher to result in the transition between fossil fuel- (NG turbines), hybrid carbon/low-carbon- (CHP), fuel cell-based micro-grids decreases. This is because for the larger loads, the efficiency of CHP saves enough fuel to outweigh the increased capital costs compared to a single cycle natural gas turbine generator.

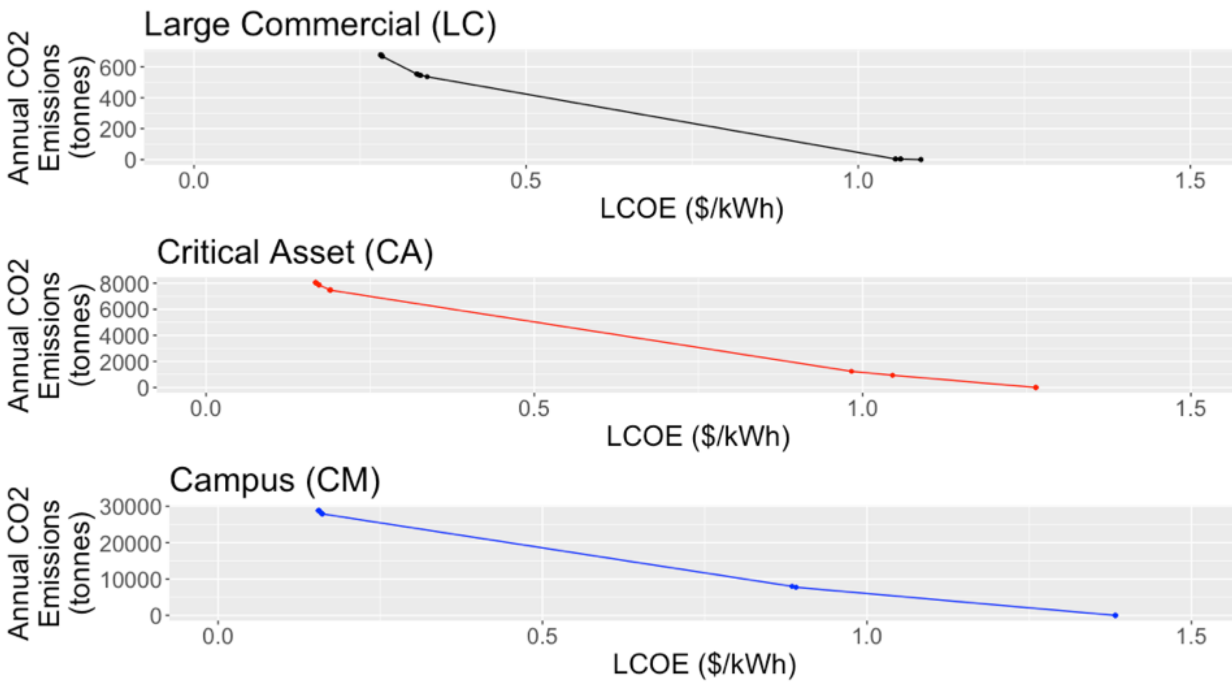

Figure 4.3: The annual CO_2 emissions from the three iconic microgrids as a function of its LCOE. Each dotted line represents all 21 scenarios of the 3 iconic loads, Campus = Blue, Critical Asset = Red, Large Commercial = Black.

All of the solutions found to this point are on the convex hull of the feasible region. Our search for gap points, using the method described in the previous section, yielded nine for the LC load, one for the CM load and zero for the CA. The results of our gap point search are shown in Figure 4.4 which displays the same trade-off curve of LCOE and CO_2 emissions for the LC and CM loads as seen in Figure 4.3, but also contains the resulting LCOE and CO_2 emissions for each gap point and lettered for easy identification. The gap points shown in the LC load are bound by points A and K, which were solutions shown in Figures 4.1 and 4.2. For the CM load, points A and C were taken from the previous results, and point B was the only gap point found. Figure 4.5 shows the typology of each load's gap points.

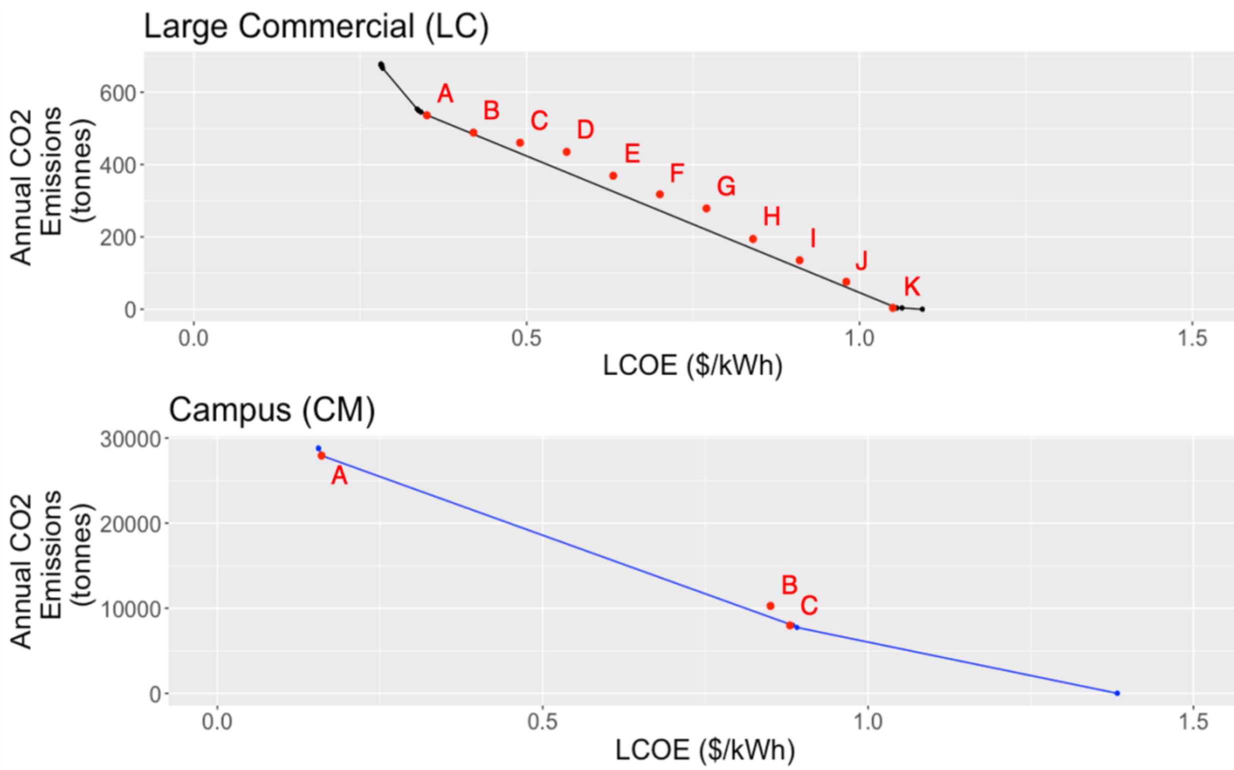

Figure 4.4: The annual CO_2 emissions from the LC and CM iconic microgrids as a function of its LCOE, with each load's gap points identified in red and lettered.

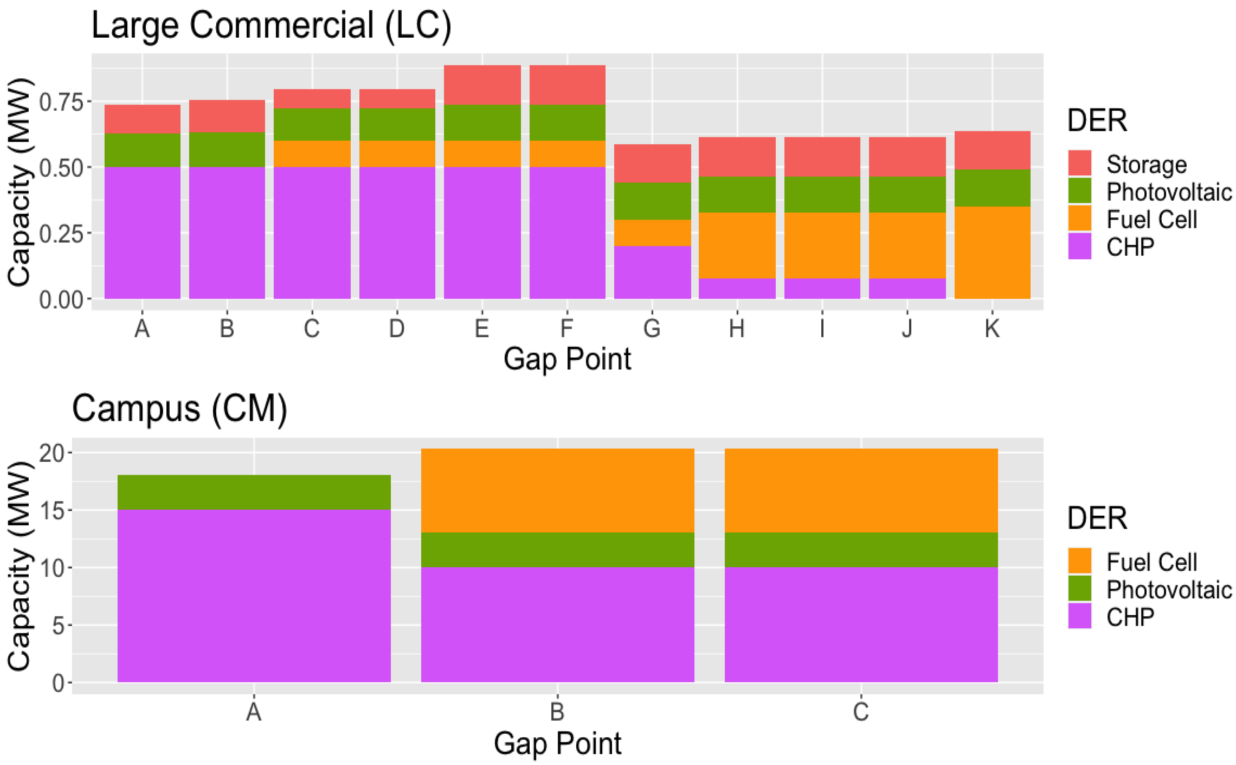

Figure 4.5: The mix of DERs in the microgrids output for the LC and CM gap point as a function of the weight assigned to cost. The vertical axis on the right shows the nameplate capacity of each microgrid, while the horizontal axis shows the relative weight applied to the cost criterion in the objective function. (The weight on emissions is 1-w_{cost}.)

The gap pint analysis shows that there are unique cost and emissions values for each solution, but despite the gradual shift between technologies, there are still clumps of nonunique microgrid configurations. Unlike the weighted method, the results from the gap point analysis show that the cost and emissions values of a microgrid do not map neatly to particular typology.

The price of NG used in the analyses reported in Figures 4.1 and 4.2 is $12 per MMBtu, a price comparable to current commercial and residential NG prices in southern California [19]. In Figure 4.6 we compare this base case to NG prices of $4 per MMBtu and $16 per MMBtu. Despite these drastic changes in the price of NG, there remain 3 unique microgrid typologies that depend entirely on NG, CHP, or fuel cells. However, different NG prices do change where the shifts between these unique typologies occur.

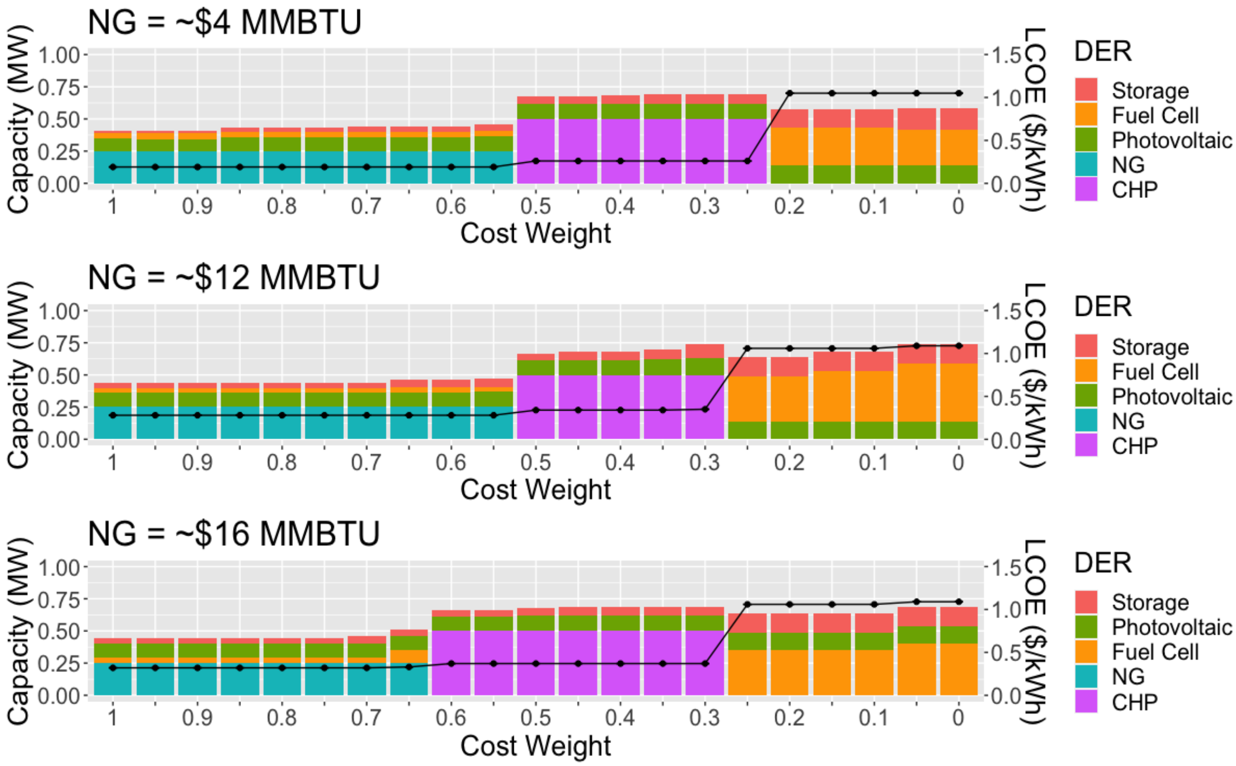

Figure 4.6: The mix of DERs in the LC microgrid as a function of the relative weight assigned to cost, as the commercial price of NG is changed. The vertical axis on the right shows the nameplate capacity of each microgrid, while the horizontal axis shows the weight applied to the cost criterion in the objective function. (The weight on emissions is 1- $\boldsymbol{w_{cost}}$.) The vertical axis on the left shows the LCOE of the microgrid as indicated by the black curve.

Along with the reliance on NG and discrete technology jumps, the third broad trend involves the role of storage. The default cost of electricity storage in DER-CAM is $500 per kWh. However, many studies predict that the cost of grid scale electricity storage will drop substantially in the coming years [20]. To explore the impact of this possible development, we modeled each iconic load with a cost of $100/kWh [20]. The results are shown in Figure 4.7. At a lower cost per kWh, storage gets deployed more widely in the low-carbon microgrids, resulting in a radical change in the role of storage.

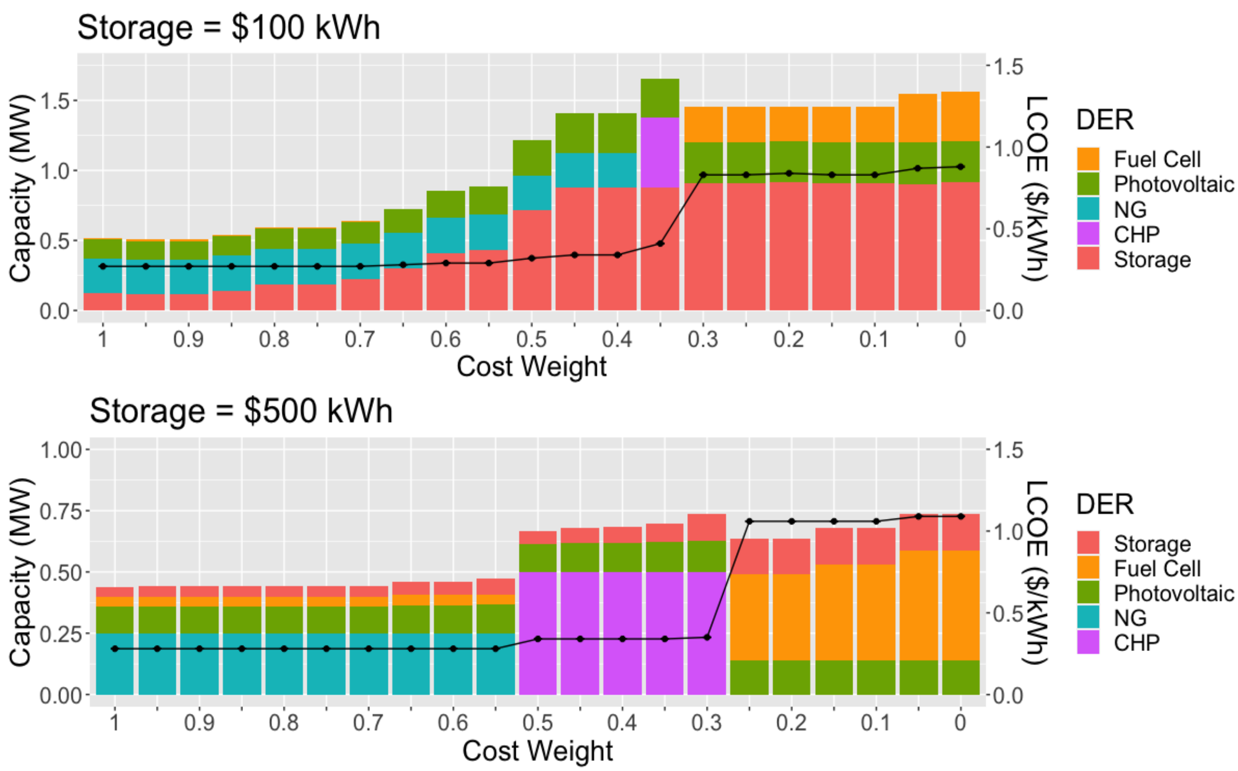

Figure 4.7: The mix of DERs in the LC microgrid as a function of the relative weight assigned to cost, as the cost of electricity storage is changed from $500 to $100kWh. The vertical axis on the right shows the nameplate capacity of each microgrid, while the horizontal axis shows the weight applied to the cost criterion in the objective function. (The weight on emissions is 1- $\boldsymbol{w_{cost}}$.) The vertical axis on the left shows the LCOE of the microgrid as indicated by the black curve.

The results above used the Trump administration's recommended social cost of carbon (SCC) of $1 per ton. Figure 4.8 shows the changes in typology across all three iconic loads when that is increased to $50 per ton. Raising the SCC to $50/ton CO_2 results in a transformation of the evolutionary profile across all iconic loads, by deploying DER-CAM's only zero-carbon dispatchable asset: fuel cells. In this case, NG and CHP are only used when cost is weighted much more heavily than emissions.

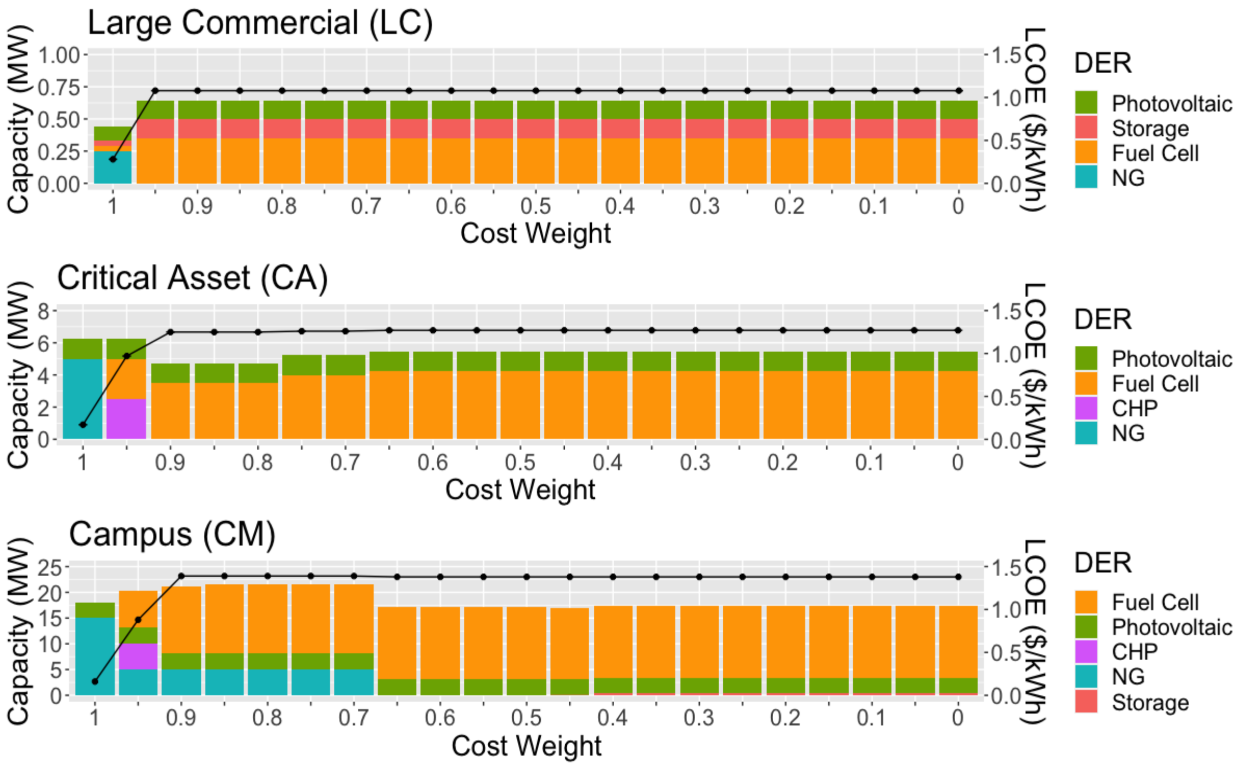

Figure 4.8: The mix of DERs in the three microgrids as a function of the relative weight assigned to cost, when a social cost of carbon of $50 per ton is applied. The vertical axis on the right shows the nameplate capacity of each microgrid, while the horizontal axis shows the weight applied to the cost criterion in the objective function. (The weight on emissions is 1- $\boldsymbol{w_{cost}}$.) The vertical axis on the left shows the LCOE of the microgrid as indicated by the black curve.

4.5: Discussion

4.5.1: Hypothetical mapping of weights to a decision-makers preference

If we assume that a decision-maker such as a facility operator has preferences that are additive and linear, then a hypothetical mapping could be made between the weights applied to the cost and emission criteria and that facility operators' preferences. Such a mapping would allow the weighted problem to accurately model a facility operator's preferences. In such a case, the criteria weights would not only be used in solving for a nondominated set, but also used in deciding which microgrid is best. If a facility operator's preferences are represented as additive and linear, there will always be a solution on the convex hull that is preferred to a gap point. However, if their preferences are not additive and linear, and there is much research to support this is the norm and not the exception [19], then mapping weights to preferences would not hold, since there is no set of weights that will produce the gap points we found as the optimal solution of a weighted problem. Nevertheless, adding the preference interpretation to the weights would indicate a neighborhood of the nondominated set in which a decision maker's preferred solution is likely to lie.

4.5.2: Implications for decarbonizing microgrids

For each of the iconic loads there are shifts in microgrid typology (Figure 4.2) that align with the shift in the weights on cost and emissions (Figure 4.3). When DER-CAM is run over 21 cost and emission weighting schemes, only 3 or 4 microgrid typologies emerge, each primarily powered by a different form of generation. However, the weighting scheme does not tell the full story, since the gap point analysis showed a more gradual shift towards different primary forms of generation.

Facility operators keen on decarbonization might be tempted to invest in a microgrid that relies heavily on CHP. However, despite being attractive in the near term, CHP will not be an attractive solution as deeply decarbonizing the energy system (i.e., the transition from low to no emissions) becomes more salient in society. To avoid stranded microgrid investments in the face of more restrictive future policies on CO2 emissions, credible business cases and policies around zero-carbon-based microgrids need to be developed. Their early deployment is critical to reducing their future costs through learning economies, enhanced system integration, and the rollout of hydrogen or biogas infrastructure.

4.5.3: Flexibility in microgrid operation

Figure 4.5 shows a slow transition from the CHP dominated microgrid in point A to the fuel cell dominated microgrid in point K. Therefore, off of the convex hull, there do exist microgrids that can gradually shift between the large discrete changes we noted above.

Though the gap points in the small peaking LC load do show a more gradual shift away from NG fuels, the transition from point A to point B, as well as points H, I and J, show the same microgrid can operate under different emission and cost scenarios. The smaller peaking load of the LC has multiple gap points, while the larger loads like CA and CM have 1 and 0 gap points, respectively. This is caused by the amount of excess generation being built into the microgrid. For smaller loads it is cheaper to buy 1 large dispatchable DER to meet demand, while for larger loads an investor must buy multiple generators to just barely meet demand. Having excess generation creates a level of flexibility in the DER dispatch of the microgrid. This points to a level of uncertainty around the cost and emissions parameters based on how it dispatches each of its DERs. Such an observation is supported by the gap point found for the CM load. Points B and C for the CM load have the same typology, but different cost and emissions. How much uncertainty should be accounted for by the decision-maker, however, will be left for future work.

4.5.4: The role of natural gas prices in effecting a faster exit from fossil-fuels

While changes in NG prices do not change the broad evolution in microgrid types they do result in a change in where the transition occurs to low-carbon typologies that are dominated by fuel cells, solar PV, and electricity storage. CHP maintains its role as a bridge between NG systems and low-carbon systems, with its role increasing as NG prices rise.

4.5.5: The role of storage and space constraints in decarbonized microgrids

As the cost of storage falls, this will change how microgrids operate, with large financial implications to infrastructure, like gas turbines, that is often purchased through debt. As storage costs fall and its deployment increases, the load factor of the CHP system decreases, and storage is actively used to meet a larger portion of the load. Given the cost premium associated with CHP systems (compared to single-cycle natural gas turbines), the reduced load factor could force a shift back to less efficient single cycle generation, coupled with storage.

At extremely low storage costs, and even when emissions are the only attribute being considered, our results do not result in a microgrid that is only comprised of solar PV and storage. Every microgrid developed contains some amount of dispatchable DERs. In addition, for the CA and CM iconic loads there is not enough land available to build a solar PV + storage microgrid. For the LC load, the deployment of solar PV was restricted by the amount of solar generation being curtailed, with DER-CAM choosing to either store or use all solar generation.

If curtailment is ignored, land availability once again restricts the feasibility of a PV + storage only microgrid. For a PV + storage grid to be developed in the case of the LC iconic load, there would need to be approximately 10,000 m^2 available for solar development. That is roughly 2.5x the size we assume is available. If space is not a factor, which could be the case for rural or agricultural communities, cost becomes a major consideration. For example, the LCOE for the low-carbon LC iconic load reaches $1.09 per kWh and is mostly powered by expensive fuel cells. In comparison, a solar PV + storage microgrid has an expected LCOE that is 70% higher at $1.87 per kWh. Unless a facility operator has access to large amounts of land and is willing to incur a substantial cost premium, our results suggest that there will always be a need for dispatchable DERs.

4.5.6: Promising near-term applications for low-carbon, islanded microgrids

Southern California currently pays roughly $0.20 per kWh for electricity [20], which is slightly more than the least-cost microgrids in our analysis. As the weight placed on emissions increases and costs rise, the LCOE of the microgrid rises to approximately 7x the current cost of electricity in southern California. The microgrids shown in our results are designed for islanding, and while we concede that they incur a steep premium for added resilience, there are three promising deployment options that warrant further study. First, the California grid is becoming less stable and the state is facing devastating disasters like wildfires, some of which are caused by transmission and distribution infrastructure. This is one reason why the state is considering expanded deployment of microgrids as a strategy to both mitigate disasters and enhance resilience [21]. Second, certain rural communities in Alaska or Canada, where there is no ready access to the bulk electricity grid, today use dirty fossil-based generation whose high fuel costs result in an LCOE that is comparable to the LCOE of some low-carbon configurations we analyze that depend on zero-emission dispatchable DERs [22]. However, these comparisons are not one to one because our solar assumptions are for southern CA. The comparable LCOE between a microgrid and connecting the community to the bulk power grid may make it easier for such communities to justify the deployment of environmentally friendly and resilient microgrids. Third, agricultural communities do not have to contend with space constraints, may have large amounts of potential biogas resource, and often sit at the end of a distribution feeder. This makes the cost of delivering reliable grid-based service high. Islanded microgrids that deploy large amounts of solar, storage, and fuel cells might prove attractive in decreasing their energy costs and enhancing the resilience of their electricity service.

4.5.7: Impacts of increasing the social cost of carbon

Including even a modest but realistic social cost of carbon brings about the switch to fuel cells much sooner. The cost of \$50/tonCO_2, used in Figure 4.8, is on the lower end of the range discussed in much of the literature. Some assessments suggest that costs of \$200-\$800 per ton CO_2 may be needed to incentivize more expensive, yet lower or zero emissions, technologies [23]. While these assessments apply to large utility scale technologies, our results suggest that on the microgrid level a much lower social cost of carbon than that is needed to incentivize such a change.

4.6: Conclusion

We explored the extent to which decentralization and decarbonization are complementary or orthogonal goals in the context of microgrid development. We did this by examining the changes of microgrid typology as carbon constraints tighten. Our approach has yielded a more robust and comprehensive assessment of the likely trajectory of microgrid adoption than existing models currently offer, because it explicitly analyzes the importance placed on two key properties that drive microgrid investments: cost and emissions. Moreover, it does this by combining scenarios of stakeholder preferences with an established microgrid investment planning model.

Our work found that as one varies the relative weights applied to cost and emissions, only 3 or 4 different microgrid typologies emerge, while our gap point analysis showed a gradual change between these discrete shifts. A range of realistic NG prices had no impact on the typologies of microgrids being developed. However, different NG prices change where in the weighting scheme different microgrid typologies occur.

Our results also point to the impracticality of microgrids that consist only of PV + storage. Even in the sunny environment of southern California, where our hypothetical microgrids are located, solar use is limited by limits on space and large amounts of curtailment, leading to the inclusion of some form of dispatchable generation in all of our microgrid typologies. Even when a relatively small social cost of carbon is used, the incorporation of zero-emission dispatchable DERs happens whenever emissions are considered.

The microgrids examined for this work are only built for islanding and the incorporation/availability of large utility generation would impact the cost and size of these microgrids. Hence, as noted above, the cost can be considered an upper bound estimate when compared with microgrids that buy power from and sell power to the main grid. Our microgrids also only have one zero-emission dispatchable DER available to use, fuel cells, and do not consider other possible zero-emission dispatchable DERs such as micro-nuclear. Both of these factors could change the typology of the microgrids, which would impact emissions and cost accordingly. However, the relationship between cost and emissions would stay the same, with cleaner "green" DERs leading to higher costs compared to the currently standard fossil-fuel based DERs used for decentralization. Nonetheless, the presented results provide a good decision aid for facility operators looking to invest in a microgrid, especially as future emissions policies around microgrids tighten.

4.7: References

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Chapter 5: Conclusion

The first goal of this work was to assess the U.S. energy system, and to examine what extent, if any, nuclear power will play as the energy system transitions towards little to no carbon dioxide emissions into the atmosphere. For nuclear power to play a role in this transition, nuclear technology must move away from large-light-water nuclear reactors and instead develop factory manufactured SMRs. To facilitate the move towards SMRs, I looked at the feasibility of creating a large enough market to spur mass manufacturing of SMR through a hybrid power-desalination system. The nuclear power industry must also address its public perception problem head on; as such, I created a survey to gauge public perception of nuclear power. The second goal was to explore the potential for, and implications associated with decarbonization using decentralized micro-grids. To do this, I developed a novel approach to simulate facility operator's decision preferences, which informed tradeoffs between costs and emissions.

Chapter 2 resulted in three main conclusions. Despite my best effort, I was unable to justify that the use of the proposed hybrid system will likely be the mass market needed to facilitate the mass manufacturing of SMRs. At present, the SMRs used in this system are unlikely to be cost competitive in the U.S. relative to similar low carbon technologies such as NGCCS. Additionally, while there is considerable talk of the "water energy nexus" and potential water shortages, we concluded that the need for water desalination over the next several decades in the U.S. is modest. Finally, this chapter found that while such a system is not competitive in the U.S., there might exist some international market in countries where NG prices exceed 12 $/mscf and there is a strong geopolitical desire to adopt nuclear power.

Chapter 3 investigated the perceptions of nuclear power as supported by existing theories around differing nuclear views. Our survey participants held significantly less favorable views about nuclear energy if they cited Chernobyl and Fukushima as noteworthy events that shaped their perception. The survey results also suggested that participants who are both non-white and non-male hold significantly less favorable views compared to white males.

Chapter 4 results showed that decarbonization is orthogonal with current fossil fuel-based decentralization efforts; micro-grids that are built for decarbonization always have a higher cost than those that are not. Our results indicated that there were three to four different micro-grid typologies for a facility operator to choose from, allowing facility operators to only need a rough approximation of their preferences when balancing decarbonization into their micro-grid investments. All the results in this chapter contain micro-grids with some form of dispatchable generation in their typology, ranging from dirty NG, to efficient CHP, to zero-emission fuel cells. The grids were dominated by natural gas generation when emissions were weighed as not important, and when emissions become of extreme importance, fuel-cells became the most relied upon dispatchable generation. When a relatively small social cost of carbon is used, the dispatchable DERs almost always used was zero-carbon, as long as there was some weight applied to emissions.

Supporting Information For:

Case Studies in Decisions Related to Nuclear and Other Energy Systems

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Supporting Information

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Appendix 1: Supplemental Information for Chapter 2

Appendix 1.1

Text A1.1.1: Analytica® Model Description and Write-up

Figure A1.1.1: Top-level Analytica® diagram

Figure A1.1.2: Module Node Analytica® diagram

Appendix 1.2

Figure A1.2.1: Overnight Capital Costs

Figure A1.2.2: Operation and Maintenance Costs

Figure A1.2.3: LCOE 60MW NuScale SMR

Figure A1.2.4: LCOE 60MW NuScale SMR with reduced O&M costs

Appendix 2: Supplemental Information for Chapter 2

Text A2.1: Recruitment text

Text A2.2: Presurvey text

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Appendix 3.1

Text A3.1.1: Alternative optima

Text A3.1.2: Exploration of gap points

Figure A3.1.1: Gap points for a large commercial load

Figure A3.1.2: DER make off gap point solutions for a large commercial load

Appendix 3.2 (Taken from Hanna et. al. 2017)

Text A3.2.1: Iconic load profiles: Model parameterizations

Table A3.2.16: Options table for the micro-grid customer model runs

Table A3.2.17: Parameter table for the micro-grid customer model runs

Table A3.2.18: Number of days

Table A3.2.19: Solar insolation

Appendix 1

Appendix 1.1

Text A1.1: Analytica® Model Description and Write-up

The analysis for this paper has been performed using a system called Analytica® that is widely used for policy and engineering-economic analysis. This system structures analysis in terms of influence diagrams, which can be hieratically ordered. Variables can be defined as point values, as vectors of values, or as full probability distributions. In the latter case, the model can then be executed using stochastic simulation.

This is the top-level diagram for the model used in this analysis:

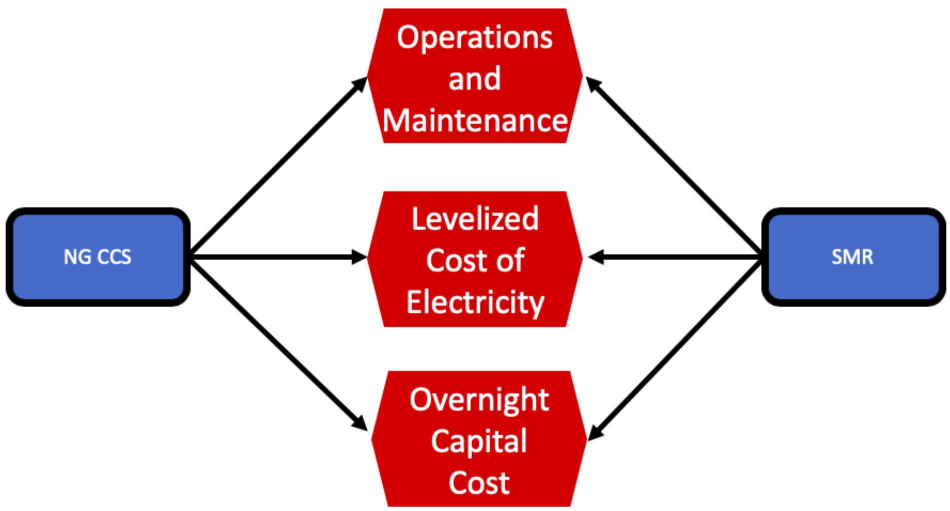


Figure A1.5.1: The top-level diagram for the model used in this analysis, the red trapezoids represent the final outputs of the model, the blue rectangles are module nodes that contain further calculations.

The bold boarders of each of the nodes in this top-level diagram indicate the presence of a more detailed sub-model. Diagrams that show the structure of those parts of the model are shown below:

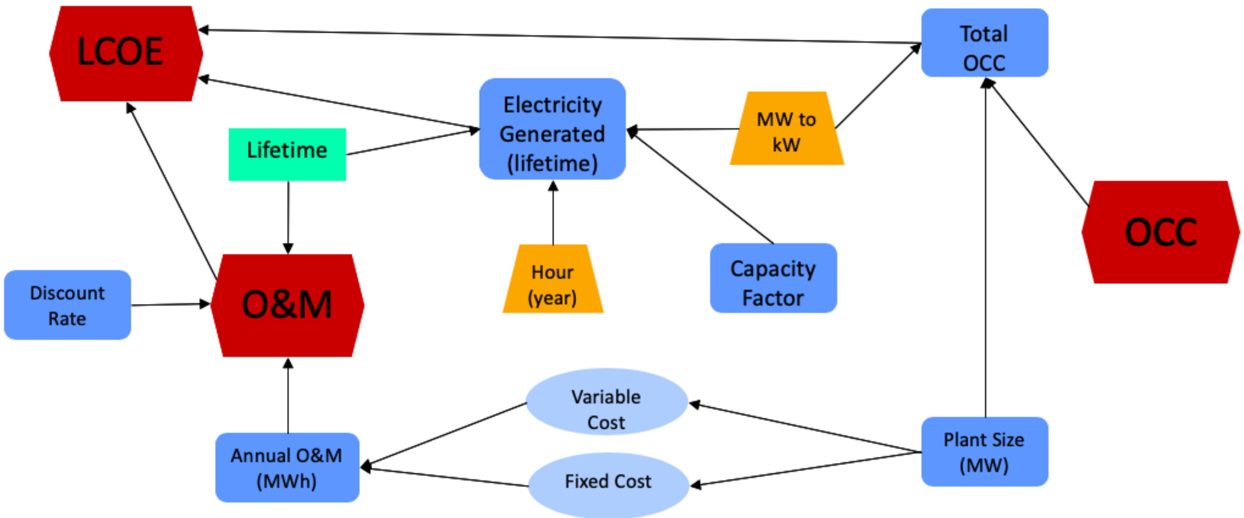


Figure A1.1.2: The figure is a recreation of what is contained in the SMR and NG CCS nodes shown figure A1.1. The red nodes are the outputs of the model presented in the main text of the paper, along with the figures shown in Appendix 3.

Additional details on Analytica® can be found at:

http://www.lumina.com/why-analytica/what-is-analytica1/

Appendix 1.2

Figure A1.2.1: Overnight Capital Costs

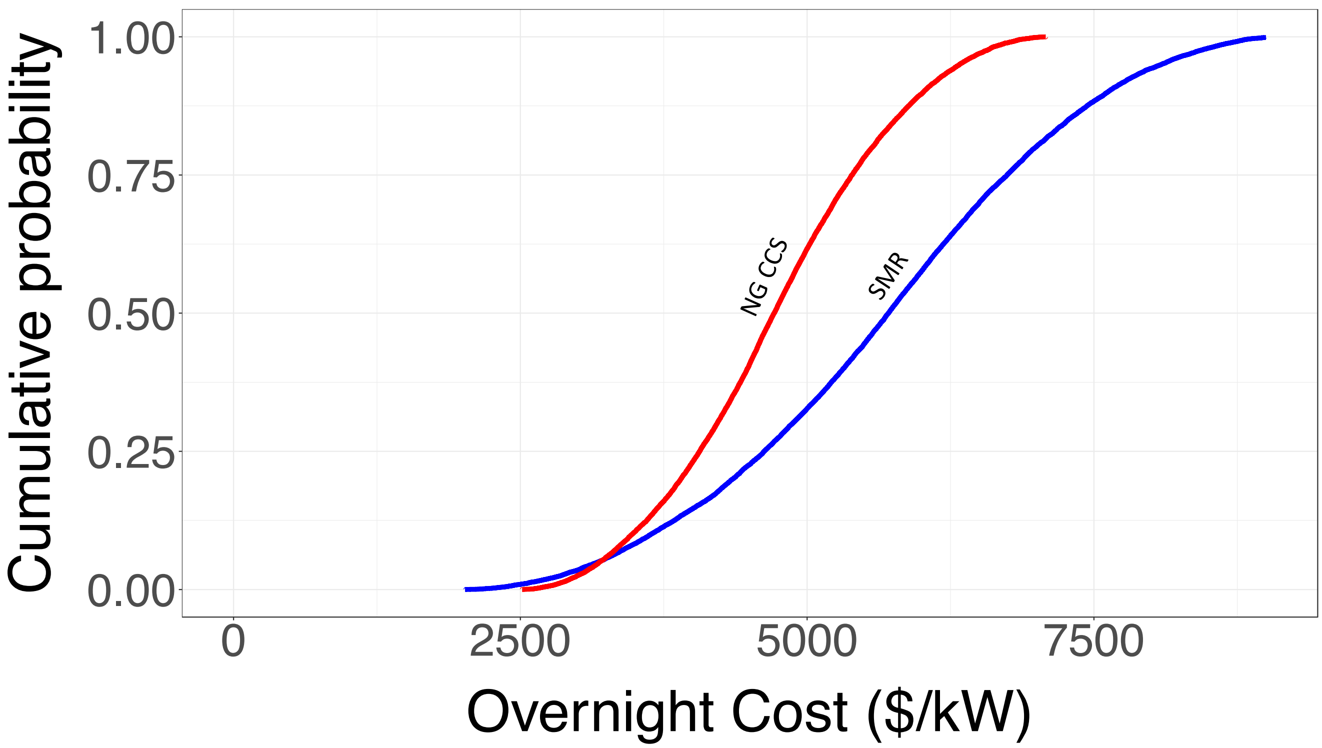


Figure A1.2.1: The CDF on the left (red curve) reports the uncertaunty in the overnight capital cost for a natural gas plant with an amine CCS plant. The CDF on the right (blue curve) reports the unucertainty in the the overnight capital cost for a 45MW$_e$ SMR.

Figure A1.2.2: Operation and Maintenance Costs

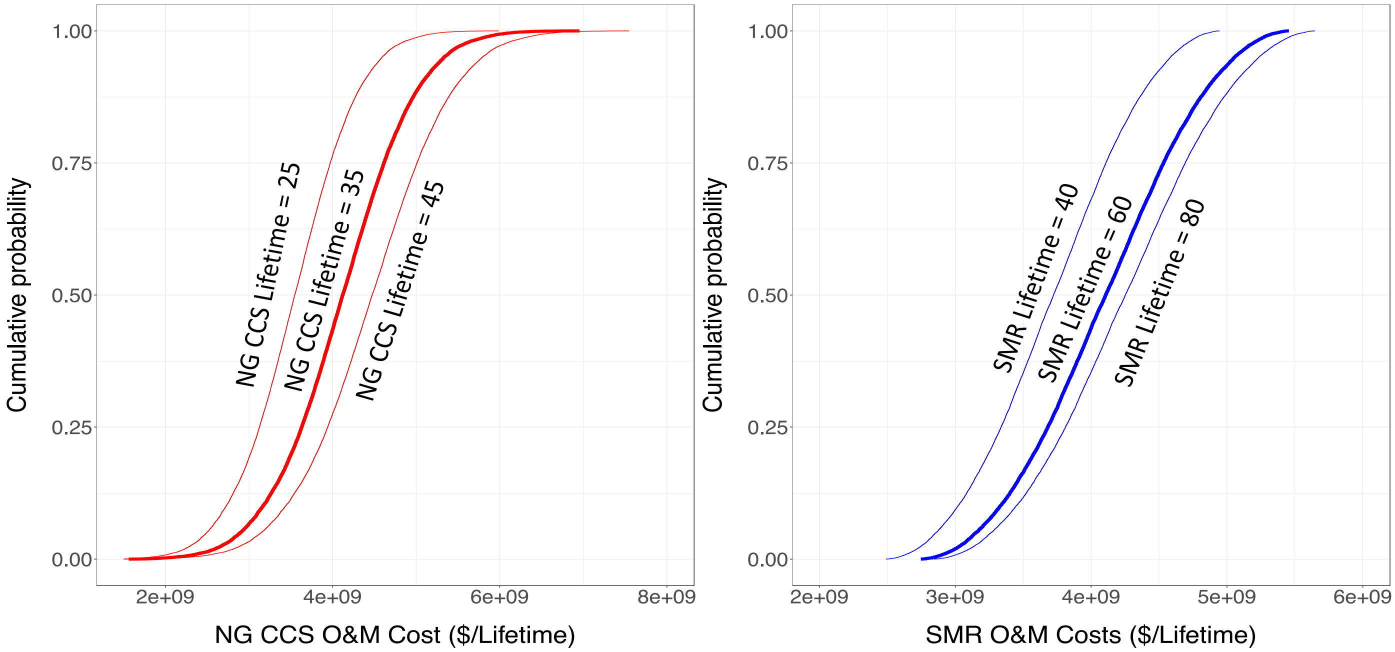


Figure A1.2.2: Total O&M costs for above expected, expected, and below expected, lifetimes for both a 45MW SMR and a natural gas plant with an amine CCS system are displayed.

Figure A1.2.2 Comment:

The O&M costs shown in figure A1.2 assume that the NG CCS plant will be run as a baseload energy plant, in order to provide a fair comparison to the SMR. Today because of the influx of renewables many NG plants are moving down the dispatch order from baseload to peaking operation. Running NG CCS as a peaker would consume the lifetime start allowance more quickly before an extension is required. Such extensions would impact the O&M costs. However, The NG CCS plant we are considering will run all the time but will only provide power to the grid when the wind is not blowing. Thus, at least from the perspective of the grid, it will look like a peaker.

Figure A1.2.3: LCOE 60MW NuScale SMR

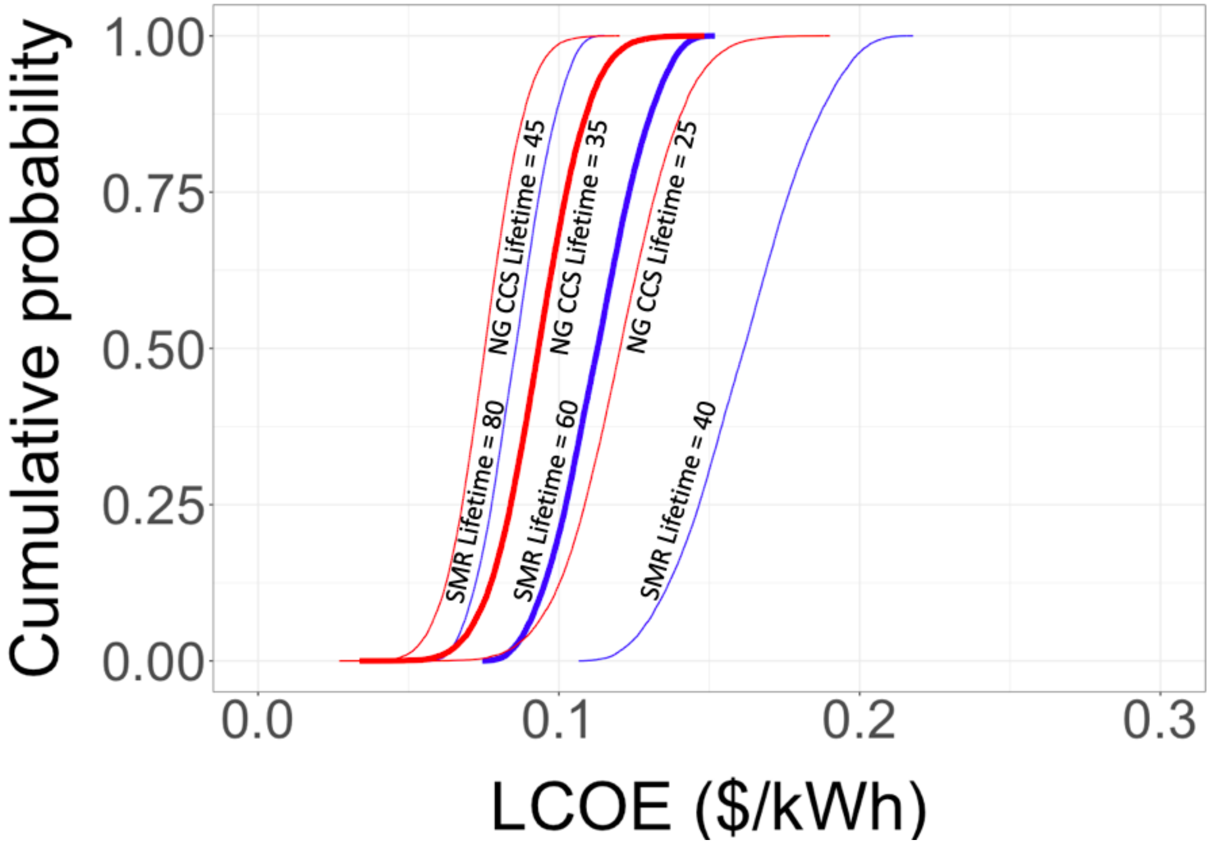


Figure A1.2.3: LCOE as a function of plant lifetimes for a 60MW SMR similar to the NuScale design (blue curves with labels on the left) and a natural gas plant with an amine CCS system (red curves with labels on the right) with uncertainty in the expected lifetime for each plant. Results for the best estmate plant lifetimes are in bold.

Figure A1.2.4: LCOE 60MW NuScale SMR with reduced O&M costs

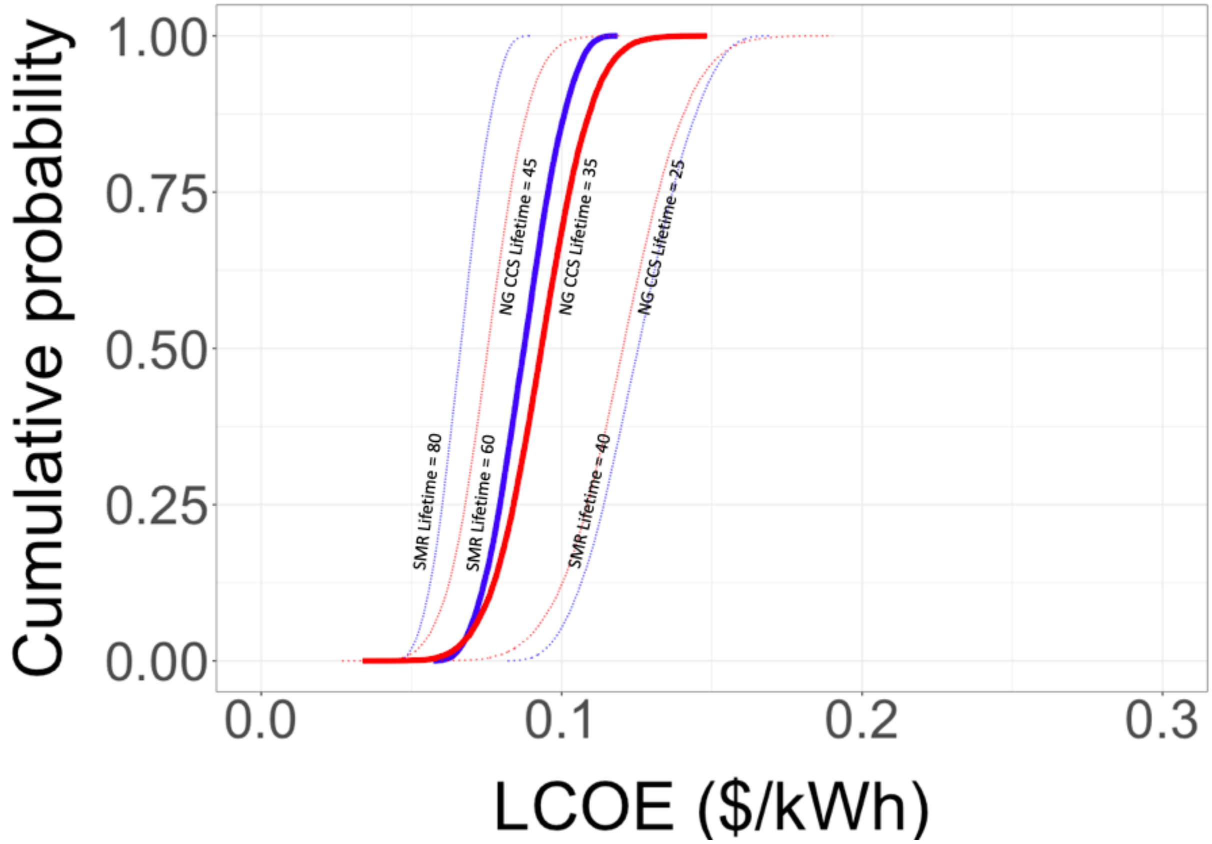


Figure A1.2.4: LCOE as a function of plant lifetimes for a 60MW SMR similar to the NuScale design with O&M costs 25% below estimated O&M cost used in the main text (blue curves with labels on the left) and a natural gas plant with an amine CCS system (red curves with labels on the right) with uncertainty in the expected lifetime for each plant. Results for the best estmate plant lifetimes are in bold.

Appendix 2

Text A2.1: Recruitment text

We are conducting a research study about nuclear energy in the U.S. This study is conducted by researchers at Carnegie Mellon University. This survey will ask you questions about your perception of nuclear energy and is expected to take no longer than 5 min, with a compensation rate of $6.50 per hour of your time. The maximum time allowed on the survey is 7 min.

All participants should be 18 or older and participation is voluntary. All questions should be directed to mrath@andrew.cmu.edu

Text A2.2: Consent Form

CONSENT FORM

This survey is part of a research study conducted by Michael Rath, Ahmed Abdulla, Ph.D. and M. Granger Morgan, Ph.D. at Carnegie Mellon University.

This study is investigating people's attitudes toward nuclear energy and whether monumental nuclear events create a lasting impact on people’s perception of nuclear energy.

Procedure

We will be conducting a basic survey to understand the participants attitude toward nuclear energy. Respondents will be asked to fill out a short survey, asking them to answer 1 word-association question, 3 multiple choice questions and 1 open ended question, followed by several demographic questions. The survey is anticipated to take less than 3 minutes to complete.

Participant Requirements

Participation in this study is limited to individuals age 18 and older.

Risks

The risks and discomfort associated with participation in this study are no greater than those ordinarily encountered in daily life, during other online activities, or when evaluating purchase decisions when shopping for a car.

Benefits

There may be no personal benefit from your participation in the study, but the knowledge received may be of value to humanity.

Compensation & Costs

There will be no cost to participate in this survey.

You will be paid $0.20 for completing the survey which is expected to take 1-3 minutes. If it takes you 1 minute to finish, $0.20 ends up being at the rate of $12/hour. The maximum time allowed is 13 minutes.

Confidentiality

The data captured for the research does not include any personally identifiable information about you.

Right to Ask Questions & Contact Information

If you have any questions about this study, you should feel free to ask them by contacting the Principal Investigator now at cmunuclearsurvey@gmail.com. If you have questions later, desire additional information please contact the Principal Investigator by mail, phone or e-mail in accordance with the contact information listed above.

If you have questions pertaining to your rights as a research participant; or to report objections to this study, you should contact the Research Regulatory Compliance Office at Carnegie Mellon University. Email: irb-review@andrew.cmu.edu. Phone: 412-268-1901 or 412-268-5460

The Carnegie Mellon University Institutional Review Board (IRB) has approved the use of human participants for this study.

Voluntary Participation

Your participation in this research is voluntary. You may discontinue participation at any time during the research activity.

The following questions will be included in the web page so that they must be answered appropriately before the individual can proceed to the study task:

1. I am age 18 or older. ☐ Yes ☐ No
2. I have read and understand the information above. ☐ Yes ☐ No
3. I want to participate in this research and continue with the survey. ☐ Yes ☐ No

---

Text A2.3: Survey

Q1 Which one of the following words do you most associate with nuclear energy?

▼ Safe (1), Unsafe (2), Cheap (3), Expensive (4), Low carbon emissions (5), High carbon emissions (6), Dirty (7), Clean (8), Weapons (9), Accidents(10), Other (11)

Q1a If you selected "other", in the previous question, what word do you most associate with nuclear energy?

____

Q2 Nuclear energy should be developed further in order to meet the U.S.'s energy needs.

- ○ Strongly agree (9)
- ○ Agree (10)
- ○ Somewhat agree (11)
- ○ Neither agree nor disagree (12)
- ○ Somewhat disagree (13)
- ○ Disagree (14)
- ○ Strongly disagree (15)

Q3 In general, how safe are nuclear power stations?

- ○ Extremely safe (1)
- ○ Moderately safe (2)
- ○ Slightly safe (3)
- ○ Neither safe nor unsafe (4)
- ○ Slightly unsafe (5)
- ○ Moderately unsafe (6)
- ○ Extremely unsafe (7)

Q4 What event(s), if any, shaped your view of nuclear energy?

____

Q5

What is your age in years?

- ○ Under 18 (1)
- ○ 18 - 24 (2)
- ○ 25 - 34 (3)
- ○ 35 - 44 (4)
- ○ 45 - 54 (5)
- ○ 55 - 64 (6)
- ○ 65 - 74 (7)
- ○ 75 - 84 (8)
- ○ 85 or older (9)

Q6 Which gender do you most identify with?

- ○ Male (1)
- ○ Female (2)
- ○ Not listed above (3)

Q7 How would you describe your ethnic background?

- ○ White (1)
- ○ Black or African American (2)
- ○ Hispanic or Latinx (7)
- ○ American Indian or Alaska Native (3)
- ○ Asian (4)
- ○ Native Hawaiian or Pacific Islander (5)
- ○ Other (6)

Q9 What is the highest level of education you have obtained?

- ◯ Less than high school (1)
- ◯ High school graduate (2)
- ◯ Some college (3)
- ◯ 2 year degree (4)
- ◯ 4 year degree (5)
- ◯ Professional degree (6)
- ◯ Doctorate (7)

Q10 For this question, please take your best guess even if you do not know the exact answer.

Please choose the total income earned by the adults in your household in the previous year.

- ○ Less than $25,000 (1)
- ○ $25,000 - $49,999 (2)
- ○ $50,000 - $74,999 (3)
- ○ $75,000 - $99,999 (4)
- ○ $100,000 - $149,999 (5)
- ○ More than $150,000 (6)

Appendix 3

Appendix 3.1

Text A3.1.1: Alternative optima

DER-CAM, along with its underlying solver CPLEX, is designed to stop after calculating 1 optimal solution. If a set of optimal solutions exist, DER-CAM might not output the most efficient solution from the set, but rather one of the existing inferior solutions. There may be other solutions that are not displayed, which may dominate the outputted optimal solution. In order to check that our results contain only the most efficient optimal solutions, we examined the out-puts of DER-CAM for alternate optima.

To check for alternative optima, we turned the multi-objective program we used within DER-CAM into a single objective program. This single objective program minimizes on one criterion and uses a hard constraint to account for the other. The hard constraint is determined by the original value outputted by DER-CAM for each criterion.

Only the most efficient solutions are displayed in the main body of our work.

Text A3.1.2: Exploration of gap points

The weighting method used to solve for optimal solutions will not find possible discrete optima that do not fall on the implied convex hull, despite these solutions still being non-dominated. These solutions are called gap points, and to check for these we once again have to turn the multi-objective program used by DER-CAM into a single objective one. Unlike the hard constraint used for solving alternative optima, solving for gap points requires two new inequality constraints. These inequality constraints state that both criteria have to be less than or equal to the criteria values of the previous solution, while the program minimizes cost.

We tested for gap points on all three iconic loads, but only the large commercial load showed any evidence of gap points. Figure A1.1 shows the results of our gap point tests. Both points A and K were outputs by DER-CAM using the weighted method for the large commercial iconic load. To solve for point B, we built a constraint in DER-CAM that requires point B to have a cost less than or equal to the cost of point A. In the same program, we then built a similar constraint for emissions.

Figure A1.2 shows the DER make up of each gap point presented in Figure A1.1. The gap points are bound by points A and K, which were taken from the main body of our results, points B through J are solved with our gap point method. The transition from point A to point B, as well as points H, I and J, show the same micro-grid can operate under different emission and cost scenarios based on how it dispatches each of its DERs. But as DER-CAM moves from point B to point C and beyond, DER-CAM struggles to minimize the incorporation of fuel cells into the micro-grid mix. Fuels cells are drastically more expensive than CHP (Table A2.11), in order to minimize costs DER-CAM will avoid deploying them as much as possible. But as the limit on emissions tightens, DER-CAM slowly begins to incorporate fuel cells into its micro-grid typology.

The drastic CHP capacity differences between different gap point solutions is an artifact of DER-CAM being a MIP, and CHP being a discrete, integer, variable. Priority of dispatch is as follows; PV has the most priority with storage being used on its shoulders. CHP is then used as much as possible before fuel-cells are needed to lower the micro-grids emissions. As emissions tighten, there is a gradual increase in the number of fuel-cells, while the usage of CHP drops.

Figure A3.1.1: Gap points for a large commercial load

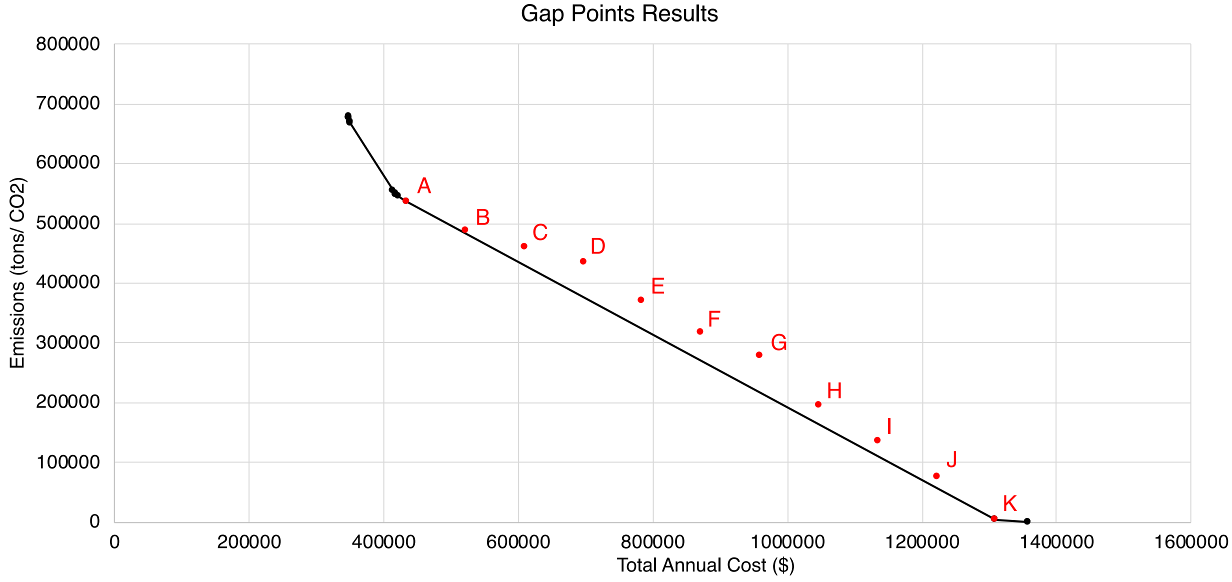
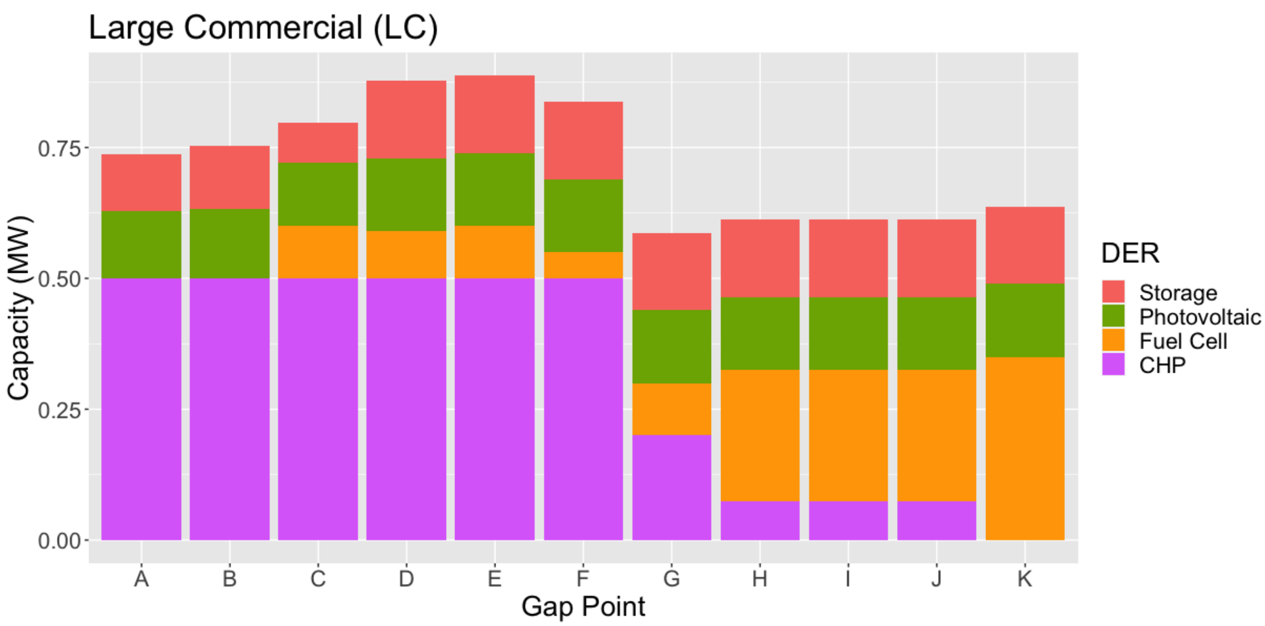


Figure A3.1.2: DER make off gap point solutions for a large commercial load



Appendix 3.2

Text A3.2.1 Iconic load profiles: Model parameterizations

In this section we present those parameters configured by our team for use in our modeling and analysis. We present parameters used in the baseline analysis. Parameterizations for sensitivity analysis are changed as reported in the journal submission. We do not present parameters in DER-CAM 4.4.1.1 that we did not modify, and further note parameterizations unique to an iconic micro-grid.

The parameter "OptionsTable" defines high-level options within the model.

Table A3.2.27: Options table for the micro-grid customer model runs

DiscreteInvest	1
ContinuousInvest	1
DFChillInvest	1
SwitchInvest	1
Sales	0
PVSales	0
NetMetering	0
InvestmentConst	0
StandbyOpt	0
VaryPrice	0
CHP	0
CO2Tax	1
MinimizeCO2	0

ZNEB	0
MultiObjective	0
DiscreteElecStorage	0
LS	0
CentralChiller	1
GSHPAnnualBalance	0
FuelCellConstraint	0
BuildingWallInvest	0
BuildingWindowInvest	0
BuildingDoorInvest	0
BuildingRoofInvest	0
BuildingGroundInvest	0

The parameter “ParameterTable” defines global parameters within the model. BaseCaseCost, FractionBaseLoad, FractionPeakLoad, and MaxSpaceAvailablePVSolar are unique to each micro-grid.

Table A3.2.28: Parameter table for the micro-grid customer model runs

	Large Commercial	Critical Asset	Campus
IntRate	0.07	0.07	0.07
Standby	13.76	13.76	13.76
Contrct	0	0	0
turnvar	0	0	0

CO2Tax	0.012	0.012	0.012
macroeff	0.34	0.34	0.34
cooleff	0	0	0
BaseCaseCost	263699.7	3473758	13978933
MaxPaybackPeriod	*Parameter removed from our model's source code		
FractionBaseLoad	0.6	0.8	0.6
FractionPeakLoad	0.4	0.8	0.4
ReliabilityDER	0.9	0.9	0.9
MaxSpaceAvailablePVSolar	4050	8100	20250
PeakPVEfficiency	0.1529	0.1529	0.1529
MultiObjectiveMaxCosts	2900000	2900000	2900000
MultiObjectiveMaxCO2	4400000	4400000	4400000
MultiObjectiveWCosts	0.6	0.6	0.6
MultiObjectiveWCO2	0.4	0.4	0.4
ZNEBsolarAreaMultiplier	200	200	200
ZNEBCostsMultiplier	2	2	2
BldgShellLifetime	20	20	20

The parameter "NumberOfDays" defines the number of day-types (peak-days, week-days, weekend-days) in each month.

Table A3.2.29: Number of days

	Peak	Week	Weeken d
January	0	23	8
February	0	20	8
March	0	21	10
April	0	22	8
May	0	23	8
June	0	20	10
July	0	23	8
August	0	22	9
September	0	21	9
October	0	23	8
November	0	21	9
December	0	22	9

The parameter “SolarInsolation” defines solar irradiance by month and hour. Units are Wm^{-2}. A general profile for California is used.

Table A3.2.30: Solar insolation

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0.000011113	0.000897	0.001241	0.001574	0.000008909	0	0	0	0
7	0	0	0.001155	0.039436554	0.067892	0.034132	0.03458	0.025661327	0.014179	0.007531	0.000056166	0
8	0.040666	0.089642	0.201794	0.251742059	0.234939	0.183715	0.192092	0.218280894	0.201542	0.199117	0.181629264	0.117555

	0.2930	0.2937	0.4227	0.4538912	0.4127	0.3866	0.3492	0.4260131	0.4299	0.3938	0.3973678	0.3363
9	93	93	4	44	53	3	64	12	66	82	58	59
1	0.4336	0.4642	0.6011	0.6132374	0.5736	0.5592	0.5217	0.5894729	0.6030	0.5090	0.5499224	0.5083
0	1	83	47	14	93	52	13	08	59	01	7	01
1	0.5874	0.5129	0.7107	0.7319562	0.7014	0.6993	0.6853	0.7354117	0.7309	0.5960	0.6919892	0.6039
1	94	1	95	05	39	42	31	14	85	91	17	91
1	0.6558	0.5990	0.8197	0.8089298	0.7616	0.7578	0.7727	0.8233977	0.7990	0.6505	0.6795981	0.6368
2	92	31	34	21	3	22	37	29	34	24	74	8
1	0.6422	0.5811	0.8176	0.8086790	0.7779	0.8099	0.8077	0.8266447	0.7480	0.6903	0.6865913	0.6033
3	84	54	84	66	55	23	06	97	14	02	84	81
1	0.6237	0.5945	0.7624	0.7928549	0.7373	0.7548	0.7774	0.7663020	0.7152	0.6032	0.6068210	0.5562
4	11	49	9	01	01	53	33	05	97	08	75	39
1	0.5119	0.5074	0.6626	0.6471099	0.6018	0.6320	0.6611	0.6528012	0.6127	0.4829	0.4788374	0.4200
5	61	71	54	42	29	5	27	3	2	56	86	48
1	0.3411	0.3430	0.4642	0.4941041	0.4403	0.4646	0.5013	0.4687954	0.4207	0.2931	0.2782891	0.2665
6	01	99	36	16	45	63	19	11	43	99	63	72

17	0.049232	0.193289	0.241556	0.254367714	0.253973	0.271369	0.293051	0.253153333	0.210109	0.059559	0.00810668	0.004395
18	0	0.000104	0.000573	0.041796176	0.072307	0.104134	0.122424	0.068604709	0.00023	0	0	0
19	0	0	0	0	0.000238	0.000416	0.000202	0.000007881	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0

The parameter “AmbientHourlyTemperature” defines the average hourly ambient dry-bulb temperature by month. Units are degrees Celsius.

Table A3.2.31: Ambient hourly temperature

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	8.1	9.7	11.1	10.3	11.2	13	13.4	14	14.8	13.4	10.8	8.2
2	7.9	9.5	10.6	9.8	11.1	12.9	13.3	13.8	14.5	12.9	10.2	7.9
3	7.8	9.3	10.1	9.4	10.8	12.7	13.1	13.6	14.1	12.4	9.6	7.4
4	7.7	9.1	9.6	9	10.4	12.3	13	13.4	13.7	11.9	9.2	6.9
5	7.8	8.8	9.3	9.4	10.9	12.9	13.4	13.5	13.5	12.1	9.3	6.9
6	7.9	8.6	9	9.7	11.3	13.6	13.7	13.7	13.7	12.3	9.3	7
7	8	8.2	8.7	10.1	11.7	14.2	14.1	13.9	14.7	12.5	9.9	7
8	8.9	9.5	9.9	11.5	13.2	15.5	15.5	15.2	16.2	14.2	11.5	8.1
9	9.7	10.7	11.1	13	14.6	16.7	16.9	16.5	17.7	15.8	13.4	9.3
10	10.6	12	12.3	14.5	16.1	18	18.3	17.9	19	17.4	14.4	10.4
11	11.5	13.2	13.4	15.6	17.5	19.4	19.8	19.6	20.6	18.6	15.3	11.5
12	12.4	14.4	14.5	16.8	18.9	20.7	21.3	21.4	22.2	19.9	16.6	12.6
13	13.3	15.5	15.6	18	20.4	22	22.8	23.1	23.4	21.1	17.1	13.6
14	13.4	15.6	15.9	18.1	20.2	21.6	22.4	22.6	23.6	21.2	17.4	13.8
15	13.6	15.7	16.1	18.2	20	21.1	22.1	22.1	23.2	21.2	17.3	13.9
16	13.8	15.8	16.4	18.4	19.8	20.7	21.8	21.6	22.4	21.3	16.3	14.1
17	12.8	14.9	15.6	17	18.2	19.3	20.2	20.1	21.3	19.9	15	13
18	11.9	13.9	14.8	15.5	16.6	17.8	18.6	18.5	19.5	18.6	14.1	12

19	10.9	13	14	14.1	15	16.4	17.1	17.1	18.2	17.2	13.3	11
20	10.4	12.3	13.6	13.5	14	15.5	16.3	16.3	17.2	16.6	12.7	10.3
21	9.9	11.7	13.1	12.9	13.2	14.7	15.5	15.7	16.6	16	11.9	9.7
22	9.3	11.1	12.6	12.2	12.2	13.8	14.7	14.9	16.1	15.3	11.7	9.1
23	8.9	10.5	12.1	11.5	11.7	13.3	14	14.4	15.6	14.6	11.5	8.6
24	8.5	10.1	11.6	10.8	11.5	13.1	13.7	14.1	15.2	13.9	11.2	8.3

We do not modify global settings for utility parameters—i.e. the marginal marketplace CO_2 emissions rate and CO_2 emission factors for generator fuels.

The parameter "MonthSeason" defines each month as either "summer" or "winter" per the electric tariff SDG&E AL-TOU. Data is presented as follows: 1 indicates "yes" and 0 "no".

Table A3.2.32: Month season

	Summer	Winter
January	0	1
February	0	1
March	0	1
April	0	1
May	1	0
June	1	0
July	1	0
August	1	0

September	1	0
October	1	0
November	0	1
December	0	1

The parameter "ListOfHours" defines the on-, mid-, and off-peak periods in the electric tariff by hour, season, and day-type. Data is presented as follows: columns 2-4 assign tariff periods for the summer season for the week, peak, and weekend day-type respectively; columns 5-7 do the same for the winter season. A value of 1 indicates on-peak, 2 mid-peak, and 3 off-peak.

Table A3.2.33: List of hours

Hour	Summer, week	Summer, peak	Summer, weekend	Winter, week	Winter, peak	Winter, weekend
1	3	3	3	3	3	3
2	3	3	3	3	3	3
3	3	3	3	3	3	3
4	3	3	3	3	3	3
5	3	3	3	3	3	3
6	3	3	3	3	3	3
7	2	2	3	2	2	3
8	2	2	3	2	2	3
9	2	2	3	2	2	3
10	2	2	3	2	2	3

11	2	2	3	2	2	3
12	1	1	3	2	2	3
13	1	1	3	2	2	3
14	1	1	3	2	2	3
15	1	1	3	2	2	3
16	1	1	3	2	2	3
17	1	1	3	2	2	3
18	1	1	3	1	1	3
19	2	2	3	1	1	3
20	2	2	3	1	1	3
21	2	2	3	2	2	3
22	2	2	3	2	2	3
23	3	3	3	3	3	3
24	3	3	3	3	3	3

The parameter “MonthlyFee” defines monthly fees for utility electric service (“UtilElectric”) and gas service (“UtilNGbasic”). Units are $.

Table A3.2.34: Monthly fee

	Large Commercial	Critical Asset	Campus
UtilElectric	31.4	37.35	37.35
UtilNGbasic	15	15	15

UtilNGforDG	0	0	0
UtilNGforABS	0	0	0
UtilDiesel	0	0	0
UtilBiofuel	0	0	0
UtilOther	0	0	0

The parameter “ElectricityRates” defines the volumetric rates in the electric tariff. Data is presented as follows: columns 2-4 give rates for the on-, mid-, and off-peak periods, respectively. Units are $/kWh.

Table A3.2.35: Electricity rates

	On	Mid	Off
January	0.11659	0.100341	0.077957
February	0.11659	0.100341	0.077957
March	0.11659	0.100341	0.077957
April	0.11659	0.100341	0.077957
May	0.128858	0.118732	0.086599
June	0.128858	0.118732	0.086599
July	0.128858	0.118732	0.086599
August	0.128858	0.118732	0.086599
September	0.128858	0.118732	0.086599
October	0.128858	0.118732	0.086599
November	0.11659	0.100341	0.077957
December	0.11659	0.100341	0.077957

The parameter “MonthlyDemandRates” defines the demand charges in the electric tariff. Data is presented as follows: columns 2-3 give the coincident and noncoincident charges, respectively; columns 4-6 give charges for the on-, mid-, and off-peak periods, respectively. Units are $/kW.

Table A3.2.36: Monthly demand rates

	Coincident	Noncoincident	On-peak	Mid-peak	Off-peak
January	0	23.83	7.62	0	0
February	0	23.83	7.62	0	0
March	0	23.83	7.62	0	0
April	0	23.83	7.62	0	0
May	0	23.83	20.93	0	0
June	0	23.83	20.93	0	0
July	0	23.83	20.93	0	0
August	0	23.83	20.93	0	0
September	0	23.83	20.93	0	0
October	0	23.83	20.93	0	0
November	0	23.83	7.62	0	0
December	0	23.83	7.62	0	0

The parameter “FuelPrice” defines monthly fuel prices for fuel purchases. Fuels include natural gas for basic service (“NGbasic”), natural gas for distributed generation (“NGforDG”), and natural gas for direct-fired absorption chillers (“NGforAbs”). Natural gas is the only fuel used in the model, and use we use a single price for all months and end-uses. Units are $/kWh.

Table A3.2.37: Fuel price

	NGbasic	NGforDG	NGforAbs	Diesel	Biodiesel	Other
January	0.027297	0.027297	0.027297	0	0	0
February	0.027297	0.027297	0.027297	0	0	0
March	0.027297	0.027297	0.027297	0	0	0
April	0.027297	0.027297	0.027297	0	0	0
May	0.027297	0.027297	0.027297	0	0	0
June	0.027297	0.027297	0.027297	0	0	0
July	0.027297	0.027297	0.027297	0	0	0
August	0.027297	0.027297	0.027297	0	0	0
September	0.027297	0.027297	0.027297	0	0	0
October	0.027297	0.027297	0.027297	0	0	0
November	0.027297	0.027297	0.027297	0	0	0
December	0.027297	0.027297	0.027297	0	0	0

The parameter “ContinuousVariableForcedInvest” forces investment in technologies. Column 2 forces investment when set to one and column 3 sets the investment capacity. Heat pumps are neglected (i.e. forced investment is set to 0).

Table A3.2.12: Continuous variable forced invest

	ForcedInvest	ForcedInvestCapacity
ElectricStorage	0	0
HeatStorage	0	0
ColdStorage	0	0
FlowBatteryEnergy	0	0
FlowBatteryPower	0	0
AbsChiller	0	0
Refrigeration	0	0
PV	0	0
SolarThermal	0	0
EVs1	1	0
AirSourceHeatPump	1	0
GroundSourceHeatPump	1	0

The parameter "StaticSwitchParameter" defines the switchgear. We do not modify costs ("CostM", "CostB"), but force investment ("ForcedInvest" is set to 1) and set the value of investing in switchgear to 0 ("Value" is set to 0).

Table A3.2.13: Static switch parameters

CostM	100
CostB	0
Lifetime	10

Value	0
ForcedInvest	1

We do not permit energy management and resiliency parameters in our models, including load shifting, demand response, and direct controllable loads. We also do not enable or use “advanced user settings” such as building retrofits, financial incentives, or the California Self-Generation Incentive Program (SGIP).

Text A3.2.2 Iconic load profiles: Load profiles for the three iconic micro-grids

Load profiles are presented in A3.2.14, A3.2.15, and A3.2.16 for the large commercial, critical asset, and campus micro-grids, respectively. Notations are as follows. Dor end-use loads (in column 1): electricity ‘e’, cooling ‘c’, space heating ‘s’, water heating ‘w’, and natural gas ‘g’. Months are given as JFMAMJJASOND. For day-types: week-day ‘w’ and weekend-day ‘e’. The refrigeration load is zero and peak days are not used. Neither are shown here. Data is presented as follows: column 1 end-use load type; column 2 month; column 3 day-type; and columns 4-27 hours of the day 1-24. Units are kW.

Table A3.2.14: Load for the large commercial micro-grid

			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
e	J	w	63.1	63.1	63.1	63.1	63.1	68.4	118.3	135.0	253.0	235.9	234.1	240.4	240.9	244.4	235.3	232.4	235.9	224.9	152.7	149.6	122.5	123.1	68.4	63.1
e	F	w	63.1	63.1	63.1	63.1	63.1	68.4	111.0	131.2	252.2	234.8	232.5	238.6	239.1	242.8	234.4	232.1	235.5	220.6	150.9	147.5	120.2	121.0	68.4	63.1
e	M	w	63.1	63.1	63.1	63.1	66.6	92.3	117.1	207.1	239.4	232.0	235.2	238.2	241.4	237.6	234.1	237.0	222.7	165.9	147.4	126.9	117.3	86.0	64.9	63.1
e	A	w	63.1	63.1	63.1	63.1	68.4	90.6	122.6	251.2	234.8	232.3	237.8	238.7	243.5	235.8	235.7	241.9	218.5	138.9	144.3	115.1	114.5	68.4	63.1	63.1
e	M	w	63.1	63.1	63.1	63.1	65.7	75.1	118.4	252.9	237.7	236.1	242.7	243.5	249.3	242.8	243.3	249.4	225.0	143.5	142.5	116.2	113.9	68.4	63.1	63.1
e	J	w	63.1	63.1	63.1	63.1	63.5	74.4	118.5	259.7	247.1	248.0	256.0	255.4	263.3	256.6	258.3	265.1	238.7	154.0	147.7	123.8	120.1	68.4	63.1	63.1
e	J	w	63.1	63.1	63.1	63.1	66.3	81.3	125.0	273.2	262.0	263.0	271.3	269.6	279.3	273.2	275.6	283.7	257.7	167.2	158.1	132.1	128.1	68.4	63.1	63.1
e	A	w	63.1	63.1	63.1	63.1	68.4	85.8	127.7	280.6	270.8	274.5	283.8	281.8	292.1	286.0	287.7	295.2	266.5	172.3	168.7	136.9	132.2	68.4	63.1	63.1
e	S	w	63.1	63.1	63.1	63.1	68.4	83.1	120.4	267.5	257.1	261.2	271.9	272.1	281.6	275.4	277.2	282.6	253.0	163.0	163.4	127.6	123.4	68.4	63.1	63.1
e	O	w	63.1	63.1	63.1	63.1	68.4	89.8	120.1	261.8	249.3	250.2	259.3	260.5	268.8	260.7	260.6	264.0	235.0	162.2	156.0	121.8	118.6	68.4	63.1	63.1
e	N	w	63.1	63.1	63.1	63.1	63.8	71.5	94.8	140.0	251.3	238.4	237.8	243.3	245.0	248.0	239.7	238.3	241.7	218.8	152.5	144.0	118.3	110.6	67.7	63.1
e	D	w	63.1	63.1	63.1	63.1	63.1	68.4	115.1	132.9	254.4	239.0	238.0	243.6	243.1	246.7	237.6	234.3	241.9	226.0	152.5	149.4	122.6	122.9	68.4	63.1
e	J	e	52.3	52.3	52.3	52.3	52.3	52.3	73.9	61.7	80.8	83.6	83.5	87.5	88.8	87.2	60.9	56.0	57.3	64.7	52.3	52.3	52.3	52.3	52.3	52.3
e	F	e	52.3	52.3	52.3	52.3	52.3	52.3	74.9	67.0	87.1	88.2	87.1	91.0	91.2	89.4	60.9	57.7	57.5	60.9	52.3	52.3	52.3	52.3	52.3	52.3
e	M	e	52.3	52.3	52.3	52.3	52.3	66.1	68.2	75.7	86.7	88.0	89.7	90.7	90.1	74.2	58.4	58.2	55.3	47.0	52.3	52.3	52.3	52.3	52.3	52.3
e	A	e	52.3	52.3	52.3	52.3	52.3	65.2	62.3	86.0	89.6	89.2	91.4	90.2	87.5	58.4	57.8	59.7	51.7	38.2	50.4	52.3	52.3	52.3	52.3	52.3
e	M	e	52.3	52.3	52.3	52.3	49.9	54.3	61.0	88.6	92.2	92.2	93.0	92.2	89.7	60.7	61.8	63.9	55.7	41.9	45.6	52.3	52.3	52.3	52.3	52.3
e	J	e	52.3	52.3	52.3	52.3	47.4	55.0	61.3	90.3	95.8	96.0	95.9	93.7	92.0	64.8	69.4	71.8	62.0	47.3	44.3	52.5	52.3	52.3	52.3	52.3
e	J	e	52.3	52.3	52.3	52.3	49.9	59.0	64.4	95.7	103.9	104.8	104.0	99.4	96.9	70.0	76.7	77.0	70.7	54.2	49.8	52.3	52.3	52.3	52.3	52.3
e	A	e	52.3	52.3	52.3	52.3	52.3	63.0	67.9	101.4	108.1	111.2	109.8	107.7	105.8	76.4	78.1	80.1	70.8	57.5	54.3	53.1	52.3	52.3	52.3	52.3
e	S	e	52.3	52.3	52.3	52.3	52.3	68.4	67.2	98.9	106.2	107.2	111.2	111.3	111.0	78.4	77.7	75.8	64.7	44.5	52.3	52.3	52.3	52.3	52.3	52.3
e	O	e	52.3	52.3	52.3	52.3	52.3	66.8	58.2	83.2	87.5	88.2	95.8	98.0	98.0	72.4	68.7	66.3	55.2	50.5	52.3	52.3	52.3	52.3	52.3	52.3
e	N	e	52.3	52.3	52.3	52.3	52.3	57.8	62.0	62.0	74.8	76.6	79.1	81.3	80.9	71.3	55.7	53.7	55.2	59.5	52.3	52.3	52.3	52.3	52.3	52.3
e	D	e	52.3	52.3	52.3	52.3	52.3	52.3	78.6	68.0	88.8	90.3	89.8	94.1	94.1	90.3	60.3	57.3	63.2	66.6	52.3	52.3	52.3	52.3	52.3	52.3
c	J	w	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1.7	5.0	8.4	11.5	12.7	12.9	11.3	8.9	5.3	2.0	0.9	0.4	0.3	0.2	0.0	0.0
c	F	w	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	2.0	4.5	7.2	10.1	11.4	11.4	10.3	8.2	6.1	3.1	0.9	0.3	0.1	0.0	0.0	0.0
c	M	w	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.9	3.2	6.0	8.9	11.2	12.1	11.7	10.8	9.8	7.7	4.3	1.9	1.0	0.5	0.1	0.0	0.0
c	A	w	0.0	0.0	0.0	0.0	0.0	0.3	1.4	4.0	6.6	8.9	10.9	12.7	13.3	12.7	12.5	12.3	10.8	7.0	4.5	2.7	1.9	0.0	0.0	0.0
c	M	w	0.0	0.0	0.0	0.0	0.0	4.0	5.5	8.1	10.8	13.4	16.0	17.7	18.9	19.4	19.5	19.1	16.8	11.7	8.6	6.0	4.9	0.0	0.0	0.0
c	J	w	0.0	0.0	0.0	0.0	0.0	11.9	12.4	15.8	19.9	24.6	28.4	29.0	31.7	31.8	32.8	33.0	29.1	21.6	17.8	14.5	12.8	0.0	0.0	0.0

c	J	w	0.0	0.0	0.0	0.0	0.0	21.1	21.3	28.4	33.4	37.8	41.7	41.4	45.5	46.3	47.6	48.8	45.8	34.0	27.6	22.9	21.5	0.0	0.0	0.0
c	A	w	0.0	0.0	0.0	0.0	0.0	22.9	24.2	35.0	41.1	47.8	52.3	51.8	55.9	56.5	57.2	58.1	52.8	38.5	32.4	27.6	25.6	0.0	0.0	0.0
c	S	w	0.0	0.0	0.0	0.0	0.0	14.8	16.1	22.9	28.8	35.7	41.5	42.8	46.3	46.9	47.9	47.2	41.1	26.8	21.9	18.5	17.0	0.0	0.0	0.0
c	O	w	0.0	0.0	0.0	0.0	0.0	9.6	10.7	17.1	21.8	26.0	30.3	32.4	35.4	34.4	34.0	31.7	25.6	17.5	14.7	12.4	10.7	0.0	0.0	0.0
c	N	w	0.0	0.0	0.0	0.0	0.0	0.0	1.2	3.0	7.4	11.1	13.6	15.8	17.4	17.7	15.8	13.8	10.6	7.4	5.4	4.1	3.1	2.1	0.0	0.0
c	D	w	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.8	4.0	8.5	12.7	15.0	15.4	15.4	13.8	10.9	6.4	2.8	1.0	0.4	0.4	0.3	0.0	0.0
c	J	e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.8	4.1	5.5	7.3	9.2	10.4	9.2	5.9	3.9	1.9	0.0	0.0	0.0	0.0	0.0	0.0
c	F	e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	1.9	3.3	5.3	6.9	8.3	7.6	4.7	3.1	1.6	0.0	0.0	0.0	0.0	0.0	0.0
c	M	e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1.6	3.7	5.6	6.6	8.1	8.1	6.9	6.5	5.8	1.7	0.0	0.0	0.0	0.0	0.0	0.0
c	A	e	0.0	0.0	0.0	0.0	0.0	0.0	0.4	2.6	5.3	6.7	7.2	7.6	7.6	7.0	7.0	7.3	6.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0
c	M	e	0.0	0.0	0.0	0.0	0.0	1.9	3.8	6.9	8.9	10.2	9.4	10.0	10.1	9.6	11.3	12.3	11.3	3.3	0.5	0.0	0.0	0.0	0.0	0.0
c	J	e	0.0	0.0	0.0	0.0	0.0	4.6	5.7	9.2	12.6	13.9	12.3	11.6	12.4	13.4	18.1	19.5	17.6	7.8	2.9	0.1	0.0	0.0	0.0	0.0
c	J	e	0.0	0.0	0.0	0.0	0.0	10.2	10.5	14.9	20.1	22.0	19.8	17.1	17.2	18.4	25.0	24.8	25.8	13.6	7.3	0.0	0.0	0.0	0.0	0.0
c	A	e	0.0	0.0	0.0	0.0	0.0	11.8	13.9	19.9	23.9	27.6	24.7	24.0	24.5	23.7	26.1	27.3	25.9	16.4	6.4	0.6	0.0	0.0	0.0	0.0
c	S	e	0.0	0.0	0.0	0.0	0.0	10.5	11.2	13.9	18.2	20.2	21.6	22.9	25.1	24.3	24.9	22.9	20.5	3.3	0.0	0.0	0.0	0.0	0.0	0.0
c	O	e	0.0	0.0	0.0	0.0	0.0	2.4	3.3	6.8	9.4	11.1	15.9	18.7	20.5	20.2	18.2	16.0	11.6	0.5	0.0	0.0	0.0	0.0	0.0	0.0
c	N	e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	2.7	4.2	6.4	7.7	8.6	8.0	7.1	5.6	3.2	1.8	0.0	0.0	0.0	0.0	0.0	0.0
c	D	e	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.4	2.1	3.7	5.1	7.6	9.0	8.9	7.6	5.2	2.4	0.8	0.0	0.0	0.0	0.0	0.0	0.0
s	J	w	0.0	0.0	0.0	0.0	0.0	0.0	46.7	32.1	8.0	4.4	2.6	1.5	1.5	0.3	0.3	0.2	0.4	1.5	5.4	8.0	13.3	16.6	0.0	0.0
s	F	w	0.0	0.0	0.0	0.0	0.0	0.0	43.7	27.5	6.8	3.8	2.3	1.2	1.3	0.5	0.6	0.6	0.4	1.2	3.6	6.1	11.1	14.6	0.0	0.0
s	M	w	0.0	0.0	0.0	0.0	0.0	21.5	27.9	11.6	3.8	2.0	1.0	0.8	0.3	0.2	0.1	0.1	0.1	1.0	2.6	5.7	9.4	4.3	0.0	0.0
s	A	w	0.0	0.0	0.0	0.0	0.0	26.2	17.8	3.9	1.7	0.8	0.3	0.3	0.1	0.0	0.0	0.0	0.1	0.3	1.0	3.4	6.1	0.0	0.0	0.0
s	M	w	0.0	0.0	0.0	0.0	0.0	11.5	9.5	1.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.2	2.6	0.0	0.0	0.0
s	J	w	0.0	0.0	0.0	0.0	0.0	2.7	2.7	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.8	0.0	0.0	0.0
s	J	w	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
s	A	w	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
s	S	w	0.0	0.0	0.0	0.0	0.0	0.7	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
s	O	w	0.0	0.0	0.0	0.0	0.0	7.8	6.0	0.7	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.4	0.0	0.0	0.0
s	N	w	0.0	0.0	0.0	0.0	0.0	2.3	23.3	13.5	2.9	1.1	0.4	0.1	0.1	0.0	0.0	0.0	0.0	0.2	1.5	3.4	6.6	7.5	0.0	0.0
s	D	w	0.0	0.0	0.0	0.0	0.0	0.0	44.9	30.2	7.1	3.8	2.0	1.1	1.0	0.1	0.0	0.0	0.2	1.4	5.2	7.8	13.2	16.2	0.0	0.0
s	J	e	0.0	0.0	0.0	0.0	0.0	0.0	14.3	9.7	3.9	2.4	1.6	1.4	1.1	0.4	1.0	1.5	3.0	6.7	0.0	0.0	0.0	0.0	0.0	0.0
s	F	e	0.0	0.0	0.0	0.0	0.0	0.0	18.7	13.4	6.7	4.2	2.7	2.1	1.5	0.6	1.5	3.1	4.3	7.6	0.0	0.0	0.0	0.0	0.0	0.0
s	M	e	0.0	0.0	0.0	0.0	0.0	9.5	16.9	8.9	4.2	2.7	1.8	1.3	0.8	0.5	0.8	1.3	2.2	1.6	0.0	0.0	0.0	0.0	0.0	0.0

s	A	e	0.0	0.0	0.0	0.0	0.0	11.8	8.3	3.5	1.9	1.2	0.8	0.5	0.3	0.2	0.7	1.1	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
s	M	e	0.0	0.0	0.0	0.0	0.0	3.9	3.6	1.5	0.8	0.3	0.2	0.1	0.0	0.0	0.1	0.2	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
s	J	e	0.0	0.0	0.0	0.0	0.0	1.7	1.9	0.6	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
s	J	e	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
s	A	e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
s	S	e	0.0	0.0	0.0	0.0	0.0	0.3	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
s	O	e	0.0	0.0	0.0	0.0	0.0	4.0	3.1	1.1	0.6	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
s	N	e	0.0	0.0	0.0	0.0	0.0	2.7	10.7	5.3	2.3	1.6	1.2	0.9	0.5	0.2	0.5	0.9	2.0	2.9	0.0	0.0	0.0	0.0	0.0	0.0
s	D	e	0.0	0.0	0.0	0.0	0.0	0.0	19.5	14.4	7.0	4.5	3.4	2.5	1.8	0.8	1.3	2.2	4.2	8.7	0.0	0.0	0.0	0.0	0.0	0.0
w	J	w	0.4	0.7	0.2	0.5	0.5	0.5	0.6	1.1	1.4	1.9	2.1	2.1	2.3	2.5	1.9	1.6	2.0	1.6	1.2	0.7	0.9	0.7	0.4	0.6
w	F	w	0.5	0.2	0.7	0.3	0.6	0.4	0.8	0.9	1.6	1.9	1.7	2.1	2.8	2.4	1.8	1.5	2.1	1.2	1.2	1.0	1.0	0.8	0.4	0.5
w	M	w	0.4	0.5	0.5	0.3	0.6	0.5	0.9	1.5	1.7	1.9	2.0	2.4	2.5	2.0	1.6	1.9	1.7	1.2	0.9	0.9	0.8	0.5	0.4	0.4
w	A	w	0.3	0.4	0.6	0.4	0.7	0.4	0.9	1.8	1.6	1.9	2.1	2.4	2.4	1.7	1.6	1.9	1.4	1.1	0.9	0.9	0.6	0.5	0.5	0.3
w	M	w	0.5	0.4	0.4	0.6	0.4	0.7	1.0	1.4	1.5	1.8	2.0	2.3	2.2	1.8	1.4	2.0	1.3	1.1	0.9	0.8	0.7	0.3	0.7	0.3
w	J	w	0.5	0.3	0.7	0.4	0.5	0.6	0.9	1.4	1.7	1.5	2.1	2.2	2.2	1.5	1.6	1.7	1.2	1.1	0.9	0.9	0.5	0.7	0.4	0.4
w	J	w	0.4	0.4	0.5	0.3	0.7	0.4	0.9	1.3	1.8	1.5	2.0	2.2	2.2	1.5	1.5	1.6	1.4	0.9	0.9	0.9	0.4	0.7	0.3	0.6
w	A	w	0.4	0.5	0.4	0.4	0.5	0.4	1.0	1.4	1.5	1.7	1.9	2.2	2.2	1.6	1.4	1.8	1.2	1.1	0.8	0.9	0.6	0.4	0.4	0.5
w	S	w	0.5	0.6	0.3	0.4	0.6	0.5	1.0	1.5	1.6	1.6	1.9	2.3	2.2	1.6	1.5	1.8	1.3	1.0	0.8	0.9	0.6	0.5	0.4	0.5
w	O	w	0.6	0.4	0.4	0.6	0.3	0.8	0.8	1.5	1.7	1.7	2.1	2.2	2.3	1.8	1.4	1.9	1.3	1.1	0.9	0.7	0.7	0.3	0.7	0.3
w	N	w	0.4	0.6	0.4	0.4	0.5	0.5	0.6	1.2	1.5	1.9	1.6	2.1	2.5	2.4	1.5	1.7	1.8	1.4	1.1	0.9	0.7	0.7	0.3	0.7
w	D	w	0.5	0.5	0.4	0.5	0.6	0.5	0.7	0.9	1.6	1.9	1.8	2.0	2.6	2.6	1.5	1.8	1.9	1.5	1.1	1.0	0.8	0.6	0.5	0.5
w	J	e	0.4	0.4	0.5	0.5	0.4	0.6	0.4	0.6	0.6	0.7	0.7	0.7	0.9	0.7	0.7	0.6	0.6	0.5	0.5	0.4	0.6	0.4	0.7	0.3
w	F	e	0.6	0.3	0.6	0.4	0.4	0.7	0.3	0.7	0.7	0.8	0.7	0.8	0.8	0.8	0.7	0.4	0.7	0.7	0.3	0.7	0.3	0.7	0.4	0.4
w	M	e	0.7	0.3	0.3	0.8	0.3	0.7	0.3	0.6	1.0	0.6	1.0	0.7	0.8	0.8	0.6	0.6	0.7	0.4	0.6	0.3	0.8	0.3	0.7	0.3
w	A	e	0.5	0.7	0.3	0.7	0.3	0.3	0.9	0.2	0.9	0.8	0.6	1.1	0.6	1.1	0.5	0.6	0.7	0.0	1.1	0.0	1.0	0.1	0.6	0.6
w	M	e	0.4	0.6	0.3	0.4	0.7	0.4	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.7	0.6	0.4	0.6	0.4	0.4	0.7	0.4	0.6	0.3	0.4
w	J	e	0.3	0.8	0.0	0.7	0.4	0.6	0.6	0.6	0.7	0.8	0.6	0.7	0.7	0.7	0.8	0.3	0.8	0.2	0.6	0.6	0.6	0.3	0.7	0.2
w	J	e	0.3	0.5	0.5	0.5	0.6	0.5	0.5	0.6	0.8	0.7	0.9	0.3	1.0	0.7	0.7	0.5	0.3	0.6	0.6	0.3	0.8	0.2	0.5	0.5
w	A	e	0.3	0.3	0.6	0.3	0.7	0.4	0.6	0.4	0.8	0.4	0.8	0.8	0.8	0.6	0.4	1.0	0.2	0.6	0.6	0.4	0.4	0.7	0.2	0.6
w	S	e	0.3	0.5	0.5	0.4	0.6	0.5	0.5	0.6	0.6	0.9	0.9	0.6	0.9	0.5	0.7	0.5	0.6	0.4	0.5	0.5	0.6	0.3	0.6	0.3
w	O	e	0.4	0.4	0.4	0.4	0.6	0.4	0.7	0.6	0.6	0.5	0.6	0.9	0.7	0.7	0.7	0.4	0.6	0.3	0.6	0.4	0.7	0.3	0.5	0.5
w	N	e	0.4	0.6	0.4	0.4	0.3	0.6	0.7	0.4	0.4	0.8	0.7	0.8	0.7	0.7	0.6	0.4	0.7	0.4	0.6	0.3	0.6	0.6	0.4	0.4
w	D	e	0.3	0.7	0.2	0.6	0.5	0.6	0.6	0.5	0.6	0.8	0.8	0.8	0.9	0.9	0.7	0.6	0.7	0.5	0.6	0.5	0.6	0.5	0.6	0.5

g	J	w	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
g	F	w	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
g	M	w	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
g	A	w	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
g	M	w	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
g	J	w	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
g	J	w	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
g	A	w	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
g	S	w	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
g	O	w	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
g	N	w	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
g	D	w	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
g	J	e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
g	F	e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
g	M	e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
g	A	e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
g	M	e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
g	J	e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
g	J	e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
g	A	e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
g	S	e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
g	O	e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
g	N	e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
g	D	e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A3.2.15: Load for the critical asset micro-grid

			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
e	J	w	1232.8	1220.6	1224.8	1220.8	1457.5	1490.9	2082.1	2331.5	2397.5	2455.2	2483.7	2484.0	2420.0	2466.7	2458.8	2462.4	2481.6	2517.5	1868.8	1847.0	1516.1	1418.8	1270.4	1269.7
e	F	w	1244.3	1222.6	1230.2	1222.7	1462.7	1496.3	2083.6	2343.2	2410.7	2466.8	2488.6	2486.3	2421.6	2478.7	2469.6	2465.2	2481.8	2511.5	1874.0	1851.3	1520.9	1422.2	1279.6	1271.7
e	M	w	1222.4	1222.2	1223.7	1370.1	1471.2	1870.3	2234.1	2370.9	2428.8	2465.4	2469.9	2425.4	2433.6	2447.6	2447.4	2462.6	2478.3	2077.4	1870.5	1648.9	1467.4	1333.2	1270.5	1244.0
e	A	w	1215.9	1230.0	1216.7	1461.6	1482.9	2066.3	2331.5	2390.5	2443.0	2466.8	2465.7	2397.0	2448.9	2443.1	2447.8	2466.5	2480.5	1839.9	1853.8	1538.0	1434.4	1282.1	1264.8	1237.7
e	M	w	1220.3	1236.9	1220.0	1473.8	1491.5	2071.3	2335.3	2387.3	2431.3	2450.9	2446.7	2379.3	2431.7	2424.1	2427.0	2444.7	2460.1	1820.9	1841.2	1541.3	1441.4	1295.6	1272.1	1248.6
e	J	w	1182.7	1201.4	1179.3	1441.3	1450.7	2035.9	2298.0	2348.6	2392.4	2421.0	2430.2	2370.9	2426.5	2422.2	2425.5	2444.1	2459.3	1776.8	1769.7	1481.5	1388.8	1248.3	1228.7	1210.4

e	J	w	1159.3	1169.6	1157.2	1413.5	1432.2	2020.9	2300.5	2364.8	2427.0	2463.7	2476.9	2420.2	2478.1	2477.0	2483.3	2500.2	2516.7	1779.8	1770.0	1468.2	1368.4	1225.7	1208.9	1187.6
e	A	w	1149.3	1167.5	1146.2	1412.9	1438.4	2032.2	2314.2	2386.6	2453.3	2495.0	2515.8	2464.5	2524.3	2521.6	2526.6	2543.4	2553.2	1789.8	1790.3	1475.8	1370.1	1225.3	1206.9	1183.6
e	S	w	1161.4	1180.6	1158.7	1427.8	1449.3	2042.6	2293.8	2354.8	2415.7	2456.6	2472.9	2418.4	2476.2	2472.8	2479.2	2497.5	2511.0	1787.9	1793.1	1473.1	1378.3	1233.3	1216.3	1194.9
e	O	w	1208.1	1222.3	1213.4	1470.1	1489.2	2090.9	2335.7	2387.1	2435.1	2462.4	2466.7	2403.0	2455.9	2447.3	2449.7	2458.4	2466.5	1837.3	1844.9	1531.1	1437.2	1291.9	1270.8	1245.6
e	N	w	1259.3	1242.8	1251.6	1280.6	1491.3	1600.4	2133.6	2361.5	2409.5	2448.6	2469.2	2460.9	2414.3	2453.8	2442.7	2449.9	2479.6	2417.5	1867.8	1816.4	1529.1	1426.3	1299.3	1283.4
e	D	w	1249.5	1233.1	1240.2	1243.4	1481.9	1509.5	2098.3	2348.2	2412.1	2470.2	2497.4	2501.5	2433.7	2476.3	2467.3	2473.6	2507.7	2526.5	1869.2	1848.3	1522.0	1434.9	1293.3	1282.5
e	J	e	1213.9	1202.9	1206.6	1205.0	1230.3	1243.8	1431.4	1560.9	1662.8	1771.3	1788.5	1795.2	1764.9	1752.1	1736.5	1654.3	1637.2	1584.6	1484.9	1470.3	1291.9	1273.8	1236.4	1252.8
e	F	e	1213.9	1194.7	1203.5	1198.0	1233.4	1242.7	1425.6	1585.9	1692.4	1811.0	1831.3	1831.9	1794.5	1776.0	1761.7	1670.5	1650.3	1586.9	1496.1	1489.6	1306.4	1297.8	1266.3	1276.2
e	M	e	1183.6	1181.1	1178.4	1200.2	1220.5	1351.4	1496.4	1663.9	1747.2	1818.9	1817.3	1801.3	1775.4	1770.4	1708.4	1645.7	1590.3	1517.7	1492.5	1373.0	1267.2	1237.7	1229.7	1218.3
e	A	e	1214.4	1220.7	1215.5	1238.3	1244.3	1424.6	1586.3	1672.9	1788.8	1808.9	1813.0	1775.9	1764.3	1746.3	1657.7	1641.1	1565.4	1455.8	1468.3	1311.7	1287.6	1268.2	1263.6	1221.4
e	M	e	1214.6	1229.6	1223.0	1260.2	1261.4	1428.3	1579.1	1659.8	1768.1	1785.7	1788.3	1753.5	1739.4	1730.0	1638.9	1616.6	1535.2	1436.1	1452.9	1294.3	1271.2	1260.0	1268.6	1226.0
e	J	e	1186.8	1185.1	1178.7	1222.8	1227.2	1411.5	1558.3	1635.2	1738.9	1762.4	1769.0	1736.9	1725.8	1712.1	1615.8	1595.0	1511.4	1401.5	1396.2	1250.5	1230.1	1220.4	1241.6	1197.2
e	J	e	1132.0	1154.8	1129.6	1181.0	1181.8	1369.8	1525.8	1612.0	1730.9	1755.2	1766.7	1736.3	1726.6	1710.9	1609.6	1586.6	1508.4	1392.0	1382.7	1229.6	1219.7	1203.0	1198.5	1159.3
e	A	e	1131.2	1158.5	1129.8	1181.8	1173.5	1369.9	1509.7	1609.5	1721.0	1765.0	1766.3	1752.3	1726.7	1724.9	1602.1	1591.0	1497.4	1401.7	1389.4	1237.3	1192.9	1194.4	1171.7	1156.1
e	S	e	1144.7	1171.7	1146.2	1200.8	1195.8	1404.5	1549.3	1630.1	1748.3	1785.5	1784.0	1764.4	1744.5	1742.7	1615.3	1604.2	1510.2	1412.5	1410.2	1243.3	1203.3	1205.9	1184.0	1168.4
e	O	e	1211.3	1227.1	1215.9	1254.3	1257.5	1455.2	1568.5	1658.4	1745.8	1765.6	1765.8	1737.2	1722.8	1709.1	1625.6	1603.8	1527.0	1454.5	1450.4	1284.4	1267.6	1253.3	1256.6	1218.4
e	N	e	1218.1	1201.8	1208.0	1205.4	1232.1	1281.4	1448.8	1550.1	1670.8	1719.8	1740.7	1728.4	1716.7	1697.6	1675.5	1618.8	1591.2	1508.0	1446.3	1397.5	1294.7	1275.7	1268.7	1254.7
e	D	e	1211.8	1200.6	1201.0	1200.7	1232.2	1248.1	1434.1	1583.4	1677.5	1793.7	1817.5	1829.1	1795.8	1783.4	1763.3	1672.6	1674.7	1609.5	1483.0	1471.8	1293.1	1283.0	1257.6	1271.0
c	J	w	477.5	473.3	473.0	468.9	473.5	476.4	474.9	489.6	501.3	505.2	505.0	499.7	497.5	497.7	501.5	508.8	516.0	517.0	507.9	500.9	492.4	477.5	480.9	480.3
c	F	w	473.8	466.2	464.4	461.0	465.4	468.0	468.7	483.9	494.6	497.6	493.6	492.1	495.4	497.0	497.0	503.8	512.0	517.1	512.0	502.0	490.2	476.9	479.4	474.9
c	M	w	475.0	475.3	475.5	472.5	475.3	476.6	487.8	504.2	510.0	509.5	502.5	497.8	494.3	495.2	496.1	500.4	503.3	511.5	513.2	506.7	494.1	487.5	481.1	476.9
c	A	w	487.8	492.3	487.6	494.4	492.5	494.0	504.1	506.7	507.3	504.0	498.8	493.8	493.2	494.6	496.1	498.0	501.0	510.4	511.9	513.7	498.0	496.3	489.1	493.4
c	M	w	493.0	499.3	491.8	503.8	507.1	508.8	506.3	501.3	493.3	485.4	476.2	472.7	472.2	470.2	468.7	468.9	472.9	486.5	503.3	510.1	497.7	502.7	495.3	502.2
c	J	w	451.9	459.4	447.9	465.2	469.8	469.4	462.2	454.6	446.4	446.9	449.5	451.2	452.2	451.9	450.6	449.0	448.2	440.2	441.6	449.1	443.7	454.1	446.7	457.7
c	J	w	423.0	427.2	421.0	436.8	441.5	441.7	440.6	441.4	446.6	454.0	459.7	462.8	464.2	464.3	463.3	461.2	460.1	441.6	438.7	433.4	418.1	427.5	421.2	431.7
c	A	w	415.1	421.1	412.6	435.9	439.0	441.1	442.6	449.0	457.9	467.0	474.5	478.8	479.8	478.2	475.4	472.6	470.7	449.9	445.6	440.4	419.2	426.4	418.0	427.6
c	S	w	429.6	436.4	427.8	452.2	455.0	453.8	447.0	444.9	449.3	455.9	460.6	465.0	465.5	463.9	462.4	460.2	457.2	441.2	439.3	439.8	429.8	437.2	430.8	441.1
c	O	w	462.8	467.3	464.8	478.2	477.9	475.5	476.3	466.8	460.7	460.8	461.7	462.9	463.6	463.2	462.1	460.7	459.8	471.0	486.0	487.6	477.2	482.0	473.5	477.9
c	N	w	500.8	496.9	497.8	497.0	501.7	500.2	502.4	504.1	497.7	489.6	485.9	482.7	482.6	481.9	480.4	484.8	493.4	499.0	500.5	506.0	506.8	498.4	498.7	493.6
c	D	w	461.1	454.3	455.3	454.8	457.5	453.8	449.5	457.9	468.3	472.9	476.2	479.6	480.5	483.3	486.4	493.4	503.5	504.7	489.8	480.2	473.8	465.7	470.5	466.6
c	J	e	477.9	474.6	474.3	471.4	471.1	470.0	468.9	486.0	494.8	494.9	484.0	484.0	481.4	480.6	479.3	486.9	503.8	512.2	510.4	506.1	490.2	476.7	460.3	468.1
c	F	e	478.6	470.8	473.4	471.0	475.0	471.4	467.1	487.8	503.0	507.0	500.1	495.7	492.6	491.4	491.5	502.5	511.6	515.2	513.8	513.8	498.6	490.6	484.8	484.0
c	M	e	443.0	437.2	432.0	433.9	436.6	437.4	451.6	477.3	489.0	485.8	478.7	481.9	482.8	486.1	487.0	495.1	501.2	508.8	511.1	492.5	465.6	444.1	445.8	458.2
c	A	e	495.1	495.2	491.4	487.9	484.6	490.0	503.7	504.0	505.3	499.9	498.9	494.3	498.5	492.7	496.6	500.7	507.3	504.3	506.3	512.2	505.1	498.8	493.4	492.2
c	M	e	502.7	508.7	505.8	509.5	506.2	501.2	495.6	489.3	486.4	480.8	479.2	472.8	471.8	473.9	478.0	476.0	478.0	483.3	494.7	495.6	486.8	492.4	493.9	495.0
c	J	e	466.1	461.5	460.4	470.4	478.1	480.4	473.7	463.3	455.8	456.9	459.2	454.9	457.1	454.1	454.0	453.5	451.3	444.7	446.0	447.9	443.1	450.2	465.7	468.5
c	J	e	413.9	422.7	411.5	424.7	424.5	434.8	436.7	436.7	441.5	444.0	450.3	448.7	450.5	446.0	446.1	444.3	446.2	433.3	428.2	426.2	427.1	427.8	424.2	426.4
c	A	e	414.3	427.7	413.5	424.7	418.0	429.8	425.9	432.3	435.0	448.0	449.4	455.6	449.3	451.7	442.0	445.8	440.2	439.2	428.3	428.2	406.4	414.5	403.7	417.3
c	S	e	424.9	437.6	427.2	440.9	435.2	446.5	440.6	440.2	437.3	444.7	443.6	448.5	446.3	449.2	444.0	444.1	435.4	429.8	423.3	431.6	416.1	424.4	414.3	427.6
c	O	e	479.0	487.1	480.9	484.7	481.6	484.1	486.1	479.6	472.5	473.5	472.9	469.5	470.2	468.1	470.0	470.2	472.7	473.7	480.8	476.9	468.7	472.3	475.1	477.4

c	N	e	490.6	487.1	486.6	483.3	483.8	480.1	484.2	492.5	494.3	490.2	487.8	483.8	486.2	484.7	491.5	492.7	494.4	491.9	494.6	500.1	501.4	497.1	499.5	496.7
c	D	e	459.3	451.1	444.9	446.2	448.6	449.8	444.6	459.7	475.8	478.8	477.2	481.6	483.8	489.1	486.4	494.8	506.9	506.5	484.5	476.4	473.9	466.9	462.7	459.0
s	J	w	554.9	541.4	551.5	552.8	555.3	930.6	661.9	572.3	521.9	490.6	462.3	442.2	428.6	415.5	403.5	399.2	419.8	437.9	419.1	435.2	496.5	475.0	517.5	514.6
s	F	w	556.1	533.8	552.4	546.0	554.7	912.8	654.0	560.0	511.0	482.3	457.1	439.1	428.1	417.4	406.8	401.7	406.9	426.7	413.0	430.3	492.9	472.1	519.9	514.8
s	M	w	526.7	530.1	533.8	535.3	753.0	709.4	574.5	518.2	490.3	465.7	445.7	428.9	415.4	404.5	394.9	390.6	396.8	400.3	414.5	462.0	468.7	492.2	503.5	524.9
s	A	w	508.3	534.8	519.4	535.5	838.9	609.0	527.2	488.7	466.0	446.9	435.5	424.8	414.9	404.4	391.3	382.8	384.7	376.8	404.6	470.6	447.7	496.4	486.2	527.6
s	M	w	487.4	513.3	495.9	519.4	793.5	573.9	503.3	472.5	448.3	429.4	414.9	403.1	391.6	375.0	360.1	356.5	359.7	352.4	385.4	455.4	433.2	479.2	462.7	504.2
s	J	w	454.7	484.0	462.2	488.5	712.0	521.7	462.2	428.6	389.2	350.1	317.1	293.7	280.3	265.8	253.0	245.8	241.5	264.6	312.7	407.0	400.3	449.3	432.7	473.3
s	J	w	384.3	401.3	392.3	410.1	621.2	417.6	340.7	293.5	246.8	217.1	201.1	186.2	171.2	154.5	140.7	138.5	132.7	172.6	212.5	294.5	298.4	350.2	349.0	388.7
s	A	w	352.1	386.4	366.7	382.2	563.0	374.9	289.7	230.6	190.4	157.7	127.1	105.9	93.1	84.5	76.8	73.6	78.2	135.4	184.1	264.8	274.3	324.2	324.2	363.9
s	S	w	422.4	450.5	422.4	450.4	676.7	490.1	417.9	363.7	312.2	258.8	220.2	196.6	183.4	171.1	161.9	160.0	156.3	211.8	265.0	351.8	353.0	402.1	396.3	438.4
s	O	w	452.6	478.2	465.9	484.7	741.2	530.1	458.2	417.1	389.0	368.9	351.9	337.1	320.3	306.6	299.7	304.3	321.3	337.3	360.7	424.1	408.8	449.5	437.7	471.4
s	N	w	530.0	516.4	531.5	525.6	570.7	829.5	605.5	525.3	483.8	459.0	436.6	420.5	405.9	390.9	382.3	382.3	400.7	414.9	401.7	423.7	473.2	457.9	495.6	489.3
s	D	w	546.2	535.0	545.7	547.9	551.3	909.9	655.2	562.0	508.2	476.7	449.5	433.2	421.4	408.6	397.8	395.7	416.9	435.4	418.9	435.6	496.6	474.4	514.8	512.6
s	J	e	555.1	545.8	553.1	557.2	560.8	589.3	509.4	609.5	525.5	490.4	463.2	457.2	439.1	429.6	412.6	364.0	385.1	416.1	468.7	489.6	531.5	540.6	555.0	576.5
s	F	e	548.2	531.6	546.0	542.8	555.3	577.6	504.6	617.1	544.9	504.4	480.7	462.9	450.3	436.1	425.0	363.6	374.1	399.0	455.9	482.4	521.4	525.7	538.8	560.2
s	M	e	536.0	538.2	538.6	546.6	564.2	535.8	552.8	567.6	503.8	474.0	451.5	441.7	427.2	419.6	371.5	343.2	349.0	398.3	451.9	489.7	516.0	530.8	545.3	554.4
s	A	e	516.1	528.2	530.9	536.9	561.8	475.8	581.1	512.8	479.0	455.5	448.7	433.0	432.8	417.1	350.9	342.5	355.4	409.1	434.7	504.5	486.4	522.6	531.8	548.4
s	M	e	479.4	505.6	499.6	517.1	529.3	444.2	535.0	482.0	448.9	426.9	423.0	408.0	407.5	398.2	338.8	331.4	340.2	383.9	420.0	470.5	454.6	484.2	503.1	513.7
s	J	e	465.8	476.1	468.7	489.9	500.1	425.7	505.0	450.3	410.9	385.0	375.8	359.4	356.5	340.2	279.8	278.6	293.4	335.9	366.6	428.0	418.0	451.4	470.3	476.1
s	J	e	350.4	386.5	370.1	399.2	405.6	338.8	394.5	342.5	310.5	286.1	279.1	267.6	265.5	255.8	211.6	209.8	229.0	276.0	308.8	368.9	366.7	388.9	386.1	395.7
s	A	e	379.2	408.5	380.3	401.6	389.3	336.3	370.7	325.0	274.6	253.3	222.8	216.0	211.9	215.7	180.3	198.6	210.5	280.6	305.0	369.7	337.7	375.8	356.8	400.6
s	S	e	387.4	420.5	392.1	418.5	405.8	356.2	414.7	375.8	328.0	301.7	270.2	260.1	244.7	243.4	191.3	201.7	218.4	296.4	313.2	382.4	351.4	405.2	386.1	424.1
s	O	e	477.6	494.5	484.4	501.3	502.7	435.7	517.1	460.8	424.0	395.4	376.8	360.1	350.9	339.4	293.2	300.0	327.7	391.4	413.9	457.2	452.1	474.3	480.3	491.7
s	N	e	530.0	515.9	531.5	525.8	549.3	534.5	514.9	540.1	484.6	451.9	442.5	424.2	421.2	400.7	384.2	351.7	380.1	402.2	451.9	473.3	510.8	508.3	534.8	540.1
s	D	e	548.2	535.4	542.1	548.4	554.2	583.5	504.9	629.6	546.7	503.8	475.0	462.1	443.3	435.5	416.9	358.8	380.3	415.8	465.2	489.2	528.2	536.9	545.9	573.7
w	J	w	13.1	16.2	12.2	14.9	12.2	15.7	12.9	29.2	32.8	37.9	44.7	44.2	40.5	42.9	43.3	39.8	33.5	26.5	20.6	21.0	21.1	19.4	14.6	17.4
w	F	w	14.9	13.1	14.4	13.2	14.3	14.2	15.5	26.6	32.7	39.5	42.9	44.9	40.7	42.8	43.5	39.0	37.6	23.9	21.5	22.2	18.9	17.7	17.9	14.9
w	M	w	13.1	14.2	12.6	14.1	12.6	14.6	22.6	30.8	36.7	41.7	42.9	41.2	42.0	42.5	42.3	34.0	28.4	22.2	21.0	20.1	18.7	18.3	15.0	16.1
w	A	w	14.3	12.8	12.6	14.5	12.6	15.2	25.2	32.9	35.8	41.2	44.9	37.0	43.6	40.2	39.4	33.0	24.2	19.1	21.0	18.5	18.7	15.8	15.5	13.7
w	M	w	13.7	12.9	12.2	12.9	12.5	15.1	25.7	31.9	32.8	41.2	42.4	36.1	42.3	39.3	36.2	33.7	22.1	19.0	20.7	18.4	16.9	14.7	16.4	12.6
w	J	w	11.7	11.4	13.3	13.3	10.2	15.4	27.0	30.7	32.3	39.0	40.0	35.5	41.6	36.7	35.3	32.8	22.2	18.6	17.1	21.1	15.8	14.5	13.3	14.6
w	J	w	12.0	14.1	10.2	13.0	13.3	11.6	25.0	29.3	32.5	40.3	40.2	32.1	41.7	36.4	35.7	31.1	21.4	18.3	17.5	21.1	13.1	14.6	15.4	11.9
w	A	w	13.2	11.9	10.9	13.6	11.9	12.1	26.0	28.2	33.6	37.7	40.6	34.1	39.8	37.7	34.8	30.2	21.4	20.1	16.7	19.6	15.6	16.9	12.7	12.5
w	S	w	12.1	12.4	14.7	11.9	11.2	13.8	23.8	31.9	32.9	38.2	42.6	33.6	39.7	40.0	33.3	30.9	22.8	20.6	19.3	17.2	17.5	13.5	14.1	14.1
w	O	w	11.4	13.2	13.1	11.5	13.9	12.4	25.3	31.5	37.4	37.4	41.5	38.5	38.3	40.7	38.6	30.8	21.9	19.5	20.2	20.4	15.5	17.0	12.6	15.5
w	N	w	13.4	14.1	13.2	13.5	13.6	12.8	17.5	26.6	31.8	37.2	41.4	42.8	37.7	43.5	39.0	40.0	31.3	21.3	20.5	18.7	21.0	18.8	16.1	14.3
w	D	w	14.7	13.5	14.4	12.5	13.7	12.4	15.3	26.4	34.0	37.4	41.9	44.5	39.5	43.9	41.6	39.8	34.5	23.3	21.7	20.1	20.8	17.4	16.3	15.9
w	J	e	15.4	12.9	13.8	12.9	14.7	12.0	15.7	12.9	20.7	27.8	30.9	31.0	29.8	29.5	31.0	29.1	30.8	25.9	18.9	16.4	16.8	17.4	16.6	14.5
w	F	e	17.1	13.2	13.4	14.5	12.1	15.8	13.2	15.3	20.0	23.4	33.1	31.1	31.8	29.8	30.2	29.0	28.9	26.8	16.2	20.2	15.3	18.0	17.2	16.0

w	M	e	16.0	11.3	15.4	11.3	15.5	11.8	16.6	17.6	20.4	30.7	30.1	29.8	29.6	29.8	30.7	31.0	30.1	18.7	18.1	15.4	18.8	15.4	16.4	13.9
w	A	e	16.3	13.9	11.5	15.2	12.3	12.9	14.1	18.8	24.3	29.7	29.0	30.5	30.3	27.2	30.4	28.1	23.1	16.8	15.8	17.3	15.8	16.0	15.0	14.0
w	M	e	11.0	16.7	12.2	12.3	13.3	12.1	17.5	16.5	25.3	26.3	28.7	28.4	30.5	26.6	27.7	29.7	20.4	14.5	19.9	12.8	19.2	13.2	11.8	16.9
w	J	e	14.1	12.4	12.3	11.1	14.4	12.0	13.2	18.6	24.1	26.4	28.5	28.2	28.1	27.8	24.3	28.7	21.3	15.6	17.4	14.0	16.5	13.6	13.8	13.7
w	J	e	13.1	13.5	9.8	14.2	11.6	10.7	15.1	16.9	25.7	24.5	28.6	26.7	26.5	25.2	28.7	27.6	22.5	13.5	16.6	15.5	12.5	17.4	13.9	12.2
w	A	e	14.4	12.2	10.2	15.4	11.3	11.0	15.3	18.6	21.9	28.1	25.4	28.3	25.7	26.7	25.5	27.3	23.6	13.3	17.3	14.0	15.3	15.6	12.6	12.6
w	S	e	10.9	14.7	10.9	10.9	14.8	11.9	12.8	18.6	25.7	26.7	27.4	28.6	27.3	25.9	27.7	26.6	22.3	17.8	14.2	14.7	17.1	13.1	12.5	15.2
w	O	e	13.2	10.9	12.8	11.8	14.8	13.9	12.1	18.4	24.3	29.9	26.9	28.4	28.4	26.9	25.9	29.3	22.4	19.0	15.3	15.8	16.9	16.3	14.4	13.2
w	N	e	14.6	12.1	15.6	11.1	15.5	11.5	16.1	13.6	18.9	25.5	31.0	29.5	27.5	29.3	26.4	28.0	26.6	21.7	17.8	13.8	17.0	16.4	16.7	14.8
w	D	e	15.7	13.3	14.3	14.1	14.2	13.4	14.2	14.3	18.9	25.2	30.7	30.3	30.3	29.6	29.1	28.1	30.6	27.5	15.2	18.7	15.4	18.7	15.1	15.8
g	J	w	11.6	11.6	11.6	11.6	13.6	23.6	51.7	73.4	81.6	67.4	113.7	121.2	116.7	98.1	73.4	86.1	117.4	120.4	115.4	87.1	82.1	66.5	49.3	20.1
g	F	w	11.6	11.6	11.6	11.6	13.6	23.6	51.7	73.4	81.6	67.4	113.7	121.2	116.7	98.1	73.4	86.1	117.4	120.4	115.4	87.1	82.1	66.5	49.3	20.1
g	M	w	11.6	11.6	11.6	12.9	20.1	42.0	65.9	78.7	72.3	97.6	118.6	118.3	104.6	82.0	81.7	106.5	119.3	117.2	97.0	83.9	71.9	55.3	30.3	14.6
g	A	w	11.6	11.6	11.6	13.6	23.6	51.7	73.4	81.6	67.4	113.7	121.2	116.7	98.1	73.4	86.1	117.4	120.4	115.4	87.1	82.1	66.5	49.3	20.1	11.6
g	M	w	11.6	11.6	11.6	13.6	23.6	51.7	73.4	81.6	67.4	113.7	121.2	116.7	98.1	73.4	86.1	117.4	120.4	115.4	87.1	82.1	66.5	49.3	20.1	11.6
g	J	w	11.6	11.6	11.6	13.6	23.6	51.7	73.4	81.6	67.4	113.7	121.2	116.7	98.1	73.4	86.1	117.4	120.4	115.4	87.1	82.1	66.5	49.3	20.1	11.6
g	J	w	11.6	11.6	11.6	13.6	23.6	51.7	73.4	81.6	67.4	113.7	121.2	116.7	98.1	73.4	86.1	117.4	120.4	115.4	87.1	82.1	66.5	49.3	20.1	11.6
g	A	w	11.6	11.6	11.6	13.6	23.6	51.7	73.4	81.6	67.4	113.7	121.2	116.7	98.1	73.4	86.1	117.4	120.4	115.4	87.1	82.1	66.5	49.3	20.1	11.6
g	S	w	11.6	11.6	11.6	13.6	23.6	51.7	73.4	81.6	67.4	113.7	121.2	116.7	98.1	73.4	86.1	117.4	120.4	115.4	87.1	82.1	66.5	49.3	20.1	11.6
g	O	w	11.6	11.6	11.6	13.6	23.6	51.7	73.4	81.6	67.4	113.7	121.2	116.7	98.1	73.4	86.1	117.4	120.4	115.4	87.1	82.1	66.5	49.3	20.1	11.6
g	N	w	11.6	11.6	11.6	11.9	15.0	27.6	54.8	74.6	79.5	74.0	114.8	120.6	114.1	94.5	75.2	90.5	117.8	119.7	111.4	86.4	79.9	64.0	45.1	18.9
g	D	w	11.6	11.6	11.6	11.6	13.6	23.6	51.7	73.4	81.6	67.4	113.7	121.2	116.7	98.1	73.4	86.1	117.4	120.4	115.4	87.1	82.1	66.5	49.3	20.1
g	J	e	11.6	11.6	11.6	11.6	11.6	21.6	44.8	67.3	76.6	63.8	110.1	117.6	113.1	94.4	69.8	81.1	112.4	114.3	114.3	86.0	82.1	66.5	49.3	20.1
g	F	e	11.6	11.6	11.6	11.6	11.6	21.6	44.8	67.5	76.6	63.9	110.3	117.8	113.3	94.6	69.9	81.1	112.4	114.4	114.4	86.1	82.1	66.5	49.3	20.1
g	M	e	11.6	11.6	11.6	11.6	17.9	36.1	58.8	73.3	68.5	92.9	114.9	114.9	101.6	79.2	77.1	100.7	113.6	114.4	96.7	83.7	72.3	55.7	31.1	14.8
g	A	e	11.6	11.6	11.6	11.6	21.6	44.8	67.5	76.6	63.9	110.3	117.8	113.3	94.6	69.9	81.1	112.4	114.4	114.4	86.1	82.1	66.5	49.3	20.1	11.6
g	M	e	11.6	11.6	11.6	11.6	21.6	44.8	67.5	76.6	63.9	110.3	117.8	113.3	94.6	69.9	81.1	112.4	114.4	114.4	86.1	82.1	66.5	49.3	20.1	11.6
g	J	e	11.6	11.6	11.6	11.6	21.6	44.8	67.5	76.6	63.9	110.3	117.8	113.3	94.6	69.9	81.1	112.4	114.4	114.4	86.1	82.1	66.5	49.3	20.1	11.6
g	J	e	11.6	11.6	11.6	11.6	21.6	44.8	67.5	76.6	63.9	110.3	117.8	113.3	94.6	69.9	81.1	112.4	114.4	114.4	86.1	82.1	66.5	49.3	20.1	11.6
g	A	e	11.6	11.6	11.6	11.6	21.6	44.8	67.5	76.6	63.9	110.3	117.8	113.3	94.6	69.9	81.1	112.4	114.4	114.4	86.1	82.1	66.5	49.3	20.1	11.6
g	S	e	11.6	11.6	11.6	11.6	21.6	44.8	67.6	76.6	64.1	110.4	117.9	113.4	94.8	70.1	81.1	112.4	114.6	114.6	86.2	82.1	66.5	49.3	20.1	11.6
g	O	e	11.6	11.6	11.6	11.6	21.6	44.8	67.3	76.6	63.8	110.1	117.6	113.1	94.4	69.8	81.1	112.4	114.3	114.3	86.0	82.1	66.5	49.3	20.1	11.6
g	N	e	11.6	11.6	11.6	11.6	14.1	27.4	50.5	69.5	73.4	75.1	111.8	116.3	108.2	88.1	72.4	88.9	112.9	114.2	107.1	84.9	78.2	62.2	42.0	18.0
g	D	e	11.6	11.6	11.6	11.6	11.6	21.6	44.8	67.5	76.6	63.9	110.3	117.8	113.3	94.6	69.9	81.1	112.4	114.4	114.4	86.1	82.1	66.5	49.3	20.1

Table A3.2.16: Load for the campus micro-grid

			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
e	J	w	3480.9	3425.4	3418.6	3413.0	3677.5	3896.9	5369.0	6952.2	10616.2	11172.4	11422.7	11806.6	11668.7	11897.3	11801.6	11600.4	11355.9	10187.0	8453.5	8242.8	7130.3	5211.1	3804.8	3703.9

e	F	w	3479.9	3421.2	3412.4	3408.7	3672.1	3893.3	5277.7	6977.6	10677.2	11196.6	11381.9	11725.9	11552.5	11741.5	11684.0	11564.4	11484.4	10245.1	8464.8	8222.8	7094.5	5178.2	3801.4	3698.1
e	M	w	3447.0	3425.0	3421.8	3586.6	3818.9	4855.6	6338.2	9323.3	10928.6	11232.5	11565.9	11602.0	11718.1	11799.3	11734.5	11723.7	10875.6	9174.0	8511.5	7621.9	5932.5	4311.9	3743.9	3559.2
e	A	w	3439.1	3433.4	3428.5	3690.3	3906.4	5238.2	7088.1	10832.6	11330.3	11505.3	11812.4	11682.6	11930.8	11929.5	11907.9	11944.8	10725.0	8842.2	8687.3	7426.9	5352.5	3831.3	3719.8	3498.4
e	M	w	3472.6	3467.3	3461.1	3726.2	3889.0	5568.2	7522.0	11246.3	11753.9	11924.5	12198.2	12026.3	12252.8	12264.1	12258.2	12378.8	11151.8	9331.0	9056.0	7841.3	5625.1	3864.7	3750.1	3533.1
e	J	w	3467.8	3460.6	3452.2	3718.7	3832.5	6389.1	8226.9	11971.9	12323.2	12364.7	12567.2	12357.6	12577.4	12554.9	12553.6	12735.2	11567.2	9840.9	9637.8	8663.8	6108.6	3868.4	3733.8	3525.6
e	J	w	3378.5	3371.1	3363.8	3626.4	3803.7	6627.7	7521.3	11264.0	11615.9	11666.3	11850.2	11618.6	11871.9	11852.4	11814.0	11971.2	11179.1	9279.2	9171.0	7811.7	6082.9	3766.4	3647.1	3444.5
e	A	w	3384.4	3371.8	3366.9	3638.6	3865.6	6736.8	7616.4	11407.4	11827.5	11947.4	12163.1	11941.8	12217.4	12202.3	12157.2	12301.9	11451.0	9423.8	9393.4	7908.6	6146.7	3799.5	3676.2	3455.0
e	S	w	3453.0	3443.8	3439.2	3712.9	3935.4	6647.2	8333.1	12073.4	12472.1	12606.1	12879.8	12688.9	12892.7	12856.8	12852.1	13067.5	11859.0	10071.0	10022.9	8774.1	6232.3	3867.0	3721.2	3516.4
e	O	w	3461.3	3452.4	3451.1	3718.9	3936.2	6141.3	7811.7	11755.6	12295.6	12389.6	12624.6	12427.1	12650.0	12613.5	12585.4	12713.9	11480.6	9927.1	9639.7	8325.9	5837.8	3852.3	3738.7	3521.7
e	N	w	3512.2	3463.0	3455.6	3491.2	3745.1	4140.8	5622.1	7774.0	11199.2	11769.1	11963.2	12139.8	11998.2	12183.7	12112.4	12038.0	11855.3	10534.3	8956.7	8525.4	7189.8	5200.6	3830.5	3707.2
e	D	w	3468.9	3412.9	3410.8	3411.8	3678.1	3891.2	5360.6	7016.6	10776.3	11384.8	11649.9	11947.9	11703.3	11901.9	11833.9	11643.7	11586.7	10281.0	8458.1	8218.4	7117.8	5200.0	3801.4	3695.3
e	J	e	3219.2	3165.2	3159.7	3155.7	3233.2	3338.1	4089.4	4101.5	5040.6	5210.5	5596.2	5850.2	5943.2	6052.3	5472.2	5404.8	5258.4	5131.7	4651.8	4321.9	4119.5	3853.9	3414.3	3428.9
e	F	e	3226.1	3166.2	3161.0	3157.9	3240.2	3344.9	4039.1	4147.7	5093.7	5284.0	5621.5	5857.1	5962.2	5979.8	5429.3	5306.7	5294.6	5083.3	4687.0	4361.8	4157.8	3889.1	3458.0	3463.1
e	M	e	3157.5	3128.2	3123.4	3174.2	3273.1	3780.8	4037.6	4620.8	5166.0	5552.9	5672.0	5912.9	6003.1	5768.1	5451.9	5536.9	5388.2	4777.9	4488.1	4225.7	3964.5	3568.8	3407.9	3289.7
e	A	e	3195.2	3188.2	3178.4	3251.0	3350.1	3982.7	4191.5	5286.5	5528.4	5743.7	5819.1	5847.7	5908.1	5330.1	5338.3	5650.7	5336.0	4473.4	4328.9	4168.3	3900.6	3463.4	3461.2	3239.3
e	M	e	3230.6	3222.1	3215.9	3295.5	3344.3	4088.2	4524.3	5468.4	5620.4	5825.4	5910.1	5985.3	5975.5	5450.0	5683.6	5893.2	5675.9	4869.3	4376.3	4203.1	3928.6	3499.8	3496.0	3281.2
e	J	e	3217.7	3204.7	3201.6	3284.8	3288.5	4279.4	4641.1	5660.0	5840.4	6112.3	6069.8	6134.4	6267.8	5914.3	6184.2	6446.1	6115.7	5451.4	4674.0	4342.7	3941.3	3492.3	3490.5	3282.5
e	J	e	3124.9	3115.6	3108.6	3191.2	3244.8	4288.4	4618.9	5727.7	5943.2	6279.0	6319.1	6358.3	6518.3	6204.1	6416.1	6623.5	6429.9	5716.2	5044.5	4410.6	3897.9	3427.7	3394.8	3189.8
e	A	e	3129.0	3122.2	3113.9	3191.8	3298.6	4345.0	4737.0	5867.8	6127.6	6564.5	6825.5	7028.2	7076.0	6647.7	6619.9	6821.8	6562.0	5910.3	5238.3	4578.1	4030.0	3476.1	3432.0	3184.9
e	S	e	3210.4	3204.4	3199.5	3280.3	3386.1	4601.2	4742.8	5825.8	6009.2	6432.9	6757.8	7060.0	7131.6	6540.1	6434.4	6596.1	6236.9	5198.2	4796.0	4425.5	4041.0	3500.0	3474.2	3270.2
e	O	e	3213.4	3210.0	3203.9	3281.8	3386.7	4328.2	4352.9	5316.1	5459.7	5952.9	6301.1	6600.6	6760.0	6245.2	6179.7	6189.8	5684.0	4923.8	4493.9	4271.7	3980.6	3503.1	3487.3	3272.5
e	N	e	3237.9	3191.4	3183.4	3197.5	3276.8	3562.2	3965.9	4323.6	5009.9	5235.0	5557.2	5778.8	5901.7	5845.9	5473.7	5289.2	5188.8	4944.2	4543.9	4265.9	4071.0	3789.9	3475.2	3420.2
e	D	e	3215.0	3159.0	3148.6	3144.5	3225.0	3331.0	4109.2	4159.6	5155.4	5314.4	5740.9	5949.7	6089.4	6130.9	5556.7	5359.7	5279.3	5106.0	4647.9	4311.0	4117.7	3850.5	3424.2	3431.1
c	J	w	462.2	458.9	457.5	454.4	453.8	453.9	452.6	473.2	616.8	884.6	1159.5	1408.3	1547.7	1591.2	1534.5	1385.6	1007.7	677.2	575.4	523.9	499.7	482.7	466.6	467.9
c	F	w	458.1	452.7	448.9	447.7	446.5	446.1	448.8	497.5	655.1	894.8	1125.8	1336.4	1446.5	1446.8	1429.8	1365.1	1161.5	814.1	576.7	506.4	480.5	467.9	464.8	462.6
c	M	w	460.4	460.1	460.0	454.5	453.1	459.7	478.8	555.3	745.5	974.5	1240.2	1410.5	1496.0	1524.9	1493.2	1401.7	1205.0	896.8	669.7	571.3	512.6	481.6	468.8	462.2
c	A	w	475.0	475.1	474.2	473.1	468.6	496.0	587.3	792.1	1032.8	1252.9	1443.1	1580.1	1629.6	1650.6	1650.5	1553.7	1401.3	1160.3	915.6	735.1	586.5	481.8	479.1	476.4
c	M	w	480.2	480.6	478.2	476.8	477.7	838.2	930.2	1127.8	1392.1	1608.6	1765.5	1868.5	1887.5	1914.1	1926.1	1906.5	1752.8	1576.7	1313.1	1064.1	785.7	488.4	486.4	483.7
c	J	w	439.4	438.7	433.9	431.4	433.6	1576.0	1569.5	1769.3	1862.4	1933.3	2026.0	2085.2	2087.8	2084.7	2099.6	2134.8	2048.3	1994.5	1894.0	1798.3	1196.0	460.6	438.6	437.6
c	J	w	410.4	409.4	405.8	401.6	402.4	1842.3	1852.8	1914.5	1998.3	2105.3	2201.4	2255.6	2278.7	2285.2	2259.1	2219.7	2189.2	2048.3	2024.7	1968.5	1218.9	419.0	415.7	413.4
c	A	w	407.5	401.8	401.4	402.4	402.7	1875.5	1921.5	2014.4	2165.0	2323.5	2438.5	2488.3	2513.6	2521.3	2494.1	2451.7	2394.2	2169.9	2108.9	2046.6	1269.5	439.9	433.6	412.3
c	S	w	418.0	415.1	414.8	417.9	418.5	1659.2	1701.7	1852.2	1969.2	2101.9	2246.2	2318.3	2295.8	2284.0	2295.6	2332.1	2227.4	2128.4	2031.3	1925.4	1306.4	453.0	423.2	421.8
c	O	w	451.2	450.1	451.9	450.5	448.1	1127.0	1206.1	1563.5	1836.3	1959.3	2062.9	2140.6	2147.1	2136.1	2136.5	2141.5	2009.5	1869.3	1705.0	1509.7	968.4	469.2	465.5	460.2
c	N	w	483.7	482.1	480.2	480.7	478.4	475.1	591.3	728.7	1058.3	1416.2	1627.0	1736.7	1803.6	1824.4	1792.5	1741.7	1518.4	1161.6	994.3	862.0	751.8	608.3	484.5	482.1
c	D	w	446.5	440.8	440.9	440.7	438.7	432.6	440.7	504.9	742.0	1068.6	1365.5	1525.4	1576.7	1594.8	1562.6	1426.5	1133.3	756.5	564.7	495.5	494.3	474.3	456.6	454.1
c	J	e	462.9	460.0	459.1	457.0	454.8	453.1	453.4	476.4	555.2	647.8	772.9	895.1	928.3	1053.9	1015.3	1036.1	761.2	603.2	497.1	491.0	476.5	463.9	448.6	453.8
c	F	e	462.9	456.6	457.4	456.7	457.2	454.4	450.5	468.7	515.7	594.8	686.4	784.2	846.4	905.1	935.0	903.0	765.5	618.2	500.6	497.2	484.1	477.3	471.9	468.6
c	M	e	429.9	423.2	419.3	419.5	421.9	422.0	435.9	461.5	549.3	695.4	683.9	800.2	892.7	971.8	1000.5	1007.9	933.8	626.2	499.1	480.1	453.8	432.5	433.0	444.3
c	A	e	480.6	479.1	475.8	470.4	466.5	472.9	500.8	654.5	776.9	798.7	791.1	784.0	876.6	883.2	948.9	1027.5	949.3	568.5	501.0	499.1	497.6	486.4	479.9	476.8
c	M	e	491.2	491.8	490.9	487.4	483.9	608.2	732.2	792.1	844.8	852.2	849.0	877.1	905.6	957.3	1212.5	1239.7	1237.1	838.9	588.0	487.3	483.2	483.7	479.6	479.2
c	J	e	451.2	444.2	445.5	447.2	455.5	753.8	818.4	929.2	990.6	1043.8	956.6	968.7	1143.5	1330.8	1614.1	1691.6	1598.6	1297.8	883.9	583.3	469.7	452.7	452.9	456.0
c	J	e	406.2	402.8	400.6	399.6	402.2	798.4	838.8	1013.6	1107.4	1230.7	1210.6	1225.7	1400.7	1630.7	1876.8	1902.8	1918.3	1597.8	1239.0	700.9	486.6	448.7	418.9	415.7
c	A	e	408.7	409.2	405.1	398.9	400.9	800.4	921.6	1126.8	1245.5	1467.5	1627.0	1779.2	1851.2	1980.7	2026.8	2050.9	2009.0	1736.9	1297.5	845.3	603.4	486.2	446.8	402.4
c	S	e	416.3	416.1	416.2	414.6	414.5	837.2	844.2	956.1	994.0	1195.7	1421.2	1649.8	1735.5	1789.0	1783.5	1779.1	1648.2	1050.3	775.9	623.5	541.2	437.0	414.5	411.4
c	O	e	467.7	470.7	468.3	464.2	463.4	602.2	634.7	752.8	816.2	1060.0	1268.6	1469.6	1641.2	1652.4	1663.5	1538.6	1285.6	726.5	593.2	562.9	531.4	483.2	466.6	464.4
c	N	e	473.5	472.2	469.9	468.6	464.5	462.3	465.7	504.1	617.4	750.2	839.7	971.2	1028.6	1123.8	1087.5	951.7	725.3	564.3	483.0	486.6	486.8	485.7	484.9	481.7
c	D	e	445.0	437.6	430.8	432.7	432.8	433.4	442.3	464.3	564.7	627.1	771.5	846.6	942.7	1016.0	1032.7	950.4	649.0	529.6	471.5	461.3	460.4	454.8	451.5	444.4
s	J	w	520.7	476.2	485.4	494.4	477.5	808.3	3950.6	3021.9	1756.1	1161.9	853.4	606.0	525.5	489.4	503.0	557.0	608.0	879.4	1173.1	1444.7	1760.8	954.4	466.3	480.5
s	F	w	514.9	468.5	479.3	490.4	476.5	795.4	4160.5	2931.1	1600.6	1083.9	847.6	640.3	574.8	567.6	562.5	579.1	576.9	783.6	995.7	1277.4	1703.4	946.1	463.6	480.0
s	M	w	463.1	453.1	461.1	456.1	638.3	2587.6	3113.8	1979.0	1281.6	953.0	698.3	583.6	541.7	520.0	506.3	487.7	555.8	715.6	936.4	1189.9	1052.2	598.6	459.6	480.0

s	A	w	437.6	443.3	449.8	435.0	698.7	3147.4	2310.9	1363.7	979.3	766.8	591.1	499.6	473.6	443.3	426.6	423.9	492.6	613.7	781.4	998.1	667.3	433.8	450.6	471.5
s	M	w	425.5	429.1	432.6	415.0	637.6	1863.5	1468.9	934.0	664.6	527.1	427.7	383.2	354.9	327.1	303.8	303.4	327.6	403.3	530.9	710.2	529.6	409.2	422.0	440.1
s	J	w	399.6	403.0	405.0	387.5	549.0	936.0	861.7	556.5	411.4	320.5	267.2	242.8	228.9	212.9	197.4	189.6	184.9	223.7	288.2	419.8	376.1	375.0	384.7	398.5
s	J	w	328.1	331.1	334.7	317.4	463.3	350.1	428.7	287.0	190.8	168.1	161.4	151.4	139.2	124.4	110.8	106.5	97.4	131.2	159.6	224.4	249.9	282.4	301.6	314.1
s	A	w	303.3	311.8	317.0	295.5	414.2	283.8	300.6	192.7	146.8	127.7	106.3	88.6	77.2	69.1	62.0	58.3	59.2	102.8	139.6	204.2	230.3	262.0	278.4	294.1
s	S	w	368.8	369.4	369.3	355.9	517.4	605.5	566.2	365.5	257.4	207.2	179.7	162.8	152.1	140.5	130.3	125.6	116.8	164.6	206.8	280.6	301.2	331.1	344.0	359.4
s	O	w	395.1	400.8	405.4	388.5	588.3	1392.7	1070.4	526.6	373.2	321.4	291.0	277.0	261.1	248.0	240.7	243.7	259.2	298.7	349.9	471.4	423.9	379.2	388.9	401.5
s	N	w	468.2	442.8	447.8	450.4	465.4	981.6	2725.7	1807.4	970.5	658.6	514.9	433.9	394.8	368.6	354.5	370.7	454.8	598.1	742.5	884.3	1017.8	691.4	435.1	448.7
s	D	w	510.9	471.4	481.0	489.0	474.4	792.8	4223.2	3151.0	1699.3	1041.4	733.5	573.6	549.3	511.1	507.1	547.8	593.6	900.0	1245.0	1569.7	1865.0	986.6	463.1	478.0
s	J	e	515.3	473.4	482.9	491.9	488.4	554.8	1499.2	1364.2	1152.5	852.7	665.9	589.1	519.7	467.3	461.9	446.4	552.0	746.9	807.7	839.5	950.1	927.9	501.4	516.6
s	F	e	505.9	462.5	471.8	482.5	479.0	547.6	1610.6	1464.1	1237.8	969.7	761.5	644.6	559.9	500.7	504.9	507.9	565.1	744.8	776.0	806.6	914.0	861.1	478.6	493.9
s	M	e	480.7	463.4	475.8	479.2	525.9	1210.0	1633.7	1407.5	1055.8	765.3	606.2	518.5	465.2	431.6	398.1	395.3	470.2	600.4	716.9	837.7	905.0	720.8	487.9	503.2
s	A	e	438.0	443.2	449.1	444.9	504.9	1287.6	1194.0	1017.2	790.8	634.0	547.5	486.2	463.9	445.0	401.2	415.4	471.3	579.9	670.9	773.1	725.7	453.5	467.8	489.9
s	M	e	420.3	425.4	428.7	419.5	452.8	872.1	865.7	755.5	623.6	526.2	467.4	402.4	378.1	360.0	321.5	321.1	362.3	461.3	538.4	623.5	540.0	421.8	432.8	453.1
s	J	e	402.8	402.2	406.5	400.4	424.8	643.3	717.3	598.0	475.1	393.3	338.2	291.1	279.2	266.5	224.9	226.8	245.1	311.2	378.6	477.6	420.7	389.0	401.1	418.6
s	J	e	305.1	311.6	321.6	317.2	324.0	313.5	430.3	351.6	274.3	231.6	217.3	209.9	205.6	199.5	169.1	171.9	182.6	221.6	243.9	323.7	311.7	328.5	330.9	335.6
s	A	e	334.1	336.7	335.0	318.7	321.8	287.9	371.0	293.0	225.6	193.7	177.3	167.2	165.8	163.7	147.2	158.3	173.9	223.2	246.5	291.2	293.4	305.2	311.5	328.2
s	S	e	339.2	343.8	344.7	331.9	336.9	339.7	463.1	373.6	297.8	239.1	217.5	199.9	190.9	186.5	157.9	161.8	182.0	236.6	269.2	328.1	308.0	329.6	339.7	348.4
s	O	e	416.2	419.1	421.7	412.6	434.5	721.9	763.2	594.2	474.3	394.8	336.4	293.2	279.6	268.6	241.4	251.0	293.1	387.6	449.6	528.6	462.8	410.5	420.7	433.6
s	N	e	462.0	444.6	451.3	456.3	469.4	704.1	1227.6	1079.0	860.7	682.6	562.0	494.7	445.6	424.3	416.0	422.6	504.8	629.6	676.6	724.0	774.3	634.1	462.6	477.4
s	D	e	522.4	473.7	485.7	495.3	490.9	557.6	1645.7	1536.3	1300.9	942.4	718.2	617.1	550.7	498.6	479.0	478.3	606.5	824.7	886.5	908.5	1004.3	972.0	497.7	515.7
w	J	w	39.1	33.6	26.0	29.9	32.2	48.3	89.5	164.4	202.6	232.6	237.5	250.1	255.3	255.8	207.2	212.1	176.0	174.3	179.9	132.0	122.9	108.3	80.9	60.9
w	F	w	36.9	29.9	32.9	29.7	29.8	45.8	94.1	164.5	202.6	233.7	237.4	245.2	258.3	255.9	207.5	211.2	185.3	164.2	185.3	132.7	122.7	107.3	80.5	60.5
w	M	w	31.1	31.4	26.4	32.7	39.7	74.7	136.7	188.2	217.5	233.2	239.5	248.4	253.2	220.5	208.9	184.7	169.3	175.9	148.6	124.2	109.8	92.1	63.8	48.2
w	A	w	29.0	31.8	26.0	30.9	43.1	91.1	156.2	195.3	217.9	225.0	241.4	240.0	247.9	196.0	203.6	170.0	162.3	172.6	127.6	116.3	102.6	80.9	55.9	36.4
w	M	w	32.2	25.9	29.9	28.7	42.5	84.1	151.2	188.0	213.0	216.8	227.5	235.4	235.9	194.0	193.3	164.9	152.9	168.1	122.3	113.1	100.2	74.0	57.7	32.4
w	J	w	28.2	24.3	29.6	29.6	40.3	81.4	145.7	173.5	188.1	191.0	200.7	206.1	201.0	168.5	169.7	158.3	149.3	160.3	117.1	110.4	97.3	71.2	54.2	35.8
w	J	w	26.3	27.6	26.4	28.3	42.1	77.8	116.6	139.4	133.9	127.7	134.5	126.6	126.4	107.4	107.5	107.9	102.1	113.5	114.3	109.3	91.5	70.1	55.5	33.6
w	A	w	29.9	25.8	27.3	26.7	42.3	76.8	118.9	138.6	129.8	131.1	130.6	127.6	129.0	106.1	105.5	110.4	100.3	114.7	113.1	108.8	92.6	73.4	49.6	35.4
w	S	w	29.1	21.7	29.5	31.6	40.1	80.4	143.8	171.4	186.8	187.9	201.2	198.6	198.0	166.0	168.7	155.9	145.0	159.1	117.1	109.7	97.0	68.8	55.7	35.8
w	O	w	29.5	28.1	27.9	27.3	46.3	80.3	154.0	185.1	211.4	217.3	226.8	229.8	238.6	187.8	194.6	163.3	153.0	168.5	120.7	112.1	97.8	78.2	51.6	35.9
w	N	w	36.8	33.8	26.0	26.6	32.3	53.8	97.0	159.8	196.9	220.2	225.4	240.3	238.7	239.8	195.0	197.4	171.5	158.5	167.9	123.4	113.9	99.4	77.1	50.4
w	D	w	41.4	30.7	27.3	27.6	31.6	47.1	89.2	159.6	200.2	229.2	232.7	242.3	250.1	252.6	203.1	208.4	172.4	167.8	179.9	129.9	120.5	104.8	82.2	55.8
w	J	e	37.4	28.7	28.5	23.0	28.4	44.9	89.5	92.1	98.7	100.5	126.0	111.0	102.8	93.4	87.2	94.7	85.6	89.2	94.2	94.6	85.8	115.2	74.5	47.7
w	F	e	37.5	30.8	25.1	28.0	28.8	45.7	84.0	99.8	93.9	110.3	118.8	118.7	100.6	96.8	92.0	90.3	84.5	95.4	92.4	94.4	81.5	127.9	71.4	49.6
w	M	e	38.3	24.0	28.8	27.9	35.6	65.2	94.5	98.8	98.3	111.9	121.0	101.3	100.1	95.4	83.6	91.4	92.5	91.0	91.0	81.8	110.5	93.9	55.0	39.1
w	A	e	29.9	24.1	24.3	31.5	39.1	84.2	88.4	93.2	99.9	124.2	104.8	98.5	93.8	87.6	84.9	86.7	84.7	92.6	87.3	80.5	122.3	65.3	48.9	35.1
w	M	e	26.0	29.1	20.6	24.3	45.5	79.4	88.2	88.4	93.8	121.5	98.4	99.1	84.9	86.0	82.1	82.4	82.6	90.2	83.4	76.5	119.3	61.1	48.2	35.9
w	J	e	22.9	24.0	19.9	23.7	42.0	81.2	88.9	83.0	90.2	110.2	103.5	95.5	82.8	87.4	70.4	76.3	86.3	90.0	83.6	74.4	105.2	59.2	50.1	39.9
w	J	e	27.8	24.3	24.0	24.8	37.4	76.4	82.8	85.3	93.7	91.1	89.4	83.6	83.2	68.0	74.2	74.8	78.0	83.8	83.6	77.9	68.0	61.9	44.6	28.6
w	A	e	26.0	21.7	22.3	27.0	40.9	73.8	83.4	86.3	88.4	92.6	90.5	83.8	79.2	71.3	69.3	77.3	85.0	81.7	81.7	73.5	68.5	61.7	42.8	36.8
w	S	e	24.2	26.7	24.6	26.1	38.8	76.1	82.2	85.3	96.7	114.4	101.2	90.3	89.2	76.2	83.7	76.8	82.4	84.5	82.0	75.7	112.0	60.5	43.5	34.3
w	O	e	28.6	20.8	24.7	30.5	44.0	77.7	82.6	90.7	90.0	124.2	93.6	97.0	92.3	78.1	83.6	80.3	81.2	89.4	86.1	74.1	117.8	62.8	46.5	33.5
w	N	e	37.7	25.7	25.4	22.2	34.7	51.8	88.8	88.9	88.4	106.2	112.0	105.0	91.1	88.9	80.0	81.5	84.7	91.6	87.7	82.5	93.0	97.3	63.6	48.9
w	D	e	39.0	26.2	26.2	25.1	29.0	44.8	88.6	91.6	93.8	101.6	132.1	103.3	103.4	94.8	85.5	92.6	85.0	90.4	90.6	95.0	82.7	121.9	63.2	55.4
g	J	w	35.1	35.1	35.1	35.1	35.1	50.1	88.6	118.6	250.2	234.7	337.9	345.4	340.9	233.5	200.5	157.2	205.2	208.2	204.7	159.7	153.2	118.6	86.1	48.6
g	F	w	35.1	35.1	35.1	35.1	35.1	50.1	88.6	118.6	250.2	234.7	337.9	345.4	340.9	233.5	200.5	157.2	205.2	208.2	204.7	159.7	153.2	118.6	86.1	48.6
g	M	w	35.1	35.1	35.1	35.1	44.9	75.2	108.2	204.4	240.1	302.0	342.8	342.5	270.8	211.9	172.2	188.5	207.1	205.9	175.3	155.4	130.6	97.4	61.6	39.8
g	A	w	35.1	35.1	35.1	35.1	50.1	88.6	118.6	250.2	234.7	337.9	345.4	340.9	233.5	200.5	157.2	205.2	208.2	204.7	159.7	153.2	118.6	86.1	48.6	35.1
g	M	w	35.1	35.1	35.1	35.1	50.1	88.6	118.6	250.2	234.7	337.9	345.4	340.9	233.5	200.5	157.2	205.2	208.2	204.7	159.7	153.2	118.6	86.1	48.6	35.1

g	J	w	35.1	35.1	35.1	35.1	50.1	88.6	118.6	250.2	234.7	337.9	345.4	340.9	233.5	200.5	157.2	205.2	208.2	204.7	159.7	153.2	118.6	86.1	48.6	35.1
g	J	w	35.1	35.1	35.1	35.1	50.1	88.6	118.6	210.0	194.5	297.7	305.2	300.7	233.5	200.5	157.2	205.2	208.2	204.7	159.7	153.2	118.6	86.1	48.6	35.1
g	A	w	35.1	35.1	35.1	35.1	50.1	88.6	118.6	210.0	194.5	297.7	305.2	300.7	233.5	200.5	157.2	205.2	208.2	204.7	159.7	153.2	118.6	86.1	48.6	35.1
g	S	w	35.1	35.1	35.1	35.1	50.1	88.6	118.6	248.2	232.7	335.9	343.4	338.9	233.5	200.5	157.2	205.2	208.2	204.7	159.7	153.2	118.6	86.1	48.6	35.1
g	O	w	35.1	35.1	35.1	35.1	50.1	88.6	118.6	250.2	234.7	337.9	345.4	340.9	233.5	200.5	157.2	205.2	208.2	204.7	159.7	153.2	118.6	86.1	48.6	35.1
g	N	w	35.1	35.1	35.1	35.1	37.2	55.6	92.9	137.4	248.0	249.4	339.0	344.7	325.5	228.8	194.3	164.0	205.6	207.7	198.2	158.7	148.2	114.0	80.8	46.7
g	D	w	35.1	35.1	35.1	35.1	35.1	50.1	88.6	118.6	250.2	234.7	337.9	345.4	340.9	233.5	200.5	157.2	205.2	208.2	204.7	159.7	153.2	118.6	86.1	48.6
g	J	e	33.3	33.3	33.3	33.3	33.3	48.3	85.1	115.1	134.8	116.9	187.3	194.8	194.2	167.2	134.2	155.2	203.2	202.3	195.3	147.2	144.2	117.1	84.4	46.8
g	F	e	33.3	33.3	33.3	33.3	33.3	48.3	85.1	115.1	135.1	117.9	187.9	195.4	194.4	167.4	134.4	155.4	203.4	202.9	195.9	147.4	144.4	116.9	84.4	46.8
g	M	e	33.3	33.3	33.3	33.3	42.7	71.3	103.9	127.2	123.7	162.1	192.6	195.2	177.5	146.8	147.5	185.4	202.7	198.5	166.0	145.5	127.6	96.3	60.9	38.4
g	A	e	33.3	33.3	33.3	33.3	48.3	85.1	115.1	135.1	117.9	187.9	195.4	194.4	167.4	134.4	155.4	203.4	202.9	195.9	147.4	144.4	116.9	84.4	46.8	33.3
g	M	e	33.3	33.3	33.3	33.3	48.3	85.1	115.1	135.1	117.9	187.9	195.4	194.4	167.4	134.4	155.4	203.4	202.9	195.9	147.4	144.4	116.9	84.4	46.8	33.3
g	J	e	33.3	33.3	33.3	33.3	48.3	85.1	115.1	135.1	117.9	187.9	195.4	194.4	167.4	134.4	155.4	203.4	202.9	195.9	147.4	144.4	116.9	84.4	46.8	33.3
g	J	e	33.3	33.3	33.3	33.3	48.3	85.1	115.1	135.1	117.9	187.9	195.4	194.4	167.4	134.4	155.4	203.4	202.9	195.9	147.4	144.4	116.9	84.4	46.8	33.3
g	A	e	33.3	33.3	33.3	33.3	48.3	85.1	115.1	135.1	117.9	187.9	195.4	194.4	167.4	134.4	155.4	203.4	202.9	195.9	147.4	144.4	116.9	84.4	46.8	33.3
g	S	e	33.3	33.3	33.3	33.3	48.3	85.1	115.1	135.5	118.9	188.5	196.0	194.6	167.6	134.6	155.6	203.6	203.5	196.5	147.6	144.6	116.7	84.4	46.8	33.3
g	O	e	33.3	33.3	33.3	33.3	48.3	85.1	115.1	134.8	116.9	187.3	194.8	194.2	167.2	134.2	155.2	203.2	202.3	195.3	147.2	144.2	117.1	84.4	46.8	33.3
g	N	e	33.3	33.3	33.3	33.3	37.1	57.5	92.6	120.1	130.0	133.2	188.5	193.9	187.2	158.7	139.2	167.0	202.9	199.9	182.5	146.2	137.1	109.2	75.0	43.5
g	D	e	33.3	33.3	33.3	33.3	33.3	48.3	85.1	115.1	135.1	117.9	187.9	195.4	194.4	167.4	134.4	155.4	203.4	202.9	195.9	147.4	144.4	116.9	84.4	46.8

Appendix 3.3

Table A3.3.38: Continuous technologies available within DER-CAM.

	Fixed Cost	Variable Cost	Lifetime	Fixed Maintenance	Power Elec Interface Oversize	Power Elec Dis Agg
Electric Storage	100	500	5	0	1.05	0
Electrolyzer	0	2000	15	10	0	0
H2 Storage	0	15	30	0	0	0
Heat Storage	10000	50	17	0	0	0
Cold Storage	10000	50	17	0	0	0
Flow Battery Energy	0	220	10	0	0	0
Flow Battery Power	0	2125	10	0	0	0
Abs Chiller	250	250	20	0	0	0
Abs Refrigeration	93912	753.74	20	2.07	0	0
PV	2500	2500	30	0	1.05	0
Solar Thermal	2140	2140	15	0	0	0
EVs1	100	5	1	0	0	0
Air Source Heat Pump	0	70	10	0.52	0	0

Ground Source Heat Pump	0	79.74	10	0.32	0	0

Table A3.3.39a: Discrete technologies available within DER-CAM.

TechNo	Description	maxp	maxs	lifetime	capcost	OMFix	OMVar	SprintCap	SprintHours
DGTech01	MT_CHP-HW_65	65	65	15	6440	0	0.00725	65	0
DGTech02	ICE_RB_CHP-HW_75	75	75	15	5761	0	0.01275	75	0
DGTech03	MT_CHP-HW_200	200	200	15	6300	0	0.0085	200	0
DGTech04	ICE_RB_CHP-HW_250	250	250	15	5228	0	0.0125	250	0
DGTech05	MT_CHP-HW_250	250	250	15	5438	0	0.006	250	0
DGTech06	MCFC_CHP-HW_300	300	300	20	20600	0	0.023	300	0
DGTech07	PAFC_HP-HW_400	400	400	20	14600	0	0.0185	400	0
DGTech08	ICE_LB_CHP-HW_500	500	500	15	4618	0	0.01075	500	0
DGTech09	ICE_LB_CHP-HW_750	750	750	20	4401	0	0.01075	750	0
DGTech10	ICE_LB_CHP-HW_1000	1000	1000	20	4969	0	0.00975	1000	0
DGTech11	MT_CHP-HW_1000	1000	1000	15	5000	0	0.00625	1000	0
DGTech12	MCFC_CHP-HW_1000	1000	1000	20	12820	0	0.01775	1000	0
DGTech13	MCFC_CHP-HW_1400	1400	1400	20	9200	0	0.01775	1400	0
DGTech14	ICE_LB_CHP-HW_2500	2500	2500	20	4223	0	0.008125	2500	0
DGTech15	MCFC_CHP-HW_2800	2800	2800	20	8300	0	0.01775	2800	0
DGTech16	CT_CHP-HW_3500	3500	3500	20	6145	0	0.006	3500	0
DGTech17	CT_CHP-HW_DB_3500	3500	3500	20	6309	0	0.00625	3500	0
DGTech18	ICE_LB_CHP-HW_5000	5000	5000	20	3074	0	0.004375	5000	0
DGTech19	CT_CHP-HW_5000	5000	5000	20	3891	0	0.00525	5000	0
DGTech20	CT_CHP-HW_DB_5000	5000	5000	20	3984	0	0.0055	5000	0
DGTech21	CT_CHP-HW_7500	7500	7500	20	3755	0	0.00505	7500	0
DGTech22	CT_CHP-HW_DB_7500	7500	7500	20	3841	0	0.0053	7500	0
DGTech23	CT_CHP-HW_15000	15000	15000	20	2888	0	0.00365	15000	0
DGTech24	CT_CHP-HW_DB_15000	15000	15000	20	2953	0	0.003775	15000	0
DGTech25	CT_CHP-HW_25000	25000	25000	20	2377	0	0.0036	25000	0
DGTech26	CT_CHP-HW_DB_25000	25000	25000	20	2429	0	0.0037	25000	0
DGTech27	MT_65	65	65	15	5474	0	0.0065	65	0
DGTech28	ICE_RB_75	75	75	15	4460	0	0.012	75	0
DGTech29	MT_200	200	200	15	5355	0	0.008	200	0
DGTech30	ICE_RB_250	250	250	15	4146	0	0.012	250	0
DGTech31	MT_250	250	250	15	4622	0	0.0055	250	0
DGTech32	MCFC_300	300	300	20	20000	0	0.0225	300	0

DGTech33	PAFC_400	400	400	20	14000	0	0.018	400	0
DGTech34	ICE_LB_500	500	500	15	3628	0	0.0105	500	0
DGTech35	ICE_LB_750	750	750	20	3504	0	0.0105	750	0
DGTech36	ICE_LB_1000	1000	1000	20	3042	0	0.0095	1000	0
DGTech37	MT_1000	1000	1000	15	4250	0	0.006	1000	0
DGTech38	MCFC_1000	1000	1000	20	12320	0	0.0175	1000	0
DGTech39	MCFC_1400	1400	1400	20	8800	0	0.0175	1400	0
DGTech40	ICE_LB_2500	2500	2500	20	2569	0	0.008	2500	0
DGTech41	MCFC_2800	2800	2800	20	8000	0	0.0175	2800	0
DGTech42	CT_3500	3500	3500	20	5048	0	0.005	3500	0
DGTech43	ICE_LB_5000	5000	5000	20	1847	0	0.00425	5000	0
DGTech44	CT_5000	5000	5000	20	3270	0	0.0045	5000	0
DGTech45	CT_7500	7500	7500	20	3179	0	0.00445	7500	0
DGTech46	CT_15000	15000	15000	20	2453	0	0.0031	15000	0
DGTech47	CT_25000	25000	25000	20	2036	0	0.0031	25000	0
DGTech48	CT_25000	25000	25000	20	2036	0	0.0031	25000	0
DGTech49	CT_25000	25000	25000	20	2036	0	0.0031	25000	0
DGTech50	CT_25000	25000	25000	20	2036	0	0.0031	25000	0
DGTech51	PEM_FC_250	250	250	20	1884	0	0.0185	250	0
DGTech52	PEM_FC_100	100	100	20	2300	0	0.0185	100	0
DGTech53	PEM_FC_10	10	10	20	2527	0	0.0185	10	0
DGTech54	PEM_FC_5	5	5	20	3946	0	0.0185	5	0
DGTech55	PEM_FC_CHP_250	250	250	20	2219	0	0.0185	250	0
DGTech56	PEM_FC_CHP_100	100	100	20	3140	0	0.0185	100	0

Table A3.3.40b: Discrete technologies available within DER-CAM continued.

TechNo	Fuel	FuelType	efficiency	alpha	Chpenable	NoxRate	NoxTreatCost	MaxRampUp	MaxRampDown
DGTech01	3	5	0.238	1.567	1	0.000077110	0	0.5	0.5
DGTech02	3	4	0.260	2.006	1	0.006803880	130	0.5	0.5
DGTech03	3	5	0.267	1.101	1	0.000063500	0	0.5	0.5
DGTech04	3	4	0.270	1.830	1	0.006803880	90	0.5	0.5
DGTech05	3	5	0.261	1.204	1	0.000104330	0	0.5	0.5
DGTech06	3	1	0.427	0.469	1	0.000004540	0	0.5	0.5
DGTech07	3	1	0.382	0.571	1	0.000004540	0	0.5	0.5
DGTech08	3	4	0.330	1.222	1	0.000802860	577	0.5	0.5

DGTech09	3	4	0.345	1.160	1	0.000802860	530	0.5	0.5
DGTech10	3	4	0.368	1.019	1	0.000802860	429	0.5	0.5
DGTech11	3	5	0.267	1.104	1	0.000063500	0	0.5	0.5
DGTech12	3	1	0.427	0.464	1	0.000004540	0	0.5	0.5
DGTech13	3	1	0.427	0.464	1	0.000004540	0	0.5	0.5
DGTech14	3	4	0.404	0.786	1	0.000802860	378	0.5	0.5
DGTech15	3	1	0.427	0.464	1	0.000004540	0	0.5	0.5
DGTech16	3	2	0.240	1.944	1	0.000594210	208	0.5	0.5
DGTech17	3	2	0.240	1.944	1	0.000594206	208	0.5	0.5
DGTech18	3	4	0.416	0.797	1	0.001197480	222	0.5	0.5
DGTech19	3	2	0.289	1.466	1	0.000294830	134	0.5	0.5
DGTech20	3	2	0.289	1.466	1	0.000294835	134	0.5	0.5
DGTech21	3	2	0.273	1.630	1	0.000312980	99	0.5	0.5
DGTech22	3	2	0.273	1.630	1	0.000312979	99	0.5	0.5
DGTech23	3	2	0.333	1.204	1	0.000258550	75	0.5	0.5
DGTech24	3	2	0.333	1.204	1	0.000258548	75	0.5	0.5
DGTech25	3	2	0.360	1.053	1	0.000235870	59	0.5	0.5
DGTech26	3	2	0.360	1.053	1	0.000235868	59	0.5	0.5
DGTech27	3	5	0.238	0.000	0	0.000077110	0	0.5	0.5
DGTech28	3	4	0.260	0.000	0	0.006803880	130	0.5	0.5
DGTech29	3	5	0.267	0.000	0	0.000063500	0	0.5	0.5
DGTech30	3	4	0.270	0.000	0	0.006803880	90	0.5	0.5
DGTech31	3	5	0.261	0.000	0	0.000104330	0	0.5	0.5
DGTech32	3	1	0.427	0.000	0	0.000004540	0	0.5	0.5
DGTech33	3	1	0.382	0.000	0	0.000004540	0	0.5	0.5
DGTech34	3	4	0.330	0.000	0	0.000802860	577	0.5	0.5
DGTech35	3	4	0.345	0.000	0	0.000802860	530	0.5	0.5
DGTech36	3	4	0.368	0.000	0	0.000802860	429	0.5	0.5
DGTech37	3	5	0.267	0.000	0	0.000063500	0	0.5	0.5
DGTech38	3	1	0.427	0.000	0	0.000004540	0	0.5	0.5
DGTech39	3	1	0.427	0.000	0	0.000004540	0	0.5	0.5
DGTech40	3	4	0.404	0.000	0	0.000802860	378	0.5	0.5
DGTech41	3	1	0.427	0.000	0	0.000004540	0	0.5	0.5
DGTech42	3	2	0.240	0.000	0	0.000594210	208	0.5	0.5
DGTech43	3	4	0.416	0.000	0	0.001197480	222	0.5	0.5

DGTech44	3	2	0.289	0.000	0	0.000294830	134	0.5	0.5
DGTech45	3	2	0.273	0.000	0	0.000312980	99	0.5	0.5
DGTech46	3	2	0.333	0.000	0	0.000258550	75	0.5	0.5
DGTech47	3	2	0.360	0.000	0	0.000235870	59	0.5	0.5
DGTech48	3	2	0.360	0.000	0	0.000235870	59	0.5	0.5
DGTech49	3	2	0.360	0.000	0	0.000235870	59	0.5	0.5
DGTech50	3	2	0.360	0.000	0	0.000235870	59	0.5	0.5
DGTech51	6	1	0.600	0.000	0	0.000000000	0	0.5	0.5
DGTech52	6	1	0.600	0.000	0	0.000000000	0	0.5	0.5
DGTech53	6	1	0.600	0.000	0	0.000000000	0	0.5	0.5
DGTech54	6	1	0.600	0.000	0	0.000000000	0	0.5	0.5
DGTech55	6	1	0.350	0.700	1	0.000000000	0	0.5	0.5
DGTech56	6	1	0.350	0.700	1	0.000000000	0	0.5	0.5