EXPLORING RENEWABLE ENERGY FUTURES IN HUMBOLDT COUNTY CONSISTENT WITH THE GOALS OF CALIFORNIA'S RENEWABLE PORTFOLIO STANDARD

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ABSTRACT

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Humboldt County has abundant wind, solar, and biomass resources, but has made limited progress towards the state's 2045 requirement of 100% clean electricity. A recently rejected onshore wind project showed that technically and economically viable projects can fall to social and political challenges, emphasizing the need for social considerations in renewable transitions. I therefore integrated community members' preferences into modeling of Renewable Portfolio Standard-consistent renewable energy scenarios in Humboldt County. My model suggests that offshore wind, utility-scale solar, distributed solar, and biomass power are technically and economically viable sources of significant local generation at varying costs.

In interviews with energy-engaged residents, I observed divergent normative conceptions of Humboldt County's energy future despite climate change mitigation through renewables growth being unanimously desired. Some envisaged a future of minimally intrusive distributed solar, while others support projects at a scale that would transform Humboldt County into "the Silicon Valley of wind energy." These opinions frequently overlaid conceptions of appropriateness and efficiency, for example, preferring offshore wind over cheaper utility-scale solar because Humboldt County's

wind resource abstractly overshadows its solar resource. Participants prioritized projects which best use Humboldt's resources. Because some support exclusively distributed solar while others believe it to be technically infeasible, a thorough study of distributed resource potential could help create the shared understanding necessary for productive discourse and concerted political effort against climate change. Continuous discussions among stakeholders could create a permission space for energy infrastructure and avoid wasting time and money on projects inconsistent with social and political desires.

ACKNOWLEDGEMENTS

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CHAPTER 1 INTRODUCTION

California has committed to generating 60% of retail electricity from renewable resources by 2030, and 100% from zero-carbon sources (including renewables plus large hydro and nuclear) by 2045 (California Legislature, 2018). Meeting these goals will require extensive deployment of renewable electricity sources through some combination of utility-scale projects and distributed (e.g., household and small commercial) systems. The recent attempt by Terra-Gen, a Manhattan-based renewable energy developer (Terra-Gen, 2021), to develop a utility-scale onshore wind project in Humboldt County has shone a spotlight on the competing ideas that stakeholders have for the future of electricity generation in Humboldt County, which I see as a microcosm of a potentially statewide (countrywide, or worldwide) struggle in the coming decades. Supporters and opponents of the project created wide-ranging discourses, from the threat to a sacred site of the Wiyot people, harms to local ecosystems, increasing local grid resilience, concern over where the electricity would be utilized, and mitigation of climate change. These viewpoints were sometimes at odds, and tensions between the positive and negative outcomes associated with projects – for example, wind turbines are associated with bird deaths due to collisions but could help the same species by mitigating climate change – is the basis of the so-called ‘green on green’ debate, discussed later. In the end, concerns of the Wiyot Tribe, whose ancestral land on which the project would have been developed, appears to have been the deciding factor in a vote against the project by the Humboldt County Board of Supervisors (Greenson, 2019). Encouraging and deepening future discussions will be a crucial step towards democratically developing renewable energy in Humboldt County, and perhaps many places in the world.

This study included three components which together aim to understand these competing discourses and the veracity and consistency of some of the claims for and against particular pathways for energy development. In the first phase, I interviewed ten Humboldt County residents with a wide a variety of viewpoints. In the second phase, I used their input to generate and analyze five renewable electricity infrastructure scenarios (in addition to a baseline scenario) and to develop the criteria used to evaluate them. In the third phase, I re-interviewed as many of the original subjects as possible (eight), presenting the results of the model I developed and solicited their reactions and reflections.

CHAPTER 2 BACKGROUND AND LITERATURE REVIEW

Humboldt County, depicted in Figure 1, is a rural county in Northern California, with a 2010 population of 134,623 (County of Humboldt, 2020). It is largely electrically isolated from the remainder of California's electrical grid, connected only by a few transmission lines with voltages up to 115-kilovolts (kV). As of this writing, Humboldt County has four large, local electricity generation sources, including Baker Station, a 1.5-megawatt (MW) run-of-river hydroelectric plant, Fairhaven[1] and Scotia, two biomass plants of 15 MW and 25 MW, respectively, and Humboldt Bay Generating Station (HBGS), a 163-MW natural gas plant (Ortega et al., 2020). Because the transmission capacity of 70 MW (Zoellick et al., 2011) is less than the historical average load of 96 MW (Ortega et al., 2020), and much less than the historic peak load of 170 MW (Zoellick et al., 2011), Humboldt County must, by technical requirements, generate a significant proportion of its electricity locally, unless and until transmission infrastructure upgrades are made.

[1] The Fairhaven plant is on the verge of closure due to financial troubles.

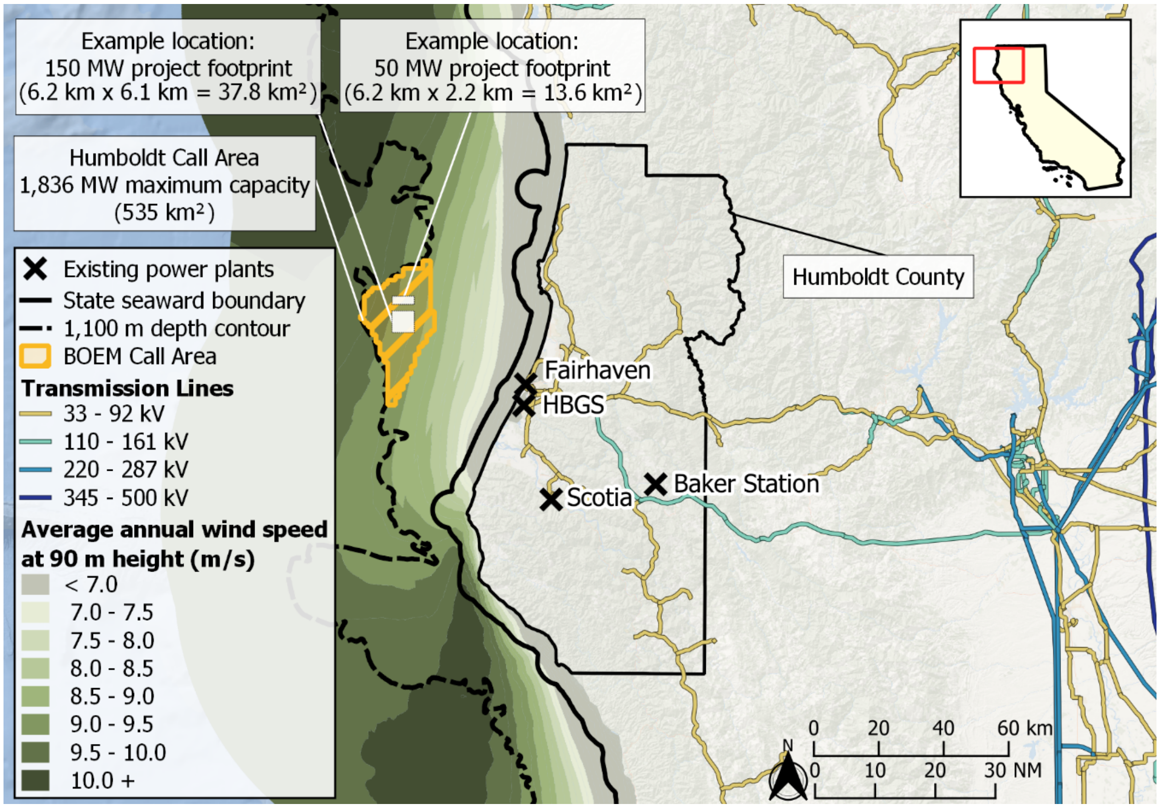

Figure 1. Map of Humboldt County showing electrical lines, potential locations of offshore wind, and existing generation plants. Reprinted from Ortega et al. (2020).

Based on the most recent data available, Humboldt County consumed 844 GWh of electricity in the twelve months from November 2017 through October 2018, served by the resources shown in Table 1, below. Nearly half of the county's generated power was historically from the local natural gas plant, about ¼ from imports, and 1/8th from each biomass plant. Rooftop solar generation is absent from Table 1 because the data source includes only utility-scale generation sources.

Table 1. Breakdown of Humboldt County electricity use by source from Nov. 2017 to Oct. 2018. Data from Ortega et al. (2020). GWh is gigawatt hours, equal to one billion watt hours.

Source	Quantity (GWh)	Share (%)
HBGS	385	45.6%
Imports	239	28.3%
Baker Station	4	0.5%
Scotia	109	12.9%
Fairhaven	108	12.7%
Total	844	100%

In addition to the small amount of hydropower available locally, the natural gas power plant, and the biomass plants (which burn a combination of mill wastes and forest residues), Humboldt County has access to “one of the most valuable wind profiles” (Collier et al., 2019, p. 65) on the West Coast, and ample but below average[2] potential for solar photovoltaics (PV). PV could be rooftop mounted on the scale of 1 to 100 kilowatts (kW) per installation, commonly referred to as “distributed,” or centralized, “utility-scale” projects, which are on the scale of tens to hundreds of MW each.

Offshore wind would likely be developed in the “Humboldt Call Area,” shown in Figure 1, above. Due to the depth of the ocean on the U.S. West Coast, turbines would be mounted on floating platforms, compared to developments on the U.S. East Coast and most of Europe in which turbines are fixed to the ocean floor (Musial et al., 2016).

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[2] Photovoltaic panels in Humboldt county have a capacity factor of around 16% (National Renewable Energy Laboratory, 2020c), compared to a statewide average of 26.5% (Younes et al., 2020).

Renewable electricity resources such as wind and solar, which do not produce electricity constantly, (commonly called variable energy resources, or VERs) are frequently developed alongside storage devices, as is being done at Humboldt's main airport (Redwood Coast Energy Authority, 2020c). In this case, if the electricity is not needed during midday, when the sun is providing the most energy to the panels, it can be stored in the battery and used in the evening or at night. Lithium-ion batteries are a representative technology for future storage projects (National Renewable Energy Laboratory, 2019), and could be added to the Humboldt County grid at either a utility-scale (e.g., in grid substations, or on the same land as utility-scale electricity generators) or distributed scale (e.g., in houses, or in government buildings). A mix of these diverse generation and storage technologies will be need across the state to enable California to meet its climate goals.

California's Renewables Portfolio Standard (RPS) is one of the state's main climate commitments. The RPS, which was set forth by Senate Bill (SB) 350 and updated by SB-100, requires that 60% of every electricity retailer's sales be from qualifying renewables – including wind, solar, small hydro, geothermal, and biomass power – by 2030. By 2045, 100% of every utility's sales must be from zero-carbon sources, including qualifying renewables, large hydro, and nuclear (California Legislature, 2015, 2018). Thus, the 2045 requirements of the RPS appear to preclude the operation of Humboldt County's current primary source of electricity, the natural gas-fired Humboldt Bay Generating Station (HBGS), unless offsets are allowed for compliance. Some combination of interregional transmission line upgrades and development of local zero-carbon generation is necessary by 2045 because the transmission lines in Humboldt cannot currently carry the county's peak (or even average) load (Zoellick et al., 2011). Developing generation locally has the advantage of reducing the need to generate electricity elsewhere in the state, whereas building transmission into the county would require that renewable energy sources still be built elsewhere. Such a transmission project would likely cost on the order of half a billion dollars (Pacific Gas and Electric, 2020), comparable to the cost of developing generation locally, and is therefore unlikely to be an economical option from a state-level perspective.

While the RPS's 2045 requirements prevent the continued reliance upon natural gas power plants like HBGS in the long term, the plant will continue to run and provide electricity to the county until alternative firm generation resources are available to meet demand. In the 2030 timeframe HBGS will only make up a small portion of Pacific Gas and Electric's (PG&E's) generation and will not significantly hinder their compliance with the RPS. Thus, California's 2030 RPS goals do not mandate changes to Humboldt County transmission or generation (including HBGS) by 2030.

Even though the RPS does not require additional renewable generation within Humboldt County in the 2030 timeframe, a strong case for expansion of renewable energy in the county can be developed from the principles of distributive justice. The field of distributive justice studies is concerned with how society's ills and goods are spread throughout society (Sovacool & Dworkin, 2015).

Distributional logics generally focus on three factors: “contributions (or equity), need, and equality” (Cook & Hegtvedt, 1983, p. 222). The Belmont Report suggests five ways by which to balance distribution, “(1) to each person an equal share, (2) to each person according to individual need, (3) to each person according to individual effort, (4) to each person according to societal contribution, and (5) to each person according to merit.” (Department of Health and Human Services, 1979).

Reliable electricity access is the primary good created by renewable electricity infrastructure, and I do not focus on its distribution beyond the implicit modeling assumption that electricity supply meets electricity demand and thus electricity is available as desired to all grid-connected Humboldt County residents. There is nuance here which I leave unexplored, such as the ways in which distributed resources may provide enhanced resilience to rural areas relative to a centralized grid model. Electricity is not the only benefit, however. Jobs and other economic growth are another important benefit of development, as could be increased grid resilience to events such as wildfires. Because Humboldt County is a relatively low-income area, it could be worthy of state or federal funding for renewables development, and thereby achieve a higher renewables development level than more prosperous counties.

The sorts of “ills” to be concerned with can be separated into two categories: burdens and risks. The risk category follows from Ullrich Beck’s “Risk Society” sociological model (Beck, 1992), in which risks tend to be probabilistic and are often not well known, including things like health risks from particulate emissions of biomass power, the unknown climate risks caused by greenhouse gas emissions, and the potential for nuclear reactors to melt down. In general, risks result from electricity generation, are difficult to assess and are not the focus of this analysis. Rather than assessing risks, I focus on the burden of renewable energy development in terms such as cost and land use, but risks are an important omission worthy of continued study.

The economic burden of renewable energy development should not fall evenly across California counties, even on a population adjusted basis. Rather, the burden should be moderated by ability, which includes factors such as regional income and renewable energy resources. Humboldt has low income for a California county and a mediocre solar resource[3] by California standards, but one of the best offshore wind resources in the country and one of the most viable ports for offshore wind development on the West Coast (Collier et al., 2019). Additionally, Humboldt Bay Generating Station is designed to (Wärtsilä, n.d.), and has an air quality permit which will allow it to, "integrate with intermittent renewable energy resources (e.g. wind and solar)" (Winstead, 2018). These factors could lead to a just burden to Humboldt County residents being either above or below the average.

These considerations relating to burdens and benefits raise questions about the degree to which Humboldt County should develop renewables, and illustrate that a judgement must be made, therefore politicizing the process. I estimate the responsibility to generate renewable electricity to be a constant proportion (guided by the RPS

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[3] PV power systems in Humboldt county have a capacity factor of around 16% (National Renewable Energy Laboratory, 2020c), compared to a statewide average of 26.5% (Younes et al., 2020).

requirement) of total energy usage, as quantified in section 3.2.1, noting that this is a significant simplification, and Humboldt County should perhaps be responsible for more or less generation.

Although the 2030 RPS requirements are less straightforward and could be implemented in a wider variety of ways in Humboldt County (or not at all as mentioned above), I found 2030 to be a more appealing time horizon for analysis for two reasons. First, existing plans by the California Energy Commission (California Energy Commission, 2020d, 2020e, 2020c) and RCEA (Redwood Coast Energy Authority, 2019) describe the evolution of electricity demand between the present and 2030. This means electricity modeling of the year 2030 will be grounded in more reliable demand assumptions. Second, 2045 is a longer way off, and the current California generation mix is only 53% carbon free (Western Interconnection Coordinating Council, 2020), a far from California's target. Analysis at a nearer date like 2030 will result in more actionable information, providing steppingstones towards the 2045 goal.

2.1 Importance of Local Viewpoints

In May of 2018, Humboldt Wind, LLC, a subsidiary of Terra-Gen sought a permit to build a 155-MW onshore wind energy project on Monument Ridge and Bear River Ridge, south of Rio Dell, in Humboldt County (County of Humboldt, 2019; Greenson, 2019). In November 2019 the County Planning Commission denied the permit over "concerns that the benefits of the project do not outweigh the impacts" (County of

Humboldt, 2019), and in December 2019 the County's Board of Supervisors voted to deny the permit again, thus terminating the project.

The failure of the Terra-Gen wind project in Humboldt County cannot be attributed to a single event or a single oversight. Anti-colonialist sentiments formed a conspicuous part of the rhetoric which apparently convinced the county Board of Supervisors to reject the project in 2019 (Greenson, 2019). As a firsthand observer of community dialogue, I believe that a lack of community involvement in early stages of project planning led to intense hostility toward the project, which underpinned discourses at the public hearings. On the other hand, residents have voiced the concern that community expectations regarding renewable energy development, namely that the county can rely entirely on distributed solar, are unrealistic (this topic is further covered in the section 4.1.8, below) (Lehman, 2019). This suggests that the county may lack plans for large-scale renewable energy projects which are both politically and technically viable and led me to intertie realistic renewable energy planning with community engagement by using community member interviews to generate and evaluate possible renewable energy futures for Humboldt County. I also leveraged this interview material to better understand competition between local discourses.

Concerns with and support for the proposed onshore wind project of 2019 framed months of debate in Humboldt County. Public meetings were a critical platform for the discussion, providing me with a basis for understanding community viewpoints additional to that which I later obtained in interviews.

In news coverage of the meetings, Greenson (2019) states that the impact to Wiyot sacred land, Tsakiyuwit, was the “most bitterly contested issue.” Supervisors were “deeply conflicted” over the “realities of the climate crisis” and “desecrating a sacred ancestral prayer site of the Wiyot Tribe.” At a meeting, Wiyot Tribal elder Cheryl Seidner said “there’s not enough money [in the world]” to justify destruction of the scared site (Greenson, 2019). Other opponents of the project criticized the project’s capitalist nature, the fossil fuel investments of the project financier, and expressed direct support for the Wiyot Tribe. On the other side of the discussion, trade workers supported the creation of jobs, and other community members supported the project’s potential to mitigate climate change by reducing reliance on fossil fuels (Greenson, 2019).

More perspectives were preserved in numerous opinion editorials written in the local newspapers such as the Times-Standard and the North Coast Journal. Greg King, Ken Miller, Sylvia De Rooy, Ann Barbata, Rick Pelren, George Waller, Jo Anne Godhino, Jennifer Fumiko Cahill, Thadeus Greenson and Carol Michael wrote op-eds largely opposed to the project, expressing a wide range of views. Miller, Pelren, Fumiko Cahill, Greenson, and King expressed concerns over damage to sacred Wiyot tribal land (Fumiko Cahill & Greenson, 2019; King, 2019; K. Miller, 2019; Pelren, 2019). Miller, De Rooy, Pelren, and King expressly mentioned risks to biodiversity, ecosystem, and/or species impacts (De Rooy, 2019; King, 2019; K. Miller, 2019; Pelren, 2019) as a problem with the project. Additional viewpoints expressed concern over turbine-caused fires (Barbata, 2019; K. Miller, 2019), damage to other cultural resources such as the Calvary Community Church and Fields Landing (Godinho et al., 2019), logging (De Rooy, 2019), carbon emissions caused by turbine construction and installation (K. Miller, 2019), a preference for solar rather than wind (De Rooy, 2019; K. Miller, 2019), the general sentiment that Humboldt County will bear the cost but not the benefits of the project (Godinho et al., 2019), concern that electricity will not be used in-county (Barbata, 2019; De Rooy, 2019), a preference for importing out-of-county wind power (Godinho et al., 2019), and a preference for community-funded energy projects (Waller, 2019).

Supportive op-ed writers included Peter Lehman, Tom Lisle, Dwight Miller, Michael Winkler, Matthew Owen, and Patrick Carr. Their positions included the idea that we must act soon to mitigate climate change (Lisle, 2019; D. Miller, 2019; Owen, 2019), that solar alone can't supply Humboldt's electricity (Godinho et al., 2019; Lehman, 2019), that wind is a stronger resource than solar in Humboldt County (Owen, 2019; Winkler, 2019), that local concerns should not outweigh global ecological concerns (Lisle, 2019), that natural gas has impacts worse than those of wind (Godinho et al., 2019), and that local wind can improve the ability of Humboldt County to island[4] (D. Miller, 2019).

Local beliefs and viewpoints are clearly diverse. The disagreement between Humboldt County residents over facts and priorities lays bare the need for deliberation and discussion, an argument which I strengthen and expand in section 4.1.8 based upon the knowledge I gained from community interviews.

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[4] Islanding means supplying electricity to residents without connection to the larger grid. See Conteras (2020) for an overview of islanding in Humboldt County.

This perceived tension between climate change and local ecological concerns is often referred to as the 'green on green' debate and is exemplified in discourses surrounding wind projects. As Warren et al. (2005) write, energy debates are generally between those focused on jobs and employment on one hand, and those focused on environments on the other, while "in the case of wind power there are strong 'green' arguments on both sides of the debate. Some environmentalists advocate windfarms because of their 'clean energy' credentials, while others oppose them because of their landscape impacts. Still others are caught awkwardly in the middle, supporting renewable energy in principle but opposing specific windfarm proposals" (Warren et al., 2005, p. 854).

Warren et al. (2005) and Hoen et al. (2019) both raise valuable insights regarding trends in perceptions of wind projects, including their spatiality and temporality. Hoen et al. find that attitudes toward existing projects improve over time. They also conclude that perception of wind turbines as a good fit and as effective solutions to climate change contributes to satisfaction, while hearing wind turbines reduces positive attitudes, and seeing them does not. Consistent with Hoen et al., Warren et al. find that people living closest to wind farms have the most positive views. They also found that people's views towards the turbines improved over time, "a key reason [for which] was that the actual impacts had been far less than expected" (Warren et al., 2005, p. 865) . Furthermore, they note that perceptions of opposition may be overemphasized, because "the press, it seems, gives disproportionate emphasis to the vocal minority that opposes wind power while ignoring the silent, contented (and less newsworthy) majority." (Warren et al., 2005, p.

872). The conclusions of Warren et al., and Hoen et al., suggest that opposition to Humboldt County's onshore wind project may have been both overzealous and overrepresented by the media. Had the project gone through, people who were previously opposed to it may have since shifted towards supporting it. That said, certain criticisms of Terra-Gen's proposed project, such as those of the Wiyot Tribe, are not the same as those studied by Warren et al. and Hoen et al.

2.2 Importance of Community Engagement

Enthusiasm for community engagement in planning projects has historically been mirrored by concerns over lack of expertise and a fear of a NIMBY (Not-In-My-Backyard) response believed to lead to political stalemate (Kraft & Clary, 1991).

> In plain language, NIMBY is the motivation of residents who want to protect their turf. More formally, NIMBY refers to the protectionist attitudes of and oppositional tactics adopted by community groups facing an unwelcome development in their neighborhood. Such controversial developments encompass a wide range of land-use proposals, including many human service facilities, landfill sites, hazardous waste facilities, low-income housing, nuclear facilities, and air ports. Residents usually concede that these "noxious" facilities are necessary, but not near their homes, hence the term "not in my back yard." (Dear, 1992)

Kraft and Cleary observe that their contemporaries, such as Michael Dear, quoted above, were predominantly critical of those with attitudes they saw as NIMBYist. Kraft and Cleary go on to question the presumption of scholars that those opposed to projects are ignorant of the details and are "selfish, irrational, and costly to society" (Kraft & Clary, 1991, p. 301). While Kraft and Cleary find some value in the "NIMBY construct," they are overall critical of it, stating that "citizens . . . were moderately well informed and able to discuss an array of technical problems," (Kraft & Clary, 1991, p. 322) and not overly driven by emotion, contrary to the beliefs of their contemporaries.

Maarten Wolsink (2007), provides a more up-to-date critique of the NIMBY explanation for dissent against renewable energy projects, which he also finds simplistic. In a survey of residents near wind farms in the Netherlands, he found that more than half of respondents had attitudes which prioritized public interest while only a quarter focused on individual benefit (consistent with, but not necessarily, NIMBYism) (Wolsink, 2000). Wolsink (2007) suggests that a better explanation is one of perceived procedural injustice. That is, residents do not believe that siting decisions are made in a fair way. Many other studies emphasize the importance of local involvement and influence in development of energy projects such as offshore wind farms (Dvarioniene et al., 2015; Haggett, 2008). This is, of course, not the only significant feature. For example, Hyland and Bertsch (2018) found that financial benefits improve community acceptance of proposed infrastructure.

Lack of community engagement by developers and divergent perceptions of ecological issues can lead to project resistance. Howe (2014) describes a case, in many ways similar to the proposed onshore wind project in Humboldt County, in which residents of the Isthmus of Tehuantepec in Oaxaca, Mexico, opposed a large wind development by *Mareña Renovables*. Public outreach by *Mareña* was characterized by inadequate information, such as misperception by residents that there would be "only 40 turbines, rather than 132" (Howe, 2014, p. 389). Resistance was founded on local ecological concerns, whereas the discourse of the developers (sincere or not) was one of global ecological concerns. Dialogues by both sides were ecoauthoritative (representing "experiential, scientific, and managerial truth-claims regarding ecological knowledge and future forecasting") rather than encouraging of discourse. This was similar to the way I observed arguments to be presented by some at the Terra-Gen panel (HSU Sustainable Futures Speaker Series, November 06, 2019), and both examples illustrate the potential friction arising from poor or insufficient communication.

Literature suggests that open communication, which is taken seriously by developers, is foundational to positive perceptions of projects by residents. Firestone et al., (2012) found, in studies of wind development offshore of Delaware and Massachusetts, that "a strong correlation exists between project support and positive feelings" regarding transparency, fairness, and local control of the planning process. In a study of community response to 'Nationally Significant Infrastructure Projects' (NSIPs) in England and Wales, Natarajan et al. (2018) found that, although the regulatory structure surrounding NSIPs "provides certain opportunities to members of the public to engage directly," locals were largely unsatisfied by their opportunity to engage with developers during the pre-application process, perceiving "that communications were one-way and developers were . . . uninterested in local views and not engaging in dialogue." While Natarajan et al. noted that the power of local communities is often limited to delaying rather than preventing projects, the project proposed in Humboldt County illustrated a case where local opposition was sufficient to lead to the rejection of a project entirely. The Humboldt County project was also atypical in another way: While local grievances against wind farms are typically centered around appearance or noise

(Devine- Wright, 2005; Wolsink, 2007), dissent against Humboldt's proposed wind farm focused on desecration of sacred land (Greenson, 2019), and to a lesser extent, potential harm to bird and bat populations (HSU Sustainable Futures Speaker Series, November 06, 2019). Thus, although community perception of an open and fair process is a critical starting point for successful development of renewable infrastructure, engaging with and addressing specific local concerns is also important.

Literature and experience support the need for community voices to be heard, and this study can be a part of that process by providing some of the informational basis for dialogue, helping to enable valuable progress in moving beyond the rejection of the onshore wind project towards a shared vision of the future. Early engagement with a diverse group of community stakeholders will be valuable regardless of the community's level of experience with energy and climate. By engaging with the community early, I explore how dialogue and collective creation of energy development planning scenarios may reduce friction in future development processes (as noted, development of some kind is necessary by 2045), with a culture of positive engagement which can enhance fairness, openness, and project implementation.

CHAPTER 3 METHODS

This section discusses the methods associated with each section of my analysis and results, namely the first round of interviews[5] and second round of interviews, discussed together, and the quantitative analyses.

3.1 Interviews

I conducted interviews following the methods in Bernard (2006) for semi-structured interviews. Before the start of any interviewing, the consent of each participant was documented via email. Interviews began with a reminder of the documented consent and a brief framing of the project stage and goals of the interview. These interviews followed a loose script, but questions were adapted to keep interviews running smoothly, per the recommendations of Bernard (2006). Guiding interview questions for the first set of interviews are listed in Appendix A.

I attempted to pose questions in a maximally open way, asking, for example: "When you say doing our part . . . how do you think about that and what do you think the role of Humboldt County is within the state?" Sometimes I asked leading questions which were still open to a broad range of responses, such as: "How about biomass, how do you see that playing a role?" This choice was partly out of an academic desire not to

[5] The research methods associated with interviews conducted for this thesis were approved by the Humboldt State University Institutional Review Board (Human Subjects protocol number IRB 20-007).

influence interviewees, but also caused by my self-perception as an outsider – someone who spent less than a year in Humboldt County. I wanted to avoid subtly influencing residents and instead influence perceptions through the results I shared in the follow-up interviews and through publication of this document.

After transcribing each interview, I tabulated the topics which that interviewee found to be important and those they expressed support, opposition, or uncertainty about. I maintained this list, adding each new subject to it, which helped me identify areas of shared importance or contention. Finally, I wrote a brief (500-1000 word) summary of viewpoints, quotes, and thought-provoking perspectives that were shared with me ("field notes"). Where possible, I contrasted statements to those from earlier interviews, as exemplified by the below excerpt from my field notes (with names removed):

> [Subject] was critical of opposers of the Terra-Gen project who [they] saw as failing to consider the alternative: more reliance on natural gas. Unlike [three participants], who saw Terra-Gen's environmental impact report as inadequate, [subject] believes it to be "probably the most thoroughly researched environmental impact report to date of any one project in the country." Compared to fracked natural gas, which requires miles of piping in short-lived wells, [subject] saw the proposed wind turbines as using less concrete and steel, and as much easier to recycle compared to the piping in wells which is essentially "gone forever." [They] also mentioned the use of water, sand, and toxic chemicals in fracked gas wells, methane leaks, and CO_2 emissions as reasons that transitioning from natural gas to wind was preferable.

I reached out to 21 Humboldt residents who I believed would present diverse and developed opinions. Importantly, each of these interviewees has been or is active in energy decisions and debates within the county. So, while these people are not necessarily representative of the greater population (from a statistical perspective), they do represent people and groups whose thoughts and opinions are particularly prominent in local energy policy and discourse. I targeted eight groups, with several interviewees identified from each group. In the end, I interviewed ten residents who responded to the invitation for an interview. Because people from some categories did not want to be interviewed, not all groups were represented in the interviews, as depicted in Table 2. Counts are based on what the interviewees told me – except for Group 1, where I also reviewed local newspapers' websites – and generally include only affiliations current at the time of interviewing.

Table 2. Account of study participants by group. Ten participants were interviewed in total, many representing multiple groups.

Group Number	Group Description	Representatives
1	Residents who expressed opinions about the onshore wind project in local papers.	3
2	Members of tribal governments.	0
3	Members of local county or city government.	4
4	Members of local environmental organizations.	5
5	Local organizers not necessarily associated with a structured (e.g. 501(c)(3)) organization.	2
6	Local business interests.	2
7	Local labor interests.	0
8	Other local organizations (e.g., a staff member of a local research organization or university).	1

After the first round of interviews and subsequent analysis, I reengaged with as many of the original participants as I could – eight – to continue the discussion. This interview process once again followed a semi-structured style. Guiding topics can be found in Appendix B, which reflects a document shared with each participant in advance of their interviews. In parallel to conducting the interviews, I continued to refine my analysis methods, and therefore figures in Appendix B are somewhat different from those contained in the rest of this document but are generally consistent. I let percipients lead the discussion in these follow-up interviews. The degree to which the discussion focused around my documented results varied widely, including one participant who preferred to instead discuss other aspects of energy development and climate change.

3.2 Techno-Economic Analysis

Following the first round of interviews, I created and evaluated renewable energy generation scenarios. These were inspired by what I learned during the interview process, as described in Section 4.1. One scenario was a baseline, intended to predict what Humboldt County's electricity resources might look like in a case where no significant efforts were made to deviate from "business as usual." Each alternative scenario included additional generation sources, and some included additional storage resources as well.

In each scenario, I aimed to quantify the amount of renewable electricity used locally, the additional cost of generation and storage, their resulting impact to California's greenhouse gas (GHG) emissions, impacts to local jobs, and the project's land footprint. Many of these factors were analyzed because they were an area of concern or interest for interviewees, as shown in Section 4.1.

One of the most critical choices in modeling Humboldt's electricity use was the consideration of a boundary and evaluation of impacts due to electricity crossing that boundary (i.e., the county's imports and exports), in terms of dollars and emissions. Because Humboldt County is relatively isolated from the state's electrical grid, it appealed to me to focus on local generation and consumption, thus creating a "levelized cost of local electricity" (LCOLE).

$$LCOLE = \frac{total\ local\ system\ expenses}{total\ local\ consumption} \quad \text{Equation 1}$$

Total local system expenses are the sum of the present value of all costs over the 20-year economic analysis period:

$$total\ system\ expenses = \sum_{n=1}^{20} e_n \cdot (1 - i)^{n-1} \quad \text{Equation 2}$$

Where e_n represents the net expenses in year n, and i is the annual discount rate of future costs and benefits. Expenses include capital cost in the first year (and sixteenth year if batteries are replaced), ongoing maintenance costs, the cost of imported electricity, the cost of purchasing renewable electricity credits, and less the revenue associated with selling any exported electricity and renewable electricity credits outside the county.

Total local consumption is defined similarly to *total system expenses*:

$$total\ local\ consumption = \sum_{n=1}^{20} c_n \cdot (1 - i)^{n-1} \quad \text{Equation 3}$$

Where c_n represents the total local electricity consumption in year n.

3.2.1 Energy Production and Renewables Target

For the non-baseline scenarios, I developed a renewables build-out target by combining California's statewide distributed generation (i.e., rooftop solar) forecasts for 2030 with the 2030 RPS target of 60% of retail sales to forecast the total 2030 renewables share across the state. This resulted in 65.8% of *total consumption* being drawn from renewables. Thus, I targeted 65.8% of energy used within Humboldt County to be generated by local renewables, including distributed solar as shown in Figure 2 and Table 3.

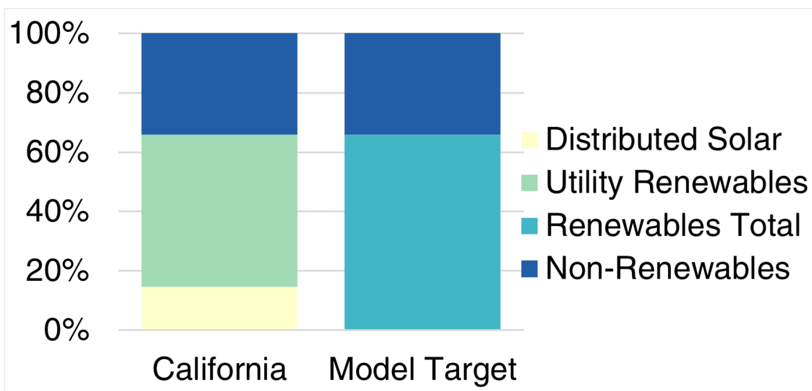

Figure 2. Projected 2030 share of distributed and utility-scale renewables across California, and the corresponding renewables target for Humboldt County.

Table 3. Projected 2030 share of distributed and utility scale renewables across California, and the corresponding renewables target for Humboldt County.

	Distributed Solar	**Utility Renewables**	**Total Renewables**
California	14.6%	51.2%[6]	65.8%
Humboldt Target	-	-	65.8%

[6] Utility renewables make up only 51.2% of total demand because they are 60% of demand after distributed generation: $\frac{51.2\%}{100\%-14.6\%} = 60\%$

Quantification of local renewable (LR) consumption share requires accounting for local consumption of locally generated renewables, which I defined as follows:

$$LR = Ren_{FTM} + Ren_{BTM} - Curtailments - Exports - Losses \qquad \text{Equation 4}$$

Where Ren_{FTM} and Ren_{BTM} are front-of-the-meter and behind-the-meter renewables, respectively. Curtailments are electricity that can neither be used locally nor exported, and losses quantifies electricity loss due to storage inefficiency. Renewables share of local consumption is defined mathematically as:

$$RE_{Share} = \frac{LR + 0.6 \cdot Imports}{LC} \qquad \text{Equation 5}$$

Where the 0.6 factor accounts for the mandated 60% renewable grid mix, and thus the expected renewable share of imports, in 2030, and LC is the annual local consumption. As noted, RE_{Share} was targeted to be at least 65.8% in alternative scenarios.

3.2.2 Considerations for Electricity Crossing the County Boundary

There were three primary impacts of boundary crossing that I was concerned with. The first, was the impact to greenhouse gas emissions. Raugei et al. (2020) estimated an emissions intensity of 0.109 kilograms of CO_2 equivalent ($kgCO_2$-eq) per kWh of electricity generated on a 2030 California grid meeting the requirements of the RPS. Thus, for each kWh imported, I considered Humboldt County to be emitting 0.109 $kgCO_2$-eq, and for each kWh of renewable energy exported, I credited Humboldt County with avoiding emissions at the same rate. Second was the cost of imports and the revenues from exports. In my model, electricity imported into Humboldt county was paid for based on the 2019 hourly market price as described in 3.2.3, while exports were credited the same amount. The final consideration is more complex. As noted above, California's RPS requires electricity *sold* in Humboldt County (which excludes distributed sources, which are not counted in sales), not electricity *generated* (or consumed) in the county, to meet the 60% renewable mandate. If Humboldt County does not generate enough local renewable electricity from front-of-the-meter sources, non-renewable electricity generated locally must be exchanged for renewable electricity (on paper). This exchange of "renewable characteristics" is referred to as a REC, or renewable electricity credit. Mathematically, I applied the following constraint:

$$0.6 \cdot (LC - Ren_{BTM}) = \ Ren_{FTM,actual} + 0.6 \cdot imports + RECs \qquad \text{Equation 6}$$

That is, 60% of the visible load (local consumption - behind the meter renewable generation) must be met by a combination of front of the meter renewables (after curtailments, exports and losses), imports (which are themselves assumed to be 60% renewable, hence the multiplier), and any additional purchased RECs. This equation is visually clearer when solving for the number of RECs which must be purchased:

$$RECs = \ 0.6 \cdot (LC - Ren_{BTM} - imports) - \ Ren_{FTM,actual} \qquad \text{Equation 7}$$

If local renewables are abundant, *RECs* will be negative, and could be sold for additional profit. Currently large utilities pay a 0.28 ¢/kWh, or 6%, premium for renewable energy (Albright et al., 2020). This 0.28 ¢/kWh was taken as a first order approximation of additional cost or revenue across scenarios where RECs were either undersupplied or oversupplied, respectively. While there is significant uncertainty regarding the value of RECs ten years in the future, at their present value RECs have little impact on the economics. They would have to rise in price significantly (e.g., tenfold) before their procurement became a significant driver in the cost of local electricity.

Further detail of the model methods is provided in Appendix C.

3.2.3 Investment and Ongoing Costs

After I completed scenario design, I estimated costs for each scenario. NREL (National Renewable Energy Laboratory, 2020a) provides an excellent database of cost resources for electricity generation, transmission, and storage projected as far as 2050. This resource is known as the Annual Technology Baseline (ATB).

For existing natural gas and biomass power plants it is important to account for the fact that while they are already constructed, there was a cost associated with initial investments in the infrastructure. To account for this I used the resource adequacy payment of $3.11/kW/month (Brant et al., 2019). This amount stood in for the capital cost needed to enable continued market participation for these plants in the analysis. Resource adequacy payments are made to electricity generators by electricity retailers and are designed to ensure grid reliability. I used them to account for the capital expense associated with the cost of electricity [7] without double counting existing infrastructure. Since HBGS is owned by PG&E, an external entity, this is consistent with my general method of drawing a border around Humboldt County. This approach has the downside of ignoring the possibility of existing infrastructure wearing out. Anecdotally, the

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[7] Although resource adequacy payments are used to incentivize investment, they likely do not account for the full capital cost.

biomass facilities are quite old, while the HBGS engines are new by comparison, having come online in 2010 (California Energy Commission, n.d.). Based on the age of the current U.S. natural gas fleet (U.S. Energy Information Administration, 2017), they will still be relatively young in 2030, and could be in operation through 2050, which is the end point of my economic analysis. These assumptions around existing infrastructure are one source of deviation between model and reality.

I included capital expenditures, fuel costs, fixed costs, and variable O&M costs in this analysis, as tabulated in Table 4. For the case of offshore wind, I later compared the cost estimate resulting from NREL's data to the cost estimate by Steve Hackett and Julia Anderson (2020), (see Appendix D) which is specific to the offshore wind project modeled by Severy et al. (2020), and which I use for one scenario, and thus likely a more reliable projection of the cost. In one investigated scenario, the existing biomass plants were closed, and fixed O&M and resource adequacy costs were accordingly removed.

Table 4. Year 2030 projected costs of considered technologies (National Renewable Energy Laboratory, 2020a). CAPEX is the project capital (up front) cost, O&M stands for operations and maintenance. Notes: [a] Three times the NREL (National Renewable Energy Laboratory, 2020a) value, as discussed below. [b] Not including $3.11 per month RA payment for existing infrastructure (Brant et al., 2019). [c] Fixed-tilt array. [d] Per KW-DC. [e] Single-axis tracking array.[f] Based on ATB fuel-price and plant-specific heat rate of 7,616 KJ/KWh (Wärtsilä, 2009).

Technology	**CAPEX ($/kW)**	**Fixed O&M ($/kW)**	**Var. O&M ($/MWh)**	**Fuel Cost ($/MWh)**
Utility-Scale Storage	$817	$20		
Residential-Scale Storage	$2,451[a]	$61[a]		
Biopower	$4,160	$123[b]	$4.72	$42
Run-of-River Hydropower	$7,628	$135		
Distributed Solar[c]	$1,125[d]	$8.4[d]		
Utility-Scale Solar[e]	$836	$9.8		
Offshore Wind	$3,480	$61		
Natural Gas	$898	$11[b]	$4.50	$25.8[f]

NREL's 2020 ATB cost estimates for utility-scale solar are given in KW-AC rather than KW-DC as in previous versions (National Renewable Energy Laboratory, 2020e). NREL assumes an inverter load ratio (ILR = KW-DC/KW-AC) of 1.34, which was applied in all solar generation simulations. These costs were converted to costs per KW-DC using the ILR, and for the remainder of this document all values for PV are referenced in KW-DC.

The battery storage CAPEX and fixed operations and maintenance (O&M) costs in Table 4 assumes a battery power to capacity ratio of four hours, a constraint which, though not a technical limitation, was used to simplify assumptions. New to the 2020 ATB are projections for two-hour batteries, but these were not used in the model.

Residential storage costs are not covered in the ATB, but a report by Ardani et al. (2016) provides a basis for comparison. In 2016 pricing, an integrated 5-kW / 20-kWh storage system was estimated to add $31,590 to the price of a residential solar project (approximately tripling it), $6,300 per kW. This is 3.3 times the cost of a utility-scale storage in the ATB (when extrapolating the moderate, or mid, scenario estimate of $1,633 from 2018 back to $1,932 in 2016). Lazard (2020), provides a range of AC ($/kW) and DC ($/kWh) costs for utility-scale four-hour batteries and residential-scale 4.2-hour batteries. Combining the mean estimates (4*$/kWh+$/kW) results in an estimated relative cost of residential storage 2.5 times that of utility-scale storage. A factor of 3 was therefore applied to the capital & ongoing costs of residential storage. It should be noted that NREL's storage cost estimate represents the additional cost necessary to create a solar PV system that meets "back-up power (kW) and energy (kWh) requirements in the event of a grid outage" (Ardani et al., 2016, p. 11), beyond the minimum services provided by storage.

Since lithium-ion storage is only expected to last 15 years, while generation technologies are expected to last at least 20 years (my analysis horizon), storage must be replaced in year 16 (National Renewable Energy Laboratory, 2020a, 2020d). This is accounted for using the 2045 cost of storage, $664/kW ($401-$934/kW), again tripled for distributed storage. To account for the remaining value of this storage at the end of the analysis horizon, 2/3 of the cost is recouped in year 20, after being appropriately discounted.

Finally, many of the resources in ATB have a variety of different scenarios with different associated costs, capacity factors, etc. The selected scenarios for each technology are tabulated in Table 5.

Table 5. Technology scenarios from NREL's Annual Technology Baseline (National Renewable Energy Laboratory, 2020a). Notes include descriptive characteristics and commentary.

Technology	**Scenario**	**Notes**
Battery Storage	4Hr	Battery capacity/inverter power = 4 hours.
Biopower	Dedicated	For power plants which burn biomass only.
Hydropower	NSD1	For non-dammed hydro.
Solar -Residential	N/A	Fixed tilt. Costs are the same for all scenarios.
Solar - Utility	N/A	Single-axis tracking. Costs are the same for all scenarios.
Offshore Wind	Class 14	Per Severy & Garcia (2020), offshore wind in the Humboldt Call Area would have a mean depth of 815 meters, closest to the Class 14 scenario (National Renewable Energy Laboratory, 2020f). The cable distance to landfall of 46 km is much less than that given for Class 14: 161 km.
Natural Gas	CT-Ave CF	Humboldt Bay Generating Station is not a combustion turbine; rather it operates on natural gas reciprocating engines (California Energy Commission, n.d.). No data for reciprocating engines were available in the ATB.

3.2.4 Import Costs and Export Revenues

In some of the investigated scenarios, electricity was exported outside of the county because it was not needed locally at the time of generation, or imported into the county, as has been done historically. In such cases, I included an estimate of the value or cost of this electricity in the CAISO (CAISO is the California Independent System Operator, which operates the wholesale electricity market in California) market. I assumed this energy was sold into CAISO's Day-Ahead Market, at a bid of $0.00, and was thus sold for the market clearing price if that price exceeded $0.00. Market clearing price was taken at the Cottonwood Node, based on 2019 market prices and methods that I have previously applied (Younes et al., 2020). The average seasonal price curve is shown in Figure 3 for reference.

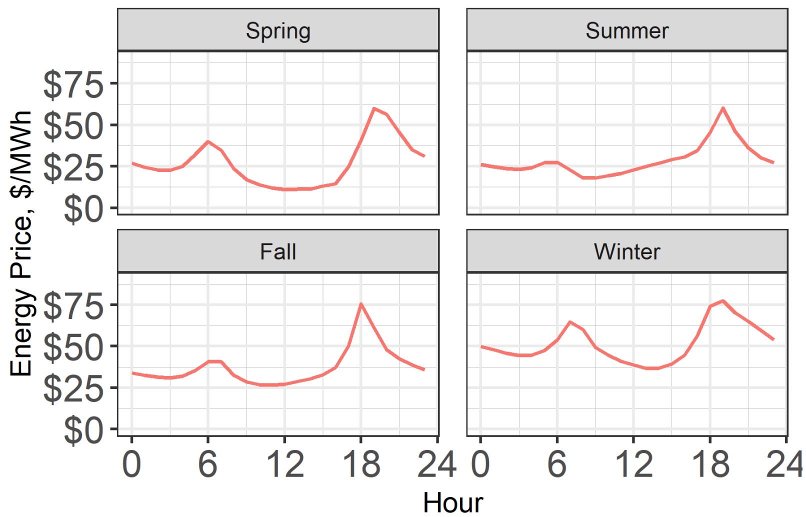

Figure 3. Seasonal averages of hourly price in the Day-Ahead-Market in Cottonwood (at CAISO node ANDERSON_6_N001). Adapted from Younes et al. (2020).

3.2.5 Greenhouse Gas Emissions

Life-cycle greenhouse (GHG) emissions associated with each technology were generally sourced from Open EI (Open EI, 2020), which uses the same dataset as NREL (2020b). Data include all subcategories, unless noted parenthetically. In some cases, alternative sources were compared to the NREL/Open EI data. These data sources are displayed in Table 6.

Table 6. Lifecycle GHG Emissions by technology type, in (g CO_2-eq/kWh) for two sources. The Open EI data for natural gas is for a combustion turbine.

Source	Open EI (2020)	U.S. EPA (2020)
Biopower (Mill Wastes)	15	
Biopower (Forest Residues)	34	
Hydropower (Run-of-river)	7.0	
Solar PV	44	
Offshore Wind	11	
Natural Gas	590	470

Analogous to the methods used in the cost model, embedded emissions associated with baseline hydropower and solar were not considered, while additional emissions from burning natural gas were included. The HBGS-specific emissions value of 470 g CO_2-eq/kWh was used rather than the Open EI result, which would have included impacts due to construction, been generalized across the industry, and applied to a different combustion technology. Biomass emissions are contentious, requiring a deeper discussion, touched on in Appendix E. For this analysis of biomass plants in Humboldt, which typically burn mill wastes and forest residues, I used the average datapoint for these two feedstocks, 24.5 g CO_2-eq/kWh, in this analysis. I also used the same value for lifecycle GHG was used whether or not the plant was part of the BAU scenario, whereas for hydropower and solar PV the embodied emissions in Table 6 were included only for additions beyond the BAU scenario. In all scenarios, emissions calculations account for all emissions associated with local generation (including embodied emission) regardless of whether the electricity is exported, but exports were credited 0.109 kgCO_2-eq for each kWh exported, while imports were considered to emit the same quantity.

3.2.6 Job Creation

I estimated long-term and short-term direct job creation from each scenario based on ranges and nominal values provided by Rutovitz et al. (2015) and nominal values provided by Ram & Aghahosseini (2019) for manufacturing, construction & installation (C&I), and operations & maintenance (O&M) related jobs per installed MW of biomass, offshore wind, utility-scale solar, rooftop solar, distributed-scale battery storage, large-scale battery storage, and natural gas, as well as fuel related jobs per Petajoule for biomass and natural gas. As a basis for comparison, manufacturing jobs are assumed to be out of region, and are therefore ignored, with the remaining relevant values tabulated in Table 7. Rutovitz et al. (2015) note that indirect jobs (e.g. room and board) would increase these figures by 50% to 100%, while inclusion of both indirect and induced jobs would increase the numbers by 100% to 350%.

Table 7. C&I, O&M, and fuel related jobs created by renewable technologies (Ram & Aghahosseini, 2019).

Technology	C&I Job-yrs/MW	O&M Jobs/MW	Fuel Jobs/PJ
Internal Combustion Engine[a]	1.30	0.14	0[b]
Offshore wind[c]	7.1 - 8.9	0.09 - 0.2	0
Utility-scale PV[c]	6.4 - 21	0.2 - 1.7	0
Distributed PV[d]	12.8 - 42	0.4 - 3.4	0
Biomass[c]	14	1.5	29.9
Large-scale storage[a]	10.8	0.4	0
“Prosumer” storage[a]	21.6	0.8	0

[a] Source: Ram & Aghahosseini (2019).
[b] Natural gas fuel related jobs are assumed to be non-local and treated as zero. For reference, Ram & Ahahosseini (2019) assume 15.1 jobs/PJ
[c] Source: Rutovitz (2015).
[d] Twice utility-scale PV, following Ram & Aghahosseini (2019).

3.3 Land-Use Impacts

This section provides a brief overview of the methods used to estimate land-use, or area-use impacts of the technologies studied herein.

3.3.1 Offshore Wind

The offshore footprint of a 144-MW offshore wind development near Humboldt County, was drawn from a study by Severy et al. (2020).

3.3.2 Biomass

I combined the electricity production from biomass resulting from the Humboldt County node model with a plant heat rate of 13.5 MMBTU/MWh (National Renewable Energy Laboratory, 2020a) and a heating value of 12.04 MMBTU/dry ton (ICF International, Inc., 2019) to calculate the mass of forest residues needed to power Humboldt County each year.

3.3.3 Utility-Scale Solar

Estimates of land-use requirement for single-axis solar farms greater than 20 MW were drawn from Ong et al. (Ong et al., 2013), who find that each MW-AC of PV has a total land-use impact to 8.7 acres in the capacity-weighted average case. Since they estimate an inverter load ratio of 1.18 (a derate factor of 0.85), this leads to an estimate of 7.4 acres per MW-DC.

3.3.4 Rooftop Solar

Gagnon et al.’s assessment of technical potential for rooftop solar across the United States (Gagnon et al., 2016) provides an excellent starting point for predicting whether there is enough usable roof space in Humboldt County to meet the requirements of the modeled scenarios. Gagnon et al. make a county-level evaluation across the U.S., which, when extrapolated, leads to my prediction that 31,000 small buildings in Humboldt County have the potential for development (Gagnon et al., 2019). They also provide an assessment of viable roof area and projected potential for installations across select cities (with lidar data available) in the U.S. These data, and the resulting extrapolation of the technical potential for installations on small building in Humboldt, 239 MW, are shown in Table 8. Note that Gagnon et al. (2016) account for viable area, not total area. Their study excludes areas of excessive tilt, shading, or northward orientation, but allows some degree of non-optimality. I determined that this caused a sufficiently small error to not be considered, as discussed in Appendix F.

Table 8. Technical potential for rooftop PV on small buildings (less than 5,000ft^2) in surveyed cities and extrapolated to Humboldt County, California.

Region	**Number of Small Buildings w/ Viable Area**	**Potential Capacity**
U.S. (Select Cities)	24,788,583[1]	189,982,891 KW[1]
Humboldt	31,203[1]	239,144 KW[2]

[1] From Gagnon et al.'s technical potential assessment (Gagnon et al., 2019). Building count data is from the 2011 U.S. Census American Community Survey.
[2] Extrapolated.

Across measured cities there was significant variation in ratios of large/medium building potential to small building potential, but no clear trends from which to extrapolate (Gagnon et al., 2019). Across the country, potential from large/medium buildings is 53% of that from small buildings. Applying this ratio to Humboldt County would lead to a potential for 367 MW of rooftop solar across all buildings.

CHAPTER 4 RESULTS AND DISCUSSION

Chapter 4 begins with important patterns which emerged from the interviews: views on climate change and the benefits of renewable energies, perceptions of justice and injustice in energy projects, and feelings towards specific sources of renewable electricity. Next, I discuss how this information shaped the analysis which followed before diving into those quantitative results, which include quantification of generation by renewable sources, their cost, job creation potential, land use, and other considerations. Finally, I circle back to the interviewees, sharing their reflections on these quantified results and my reflection on how the results may have influenced their thinking.

4.1 Interview Results

From the outset, the goal of my interviews was to engage deeply with a variety of viewpoints rather than to achieve of a statically significant sample of responses. Statistical analysis would have necessitated forgoing the unstructured interviews for structured interviews or surveys and required a number of participants impractical for a master's thesis.

The small sample did not, however, prevent me from engaging with an incredible breadth of perspectives. I fell short of gaining perspectives of local labor and local tribal leaders, though I interviewed several affiliates of the local tribes (a member of a tribe, and a past employee of a tribal government) who provided invaluable insights, and I talked to several members of the renewable energy labor force. On the other hand, as a side effect of the responses I received and the snowball sampling method I partially relied upon, many of the study participants were affiliated with the Redwood Coast Energy Authority in one way or another, which most likely skewed the perspectives I received. For example, I believe they all believed large-scale energy projects to be necessary. That said, they weren't alone in that belief, and still had wide-ranging viewpoints and inputs.

I was impressed across-the-board by the level of structure presented to me in interviews. Many interviewees demonstrated educated beliefs about the pros and cons of various technologies, how they could work within the county, and what the best options for development were. For example, one interviewee said (I believe referring to this article written by Peter Lehman (2019)): "I believe what the guys at the Schatz labs say, and that was that distributed solar on people's rooftops and stuff - there was no way that it would add up to what the power could have been from a . . . utility."

In addition to being an illustrative example of the types of information foundational to residents' perspectives, this statement alludes to one role of the Schatz Energy Research Center[8] in the community. I attended the Terra-Gen (onshore wind) panel discussion, moderated by the Schatz Center, and though their intent was to serve as an impartial host, some at the discussion saw that Schatz Center as supporting the Terra-

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[8] I am currently a graduate student assistant and fellow of the Schatz Energy Research Center.

Gen onshore project. Thus, "what the guys at the Schatz labs say" may refer to a broader set of topics than rooftop solar.

Some interviewees took a more measured approach, not endorsing a specific energy solution, but still holding a sophisticated viewpoint.

While each interviewee had a unique perspective which frequently cut across perceived groupings, I believe it convenient to categorize participants into three rough groups: government officials, energy practitioners, and organizers/activists. Each group is of approximately equal size. Some participants could have fit into multiple groups but aligned with a single category.

The final note I will provide before presenting interview results is that I have woven reflections on my own experiences with these subjects into accounts of the interviews. I do this not because I think my views are especially worthful, but because, as a central figure in the interviews and subsequent analysis, my perceptions are fundamental to interpretation of the results. By sharing my views as explicitly as possible, I hope to give the reader a better idea of what my biases are and how they may have shaped my conclusions.

4.1.1 Developing Local Renewables

Strong language on the need for development of local renewables was characteristic of the government official group, though all study participants expressed support for development of local renewables as a means to mitigate climate change.

Mitigation of climate change is an issue of fundamental importance to me for many reasons (particularly facets of intergenerational justice), and as evidenced by the personal statement in my Humboldt State University application in which I wrote that "enrolling in a graduate program is a necessary step in positioning myself to combat climate change." As such, statements made along these lines resonated with my personal beliefs.

One government official brought up the U.S.'s habit of engaging in warfare abroad to secure oil, a related justice issue, saying "our energy sources have been a pivotal factor in wars that we've been engaged in the Middle East for the last 40 years and that millions of people have died basically for . . . the type of energy policy that we have now. . . . [B]y moving to local renewable energy sources . . . we can very much decrease the reason for going to war and killing people . . . to support our lifestyle and our energy sources." As the child of a Palestinian immigrant, I saw firsthand, and at an early age, the militarized occupation under which my relatives in the Middle East lived but did not understand until much later the role which oil had played in shaping our lives. The connection between oil and policies in the Middle East is rarely made, but a critical aspect of my motivation. This line of thinking may seem extraneous to many, but to me spoke directly to the heart of the issue and was moving to hear. Furthermore, it ties into the discussion of distributive justice in Section 4.1.3, below.

At the scale where Humboldt County would become a significant exporter of electricity, there was disagreement over whether environmental costs exceeded the environmental benefits. Here, an official and a practitioner both expressed concern over the ecosystem impacts from potential large-scale developments of offshore wind (Severy & Garcia, 2020), and an organizer was concerned with this technology at any scale. On the other side, another organizer and another practitioner were quite enthusiastic over the potential for Humboldt to become “the Silicon Valley of wind energy.” As one interviewee noted, Humboldt Bay is one of just two in the state capable of serving as an assembly site for offshore wind turbines, creating the opportunity for turbines to be assembled in Humboldt Bay and transported elsewhere on the California or Oregon coasts.

4.1.2 Job Creation

Support for local job growth and economic development was a second cross-cutting area of support. Over half the participants, representing all three categories, believe jobs and economic development through investment to be a pivotal issue and a key reason for developing local renewables. The energy practitioner group was the most vocal here, with two members emphasizing the importance of high quality “long-term opportunities associated with . . . energy development.” Tying to the discussion of gigawatt-scale wind above, one interviewee noted that an offshore wind project could bring in a tremendous number of associated jobs, including those related to port development. On the other hand, an interviewee more supportive of distributed solar argued that that “the jobs involved in widespread distributed solar, for example, involve a whole lot of people: the construction trades, the electricians, the plumbers. . . . And these are jobs that are not highly specialized like with wind factories.” Supporting the idea that job growth is important to the community at large, another interviewee tied the failure of the onshore wind project to Terra-Gen’s concession to a project labor agreement with local unions occurring too late in the planning process.

This is perhaps an area where I came into the discussion with a different perspective than many interviewees. I have lived my entire life in relatively affluent cities and towns, and I don't speak of the need for high-quality jobs from personal or local economic experience. Where job quality has made an impression on me is (again quoting from my application to HSU) "the juxtaposition between factory worker and owner I observed during business trips to China [which] showed me that modern manufacturing processes have, in many cases, perpetuated inequality." So, my concerns about job development have been associated with different areas of the supply chain than those of the Humboldt County residents with whom I spoke.

Job development is not the only economic topic with a relatively common viewpoint. Dishearteningly, at least half of my ten interviewees reflected that local funding is their preferred option, but unrealistic. One interviewee referred to the ownership structure of the Terra-Gen project as one that perpetuates existing economic inequalities but was nonetheless supportive of it, while another said that large-scale development "would cost hundreds and millions of dollars and that capital is not available locally . . . even though I wasn't necessarily thrilled with the ownership of Terra-Gen I saw it as being something that actually was feasible." One interviewee cited the structure of tax incentives making bond-funded projects, due to the lack of tax liability by government bodies, significantly less financially attractive than privately funded projects.

Several interviewees were proponents of a community ownership or mixed public-private model, saying things like: “the benefits of those projects are not necessarily going to a private developer, they're going back into the community.”

Finally, one interviewee expressed concern with the role of capitalism in perpetuating the climate crisis. In their words, “capitalism is based on continuous economic growth, and that’s inherently unsustainable.” There is an irony, that the same parties who have created the climate crisis, like Energy Capital Partners, would benefit from projects like the proposed onshore wind project, which was not lost on interviewees.

4.1.3 Distributive and Procedural Justice

My undergraduate training is in Mechanical Engineering, which provided little, if any, background on the concepts of justice. This is (once again) evidenced by my graduate school application where my vocabulary on the subject was limited to “inequality,” and “social justice.” That said, the underlying concepts were of course not foreign to me. In the same document, I wrote about preserving a hospitable environment for future generations, and the inequalities that inhere in capitalistic modes of production. I had stood face-to-face with issues of injustice in the working conditions of Mexican and Chinese factories, the latter leaving a particularly durable mark, and a in a trip to Palestine, where I saw the militarized occupation, and experienced the inadequacy of racialized medical care available to Palestinians (including Palestinian Israelis and Palestinian Americans). It is no exaggeration to say that the inadequate medical care available in the West Bank nearly prevented me from leaving what was for me a visit.

These two, distinct, forms of justice – procedural and distributive – were touched on in Chapter 2, and were interwoven into many of the discussions I had with study participants. The concept of procedural justice underlies a comment that local investment could lead to "local democratic control" over projects. This could be seen to contrast with the privately funded Terra-Gen project, where Native American people were conspicuously absent from early stakeholder discussions. That said, the Terra-Gen project was ultimately rejected based on inputs from, and the political power of, the Wiyot Tribe, exercised through a democratic process. Therefore, local investment is clearly not a necessity for democratic control, though it could further democratization.

The interlocutor who mentioned local control also brought up "job creation in renewable energy sectors, you know, good, plain working class or living wage jobs." Jobs are certainly a societal good, and creation of living wage jobs aligns with fairer distribution of said good, and thereby furthers distributive justice. Finally, this interviewee explicitly mentioned justice in saying that "if we're going to try to rapidly and comprehensively rethink our economy, we shouldn't just continue to perpetuate the existing inequalities, but we should try to create a more just economy."

Procedural justice, and the perceived procedural injustice associated with Terra-Gen's lack of engagement with the Wiyot Tribe, was mentioned by several other interviewees. One interviewee saw both a procedural *and* a distributive injustice, in which one group was bearing the impacts of the siting choice while another accrued the benefits, saying that this could be avoided by "involving stakeholders early, especially tribal communities." Nearly identical sentiments were expressed by a second interviewee.

My own struggle with these concepts mediated my changing views of the onshore wind project. Initially, I supported the project because it would help address climate change but had no knowledge of the perspective of Wiyot Tribe. I was startled and concerned when the focus at the 2019 panel discussion shifted towards these local concerns and it became clear that the project was not as broadly supported as I had assumed. As with some of my interlocutors, I thought that many participants in the discussion were failing to consider the alternative to onshore wind: continued reliance on natural gas. After some discussion I became conflicted about the project. The similarity between colonialism in Palestine and in California is not a tough one to see, and this likeness tempered my enthusiasm for the greenhouse gas reducing project. In the end, I concluded that I did not personally have enough at stake and thought it best to let others decide how to deal with that project.

The Terra-Gen project is not the only area where justice concerns presented themselves. Humboldt's current use of electricity creates tremendous injustice in other ways which were identified by many participants. For example, one interviewee recognized that RCEA's recent power purchase agreement with a solar facility in Kern County (Redwood Coast Energy Authority, 2020b) leads to impacts of energy generation not being realized by those using the energy, saying "I'm not a resident of Kern County, I don't know those impacts personally." Another interview raised similar issues with the imported natural gas used to power the Humboldt Bay Generating Station, saying that "all of that is fracked gas coming from northeast of us somewhere. . . the people whose lands are being drilled and fracked, who often don't even have any choice on it because they don't own the subsurface right, and so these guys come in and they do the drilling, and they leave a giant mess in their wake . . . the pollution of the burning and the methane and all the rest," a concern echoed by several other participants.

Climate impacts are a significant distributive injustice. One interviewee shined a spotlight on the tensions inherent in distributive justice by bringing up the connection between Humboldt and the outside world, where Alaska Natives are currently losing their ancestral lands to sea-level rise, "a direct consequence of not putting in the wind farms." Here, the distribution of burdens within Humboldt County has implications for the distribution of burdens between Humboldt County and the broader world.

A final point on this topic made by two participants, both of whom have worked in the energy field, is the way perceptions of electrical grid physics plays into perceptions of distributive justice. Both participants expressed this through criticism of RCEA's power purchase agreement from Kern County, one calling it a "paper game," the other saying that "none of that electricity is going to get to Humboldt County." One interviewee linked this to the proposed onshore wind project, where, in their view, detractors disingenuously claimed that its electricity would not be utilized locally (based on power purchase agreements), while grid physics dictate otherwise. This is a case where an invisible physical phenomenon (how electricity travels in the electrical grid) has a fundamental impact on perceptions of distributive justice.

4.1.4 Intertwinement of Global and Local Concerns

As with most of the other topics discussed so far, the connection between local concerns over ecosystem impacts and biodiversity and the threat posed by climate change, part of what is often referred to as the ‘green on green debate,’ was brought up by folks in every group. Three participants made similar statements regarding the impacts of climate change on ecosystems. One said that “climate change in itself is going to affect whatever ecosystem . . . whether it’s birds, wildlife, or fish, or trees,” another commented that climate change causes tremendous environmental problems like “destruction of the oceans [where] you have these huge dead zones,” and the third noted that climate change will lead to “a radical change in the environment of Humboldt County,” including saltwater intrusion into Humboldt County’s low-lying areas such as the Arcata Marsh and Eel River Valley, and disappearance of the dunes on the Samoa peninsula.

On the other hand, a local organizer sees things differently, focusing instead the impacts of utility-scale renewable developments and their “devastating impacts” to habitats and biodiversity. In their words, “the flip side of the climate change problem is the biodiversity problem. People ignore that and think that they can just wipe out habitat and biodiversity in the interest of producing electricity without realizing that we're facing an extinction crisis and we have to protect . . . biodiversity while we produce the energy that we need . . . those two things are inseparable.”

All four reject the dichotomy of local and global, and yet there remains room for tremendous disagreement in conclusion: Are utility-scale renewables the destroyer of biodiversity, or its savior? Again, this question typifies the so-called green on green debate.

I should note that not everyone was as concerned as these four with preserving local ecosystems. Some saw the global climate crisis as so severe that they suggested making local sacrifices to focus on global outcomes.

4.1.5 The Timeline for Action

Again, diverse viewpoints supported the need for quick action with disagreement over what actions to take. One activist pushed RCEA to "move up its goal for 100% renewable energy from 2030 to 2025." Another stressed the need for rapid changes to avoid positive feedback loops (e.g., melting ice caps uncover relatively darker water which absorbs more of the sun's radiation). Yet all three of the organizers that I interviewed resisted the Terra-Gen project, so clearly, they have more nuanced opinions than blanket support of quick action.

Organizers were not the only ones to articulate the exigency of renewable development. An energy practitioner told me that "the greatest crisis facing us right now is climate change . . . we need to, as rapidly as possible, green our power supply," while a government official explained their endorsement of the Terra-Gen project by production of clean electricity in the next couple years, and "between now and 2026 we would be [producing] additional greenhouse gas emissions that we could have avoided with an onshore wind project." Yet another tied the timeline back to justification for private equity, saying that "if we want to get this stuff off the ground in our lifetime, then maybe we cannot wait for government funding."

All interviewees desire quick action to mitigate climate change; differences express themselves in terms of the types of compromises folks are willing to make, with the government officials apparently the most willing to support a project that they recognize as flawed.

4.1.6 The Role of Distributed Solar

Reliance upon rooftop solar for a significant portion of Humboldt County's electricity use is an idea that was supported fervently by two local organizers, but which all the other interviewees felt was unrealistic. The organizers prefer distributed solar projects because these can be sited "where impacts have already occurred," on houses, parking lots, or public buildings. While the impacts of utility-scale development on habitat are inherent through direct land use and transmission infrastructure, they view the impacts of producing solar panels as *controllable* ("not that the processes are ideal at the moment", one organizer told me).

On the other hands, detractors were concerned over the economic viability of rooftop solar, the relatively poor solar resource in Humboldt County[9], and the fact that solar output peaks in summer whereas Humboldt County demand peaks in winter.

The relative scarcity of solar radiation in Humboldt County means that rooftop solar may have trouble meeting county demand. One participant cited the analysis published by Peter Lehman (2019) in a local paper, which argued that there was simply not enough roof space in the county to meet demand (my own analysis, presented in Section 4.2.8.4, indicates that Humboldt's rooftops possess enough area to achieve at

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[9] Photovoltaic panels in Humboldt county have a capacity factor of around 16% (National Renewable Energy Laboratory, 2020c), compared to a statewide average of 26.5% (Younes et al., 2020).

least the 65.8% renewable target defined herein). The same subject expressed disappointment over the persistence of such an argument in the face of what they believed to be a reliable refutation, similar to the persistence of what was believed to be a myth that Terra-Gen's electricity would not be used locally (Section 4.1.3).

Humboldt's poor solar resource also means that outside investors are unlikely to build (utility-scale) solar in the county, preferring projects further south due to the higher capacity factors and closeness of experienced labor, as two energy practitioners said.

4.1.7 The Role of Biomass

Biomass power is the subject for which my groupings aligned most closely with the perspectives of participants. Organizers were unanimously opposed to biomass, government officials unanimously supported it, and energy practitioners were mixed.

The primary criticism of biomass, expressed by every activist, is that biomass is not "the low-carbon fuel that the industry claims it is." Each expressed concern along the lines that it "takes forever to grow back these trees that are burned immediately." All prefer "waste diversion programs like industrial-scale composting or biochar production." Concern was also raised over diesel emissions during transport and the harmful health impacts of particulate emissions. These criticisms reflect remarks I make in Appendix E: The alternative fate of the biomass is critical to assessing their performance. Several interviewees indicated that since it is possible to sequester the carbon contained within the biomass via a biochar process, it is therefore incorrect to assume near-zero net emissions from burning it. While this viewpoint would also need to account for the cost of such a process, it is nonetheless a reasonable way to look at things.

Others expressed the same concern over emissions (though the government officials all believe that the biomass has zero net emissions) and health impacts, but several mentioned that Humboldt has "a lot of waste wood products, both from forest thinning and sawmills that needs to be disposed in an environmentally conscious way and producing electricity from them has a lot of potential." Several noted that biomass allows Humboldt County to burden outside areas less, since biomass can come from local sources while natural gas does not, which ties back to the discussion of distributive justice in Section 4.1.3 above.

Finally, two of the government officials pointed out that biomass is an important source of baseload power (necessary during nights and winters when solar production is zero or low), to help match the generation shape to the load shape.

4.1.8 Divergent Conceptions of the Future, and the Need for Discussion

It is clear from my interviews that Humboldt County residents espouse a variety of visions for the future and beliefs about factual claims. These include already discussed topics such as whether biomass is truly a net-zero source of electricity (Section 4.1.7), the veracity of carbon credit accounting (Section 4.1.3), and whether Humboldt can rely only on rooftop solar (Section 4.1.6). They also include myriad other questions like whether wind turbine blades are "unprocessable trash" or highly recyclable, and whether Terra-Gen's environmental impact report was thorough or inadequate.

As exemplified by the failure of the onshore wind project, these divergent views can stall renewable energy development. And for a particular case this may be a good thing or a bad thing. However, since all interviewees are strong proponents of renewable energy development in general, it seems that failure to speedily deploy renewables due to disagreement over the best way forward is in no one's best interest.

Dryzek and Pickering's (2019) concept of a deliberative democracy, and the associated concept of meta-consensus can be helpful here. Deliberative democracy describes the process of citizens and experts coming together to create "productive relationships across diverse values, judgements, preferences, and discourses" (Dryzek & Pickering, 2019, p. 141). In the process of deliberative democracy, "effective engagement of different discourses is crucial" (Dryzek & Pickering, 2019, p. 139). Because of the differences in the discourse brought to the table by various parties, it is unrealistic to expect them to quickly reach a consensus. Instead, Dryzek and Pickering focus on the *meta-consensus*, which requires "agreement on the legitimacy of disputed values . . . [and] the range of acceptable options." (Dryzek & Pickering, 2019, p. 141).

In the context of renewable electricity, such a meta-consensus could include assessment of the need and timeline for renewables development, the environmental impact assessment process, and the range of acceptable renewable technologies. While this may sound easy, it is certainly not. County residents showed deep disagreement over whether, for example, wind turbines are an acceptable technology, and the degree to which the perspectives of indigenous people should be the primary concern regarding developments within their historical territory.

There is a clear need for leadership in the role of orchestrating deliberative democracy. This study can aid in creating a meta-consensus by identifying a common basis, or at least the beginning of a basis, from which competing futures can be compared; however, it can do little to bring people together, where an active participant with more resources is needed. RCEA is in perhaps a unique position to take this step, given their centrality in energy planning, though other institutions, such as Humboldt State University, could also serve as orchestrator. The perspective of local tribal governments should be central to both the decision itself as well as the decision-making process and the creation of a forum for discussion. Here, too, Humboldt State University could provide valuable resources to the community by creating the physical space for such a discussion alongside a variety of relevant subjects of expertise.

The creation of a forum for discourse enmeshes with some of the ideas put forth by my interviewees, such as the importance placed on community viewpoints and the broader acknowledgement of indigenous perspectives and their absence in early discussions over the proposed onshore wind project.

4.1.9 Interaction with Development Scenarios and Analysis

Consistent with the views of interviewees, my analysis (with results presented in Section 4.2 below) focuses on the development of local renewables in a timeframe and scale that meets California's state-level climate change mitigation goals. The model was designed with the intent of providing insight into themes which my interviewees brought up:

Two energy practitioners emphasized the importance of looking at renewable energy projects in comparison to their alternatives. This meshes with my study methodology, which entails a side-by-side comparison of the options for renewable development along with the baseline, or "business as usual" case. More generally, interviewees had competing, and to some extent mutually exclusive, visions for the development of Humboldt County which is addressed by such a side-by-side-comparison, as discussed in Section 4.1.8.

Job creation was a crosscutting priority of study participants. In order to understand the creation of construction jobs enabled by the various developments, as well as on “long-term opportunities”, I accounted for long-term and short-term direct employment associated with renewable energy developments.

Ideas about whether solar was a viable source of energy in Humboldt did not appear to be extremely well founded. The best source for skepticism was a back of the envelope calculation (Lehman, 2019), while the supporters seemed to be going on faith. Several scenarios, discussed below, investigate this in different ways.

To address the disparate views regarding future reliance on biomass, I have included an energy scenario without biomass in my analysis, as well as a scenario with significant expansion of biomass-based generation; however, because the vitally important alternative-fate of the biomass has been thoroughly studied and found to have a variety of options, I have not focused on what to do with displaced biomass. See Redwood Coast Energy Authority (2020a) for further reading.

4.2 Quantitative Analysis

Scenarios, excluding business as usual (BAU), were iterated upon in order to develop generation and storage packages which meet the renewables target set forth in

Section 3.2.1: Having 65.8% of electricity used within the county generated from renewable sources. This resulted in the following six development variants:

A. **BAU**: The baseline, or "business as usual" (BAU) generation scenario, is based on extant, planned, and forecasted generation sources. Imports match the historical trend of 28.3% of county consumption (excluding distributed resources) (Ortega et al., 2020). No other scenarios include imports.

B. **Sol-300D**: Development of 300 MW of *distributed* (fixed tilt) solar PV and 103 MW / 410 MWh of battery storage. This system requires significantly more installed capacity than the single-axis tilt system, Scenario Sol-240U, below, because of both the absolute increase in KWh/KW and the flatter daily generation profile (resulting in more generation in mornings and evenings and lower midday overgeneration) that the single-axis system provides. No detailed assumptions about the location of storage are made, but cost estimates assume it is distributed[10] residential-scale storage with backup capabilities. Based on the assumptions of Ardani et al. (2016), 23,000 homes could serve a reduced, 33%, load for four days. Interconnection of solar at this scale would require revision of interconnection processes, may require substantial changes to the distribution grid, and this storage may *need* to be distributed alongside the solar panels to maintain grid stability.

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[10] This storage could be placed centrally, with the primary benefit being lower cost associated with economies of scale, and the primary downsides being removal of this potential resiliency benefit and increased stress on distribution lines.

C. **Sol-240U**: Development of 240 MW of utility-scale single-axis tracking solar PV and 88 MW / 352 MWh of battery storage.

D. **Sol-410U**: Development of 410 MW of utility-scale single-axis tracking solar PV and 180 MW / 720 MWh of battery storage. This reflects the increases in PV and battery, compared to scenario Sol-240U, necessary to enable removal of existing biomass powerplants.

E. **OSW-144**: Development of 144 MW of offshore wind (OSW) turbines in the Humboldt Call Area following Severy et al. (2020).

F. **Bio-65**: Implementation of a 65-MW biomass plant operating at an average of 61% output, following the standard in NREL's ATB (National Renewable Energy Laboratory, 2020a).

4.2.1 Electricity Generation

Table 9 breaks down the total renewable generation in each scenario into the quantity that must be exported and the amount that is curtailed.[11] Renewable generation is similar across scenarios, except for offshore wind development which generates significantly more electricity than the other cases. This is because it is the only variable generation source without storage, so generates the most energy which cannot be used locally. The flat generation source, illustrated by Bio-65, results in the lowest levels of exports and curtailment among alternatives to BAU. In general, exports and curtailments

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[11] Curtailment reflects electricity that can neither be used within nor exported from Humboldt County with its current transmission infrastructure. This electricity is, in effect, not used.

could instead be absorbed by flexible loads such as air-source heat pumps and electric vehicles with smart chargers.

Table 9. Renewable energy generation, exports, and curtailment, by scenario. A negative value for exports is used to indicate imports.

Scenario	Local Renewable Generation (GWh)	Exports (GWh)	Curtailments (GWh)
BAU	284	-253	0
Sol-300D	688	44	7
Sol-240U	684	45	7
Sol-410U	751	54	43
OSW-144	885	248	22
Bio-65	631	6	0

Power generation profiles by source are provided in Appendix G for reference. Scenarios with high levels of solar PV impart a high degree of seasonal variation on the Humboldt Bay Generating Station, indicating a potential challenge as renewables penetration increases towards 2045: Generation must match demand seasonally, but only does so relatively well in the OSW-144 and Bio-65 scenarios.

Transmission losses were not accounted for in the model and could vary significantly between scenarios. In California, transmission and distribution losses vary from 5.4-6.9% on average (Wong, 2011), and might be lower in all scenarios herein, since much or all electricity is generated locally. A distributed solar and storage system (i.e., Sol-300D), could have even lower losses, since much of the electricity generated would not utilize the electric grid at all. This effect would to some extent compensate for, and perhaps exceed, the effect of optimistic generation assumptions for the Sol-300D scenario (see Appendix F).

4.2.2 Costs, Emissions, and Generation by Renewables

Key statistics, including capital cost, net annual expenses (including fuel cost, O&M, import cost, and REC cost minus any revenue from export sales or REC sales, but without annualization of capital costs), associated annual emissions, and the share of renewables for each scenario are given in Table 10.

Table 10. Summary of studied scenarios. Capital cost represents a one-time investment; all other costs, revenues, and emissions are reported on an annual basis and do not include annualization of capital expenses. All dollar values are given in millions. MT = metric tons (or tonnes). Renewables share is defined as the share of renewable electricity in local consumption.

Scenario	Capital Cost, $M	Net Annual Expenses, $M	Emissions, MT CO_2-eq	Renewables Share
BAU	$0	$50.0	218,000	46.6%
Sol-300D	$589	$45.5	166,000	66.0%
Sol-240U	$222	$39.8	166,000	65.9%
Sol-410U	$403	$26.0	172,000	66.1%
OSW-144	$501	$37.8	133,000	65.9%
Bio-65	$270	$61.1	157,000	66.9%

Scenario Sol-240U (240-MW of utility-scale solar with 352 MWh of battery storage) and scenario Bio-65 (a 65-MW biomass plant addition) are significantly cheaper than the remaining options in the short term, requiring between 38% and 67% of their capital expenditures. The utility-scale solar scenario without biomass (Sol-410U) is 82% more expensive than the utility-scale solar scenario which maintains biomass (Sol-240U), reflecting the substantial investment that would be required to replace Humboldt County's extant biomass generation with other equally productive renewables.

Differences in annual expenses across the studied scenarios are quite substantial. Sol-410U, which reflects the maximum removal of fueled generation (biomass and natural gas) has the lowest annual expenses by $12 million per year. Offshore wind development results in the second-lowest annual expenses due in large part to an annual $8M export revenue from electricity sold outside the county. BAU and Bio-65, reflecting high reliance on natural gas and biomass, respectively, lead to significantly higher annual expenses than other cases, at least 22% higher than the next highest because of the need to constantly buy (more) fuel.

Emissions and renewable share also show significant variability across studied cases. Emissions in the lowest case, OSW-144, are 61% of those in the highest case, BAU. Emissions are lowest with offshore wind largely because the significant exports, shown in Table 9, help decarbonize the electricity grid outside Humboldt County. Because all scenarios depend on HBGS to the nearly the same extent, the local GHG emissions would be similar across the scenarios.

All three solar scenarios rely extensively on battery storage, modeled as utility-scale and distributed-scale parallel to the solar arrays. Some of this storage, however, could come from electric vehicles (EVs) with vehicle-to-grid (V2G) charging.[12] This could lower the capital cost of these systems if EVs are independently deployed with V2G chargers. Analysis of this possibility is outside of the scope of this document, but it is safe to say that the total storage required would be larger, since not all vehicles are

[12] Otherwise known as bidirectional charging, V2G allows the EV to provide power to the electric grid.

available all of the time, requiring on the order of ten thousand of electric vehicles with bidirectional chargers (which many would argue is a necessity in and of itself).

4.2.3 Levelized Cost of Local Electricity

The levelized cost of local electricity (LCOLE) used within Humboldt county is shown in Figure 4. In calculating LCOLE, I did not include the energy exported from the county as would typically be done in an LCOE (levelized cost of electricity) calculation. Rather, I subtracted the revenue generated from the sale of this electricity (see Section 3.2.4) from the system operational costs.

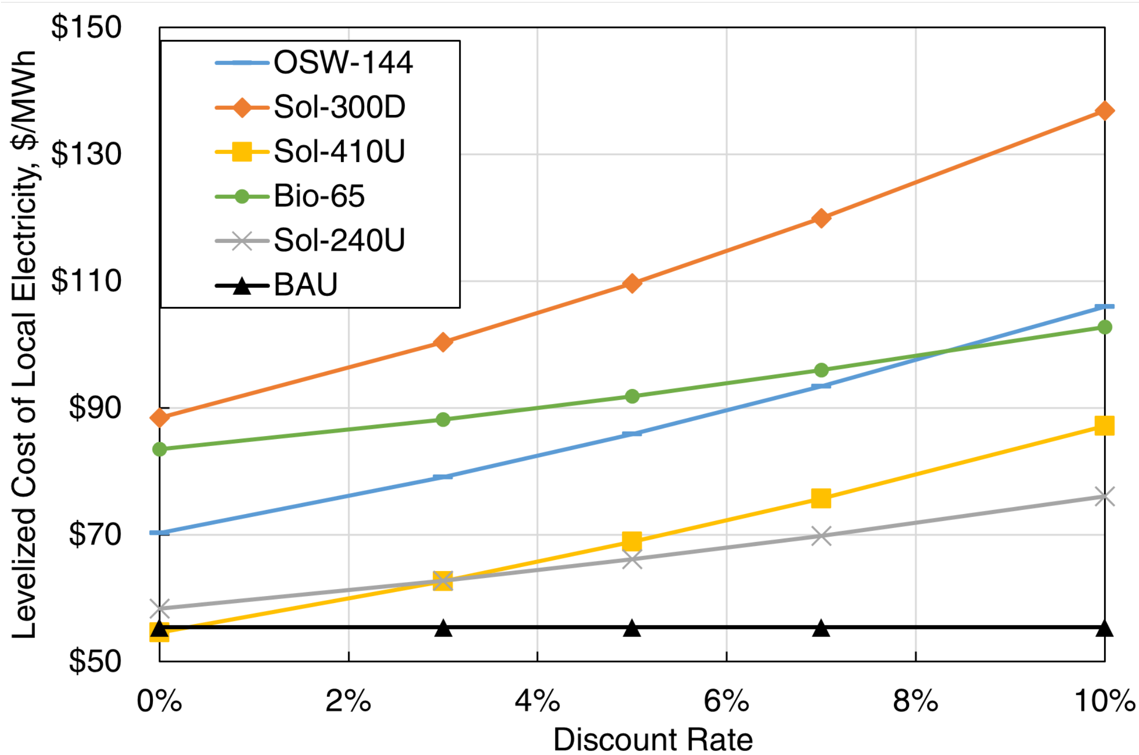

Figure 4. Calculated LCOLE values for a range of host discount rates and a project lifetime of 20 years. Per NREL (2020d), the lifetime of some of this infrastructure would be longer, and storage requires replacement after 15 years, which was included.

The costs of local renewable energy development to meet the 65.8% renewables penetration target under any of the presented scenarios would increase the cost of energy delivered to Humboldt County residents over the baseline scenario at discount rates above 1%.

Among the studied alternatives to BAU, Sol-240U is the cheapest solution at moderate and high discount rates while Sol-410U is close behind and cheaper at very low discount rates. This means that the extant biomass plants provide clean power to Humboldt at barely a lower rate than new solar plus storage (or at a higher rate, depending on discounting).

An interesting comparison can be made between the OSW-144 scenario and the Sol-410U scenario: Because exports in OSW-144 exceed the historical production by the biomass facilities, with some storage or different accounting methods, the offshore wind project could be thought of as replacing existing biomass. Nevertheless, this appears to be a more expensive option than solar plus storage. One of the main benefits is the potential for a local offshore wind project to serve as a pilot for larger projects, thereby attracting grant funding.

Because many of the costs associated with a biomass system are incurred in the future, higher host discount rates make the Bio-65 scenario more financially viable relative to distributed solar or utility-scale wind, though never cheaper than either utility-scale solar scenario.

4.2.4 Uncertainty in LCOLE

As shown in Figure 5, uncertainty in forecasts of infrastructure costs in 2030 lead to uncertainty in the LCOLE. Based on the variation within the model, a few “certain” conclusions can be drawn about the LCOLE at a 5% discount rate. These include: BAU is the cheapest option. Sol-240 is cheaper than Bio-65, which is in turn cheaper than Sol-300D. Sol-410U and OSW-144 could be cheaper or more expensive than Sol-300D or Bio-65 in 2030. Of course, these error bars do not describe the total range of possible “true” LCOLE values, as each only represents a caricature of what the real project would be. Moreover, the BAU and Bio-65 cases must have uncertainty in future pricing, but variability was not captured in the model inputs.

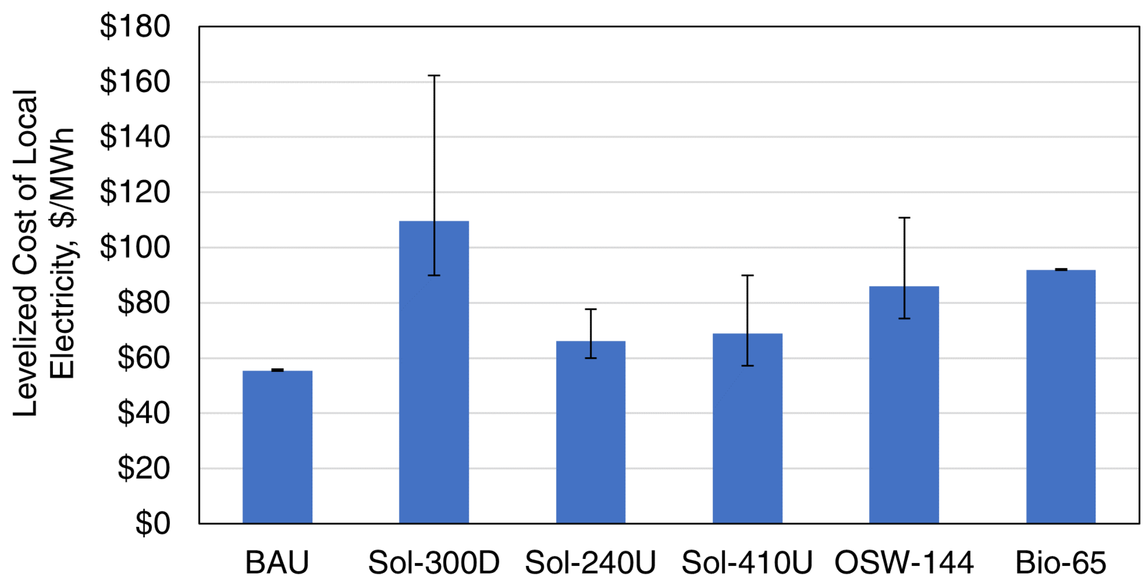

Figure 5. Point estimates of LCOLE at 5% discount rate, alongside error bars which describe the range of possible values due to uncertainty in infrastructure costs.

In addition to the variability in generation infrastructure prices shown, PG&E, the regional utility, performed a study which concluded that an additional $669 to $1,340 million in transmission upgrades were necessary to maintain grid stability with 144 MW of offshore wind (Pacific Gas and Electric, 2020). These are not otherwise reflected in this analysis and would drive the already substantial costs of offshore wind development even higher. That said, substantial transmission and/or distribution upgrade costs could be required in any of the investigated scenarios, and PG&E's study assumed full deliverability of electricity, without which transmission upgrades may be substantially cheaper. Furthermore, other systems may have additional unaccounted for costs, such as the electrical upgrades in older buildings necessary to prepare them for rooftop solar installations.

4.2.5 Funding Sources and Considerations

While all the alternatives to business as usual will require investments on the order of hundreds of millions of dollars (see Table 10), this investment wouldn't necessarily come from the same sources. Distributed PV would most likely be funded mostly by homeowners, with a significant federal subsidy in the form of investment tax credits based on current policy (DSIRE USA, 2021a). The remaining projects would most likely be funded by outside investors (as many interviewees noted), with offshore wind most likely to attract grant funding due to the potential for a 144-MW project to serve as a pilot for much larger projects. Recently, the Biden administration announced $3 billion in federal loan guarantees for offshore wind alongside $230 million in funding for port infrastructure to support offshore wind (The White House, 2021), funding that Humboldt is well positioned to capture a portion of. Biomass and offshore wind are both currently eligible for production tax credits as well (DSIRE USA, 2021b). Outside investors have already shown an interest in developing renewable energy in Humboldt County, while homeowners may not have the capital outlay. That said, resilient solar PV plus storage projects, from which the Sol-300D scenario could be composed, have attracted state grants, as exemplified by the microgrid at Blue Lake Rancheria which attracted $5 million in state funding (Gould & Barkalow, 2017), and homeowners can finance PV systems through a mortgage, PACE (property assessed clean energy financing, discussed below), or other source.

Current subsidies in the form of investment tax credits (ITCs) for solar and production tax credits (PTCs) for wind and biomass incentivize private investment or public-private partnerships over public investments because public entities don't have a tax burden to offset with credits (American Public Power Association, n.d.). Based on the current incentive rates, studied offshore wind and biomass scenarios have a potential annual PTC of 8 and 4.5 million dollars, respectively, while the Sol-240U, Sol-410U, and Sol-300D would be eligible for one-time ITCs of 39 million, 67 million, and 89 million dollars, respectively. That said, by 2030, these credits may be much closer to zero. Based on current legislation, ITCs will reduce from a present value of 26% to 10% after 2025 (though any legislation passed in the years before 2030 could result in a higher or lower subsidy in that year), which would reduce the above numbers to 15, 26, and 34 million, respectively. These substantial reductions to LCOLE are not reflected in Table 10 or Figure 4.

PACE financing is one potential private-public partnership model that could take advantage of solar ITCs. Under a PACE financing model, the capital outlay for a clean energy project, such as PV or storage, is provided by a government body (such as RCEA, or Humboldt County), and recuperated through property tax collection. Unfortunately, PACE loans are often provided at unfavorable rates in the range of 8% (National Consumer Law Center, 2016). There is potential for an entity such as RCEA to seek funding through a bond or other measure to enable cheaper financing.[13]

4.2.6 Discounting of Future Costs and Benefits

I used Figure 4 to illustrate the inextricable link between discounting of future costs and which energy systems are most economical. For example, Sol-410U is cheaper than Sol-240U at discount rates below 3%, while Sol-240U is cheaper at higher discount rates. Broadly, the discussion of which systems are most economical must account for the cost of carbon emission, a parameter which is highly uncertain and with a value linked to discounting of future costs and damages. Estimates range from $10 to $200 per ton of CO_2 (Pindyck, 2013) to as high as $2,700 to $205,000 ($10k to 750k per ton of C) (Archer et al., 2020). I will not focus on this discussion, but I have provided estimates for the annual cost of Humboldt County's emissions for each scenario in Table 11, below, which show that under differing assumptions the cost of carbon can vary from relatively minor to far greater than the capital costs associated with renewable energy projects.

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[13] This suggestion was made by RCEA's community advisory committee and is currently being evaluated.

Table 11. The range of annual costs associated with emissions based on Pindyck (2013) and Archer et al. (2020).

Scenario	**Emissions, MT CO_2e**	**Annual carbon cost at $10/ton CO_2e**	**Annual carbon cost at $205,000/ton CO_2e**
BAU	218,000	$2,200,000	$45,000,000,000
Sol-300D	166,000	$1,700,000	$34,000,000,000
Sol-240U	166,000	$1,700,000	$34,000,000,000
Sol-410U	172,000	$1,700,000	$35,000,000,000
OSW-144	133,000	$1,300,000	$27,000,000,000
Bio-65	157,000	$1,600,000	$32,000,000,000

Discount rates are less variable, ranging from 0% to about 30% across a range of circumstances. The social discount rate, R (which is related to the earlier discussion of distributive justice and the concept of intergenerational equity) can be calculated according to the Ramsey equation (Archer et al., 2020; Pindyck, 2013; Ramsey, 1928):

$$R = \delta + \eta g \qquad \text{Equation 8}$$

The social discount rate, R, is a function of the expected capital growth rate, g (i.e., the rate at which we expect society's wealth to increase), and the rate of time preference, δ (i.e., whether we care equally about the present and future) as well as risk aversion, η, which drops out of the equation under the assumptions accepted below. Stern argues that "if a future generation will be present, we suppose that it has the same claim on our ethical attention as the current one" (Stern, 2007), leading to the assumption that $\delta = 0$, an argument which Archer et al. (2020) follow. While the recent capital growth rate, g, has been around 1.5-2% (Pindyck, 2013), Dasgupta et al. argue that "over the long haul of time (say, a few thousand years), the rate of growth of per capita income has not been much more than zero" (Dasgupta et al., 2000, p. 14), and Archer et al. (2020) argue that, in the long-term we must reach a steady state economy (this assumption is perhaps a bit contentious), also justifying $g = 0$. Following these assumptions leads to an *ethical* social discount of 0%. At such a discount rate, the focus draws to the left side of Figure 4, where utility-scale solar (Sol-240U and Sol-410 U) appears to be the most economical solution, as it is on par with or cheaper than business as usual even before counting the cost of carbon.

While the 8% interest rate common to PACE loans is high for most homeowners in the current lending environment, energy projects in the OECD (Organisation for Economic Co-operation and Development) have costs of capital, and thus discount rates, in this range (when taking on a loan one's discount rate is generally equal to the interest rate one pays). Steffen (2020) documents OECD costs of capital to have been 5% for solar projects and 8% for offshore wind projects between 2009 and 2017. Under this range of discount rates, biomass and distributed solar PV are the least financially viable, but distributed PV would most likely be partially funded by private individuals who have their own discount rate, which literature suggests to be anywhere from 0% to 30%, with one study calculating it to be over 17% for a large (somewhat homogenous) group (Warner & Pleeter, 2001).

Were cheap – say 3% -- financing available for the Sol-300D project, (discount rates would then be 3%) annualizing costs over 20 years would result in net annual cost increase (accounting for the annualized capital cost and decrease in annual expenses shown in Table 10) of 35 million dollars per year to the county. With a per capita income of $27,00 and a population of 136,000, this is 0.95% of residents' $3.7 billion annual income.

Offshore wind, biomass, and distributed solar *could* be feasible investments for outsiders, but utility-scale solar appears to provide the most economical investment options for local generation by renewables across all discount rates considered. Utility-scale solar is only cheaper than business as usual under the socially optimal discount rate of 0% or when considering the cost of carbon. Distributed resources are only economically attractive to those who consider the cost of carbon or other "hidden" costs related to energy, and will continue to find funding through local measures and private individuals and firms who embed concern for the future into their decision making.

4.2.7 Job Creation

Net impacts, including reduction in biomass use in the Sol-410U case, are shown in Table 12. Construction jobs are shown in units of job years, meaning that if a project shows 10,000 job-years, they could be in the form of 5,000 two-year jobs, 2,000 five-year jobs, etc. In the highest case, Sol-300D could represent over 700 decade-long construction and installation jobs, and an equal or greater number of ongoing maintenance positions.

Table 12. Quantification of direct job creation in studied scenarios, including construction and installation (C&I), and permanent jobs through operations, maintenance, and fuel collection. Construction jobs are given in terms of job-years.

Scenario	**C&I Jobs (job-years)**	**Increase in Permanent Jobs**
Sol-300D	6,054 – 14,814	202 – 1,102
Sol-240U	2,486 – 5,990	83 - 443
Sol-410U	4,568 – 10,554	2 - 617
OSW-144	1,022 – 1,282	13 - 29
Bio-65	910	245

Variability within the predictions is significant, with a factor of two across predictions of construction and installation jobs for solar, and a factor of five in predictions of long-term jobs for solar. Nonetheless, high-solar scenarios are associated with the most short-term and long-term employment, with significant variation in predictions based on uncertainty in the job intensity of solar projects. Ram & Aghahosseini (2019) assume that distributed-scale solar and batteries have twice the job intensity of utility-scale projects, and that coarse assumption flows into the results presented above, thus, the model predicts that distributed solar produces the most long-term jobs. Eliminating local biomass entirely, as depicted in scenario Sol-410U results in more short-term jobs due to the higher demand for utility-scale solar and storage and uncertainty as to whether long-term jobs are increased or decreased relative to Sol-240U.

Utility-scale solar and biomass would result in similar numbers of permanent jobs, while offshore wind is associated with the fewest permanent jobs by far, but this accounting does not include effects of port infrastructure upgrades and possible associated job creation.

Because O&M jobs are calculated on a per-MW bases and not a per MWh basis, the reduction in HBGS output does not reduce employment in this model. Based on the employment factors I used, HBGS employs 23 people and some or all of these jobs could disappear in the medium-to-long term.

4.2.8 Land-Use Impacts

This section provides a brief overview of the land-use, or area-use impacts of the technologies studied herein.

4.2.8.1 Offshore Wind

The footprint of a 144-MW offshore wind development near Humboldt, composed of twelve 12-MW turbines would have an area of 37.8 km^2, equal to 14.6 square miles, or 9,340 acres (Severy et al., 2020) of open ocean. This would impact the ocean environment and the fishing industry.

4.2.8.2 Biomass

In the highest biomass scenario, which entails construction of an additional 65-MW biomass plant, total electricity consumption from biomass would be 557,000 MWh, requiring 625,000 dry tons of biomass annually. A study of county-level biomass availability in California estimated Humboldt County's technically recoverable potential for forest residues (including thinnings, slash, mill residue, and a small fraction of shrub) to be over twice as large, 1,313,500 dry tons (Williams, 2008). Humboldt County, therefore, has adequate forest land to provide the necessary biomass in this scenario.

4.2.8.3 Utility-Scale Solar

In the largest scenario (Sol-410U), 410-MW of presently unplanned utility-scale solar would be developed in Humboldt County. This is in addition to 15-MW solicited by RCEA, and 2.25 MW at the Arcata airport. It therefore makes sense to investigate siting 525-MW of utility-scale solar and ignoring the 2.25 MW already planned to be sited at the Arcata airport. This would occupy 3,100 acres (a 240-MW installation as in Sol-240U would consume 1,900 acres) of land in Humboldt County, about 0.12% of the total county land-area (County of Humboldt, n.d.). A more apt basis for comparison may be to Humboldt's agricultural land, which consists of 354,238 acres (County of Humboldt, 2003), of which this utility-scale developments would occupy 0.9%. Assuming this is developed over the intervening years, the conversion rate from agricultural land would be approximately equal to the “background” rate of land transformation (County of Humboldt, 2003). For visual reference, a 1,900-acre parcel is shown in Figure 6. This is a significant area, quite similar in size to downtown Arcata. Note that the location shown is not a proposed location, it is for reference only.

The footprint in Figure 6 does not include the impact of the associated storage system because it is negligible by comparison. Based on the specification sheet for the Tesla Powerwall (Tesla, 2020), 352 MWh of storage would occupy under one acre, not including space for walkways and environmental protection. Even if this increased the space requirement tenfold, it would only add 0.5% to the system footprint.

Figure 6. Depiction of 1,900 acres relative to the city of Arcata, an equivalent size to the land area that would be occupied by 240 MW of utility-scale PV. Location shown for reference only, it is not a proposed or suggested site.

4.2.8.4 Rooftop Solar

In the highest-case scenario, 300 MW of solar are added to the “baseline” prediction of 30-MW in 2030, totaling 330 MW of rooftop, or other small-scale solar. As determined in section 3.3.4, there is a technical potential for about 367 MW of rooftop solar across all buildings. This provides quite a small margin, and due to uncertainty could over or under-estimate the potential, as discussed below.

Because Gagnon et al.’s (Gagnon et al., 2016) study allowed for some degree of shading and other-than-optimal tilt and azimuth angle compared to my analysis (as noted above, their study excludes areas of excessive tilt, shading, or northward orientation) this result could overstate the potential. On the other hand, following the lead from some of my interviewees, roadsides and parking lots could be developed into solar resources as well. This is, however, likely to be more expensive due to the cost of interconnection and parking cover structures, respectively, so may better provide the final 34% of renewables developed between 2030 and 2045. Furthermore, as noted by Gagnon et al., module efficiency, among other assumptions, play a vital role in the result: “If a module efficiency of 20% were assumed instead [of 16%], which corresponds to current premium systems, each of the technical potential estimates would increase by about 25% above the values stated in this report.” (Gagnon et al., 2016, p. vii). Finally, assumptions regarding the available rooftop area in Humboldt County were extrapolated from country-wide trends, and have significant potential for error built in. The implicit assumption is that no buildings require re-roofing or upgrades to electrical panels, which would drive the system cost higher or the available stock lower (or both).

4.3 Second Interviews

I found the material which I used as the backdrop of the second set of interviews to be paradoxically helpful and unhelpful in creating structure. Materials included a summary of the scenarios I developed, their capital costs, and their associated emissions (like Table 10), levelized cost of energy (like Figure 5), and a summary of JEDI (jobs and economic development) results (like Table 12, but including estimates of local economic growth, which I have since eliminated), plus miscellaneous backup materials. The extent to which the conversation focused around any of these varied considerably. Participants were, overall, not tremendously moved by technical details and the aforementioned slides filled with tables and charts. Some interviewees were skeptical of the assumption that biomass was a near-net-zero electricity resource. Others were not concerned with the differing costs I showed, as they contended that my accounting did not include critical costs and benefits, such as reduced emissions, increased land-use or preserving the lives of, for example, a desert tortoise (which are all true). Still more interviewees remain skeptical of distributed solar as a resource due to concerns over the distribution network, age of local housing stock (i.e., needing upgrades to roofs and electrical panels), or concerns of perpetual panel soiling by redwood duff. Yet at the same time, these charts and tables provided a valuable starting point and structure for the discussion. Participants could clearly state what they found convincing, what they found moving, and had a clear way to take issue with my assumptions and conclusions. I believe this mixed interview process to be a valuable way to structure a discussion, though it is critical to keep in mind that the quantitative analysis is a starting point, rather than an ending point for discussion.

The second interview process was akin to observing a public hearing in which a project proposal is put forth, except that instead of overhearing discussions, I talked to participants directly. But, because I focused on soliciting their opinions, it was like observing the thoughts of meeting participants. To the degree that my presentation was like a typical public meeting (one significant difference being that the fate of no infrastructure development was at stake in the context of my interviews), the fact that people didn’t totally engage with it may be a substantial critique of current processes. Such meetings may benefit from focusing more on storytelling than on technical details.

4.3.1 Reiteration of the Economic Growth Priority

Participants often preferred developments that they thought would support the local economy the best, which was conceptualized in differing ways. One interviewee stated a preference for biomass because it created the most local jobs (by the analysis I showed them, see Appendix B), and would keep the logging industry, perceived as an important source of local jobs, economically viable. This participant also found it important that biomass was the cheapest option (from a capital cost perspective), and could, in their view, be completed the most quickly. Another stated a preference for offshore wind *because it was more expensive*, and if Humboldt County brings in outside investment, it should be as large of an investment as possible to maximize local economic growth. This participant also stated a desire *not* to prop up the timber industry, which they viewed as detrimental. To reiterate, both participants agreed that biomass power was the cheapest option and would support the local logging industry, but one felt both to be points in favor, while the other saw both as points against. Yet another supported offshore wind overall, but found the jobs created by the biomass industry to be motivating and a significant justification for its existence, threading their needle through a middle path. Finally, one participant supported a preference for distributed solar by asserting that it would keep the most money in the local economy, as well as lowering residents' utility bills.

4.3.2 Importance of Global Emissions Reduction

Participants had made clear concerns over global warming and the need to develop low carbon electricity, but it was only when given side-by-side options that it really became clear to me how much many of them prioritized the option which could lead to state-scale decarbonization: offshore wind. Many participants were moved by the lower emissions I calculated for offshore wind (based on accounting for the emissions reductions related to exports), or more broadly the idea that offshore wind was a resource that could make an impact beyond Humboldt County by exporting low-carbon electricity.

Not all participants saw it this way, however. One participant, who was extremely moved by the exigency of the climate risk, framing it as a cause of past, present, and future death, and an existential risk to the human species, preferred solutions which focus on decarbonization via solar PV, and afforestation. They saw this as the best solution because it would least disrupt forest ecosystems and thereby allow for the most carbon sequestration.

4.3.3 Which Comes First, Means, or Ends?

Differing levels of concern over funding were also apparent, overlying deeper differences in conceptualization. One participant saw every option as likely too expensive to be feasible, while another was unabashedly unconcerned with funding sources, stating that, since these projects provided net benefits (including health and GHG emissions reductions, etc.), societies must invest in them, and the federal government should take the lead in this. The same participant displayed a similar line of thinking regarding the impact of biomass power on jobs. They disagreed with my assessment of job loss due to potential closure of existing biomass plants because, in their view, we need to continue to clear brush to mitigate wildfires, so the need for fuel related jobs remains. That is, the work must be done, and they were not concerned over how forest health maintenance would be funded.

Other participants focused a great deal on funding, displaying dejection at the tremendous costs and implausibility of finding the funds for any of them, while others conveyed a preference for options which they believed to be the most likely to receive outside funding.

I conceptualize the fundamental difference between these two camps as a focus on means versus a focus on ends. One group focuses on the most realistic means (funding) and selects the end (project) best aligned with that, while the other selects the most desirable end (project), and believes that we, societally, must put our effort into creating the means (funding) for that project, whatever it takes.

Yet this binary framework has room for a range of opinions at each end. Another participant focused first on the ends, which in their eyes was large-scale (global) decarbonization. For this goal, offshore wind (potentially at larger scale than studied) is the most apt solution because it can reduce statewide emissions more than any other option. So, while two participants focus on ends first, the way in which they articulate those ends leads to different development preferences. Said another way, focus on means or ends does not predict support for, or opposition to, a particular project.

4.3.4 Appropriateness and Gestalt

I mentioned earlier (in Section 2.1) that Hoen et al. (2019) found that community perception of a project as appropriate and effective increased project acceptance. This is a phenomenon that I observed firsthand, as illustrated by one interviewee who articulated their support for PV over other electricity sources by saying that "the production of energy should not require flame, it should be like photosynthesis. It should be electron transfer, it should not be the turning of the wheel, you know, 19th century stuff. It should be 21st century stuff." In contrast, another interviewee supported offshore wind because of its efficiency in the region. Both interviewees use the language of appropriateness but disagree about which technologies are 'appropriate' for the region. These sentiments were mirrored by the same interviewees' assessment of the appropriateness of the manufacturing process associated with these technologies: one supported offshore wind because it is "just steel and concrete," while the asserted that since most of the process for deploying PV happened in a factory, the environmental impacts were far more controllable.

As I mentioned in Section 3.1, interviewees were selected in part due to their active roles in the local energy discussion. Though it would be a mistake to generalize my observation that each interviewee had a relatively complete vision of the future of Humboldt's energy, the people I spoke to each saw their energy solution as part of a *gestalt*. That is to say that they saw their preferred energy fitting into, for example, a booming green energy market, or a *Small is Beautiful* style world. This observation evokes the earlier discussion of economic priorities (Section 4.3.1), in which mutually accepted facts lead to different conclusions because of differing prioritizes and conceptualizations.

This, I think, is the most important point that I gleaned from the second interviews: People support the projects they view as the most appropriate. For example, one interviewee saw offshore wind as a more efficient way to develop local power than utility-scale solar with storage, despite the latter option cheaper (perhaps they were unconvinced by my economic analysis, but they did not raise issue with it). Their view was that Humboldt County has an excellent wind resource, but a poor solar resource, and thus it was more appropriate to develop offshore wind within the county. To support a project, I believe residents must see it as part of a vision for the future, and therefore developing support for a project requires either subsuming a project into an appealing *gestalt* or creating a new and appealing vision.

4.3.5 Outlook

Responses ran from cool optimism, those encouraged by the abundance of viable options suggested by my results, to some who were morose, viewing all proposals as too expensive and politically uncertain (in the wake of the onshore wind project's rejection) to move forward. One participant, who was deeply distraught over a paper which argued that the *Homo sapiens* are "destined for extinction in the near term," (McPherson, 2020) was nonetheless optimistic about our ability to curb global climate change via a tremendous, and concerted effort.

4.3.6 Development Preference

I asked each interviewee to state which pathway they prefer, depicted in Table 13. There was no convergence of opinions, and there is still a need to focus on creation of a meta-consensus across the broader community, as discussed in Section 4.1.8. I should reiterate my earlier point that while I showed the same statistics to participants, their takeaways were often diametrically opposed, even when they believed those statistics to be true. Finally, I should note that interviewees did not have concretized opinions on projects (apart from die-hard supporters of distributed PV), and were largely giving preliminary or tentative support for projects (for example, pending studies of the ecosystem impact of offshore wind).

Table 13. Stated Development Preference of second interview participants.

Scenario	Frequency as First Choice
Sol-300D	2
Sol-240U	1
Sol-410U	
OSW-144	4
Bio-65	1

While several interviewees were optimistic because of the range of available options, the takeaway of one focused on the idea that, given the range of potential options, Humboldt county has the further option to mix and match, applying distributed solar (with batteries) where the resilience would matter most, like hospitals and wastewater treatment facilities.

CHAPTER 5 CONCLUSIONS AND NEXT STEPS

My techno-economic analysis suggests that Humboldt County has a variety of reasonably cost-effective sources of renewable electricity, including offshore wind, biomass, distributed solar, and utility-scale solar. While all these resources are more expensive than business as usual under most discount rates, many of them are less than 30% more expensive across a range of discount rates. Giving equal weight to the concerns of future generations, and assuming that economic growth does not rise far into the future, developing utility-scale solar PV in 2030 would have a long-run cost equal to that of continuing business as usual, *before* taking into account the societal cost of carbon emissions.

It is worth noting that in the year this project has taken, some of the baseline assumptions have already become outdated. Fairhaven (a biomass plant) is extremely unlikely to continue operation, halving the baseline biomass derived electricity, while RCEA is planning expansion of local hydropower which would partially make up for this. Additionally, RCEA is planning about 12 MW / 48 MWh of storage paired with commercial-scale solar, unaccounted for in my model (and reducing planned solar by 2.5 MW versus my assumptions). Finally, Fairhaven's valuable interconnection rights are likely to be used by some sort of generation-storage facility (J. Gwyn, personal communication, March 5, 2021). Of course, all of these facts are likely to change by 2030, so any future studies should begin with a reevaluation of baseline assumptions.

If the results of my interviews generally hold across the residents of Humboldt County, they care about climate change and support renewable electricity generation in general. It is equally clear that residents have divergent views about what these developments should entail. Some support a future of exclusively small-scale solar projects, while others support extensive use of utility-scale biomass. Some espoused support for the onshore wind, while others instead focused on the importance of community engagement in planning.

RCEA has presented at least two plans for project funding, both of which also involve their leadership in project selection. These are a feed-in tariff program that has helped improve the economics of local solar, as well as an "energy resilience revenue bond" (Redwood Coast Energy Authority, 2018, 2020d). Continuing these processes is critical for the folks who support utility-scale developments.

Any separation into groups is artificial, but based on my interviews, I think the following has merit: People who support only distributed systems versus those who primarily support utility-scale development. As I described in Section 4.3.3, I think it is reasonable to view these groups as ends-focused versus means-focused, or perhaps "idealists" versus "realists" (a categorization that the first group may take issue with). Based on the conversations I had as well as the results of my analysis, I do not think that either group has an unreasonable or unrealistic position. Distributed resources *are* more economically expensive but come with undeniable reductions in footprint that cannot be easily compared against their fiscal costs. The idea of post-grid electricity systems relying solely on distributed resources is beginning to make its way into academia

(Callaway, 2020), likely due to the meteoric fall in PV prices over the last few decades (International Energy Agency, 2020), and speculation that storage costs may follow. Finally, these projects could reasonably be funded by the mechanisms outlined above that RCEA is already pursuing.

The proposed onshore wind project highlighted the potential for projects to be serially rejected based upon their absolute faults instead of being assessed on their relative merits. RCEA's present goals of generating 100% of Humboldt's electricity from local renewables is not specific enough to counteract this possibility, but they could mitigate this by bringing residents and stakeholders together to democratically create a united vision for the future of renewables in Humboldt. Based on my analysis, there is no shortage of technically feasible solutions; what remains to be done is to pursue those with the greatest economic, social, and political appeal. A study of distributed resources could be a step towards developing a shared understanding, leading to the necessary support.

I believe that both groups would benefit from the same type of research. While the distributed camp is not in need of a political movement to continue development (the public planning process, which rejected the onshore wind project and could prevent other utility-scale projects from being developed, doesn't apply to distributed projects, so there is no corresponding way to block them), decarbonization goals require that they work towards a broad program or number of programs (like RCEA's tariff and bond measure mentioned above) in order to hasten deployment of distributed PV. Such a program would require a thorough account of Humboldt's building stock and possible funding mechanisms, a study with much more specificity than this one. Utility proponents have a somewhat tougher political path given that they have experienced direct opposition. One plausible strategy for them would be to outmuscle detractors of utility-scale projects, but it is unclear whether they have the political strength (and rejection of the onshore wind project indicates that they may not). A less contentious approach would be to create a detailed plan for solar PV development which shows whether this resource can economically support the county's demand. If it cannot, which is possible, although my analysis does not show this, then the opposition may be moved to join forces. If it can be done, it would again appear reasonable for the two groups to ally, since none of the utility proponents opposed distributed resources in principle, but rather saw them as inadequate. The point here is that a serious, thorough, and realistic study of distributed resource potential appears to be an important step towards collaboration and mutually beneficial progress.

Whatever the technological path, distributive and procedural justice are core concerns of Humboldt residents. To be successful, any proposal must account for the distribution of burdens and benefits and must follow a fair process. These were seen as core failings of the proposed onshore wind project – and reasons for the project's rejection – by several whom I talked to.

An important lesson which I believe would hold for similar projects (and eventually community engagement in planning), is the inadequacy of having such a discussion over only two conversations. While the first interview was an excellent way to open the conversation, interviewees, except perhaps participants who were subject matter experts, were overwhelmed or confused by the amount of new information which I brought to the second meeting. While I found the core idea of discussing specific, viable scenarios to be helpful, an intermediate session which introduced scenarios before showing results would have smoothed the process. At least three meetings are necessary to have this type of conversation, and of course more would be even better. Here, I would like to again emphasize the tiny sample size of my study: ten people out of a county of over 130,000 residents. In addition to increasing the number of meetings, increasing the number and representation among residents in a follow-up study would be tremendously valuable. Furthermore, I acted as the "hub" of a set of bilateral conversations, which is not a good model for a democratic process (though it seems to have worked well for research). In future planning processes, it will be important to create an environment where sustained, democratic, multi-party discourses can take place.

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APPENDICES

Appendix A. First Interview Guiding Questions

The questions which I used to guide the first interview are shown below in approximate order. As noted in Section 3.1, these questions were not strictly asked in order, but used to loosely guide the interview process.

1. First, can you tell me a little about yourself? Which, if any, organizations are you affiliated with?
2. When it comes to Renewable energy development in Humboldt, what are the things that you think are most important to talk about?
3. What is the most important information for you to know about a project?
4. What, if any, preferences do you have regarding type of renewables development, and funding source?
    a. What factors or concerns that feed into your preferences?
        i. What negative outcomes are concerned about [e.g. bird deaths, land-use]?
        ii. What positive outcomes are you excited about [i.e. local jobs, reduction in logging, etc.]?
5. What other thoughts do you have about renewables in Humboldt County?

Appendix B. Second Interview Guiding Information

The below is a duplicate of the document shared with interview participants in advance of the second round of interviews, reformatted to match the rest of this document. Additionally, greenhouse gas emissions, as depicted in Table 10 of the main document, were frequently discussed. Numbers presented in this appendix generally differ somewhat from those in the body, since these were based on a differing set of assumptions that evolved over the course of the project. Job and economic development were estimated here using a tool by NREL but use of this tool required so many assumptions that I later pivoted to using a simpler dataset and omitting economic development estimates.

This document is intended to frame our upcoming discussion. I am hoping that during this time, I can answer your questions and hear your reflections upon these results, particularly anything which you find interesting, surprising, unbelievable, or motivating. Based on the first set of interviews, I have created and analyzed six scenarios of renewable electricity generation in Humboldt County, one "business as usual" case and five alternatives. Each alternative reaches 66% local, renewable electricity, which is the amount that I project California will reach in 2030 when combining distributed sources with the mandated 60% for utilities. The six Humboldt County scenarios are:

A. **BAU**: The baseline, or "business as usual" (BAU) generation scenario based on extant, planned, and forecasted generation sources. BAU reaches 31% renewables with 40 MW of biomass and 47 MW of solar photovoltaics (PV).

B. **Sol-300R**: BAU + 300 MW of *distributed* (mostly residential) solar PV and 460 MWh of battery storage. This occupies 90% of the estimated usable roof space in the county.
C. **Sol-225U**: BAU + 225 MW of *utility-scale* solar PV and 460 MWh of battery storage. This occupies 2,100 acres, about the size of Arcata.
D. **Sol-375U**: BAU + 375 MW of *utility-scale* solar PV, 900 MWh of battery storage, and removal of existing biomass.
E. **OSW-144**: BAU + 144 MW of offshore wind (OSW) turbines near Humboldt Bay (following the Schatz Center's research). This is located 20-30 miles offshore, occupying 15 square miles.
F. **Bio-65**: BAU + a new 65 MW biomass plant and a 10% increase in the output of existing biomass plants. This would consume 50% of potential forest and mill residues in the county.

Combining construction and annual costs for each scenario leads to the levelized cost of local electricity depicted in Figure B-1. PG&E's generation charge, the horizontal grey line, is included as a reference, but is not directly comparable to the cost of generation depicted by each bar. Nominally, utility-scale solar plus existing infrastructure (Sol-225U) is the cheapest alternative to business as usual, while distributed solar is the most expensive. All options (nominally) fall between the current calculated cost of electricity and PG&E's electricity charge. Significant uncertainty could lead to any option truly being cheapest in 2030, though correlation between scenarios mean that, for example, it is unlikely for distributed solar to be cheaper than utility-scale solar.

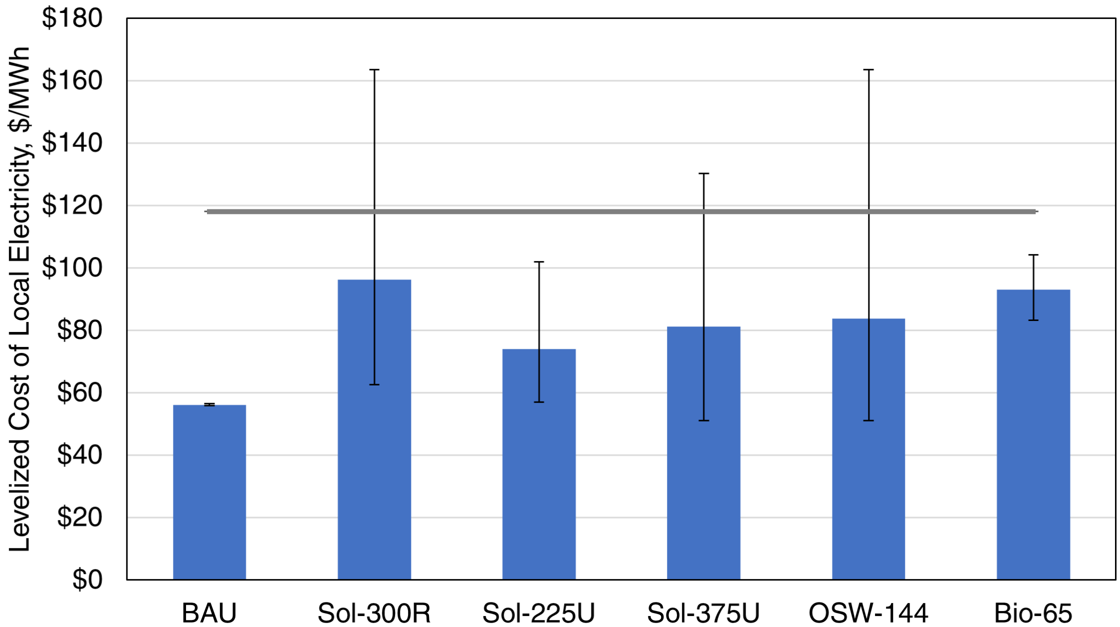

Figure B-1. Cost of local electricity, showing variability resulting from uncertain costs, and discount rates from 0% to 10%. PG&E's 2020 billed generation charge is shown for reference as a grey horizontal line.

For each scenario, I estimated the net economic impact in terms of jobs and economic activity (Table B-1), which both include direct, indirect, and induced impacts (for example, increased activity at restaurants and other retail establishments). Biomass is associated with the fewest construction jobs and the most permanent jobs, while utility-scale solar is associated with the fewest permanent jobs, and residential solar is projected to generate the most construction jobs. Output, quantified here in millions of US dollars, follows the same trend.

Table B-1. Estimated jobs and local economic output, based on NREL's JEDI models.

Scenario	Construction Jobs (job-years)	Permanent Jobs	Construction Output ($M)	Annual Output ($M)
Sol-300R	3,100	29	$490	$3
Sol-225U	990	28	$140	$3
Sol-375U	1,600	-45	$240	-$10
OSW-144	1,700	40	$370	$8
Bio-65	300	100	$44	$18

Questions to think about:

- Which option(s) do you prefer, and why?
- Are you skeptical of any of these results?
- Are you surprised by any of these results?
- Is there any missing information which might impact your viewpoint?
- Do you find these results to be hopeful, or discouraging?

Appendix C. Humboldt County Node Analysis Methods

I treated Humboldt County as a single transmission node with a maximum import and export capacity of 70 MW (Zoellick et al., 2011). Baseline generation resources are shown in Figure C-1, below. The county has, at present, four utility-scale power plants: Fairhaven and Scotia are biomass plants, Baker Station is a run-of-river hydro plant, and Humboldt Bay Generating Station (HBGS) is a natural gas plant (California Energy Commission, n.d.). Power input also includes all front-of-meter (none currently in operation) and behind-the-meter (including rooftop, as well as installations such as the solar array that is part of the Blue Lake Rancheria renewable energy microgrid (Carter et al., 2019) solar photovoltaic systems within Humboldt County. Additional generation, such as offshore wind, was added in cases other than the baseline case.

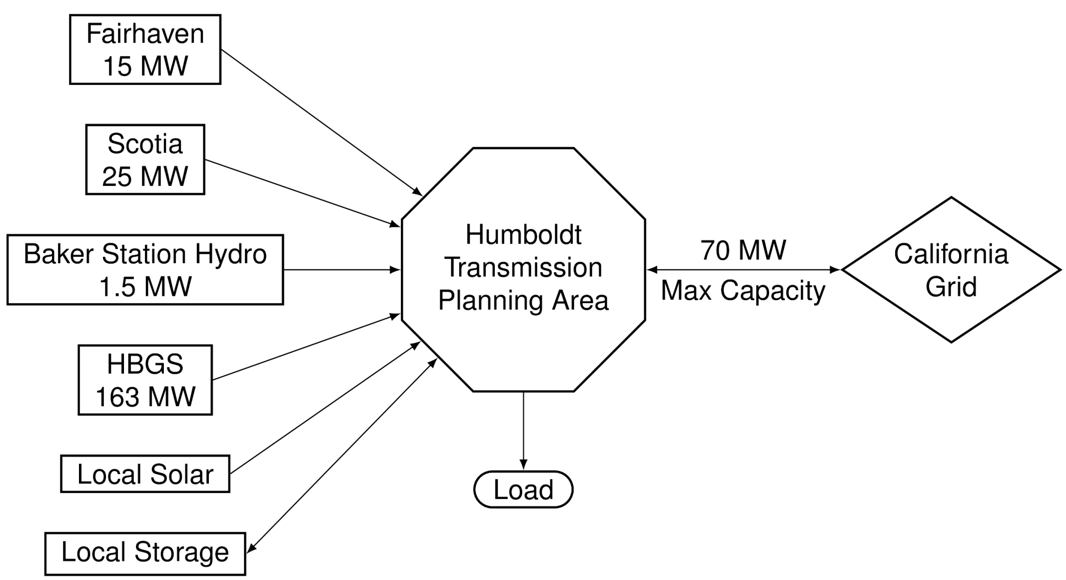

Figure C-1. Humboldt County Node Model.

I analyzed inputs and outputs across every hour of the year 2030 (8760 points total). At each hour, generation and storage output were balanced with projected local consumption (Redwood Coast Energy Authority, 2019), with the remainder, up to 70-MW, being imported or exported. In the case that exports would exceed 70-MW, this excess was curtailed.

I treated Fairhaven, Scotia, Baker Station, local solar photovoltaic (PV), and offshore wind (if applicable) as non-dispatchable. That is, they produce their full power output given available inputs (e.g., biofuel, water, sun, wind), although some of this power might be later curtailed in the model. Imports, while technically "dispatchable" have an unknown historical shape, and were also treated as a base load, if present. Next, I deployed local storage, absorbing as much of the potential exports as it could, or outputting stored energy if baseline generation were exceeded by demand. On top of these resources, I applied HBGS to meet any additional load within its operating constraints. As a load following (also known as load shaping or grid forming) power plant, HBGS can operate at any output level between 11.4 MW and full power, 163 MW (California Energy Commission, 2008). In this model, HBGS only causes exports if its output would otherwise dip below its minimum operating level of 11.4 MW.

I began the modeling process with a 2030 demand forecast created by the Redwood Coast Energy Authority (Redwood Coast Energy Authority, 2019). Next, I established generation from each extant resource in the *baseline case*. This was largely done on a per power plant basis, and to some extent by technology.

1. Imports were considered to be a flat generation source meeting 28.3% of demand (excluding distributed resources), as has historically been the case (Ortega et al., 2020). Imports are only used in the baseline, or BAU case.
2. Historical monthly generation for the two local biomass plants, Fairhaven[14], and Scotia (operated by Humboldt Redwood Company, LLC) were available through the California Energy Commission's Quarterly Fuel and Energy Report (QFER) (California Energy Commission, 2020b). These records covered all of 2001-2018. For the Fairhaven plant, all records were averaged by month, and a flat generation profile was assumed for every hour within each month. Scotia followed the same process, except that plant operation was inconsistent throughout the years, so only more recent data, 2016 to 2018, were used. This simple profile certainly produces error but was all that was possible given the available data.
3. Yearly total output for Baker Station was available for 2017 and 2018 through QFER (California Energy Commission, 2020b). Because this plant has a small impact, its average hourly output was used for each hour (that is to say it was modeled as producing a flat output across the year).
4. Distributed solar in the base case was based on the 2019 Humboldt County distributed solar installations of 11.87 MW (California Solar Initiative, 2020), and the state-wide rate of growth of distributed behind the meter PV in the CEC's forecasting

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[14] 3.7% of Fairhaven's historical heat input has come from natural gas (California Energy Commission, 2020b). For the purposes of this analysis, that small contribution was ignored; the plant was treated as being powered by only biomass.

(California Energy Commission, 2020a). This leads to a predicted distributed solar resource of 29.5 MW in 2030, which was distributed according to regional population as shown in Table C-1 (County of Humboldt, 2020; US Census, 2014) across a set of six simulations created in PVWatts (National Renewable Energy Laboratory, 2020c) to generate hourly profiles for distributed-scale solar. (That is to say, for example that, 20.2% of the solar distributed installation was assumed to be in Eureka, 12.8% in Arcata, etc.). Arrays were modeled as 37° fixed-tilt with inverter load ratio (ILR) of 1.34, following NREL's cost estimates for utility-solar (National Renewable Energy Laboratory, 2020a). This ideal tilt is unrealistic for all but the best developments and leads to an overestimation by as much as 3.3%, as discussed in Appendix F.

5. Utility- and commercial-scale solar includes a 2.25 MW installation at the Arcata airport (Redwood Coast Energy Authority, 2020c), and 15-MW of additional local generation already targeted for development by RCEA (Redwood Coast Energy Authority, 2018). The resulting 17.25-MW of utility-scale solar was distributed according to regional population as shown in Table C-1 (County of Humboldt, 2020; US Census, 2014) across a set of six simulations created in PVWatts (National Renewable Energy Laboratory, 2020c) to generate hourly profiles. Utility-scale installations were modeled as single-axis tracking[15] with inverter load ratio (ILR) of 1.34, following NREL's cost estimates for utility-solar (National Renewable Energy

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[15] Utility-scale single-axis tracking systems in Humboldt generate 20%-30% more electricity (National Renewable Energy Laboratory, 2020c) for a cost increase less than 10% (Fu et al., 2018; National Renewable Energy Laboratory, 2020c).

Laboratory, 2020a). While it would be tempting to model utility-scale projects as sited exclusively in areas of relatively high solar resource (Garberville, the location with the best resource, produces 8-16% more electricity than the lowest resource areas), the same locational balance was maintained for utility-scale projects for fear of overloading Humboldt County's limited transmission.

6. Local storage in the baseline analysis was assumed to be zero, and all additional storage was assumed to be lithium-ion battery storage, following a common assumption employed by, for example Duan et al. (Duan et al., 2020). This storage was assumed to have an 85% round-trip efficiency (National Renewable Energy Laboratory, 2020a), which was equated to an 85% charging efficiency, a 100% discharging efficiency, and zero minimum charge level, matching Cole & Frazier's capacity assumptions (2020).
7. Local offshore wind output, in scenarios where it was used, was taken directly from the model created by Severy et al. (2020).

Table C-1. Populations in Humboldt's major regions and resulting accounting after adding unincorporated regions (County of Humboldt, 2020; US Census, 2014)

Region	**Population**	**Share from Balance**	**Accounted Population**	**Percent of Development**
Eureka	27,191	0	27,191	20.2%
Arcata	17,231	0	17,231	12.8%
Fortuna	11,926	0	11,926	8.9%
Rio Dell	3,368	0	3,368	2.5%
Blue Lake	1,253	36,370.5	37,623.5	27.9%
Garberville	913	36,370.5	37,283.5	27.7%
Balance	72,741	0	0	0.0%

Appendix D. Capital and Annual Expense Uncertainty

An indication of the possible variation in annual cost and capital cost, respectively, are given in Figure D-1and Figure D-2. These are derived from the low, mid and high (or advanced, moderate, and conservative) cases in NREL's Annual Technology Baseline (National Renewable Energy Laboratory, 2020a).

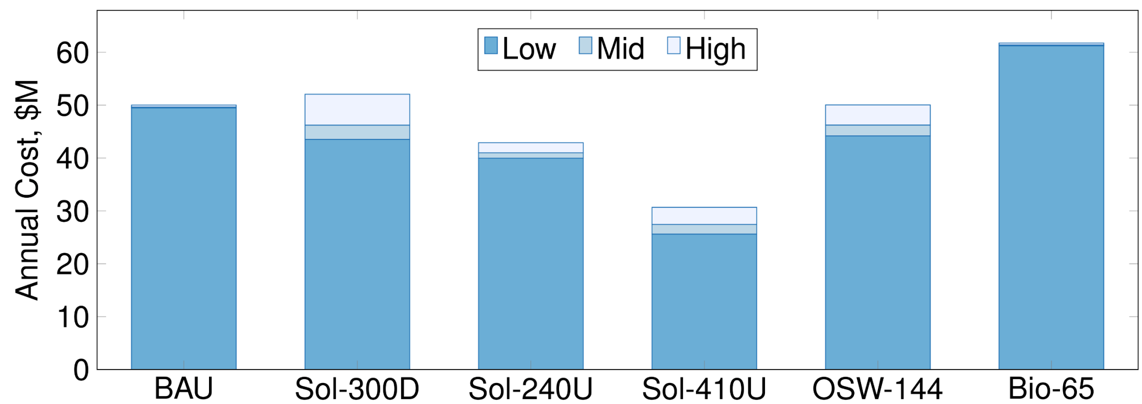

Figure D-1. High, mid, and low estimates of annual cost for the investigated scenarios from the data in NREL's ATB (National Renewable Energy Laboratory, 2020a). These gross costs are exclusive of export revenues.

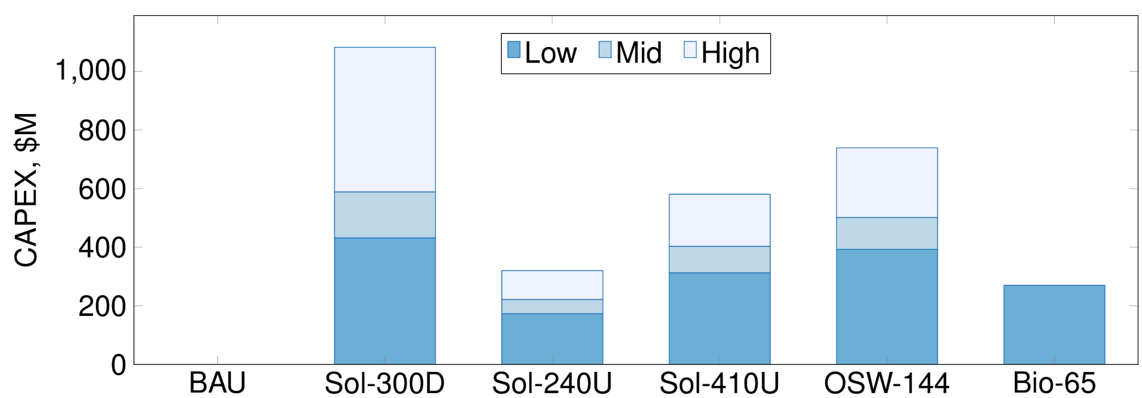

Figure D-2. High, mid, and low estimates of capital cost for the investigated scenarios from the data in NREL's ATB (National Renewable Energy Laboratory, 2020a).

Variability in annual costs (including both variable and fixed O&M, and fuel costs) is relatively small compared to the uncertainty in capital cost, particularly for residential photovoltaics and to a lesser extent offshore wind and large-scale utility solar. Biomass and the smaller utility PV scenarios on the other hand have relatively little uncertainty (though it would be a mistake to conclude that the biomass case has no uncertainty in capital cost as Figure D-2 depicts). These data are alternatively presented numerically in Table D-1.

Table D-1. High, mid, and low estimates for capital cost and net annual expenses (NAEs) across investigated scenarios based on the data in NREL's ATB (National Renewable Energy Laboratory, 2020a). All data in millions of US dollars.

Scenario	**Low Capex**	**Mid Capex**	**High Capex**	**Low NAE**	**Mid NAE**	**High NAE**
BAU	0	0	0	49	50	50
Sol-300D	432	589	1,082	43	45	51
Sol-240U	173	222	320	39	40	42
Sol-410U	313	403	581	24	26	29
OSW-144	393	501	739	36	38	42
Bio-65	270	270	270	61	61	62

Hackett and Anderson (2020) calculated a significantly higher capital cost of $733 million for a 144 MW offshore wind development in Humboldt Bay compared to NREL's "mid" scenario, slightly below their "high" scenario (National Renewable Energy Laboratory, 2020a). This can partially be explained by assumed operation date, as Hackett and Anderson's analysis assumes a commercial start date of 2026 with discounts to, for example, turbine cost based on expected learning-by-doing between now and 2026. NREL's high scenario, on the other hand assumes no future decrease in prices (i.e. constant future pricing) while my use of their mid estimate accounts for reductions in price between 2026 and 2030, which is not reflected in Hackett and Anderson's analysis. Hackett and Anderon's estimated OpEx (O&M) cost of $62.87 per kW per year is quite close to NREL's figure of $61 (Hackett & Anderson, 2020; National Renewable Energy Laboratory, 2020a).

Appendix E. Biopower Emissions

When discussing the merits of renewable energy technologies, the emissions from biopower are one of the most hotly contested. The methodology for evaluating net emissions from biomass energy is contentious, largely because it relies on assessment of a counterfactual. While some academics claim that biomass is carbon neutral because it does not increase the amount of carbon available to the global cycle, others contend that this view ignores important factors, including impacts from land-use change. Some studies have shown that switching from fossil fuels to biomass could *increase* atmospheric greenhouse gases. Gunn et al. (2012) provide a synopsis and review of literature on both sides of this debate. Biomass plants emit more greenhouse gas per unit of energy produced than coal, largely due to their lower efficiency. However, if that biomass were otherwise destined for a landfill, where it would decompose into methane, the global warming potential relative to the alternative pathway would be negative. The same reasoning applies to other pollutants: Forest residues pile-burned on location would emit more particulates than if that waste were burned in a biomass plant, though here the location of the emissions means that the exposure risk is likely higher if burned in a plant. Conversely, clearing forests in order to grow biofuel can release tremendous amounts of sequestered carbon, resulting in a net emissions increase for over a century (Searchinger et al., 2008). This highlights the need to account for changes in land-use in greenhouse gas accounting, and to firmly establish counterfactual cases.

Rather than dive deeper into these questions, I rely on the methodology and assessment of the Electric Power Research Institute (O'Connor, 2013). Their review of existing literature concluded that biopower produces significantly lower long-term emissions than fossil fuel sources, emphasizing that this analysis does not account for any land-use change. Powerplant construction and decommissioning related emissions, on the other hand, are included in their analysis. The result of this simplification should be reasonably accurate under the assumption that the biomass would otherwise burn or decompose, and particularly that no land-use changes are necessary for its production, which are reasonable assumptions for Humboldt County's current usage.

Appendix F. Reduction in PV Output due to Orientation and Shading

As noted in Section 3.3.4 and Appendix C, shading and non-optimal tilt on some houses would lead distributed PV systems providing less-than-optimal output. I determined this reduction to be about 3.3% based on the following method: I calculated the annual energy each orientation (tilt/azimuth) bin provided by Gagnon et al. (Gagnon et al., 2016) would collect compared to the optimally oriented panel, and took their weighted average (by occurrence, assuming that flat roofs allow optimal panel tilt). This resulted in 95.0% of the optimal collection. Because "[n]early all large buildings provide flat planes[,] approximately three in four medium buildings have suitable flat planes" (Gagnon et al., 2019, p. 43), and 2/3 of rooftop area is attributed to small buildings, this results in a reduction by 3.3% Useable rooftop space, as calculated by Gagnon et al., includes only areas which would "produce 80% of the energy produced by an unshaded system of the same orientation." (Gagnon et al., 2016, p. 9). According to Gagnon et al., this is accounted for by their 14.08% system losses, which is the same number I used in my analysis. Therefore, the unaccounted-for error in my model could be up to 3.3% but would be less if better sites are developed preferentially, or some amount of distributed solar is mounted on the ground, on fences, or other non-rooftop areas.

Appendix G. Electricity Generation Profiles

Monthly average power generation by source across scenarios all scenarios are shown in Figure G-1 through Figure G-6. Scenarios with high levels of solar PV impart a high degree of seasonal variation upon Humboldt Bay Generating Station as shown in Figure G-2 to Figure G-4. This indicates a potential challenge as renewables penetration increases towards 2045. Generation must match demand seasonally, but only does so relatively well with the offshore wind and biomass scenarios. In these cases, the contribution by generation by the HBGS is relatively flat, though still somewhat higher in winter months, as shown in Figure G-5 and Figure G-6. Offshore wind is also the only scenario with high levels of exports.

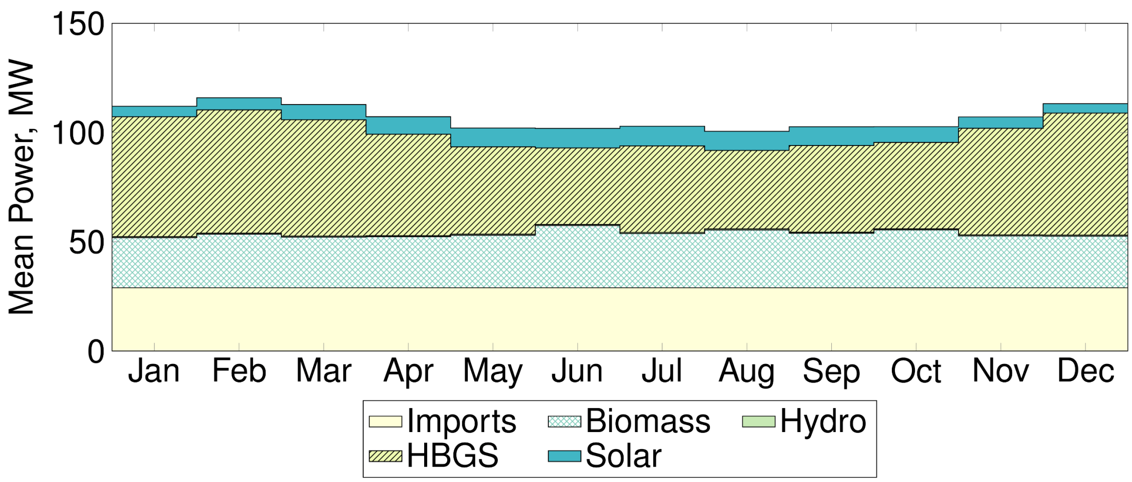

Figure G-1. Monthly average power generation by source in the BAU, or Business as Usual scenario.

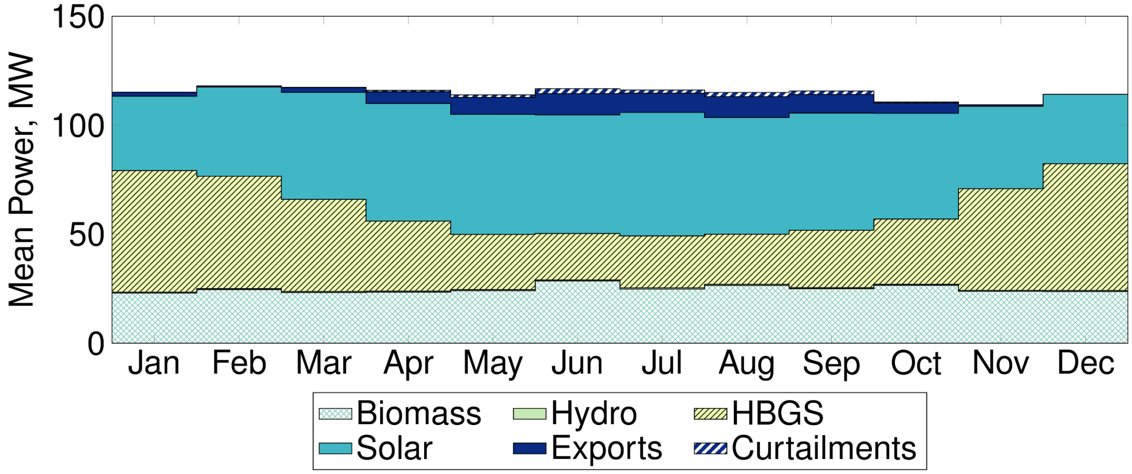

Figure G-2. Monthly average power generation by source in Sol-300D, with 300 MW of distributed residential solar and 550 MWh of battery storage more than the BAU case. Exports and curtailments are from the solar energy.

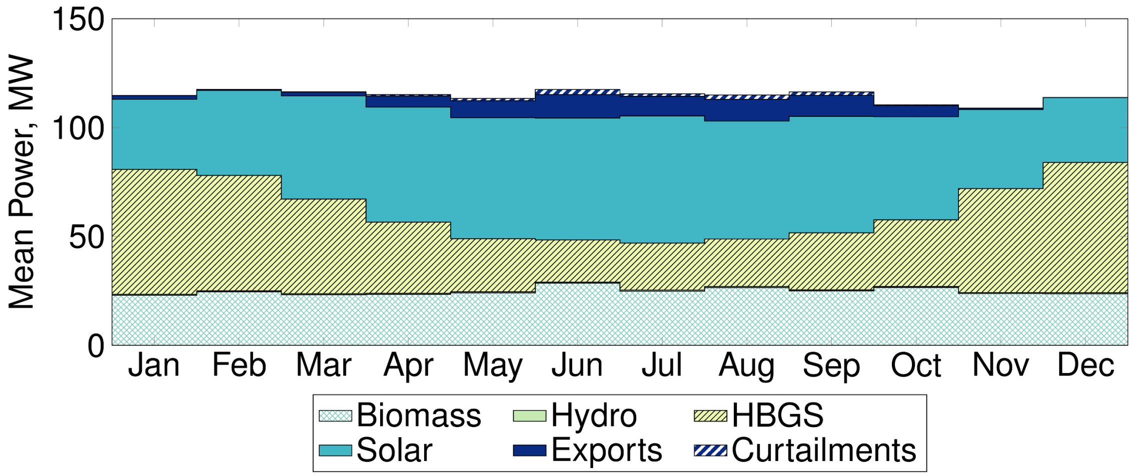

Figure G-3. Monthly average power generation by source in Sol-240U, with 240 MW of utility-scale solar and 475 MWh of battery storage more than the BAU case. Exports and curtailments are from the solar energy.

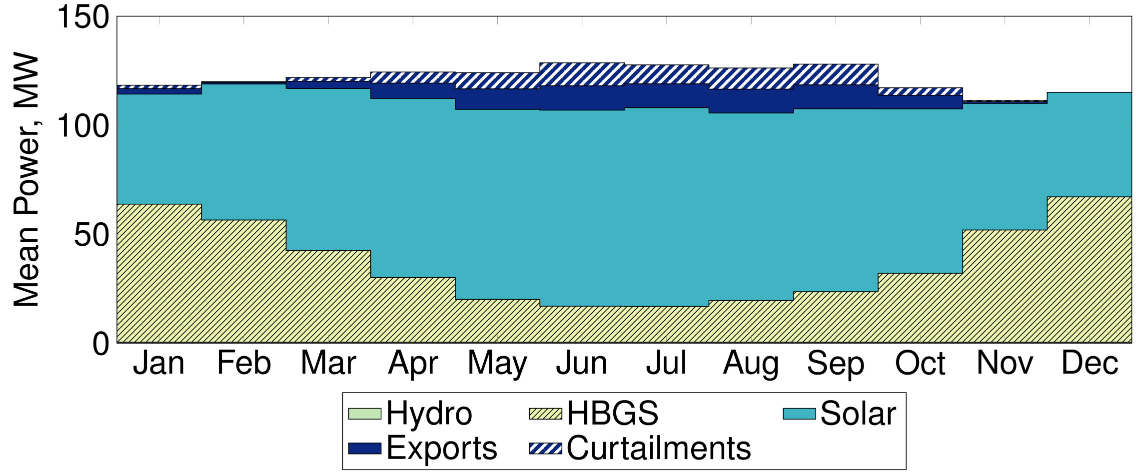

Figure G-4. Monthly average power generation by source in Sol-410U, with the addition of 410 MW of utility-scale solar and 970 MWh of battery storage, and removal of all biomass electricity from the BAU case. Exports and curtailments are from the solar energy.

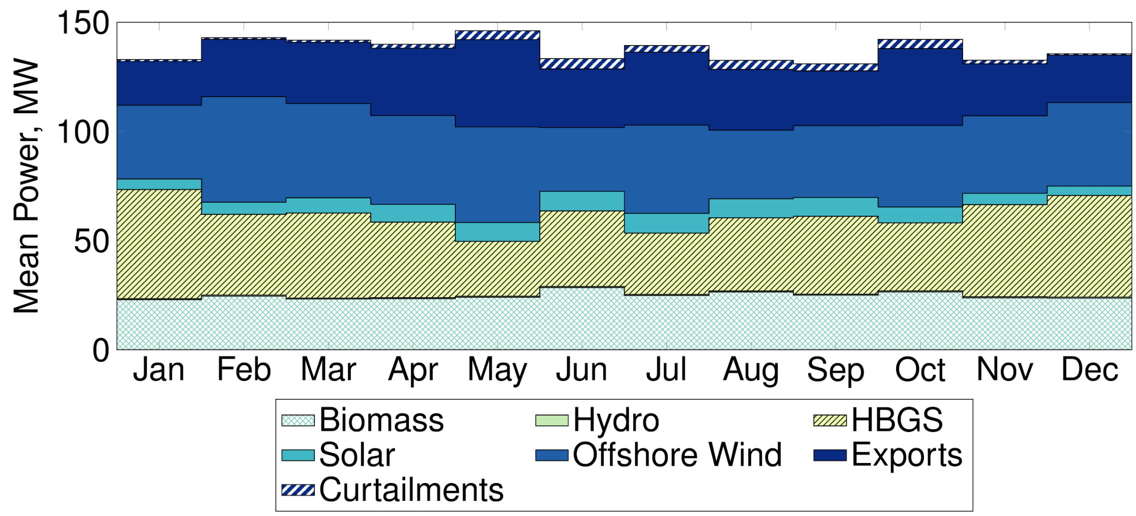

Figure G-5. Monthly average power generation by source in OSW-144, with 144 MW of offshore wind added to the BAU case. Exports and curtailments are from the offshore wind energy.

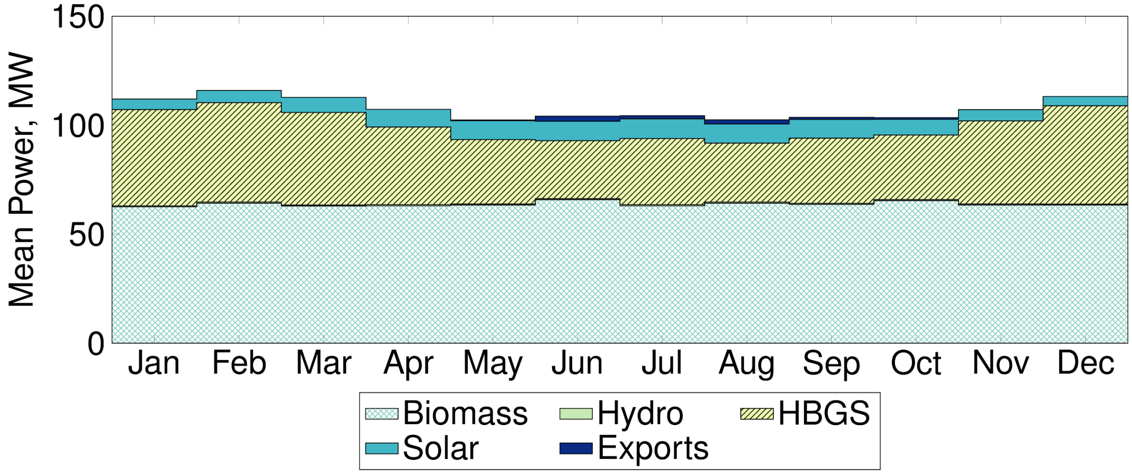

Figure G-6. Monthly average power generation by source in Bio-65, with a 65-MW biomass plant added to the BAU case. Exports and curtailments are from biomass energy.