Communicating climate change in marine renewable energy

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***Abstract*—As scholars in the field of marine energy, we often engage with the topic of climate change as a motivation for our work. When we do, we are constructing a relationship between climate change and marine energy. The relationship which we construct impacts our ability to effectively address the crisis. In this paper, we perform a textual analysis of papers from the 13th European Wave and Tidal Energy Conference (2019) to characterize the common construction of climate change among marine renewable energy scholars. We then examine how that construction is reflected in marine renewable energy technological design. We show that marine renewable energy scholars typically engage with climate change in a way which assumes that marine renewable energy is a potential part of a solution by its very nature as a renewable energy source. This assumption preempts any assessment that we may make with regard to the potential impacts of our work on climate change. By shifting how we communicate about climate change as a field, we may be able to center the ecological crisis in our design work, allowing it to reshape the fundamental design challenge. This could lead to improved integration of technical development and environmental impacts research, marine energy concepts which address human and environmental needs which are threatened by climate change (such as the need for food security and social equity), or new design tools which help designers evaluate and improve a technology's relationship with the community and the environment.**

***Index Terms*—climate change, marine energy, design, climate criteria, cognitive frames, communication.**

I. Introduction

CLIMATE change is the disruption of the earth's natural cycles due to abnormally high concentrations of greenhouse gases in the atmosphere which lead to warming average global temperatures. Warming temperatures, in turn, bring changes in weather patterns, rising sea levels, and more severe storms. Those changes lead to further disruptions, including displacement of humans, changing animal migration patterns, desertification, strain on economic systems by flooding and storm damage, and heightened threats to food and water resources. Communities of low socio-economic status tend to be at greater risk from the impacts of climate change than middle and upper-class communities [1]. Scientists have deemed a 1.5C increase in global average temperatures to be likely between 2030 and 2052, and with it, many of these effects likely as well [2]. To address this problem we have turned to—among other things—renewable energy as a means of reducing greenhouse gas emissions. Marine energy technologies are a part of the suite of renewable energy technologies, albeit a relatively nascent part.

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Marine energy faces some serious challenge economically, technically, socially, and politically. Currently, the estimated cost of grid-scale wave energy is high compared to more mature renewables and fossil fuel generation technologies [3]. An estimate of wave energy potential in the Pacific Northwest United States, the area with the largest wave resource in the continental U.S., claims that capacity for wave energy farms given current technology is about 500MW, which is approximately 1/9th the currently installed capacity of wind energy in the region [4]. Though this assessment is based on currently available wave energy technologies, and technology should continue to improve with further R&D, this figure highlights the relatively small near-term contribution of wave energy when it comes to decreasing greenhouse gas emissions from the electricity sector.

Despite that small contribution, approaching marine energy with respect to its potential impact on climate change is important for four reasons. First, with continued technology development, the amount of energy that can be provided by wave energy could increase. Stakeholders may seek decentralized and diversified energy production. Second, grid connection is not the only application of wave energy. Off-grid applications gaining in popularity include the powering of underwater vehicles and ocean research, desalination, aquaculture, and remote or island communities [5]. It is important to consider how these local and niche solutions fit into the bigger picture of climate solutions, especially given that potential off-grid applications are met with both excitement and concern [6] [7] [8]. Third, the problem of climate change is about far more than emissions. It is about ecological (referring to the web of species and environments that includes humans) destruction. Therefore, when we discuss climate solutions, technological and otherwise, emissions reduction is not the only factor to account for. Lastly, although the role of marine energy in directly mitigating climate change might be small compared to more mature renewable energy technologies, its future is within the larger ocean and energy systems that will play a major role. Oceans store approximately 25% of human carbon dioxide emissions [9] and the burning of fossil fuels for energy accounts for about 70% of greenhouse gas emissions [10], meaning changes to our ocean and ocean energy systems will undoubtedly play a major role in mitigating climate change. Marine energy *could* change the way we use our oceans by enabling offshore electricity conversion or by balancing ecosystem protection and energy generation priorities. Marine energy *could* be a generating technology among a diverse web of technologies that bring energy-related greenhouse gas emissions to zero.

Climate change is a major problem which is clearly connected to marine energy. Through the way we, as marine energy scholars, communicate about climate change, we determine the role that it plays in our technical and scientific pursuits. The role climate change plays in our research, in turn, influences our perceived connection between climate change and marine energy. It is, therefore, worthwhile to examine the way we communicate about the climate crisis.

Much of the communication research at the intersection of climate change and renewable energy discusses the ways that "we" (referring to scholars or activists) can communicate about renewable energy in such a way that it gains public support [11] [12] [13]. Endres et al. point out that there is insufficient examination of expert-to-expert rhetorics which "are especially critical as they significantly shape the future of particular aspects of energy resources, production, and consumption" [14]. Outside of energy fields, there is a significant body of scholarship which examines internal rhetoric in scientific disciplines, which is well-summarized by Endres et al. We rely on the conceptual work on cognitive framing by linguistics scholar George Lakoff as a guide in our examination [15].

In this paper, we analyze the proceedings of the 2019 European Wave and Tidal Energy Conference as a current and representative sample of inter-expert academic communication. In doing so, we identify the "frame" through which we understand the relationship between climate change and marine energy. We shed light on how that frame is constructed and how it effects our work. Finally, we suggest ways in which new frames for the relationship between climate change and marine energy could offer new opportunities in the field.

II. Analysis of EWTEC 2019 Papers

A. Methods of Data Analysis

There were 278 paper contributions to the 2019 European Wave and Tidal Energy Conference. We ran a full-text search of all the papers for ten different phrases related to climate change. These phrases included, *climate change*, *global warming*, *decarboni* (given the combination of British and American English we wanted to include decarbonize, decarbonise, decarbonization, and decarbonisation), *climate emergency*, *climate disruption*, *climate crisis*, *climate resilience*, *greenhouse*, *CO2*, and *ecological*. For each phrase, we filtered the results to eliminate instances in which the phrase was only present in the references or in naming an organization. For *ecological* we only included cases in which that phrase was referring to impacts related to fossil fuel use. More commonly, *ecological* is used to refer, somewhat generically, to the natural world. We were not concerned with those uses. In total, there are 42 papers that use these terms, with 29 that only contain one of the eight terms, and 14 which contain multiple. The counts according to keyword are shown in Table I.

TABLE I
Keyword Search on EWTEC 2019 Papers

Phrase	Occurrences	Independent Occurrences
climate change	23	12
global warming	5	1
decarboni	10	4
climate emergency	0	0
climate disruption	1	1
climate crisis	0	0
climate resilience	0	0
ecological	2	1
greenhouse	12	5
CO2	12	5

The number of occurrences are filtered as described in Section II-A, and the number of independent occurrences indicate that number of papers that contain that key word, but none of the others.

Examining each paper identified through the full-text search, we noted the location in the text where the key terms appeared and the context in which they were used. Through our initial examination, we identified some common trends in the way in which terms are used, including a normative logic used to motivate marine energy development and an externalization of the need to address cliamte change and/or greenhouse gas emissions. Therefore, we performed a second examination to determine if those trends were as common as they initially appeared.

B. Results

The total number of papers in which one of the key terms was present is about 15%. In more than half of those papers, the authors mentioned one of the key terms exclusively in the introduction. The location within the paper in which the key term is present for each paper is shown in Figure 1. Only three papers refer to climate change or emissions in the conclusion. 37 of the papers mention one of the key terms in the introduction, indicating, as one would expect, that the relationship between climate change and marine energy is predominantly one in which the former is a motivation for work on the latter. Furthermore, the relatively small number of papers that mention climate change anywhere outside of the introduction suggests that addressing the climate emergency has not been adopted as a fundamental tenet of research and design methodologies.

There were two common trends among that we noticed in the papers. First, 27 papers deployed a particular logic regarding the relationship between marine energy and climate change. The logic can be generalized as follows: climate change is caused by greenhouse gas emission*, we need to do something

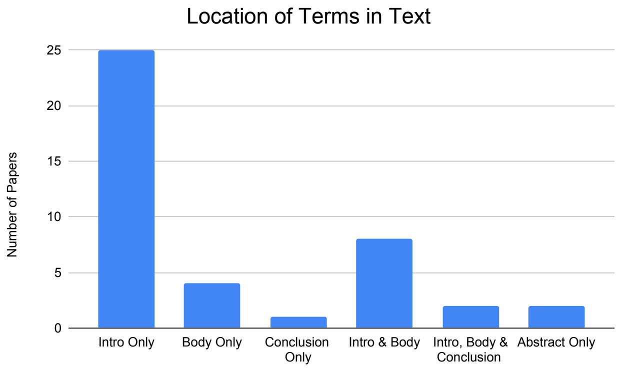

Fig. 1. The location of within the paper in which key terms appeared. One datapoint per paper.

about climate change*, renewable energy is a means of reducing greenhouse gas emissions, marine energy is a promising renewable energy, therefore we should study marine energy.

Second, the first two parts of this logic—that climate change is caused by greenhouse gas emission and that we need to do something about climate change—are often implied but not directly stated. For example, Almoghayer et al. begin their paper, "With the rapid increase in global warming, renewable energy has become an important option for electricity generation, as one of the most efficient and effective measures to slow down climate change" [16]. They go on, "Among the many available renewable energy sources, tides are favoured for their substance (up to TeraWatts globally) and due to their predictability" [16]. We see here the deployment of the normative logic described above along with an implicit assumption of what causes global warming and why it is a problem. In the case of the single paper that mentions decarbonization only in the conclusion, there is a similar assumption of understanding. When the motivation to address climate change is not simply assumed, it is externalized. Authors cite government renewable energy targets or a general "attention" on renewable energy as a reason to move forward with research. Implicit or externalized motivators for addressing climate change are used in 25 of the papers, whereas statements regarding the potential impacts of climate change are only used four times.

The independent occurrences of *greenhouse* and *CO2* (in which *climate change* or a similar phase is not present), of which there were 10 total, either rely on an assumed understanding of the relationship between climate change and emissions. Of the 15 papers that do not use the normative logic we have outlined, seven of them do not use one of the key terms to motivate their work, but instead within their work. These include papers which include a lifecycle analysis or discussion of metrics. Five of the papers that do not use the normative logic contain a significantly more complex discussion of their motivation. For instance, Lemessy et al. discuss objectives to reduce abuse of natural resources and to meet basic human needs [17].

III. Discussion

We would not expect that all papers written for a conference specifically on wave and tidal energy begin by explaining the motivation for research in those areas. Furthermore, there are other motivations, aside from those related to climate change, that researchers use to introduce work in marine energy, including energy security and profitability. It is also valid in the context of the conference to assume that people understand the relationship between emissions and climate change. With that said, we are not arguing that the relationship between climate change and renewable energy communicated in these papers is unfounded or inaccurate, but rather that it is a narrow conceptualized relationship which impedes our ability to effectively address climate change through work in marine energy.

The normative logical connecting climate change to marine energy and the externalization of climate change as a motivator to the industry have consequences for the way that we, as experts in the field, measure success. The ways we measure success, in turn, impact the way we do our work and, through the technology design process, the device concepts which we develop.

A. Cognitive Framing

To root this idea in scholarly work, we can think of that normative logic as the cognitive frame through which we understand the association between marine energy and climate change. Cognitive frames are "unconscious structures" through which we make sense of words and knowledge which is presented to us [15]. Frames are activated through words. When we say "climate change" in the context marine energy, the normative logic described above is the structure activated in our brains. The parties upon which we externalize motivation (governing bodies, the public, etc.) are a part of that structure. We reproduce this frame in the introductions to papers and in presentations, and other forums as well.

As this frame constructs all renewable energy technologies as intrinsic solutions to climate change, we choose to refer to it as the Intrinsic Solution Frame. It ascribes value to a select set of facts and data related to climate change, namely those related to emissions. Though these facts are scientifically trustworthy, they are incomplete. Emissions-related data grants only a partial understanding of the problem of climate change and therefore only a partial understanding of the potential solutions. Climate communication expert George Marshall argues that "the largest, most extraordinary, and damaging misframing of all [. . .] was that climate change could be defined entirely and exclusively as a problem of gases" [18]. The Intrinsic Solution Frame adopts this very "misframing."

We equate energy generation to emissions reduction and emissions reduction to climate change mitigation. This is reflected in the fact that, beyond energy production and embodied emissions, we do not have metrics for assessing climate change mitigation. This could explain why many authors mention climate change exclusively in the introduction of papers. There are neither metrics nor frames for understanding the impacts of specific work (as opposed to the field more generally) on the mitigation of climate change.

B. Evaluating Technologies

Further reinforcing the use of the Intrinsic Solution Frame in marine energy, most researchers lean on this frame—intentionally or otherwise—to make it unnecessary to evaluate the potential of a specific technology or project to mitigate climate change by any other means than the amount of clean energy it produces vs. the embodied emissions and energy used in construction and operations. We have already assumed the technology to be part of the renewable energy solution, so we only evaluate performance via how much energy a technology can produce and at what monetary cost, exemplified by the use of Levelized Cost of Energy (LCOE) as the primary metric of success for marine energy devices, despite its documented shortcomings [19] [20] [21]. LCOE reduces the potential benefits of a technology to the energy it produces and reduces the potential costs to those costs which can be measured monetarily, thereby undervaluing any benefits other than energy production and any costs which economists might refer to as ”externalities,” such as environmental harms. Other methods of performance assessment, such as the Technology Performance Level (TPL) assessment, have expanded the measure of success beyond energy production and cost, but remain less commonly used than LCOE [22] and they fall short in qualifying performance in terms of climate change mitigation. Ruiz-Minguela et al. use “climate change mitigation” as one of the factors in their “holistic assessment of wave energy design options,” but the metric only considers the emissions produced over the lifecycle of the technology [23].

By relying on the Intrinsic Solution Frame, which leads us to understand the connection between climate change and marine energy to be singular, we are able to overlook other potential connections. For instance, the marine energy field tends to approach the ecological impacts of marine renewable energy separately from technological development. At this conference, this is evident in the separate research tracks, which are entirely different. In device design, developers tend to adopt systems or product engineering approaches which do not facilitate integration of ecological knowledge [22]. Santos-Herran et al. point out that marine energy researchers have extensively studied the economics and supply security aspects of marine energy, but that the quantitative assessment of environmental impacts which is important to policy makers is often missing [24].

C. Tertiary Motivations

We tend not to qualify performance in terms of climate change mitigation because of our singular assumption regarding the relationship between climate change and renewable energy and the conceptual distance that assumption puts between climate change and technology development. The Intrinsic Solution Frame and our common measures of success prevent us from exploring other objectives that reduce climate impacts, such as reducing energy demand. As the time that humans have to dramatically reduce carbon emissions to avoid catastrophic global increases in temperature shrinks, major agencies and academic researchers in policy and social science have given more attention to pathways for demand reduction, but these considerations have remained outside the purview of renewable energy development [19] [20] [21]. Yet, there are instances where renewable energy generation could reduce energy demand. For example, the generation of electricity through ocean energy could replace diesel generation in remote communities, thereby reducing the need for transportation of diesel fuel [25]. Here we see an example of the kind of projects which are possible when we look beyond the Intrinsic Solution Frame. We will further discuss the opportunities related to reframing the relationship between climate change and marine energy in the following section.

We presume the motivation for addressing climate change, either implcitly or by attributing motivation to government policy or renewable energy targets. By doing so, we avoid the need to formally acknowledge why climate change is a problem that needs to be explicitly handled. The exigence to, for instance, prevent the suffering of species (including humans) on Earth is not part of our scholarly conversations. Previously, we noted that the Intrinsic Solution Frame elevates climate change-related knowledge which concerns emissions. It neglects climate change-related knowledge concerning ocean acidification, species loss, inequity, food and water insecurity, etc. That is not to say that we as individual researchers do not understand these things, but that the frame through which we relate our work in marine energy to climate change does not provide a means of understanding that relationship to *all aspects* of climate change.

D. Technology Development and Ecological Impacts

When we consider a broader spectrum of climate change-related knowledge in relation to marine energy, it becomes more difficult to separate ecological impacts from technology development. Consider the paper by Lopes de Almeida entitled *REEFS: An artificial reef for wave energy harnessing and shore protection – A new concept towards multipurpose sustainable solutions* [26]. In this paper, Lopes de Almeida does not reproduce the Intrinsic Solution Frame. Instead, they include details on several air pollutants, human deaths, and environmental degradation and suggest that wave energy could not only provide a source of non-polluting energy, but that a specific technology could also function as an artificial reef, protecting coastal areas under increased threat of flooding [26].

There is a challenge of scale, both spatially and temporally, when it comes to considering technology development for the purpose of emissions reduction simultaneously with ecological and human impacts. Ecological impacts are often local and short-term, whereas the benefits of offsetting emissions with renewable energy are global and long-term. A pathway forward will require a productive way of juxtaposing these scales which means thinking about ecological impacts and technology development together. This will require a reframing of the relationship between climate change and marine energy.

E. Beyond Scholarly Work

It is worthwhile to note that the Intrinsic Solution Frame present in scholarly circles is reflected in both public rhetoric and the publicized priorities of funding agencies. In the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy 2016-2020 strategic plan, the first sentence reads, "Today, the United States is faced with a national imperative to address the enormous challenge presented by climate change and to seize upon the multi-trillion dollar economic opportunity that a transition to a global clean energy economy will provide" [27]. At the highest level, climate change appears as a key motivator, but as priorities and funding trickle down to calls for proposals for research grants or individual assessment of energy technologies, the acknowledgement of climate change as a key motivator is phased out, similar to the way that we, as researchers, include climate change as a high-level motivator in introductory paragraphs, but rarely return to the topic. Public perceptions related to climate change and renewable energy reflect the difficulty that researchers have juxtaposing the two scales of environmental impacts of marine energy. Positive feelings about marine energy tend to be related to the need for alternatives to fossil fuels, while negative feeling are associated with the potential local environmental and human impacts [28].

IV. Opportunities through alternative frames

In the previous sections, we characterized the way that marine energy scholars communicate the connection between marine energy and climate change in our scholarly work and used concepts of cognitive framing and evidence from the field of marine energy to identify some of the implications of our communication. The Intrinsic Solution Frame that we use privileges some knowledge about climate change over other knowledge, and it depicts a singular, intrinsic connection between marine energy and climate change. In the remainder of this paper, we will outline some suggestions for going forward with communication and technical work that embrace a broader scope of knowledge about climate change and other potential connections between climate change and marine energy.

We can begin by considering the ways in which a technology could contribute to mitigating climate change. There is no published list of requirements for technical solutions to the climate emergency, therefore there is no agreed-upon way of evaluating them. We have surveyed literature on climate solutions to propose a preliminary set of requirements which we call *climate criteria* for renewable energy systems meant to address the climate emergency. These include:

- Reduce greenhouse gas emissions
- Be able to be quickly implemented and adopted
- Avoid Carbon Lock-in
- Maintain Social Legitimacy and Significance
- Protect food and water resources
- Protect human, nonhuman, and ecosystem health
- Enable other adaptive or mitigative technologies or practices
- Adapt to changing contexts

We detail each of these criteria below.

A. Reducing Greenhouse Gas Emissions

Le Quéré et al. show that the two major drivers of declining CO2 emissions were the replacement of fossil fuels by renewable energy, and decreases in energy use (in the eighteen developed countries that have decarbonized in the decade from 2005 to 2015) [29]. It is important to understand the ability of renewable energy to decrease CO2 emissions [30], [31]. Instead of simply using measures of energy production to describe a technology's ability to mitigate climate change, an accurate estimation of emissions reduction requires us to account for the greenhouse gas emissions over the technology's lifecycle including manufacturing, installation, operation, and decommissioning [30], the potential to reduce energy demand [32], and the potential to offset higher-emitting energy production resources in the long term [33]. It is difficult to estimate demand reduction from a renewable energy technology predictively or in-situ, but tracing the pathways to emission reduction via demand reduction, efficiency, and low-carbon energy alternatives is an important part of working toward climate solutions [32]. Understanding the potential to offset higher-emitting technologies in the long term requires knowledge of where a technology fits into the energy system. This knowledge can help us account for grid benefits, such as stability and locational dependencies. An analysis by Hausfather shows that even though natural gas could replace coal as a lower-emission technology, it could stall the adoption of near-zero-emissions technologies so much that greenhouse gas emissions increase. Such an analysis shows us the importance of understanding what technology we are replacing and what the long term effect of that replacement are [[33].

B. Adoptability and Carbon Lock-in

Whether a technology is implementable and adoptable depends on many factors aside from emissions reduction. These factors include cost, risk, and uncertainty. Rapid decarbonization is necessary to address climate change quickly enough to avoid massive, detrimental changes to the earth's natural systems [34]. This means that it is not only important whether a technology can be adopted, but it is important how quickly it can be adopted. Wilson et al. refer to this requirement as "rapid technology development" [35]. Rapid technology development is facilitated by short diffusion timescales and fast learning rates (which quickly decrease uncertainty), both of which are more common in granular technologies. Granular technologies have a small per-unit size and cost, and scale up by number rather than size. Their modular construction leads to lower-risk investments and allows for faster learning. That faster learning is part of rapid innovation cycles which can lead to quicker entry of low-carbon alternatives into the market [35]. We can evaluate implementability and adoptability by considering diffusion timescales, learning rates, unit size and cost, and associated uncertainty.

Technologies following the rapid innovation trajectory tend to be of low complexity and have shorter lifespans, which can reduce their dependence on the infrastructure and political systems that are built upon fossil fuels, thereby escaping carbon lock-in [35]. Carbon lock-in is described as "an inertia that helps them [fossil-fueled energy systems] persist, even as viable low-carbon alternatives become available" [36]. The longevity of fossil-fuel infrastructure is a barrier to clean energy solutions [36], [37], therefore a technological solution for climate change should not reinforce the longevity of that infrastructure. An example of a renewable energy technology that perpetuates carbon lock-in is concentrated solar, which currently relies on natural gas for production back up [38]. Wilson et al. measure the ability to escape carbon lock-in by efficiency potential, technical lifetime, and complexity [35].

C. Social legitimacy, protection, adaptation

Along with being the core of our energy system technologies, fossil fuels are also a central source of employment in many regions. Low-carbon technologies must, therefore, offer similar employment opportunities [30], [35]. Job creation is a part of gaining social legitimacy and acceptance, as is equity of access [35]. Equity of access means that improvements to the energy system lead to improvements in living standards for all people, especially low-income households which may not feel the economic benefits of such development. The equity of renewable energy technology has become an increasingly researched topic and a priority for evaluating climate change mitigation efforts [39], [40] [41] [42] [43]. Special attention should be paid to marginalized communities throughout the lifecycle of a technology, and developers should heed local and indigenous knowledge [41] [44] [45]. Energy justice, a term for the equitable distribution of benefits and impacts across society [39], is becoming important as policy makers adopt goals for "just transitions." The concept of energy justice implores developers to consider how much waste a technology produces, who bears the burden of that waste and whether those are the same people who benefits from the technology. Chapman et al. provide a comprehensive method of measuring energy justice which considers elements of distributional, procedural, and recognitional equity [39].

Research on the water-energy-food nexus highlights the need for energy technologies to protect food and water resources [46] [47] [48] [49] and foresee how future changes to those resources might impact the future of the technology [50] [51]. Equity for individuals is inextricable from environmental quality, therefore the protection of the environment is another essential requirement for climate change mitigation technologies [45], [52], [53]. Furthermore, the motivation behind addressing climate change in the first place is, broadly, to protect humans and nonhuman ecosystems from the detrimental impacts of the changing cycles and patterns. It would be counterproductive for our mitigative solutions to threaten those very ecosystems. Beier et al. emphasize the need to ensure that as climate change leads to altered animal migration patterns, we are protecting the essential corridors along which they travel [53].

Mclaughlin points out that when a technology is perceived as "one with mother nature," it is more likely to be accepted by communities [54]. When we approach individual technologies as parts of larger economic, social, and energy systems, we can value their ability to enable other technologies or practices that help ecosystems mitigate or adapt to climate change. The most common example of this is electric grid or energy storage technologies that can enable increases in renewable energy generation on the grid. Measuring ecosystem benefits and the capacity to enable other technologies may require forms of scenario analysis.

Renewable energy solutions that meet the latter six criteria are not only better able to address climate change directly, but they also have the potential to address the social, cultural, economic, and systematic barriers that stand in the way of renewable energy development today. Some of these requirements are easy to measure, but others pose evaluative challenges. Improving the requirements and evaluation techniques and considering all requirements together as measures of a renewable energy technology's suitability for addressing the climate emergency is a topic for future research.

D. Alternative Frames

In Seciton III, we argue that the Intrinsic Solution Frame contributes to the limited criteria by which we measure success of marine energy with respect to climate change. We might infer, then, that building new frames will enable us to adopt some of the climate criteria discussed above. Yet, to construct those new frames, we must, as a field, cultivate an understanding of those criteria, privileging climate change-related knowledge other than that of emissions.

We can understand the relationship between climate change and marine energy though the frame of our changing oceans, the needs of frontline communities, the environmental impacts of climate change, our changing electric grids and markets, democracy, justice, equity, resilience, and even, were one to do a careful examination, decolonial practice. Any one of these ways of understanding the relationship between climate change and marine energy could present new opportunities in the field.

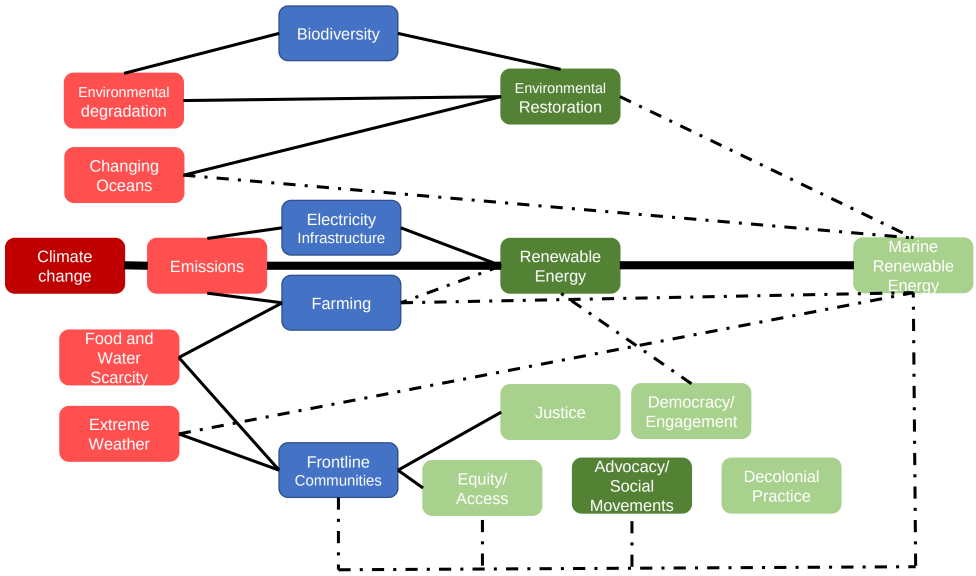

Fig. 2. A web of relationships surrounding climate change and marine energy. The relationship which is commonly produced in marine renewable energy scholarship is shown in bold. The dashed lines indicate relationships that should be further explored.

We have already begun to see examples of the potential of new frames in marine renewable energy fields. Researchers have suggested to possibility of using marine energy for ocean clean-up and observation [5], the benefits of marine renewable energy for remote communities [25], and the potential to combine wave energy with other renewables to decrease overall variability [55]. Researchers at the intersections of policy, economic, and renewable energy have examined the ways in which renewable energy projects can align with or support alternative economic and social priorities [56]. The research done in these areas can provide us with facts which serve to activate new frames which associate climate change and marine renewable energy. This is only possible if we construct that frame through careful communication [15]. Such communication requires an understanding of climate change which goes beyond emissions. As Lakoff notes, ”In the case of global warming, all too many people do not have such a system of frames in the conceptual systems in their brains. Such frame systems have to be built over time” [15]. Buildings these systems of frames takes far more work than can be presented in a single conference paper, but in Figure 2 we visualize some of the possibilities.

There are significant bodies of work from the social sciences and humanities relating democracy, justice, equity, and decolonial practice to energy. That work is regularly employed by policy makers and activists, but scholars are beginning to understand how it might be used in technological research and design to improve outcomes i.e. [57].

Within the sub-field of energy communication, Cozen et al. call for better engagement with ”everyday social struggles over energy, dissent against patterned thoughts and deep-seated assumptions about what energy is and does for society, and the composition of alternative possibilities for living in the world as it intersects with energy resources, production, and consumption” [58]. A similar engagement from the renewable energy fields, including marine renewable energy, will help us make our work relevant to the wider conversation about energy transitions.

E. Design Approaches

The opportunities we have discussed thus far relate to the ways that we measure success of marine energy technologies, with the understanding that measures of success drive the design process. We will finish with a brief discussion of design approaches which could enable improved outcomes under climate criteria.

Community-driven design, ecological engineering principles, design for X (environment, sustainability), and whole systems design are all approaches which we have discussed previously with reference to wave energy design [22]. Some properties of these approaches which contrast the dominant iterative and systems engineering approaches currently employed in WEC design include the level of engagement with coastal community members, the required knowledge of the surrounding ecosystem, the value of site-specific design decisions, the means of evaluating early design concepts, the method of selecting of materials, and the defining characteristics of survivablity and resilience. Employing such approaches may lead to new concepts for marine renewable energy.

Climate change will not only bring environmental changes, it will bring economic, political, social, cultural, infrastructure, and systematic changes, some of which we can predict, and some of which we cannot. This demands that designers of many technological systems, renewable energy especially, begin to employ design methods that help them prepare for and respond to those changes. For WEC designers, this means designing for future electricity infrastructure and markets, considering the changing needs of specific coastal communities, and designing with an awareness of the many stressors on the ocean environment.

V. Conclusion

In this paper, we shows how marine energy researchers construct the relationship between marine energy and climate change. We discuss how that communicated relationship is reflected in the work of marine energy scholars and what limitations it presents. The relationship between climate change and marine renewable energy as we commonly produce it, dominated by emissions-related knowledge of climate change, is a narrow conceptualized relationship which impedes our ability to effectively address climate change through work in marine energy. By cultivating a broader understanding of climate change and building frames which facilitate that understanding, we may find new opportunities for addressing climate change with marine renewable energy technologies.

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