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Cool as a (sea) cucumber? Exploring public attitudes toward seawater air conditioning in Hawai'i

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ABSTRACT

Seawater air conditioning (SWAC) has the potential to reduce the energy demand for air conditioning by 75–90%. This article reports the findings of a mail survey sent to residents of the Hawaiian island of O'ahu investigating attitudes toward SWAC and opinions of installing a system in Waikīkī. Results show that while only 55% of O'ahu residents were previously aware of SWAC, 62% supported its development in Waikīkī and just 7% opposed. Of those familiar with the technology, support rose to 69%. However, when compared to eight other low-carbon energy options, SWAC ranked second to last. Concern exists about the potential environmental impacts of SWAC, particularly with regard to reef damage and algae production. Logistic regression analysis shows no significant difference in the likelihood of a person supporting SWAC due to their sex or level of education; although age, political affiliation, and locality do affect the likelihood of support. Those who see tourism as very important to Hawai'i and think SWAC will benefit the tourism industry are more likely to support, along with those who have a very positive opinion of renewable energy, and those who are familiar with the technology. In contrast, high-income O'ahu residents are less likely to support SWAC.

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1. Introduction

In tropical climates, air conditioning (AC) typically accounts for a significant percentage of the energy demand of hotels and other large buildings. In Hawai'i, for example, it is estimated that 42% of the energy use from hotels and 34% from office buildings stems from AC requirements [1]. Globally, it has been estimated that one trillion kilowatt-hours of energy are required to satisfy our desires for cool indoor spaces [2] and demand is projected to increase throughout the coming century [3]. The vast majority of this increased demand will come from developing countries. Currently, the United States uses more energy for AC purposes than every other country in the world combined – a state of affairs that is unlikely to remain the case for long [4]. In an analysis of future air conditioning demand, Sivak (2013) ranked every country according to its person cooling degree days – a measure that multiplies a country's population by its cooling degree days[1] – in order to estimate potential future demand for cooling. Of the top 25 countries, 22 are developing nations, and rising global incomes, coupled with increasing temperatures, are likely to have a corresponding effect on the use of AC in these countries. If the use of air conditioning in India (which tops the list) ever matches that of the United States, its demand for cooling will be 14 times as great [4].

With this in mind, it is understandable that there is interest in finding less energy-intensive ways to cool buildings. Approaches to reducing global demand for AC range from rethinking urban planning and building design – for example by creating more open spaces, increasing the amount of shade, improving air flow, or reducing anthropogenic heat production [5] – to implementing technological advancements in AC systems, such as displacement ventilation, adsorption chillers, or desiccants [6–8]. In locations with access to a deep body of water, such as the ocean or a deep lake, one way of reducing the energy demand of AC is to harness the cooling properties of water. Depending on the location, and the source of the cold water, this process is known as seawater air conditioning, seawater district cooling, deep lake water cooling, or

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[1] Cooling degree days are calculated by subtracting 18 °C from the mean daily outdoor temperature of a region and summing the positive values over a set period of time. For example, a mean daily temperature of 25° would result in seven cooling degree days. Summing all of the cooling degree days over the course of a year provides an annual value which can be used to easily compare one region to another.

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lake-source cooling. The islands that make up the state of Hawai‘i have access to such a cooling source. Presently, Hawai‘i generates 88% of its electricity from fossil fuels and has dense population centers located within close proximity to cold ocean water (particularly on the island of O‘ahu) – two factors that make seawater air conditioning (SWAC) an appealing alternative to traditional AC.

AC is not only energy intensive, but also expensive, due to the specific mix of fuel sources in Hawai‘i. As Hawai‘i has no fossil fuel resources of its own, the state must import all of the fuel it requires for power generation. In 2011, 73% of Hawai‘i's electricity was generated from petroleum products, 15% from coal, and the remaining 12% from renewables [9]. This reliance on petroleum products results in Hawai‘i having the highest electricity prices in the United States. In the year of our survey (2012), residential electricity rates in Hawai‘i ranged from 35.1¢ per kilowatt-hour (kWh) on O‘ahu to 46.6¢ per kWh on Lana‘i; the U.S. average at the time was 11.9¢ per kWh.

In response to Hawai‘i's reliance on imported energy, the Hawai‘i Clean Energy Initiative, a partnership between the state and the U.S. Department of Energy, was established in 2008 with a goal of “transforming Hawai‘i to a 70% clean energy economy by 2030” [10]. This transformation is to be achieved by a combination of increased renewable energy generation (40%) and improved energy efficiency (30%). As an energy displacement technology, SWAC would contribute to the state's energy efficiency target.

A SWAC project in the Waikīkī district, Honolulu's top tourist destination, is an especially attractive business proposition. The visitor industry requires year-round climate control and tourists typically use more electricity than locals. Nasseri et al. estimated that in 2007 the average visitor to Hawai‘i used 1.5 times more electricity per day than the average resident [11]. By displacing electricity, district cooling offers significant benefits in terms of energy security and greenhouse gas emissions reductions, as well as reduced costs. Sustainable tourism benefits may also have marketing value. Yet, the initial development project would involve significant upfront investment and construction inconvenience. Moreover, given the tremendous value of the Waikīkī shore, even small impacts on surf, reef, beach, and water quality would have consequential impacts on the many users of the resource. Technical implementation is key to the success of Waikīkī SWAC.

It is against this backdrop that public attitudes toward SWAC are considered. Hawai‘i provides an interesting case study for such an investigation for two reasons. First, SWAC is a viable option for Hawai‘i, and second, past public opposition in the state to wind power, ferry transportation, and geothermal energy has proven to be an effective barrier to the implementation of otherwise sound business models. Unlike most of the United States, Hawai‘i has a sizeable indigenous population[2] and, while the NIMBY (not in my backyard) effect cannot be discounted as a factor behind anti-development sentiment, there also exist deeper concerns about indigenous culture and the environment. For example, initial opposition to volcanic geothermal energy stemmed from a respect for the Hawaiian goddess Pele [12] and was tempered through involvement of indigenous leaders.

This article presents a survey analysis of O‘ahu island residents concerning their knowledge and opinion of SWAC and other public issues related to energy, environment, education, and the economy. A key finding is that just over half of the population of O‘ahu is familiar with SWAC, and those who are aware of the technology are significantly more disposed to support its implementation in Waikīkī. Thus, findings of this study inform potential project design and related educational efforts. The level of support seen for SWAC in this study (62% in favor among all respondents, 69% among those who were previously aware of the technology) is in line with past research into public support for marine energy. While other studies have focused on energy generation (primarily offshore wind and wave energy) our findings indicate that people are as likely to accept a marine energy displacement technology such as SWAC.

In addition to addressing a specific technology, this article also touches on a number of more general questions related to energy and society [13]. For example, the financial benefits of a SWAC project in Waikīkī are likely to only be realized by the project developer and the owners of the hotels and other large buildings who adopt the system. Most residents of O‘ahu would not benefit financially from SWAC (unless they happened to live in a condominium that used the technology). However, SWAC also generates benefits to society, such as reductions in carbon dioxide emissions and freshwater use. Are these societal benefits high enough for people to support such a project – especially if it were to be subsidized with public funds? Secondly, how do people trade off the benefits of SWAC with potential local negative impacts? As will be seen below, while building a SWAC system does not necessarily cause damage to the local environment, depending on how the project is designed there is the possibility of reef degradation or algal blooms. Do the broader benefits of SWAC outweigh local impacts, or do local concerns trump global ones?

2. Background

Seawater air conditioning works by pumping cold (4–7 °C) seawater into a cooling station where, through a heat exchanger, it chills fresh water flowing in a separate closed loop. The slightly-warmed seawater is then returned to the source at a shallower depth and the newly-chilled fresh water is circulated through a district cooling system (Fig. 1).

A number of seawater or deep lake water cooling systems exist worldwide. In Hawai‘i at the site where the basic technology for SWAC was invented, a small facility (rated at 30–50 tons of refrigeration) has been operating at the Natural Energy Laboratory of Hawai‘i Authority (NELHA) since 1986,[3] and other systems exist in Bora Bora (450 tons), Toronto (58,000 tons), Stockholm (80,000 tons), and at Cornell University (20,000 tons). Lastly, a 25,000 ton system (different from the proposed Waikīkī system that is the focus of this study) is planned for downtown Honolulu with construction expected to be completed in 2017 [14].

Traditional air conditioning systems in large buildings have a number of components. Pipes circulate chilled water through the building, fans blow over the pipes to supply cool air to the rooms, and chillers and cooling towers chill the water that is circulated through the pipes. Chillers reduce the temperature of the water through the evaporation and condensation of a refrigerant. In the low-pressure environment of an evaporator, the refrigerant is converted into a gas, absorbing heat as it evaporates. The gas then enters a condenser where, under higher pressure, it is compressed back into a liquid state, heating up along the way. The excess heat from the liquid is transferred to a heat sink where it is expelled to the surrounding area. The newly cooled liquid refrigerant is then circulated back to the evaporator where the cycle begins again.

[2] According to the 2010 U.S. Census, 10% of Hawai‘i's population identified themselves as Hawaiian or Other Pacific Islander and a further 16% classified themselves as part Hawaiian or Other Pacific Islander.

[3] Seawater air conditioning in Hawai‘i actually dates back to 1983 when Arlo Fast, a University of Hawai‘i Sea Grant-funded researcher, jury-rigged a makeshift seawater air conditioner while studying Pacific Northwest salmon at NELHA on the Big Island. With ready access to cold seawater for his research, Fast built Hawai‘i's first functioning SWAC system out of an old truck radiator and household box fan [15]. In 1986, NELHA adopted SWAC in its main laboratory and has been operating the system ever since.

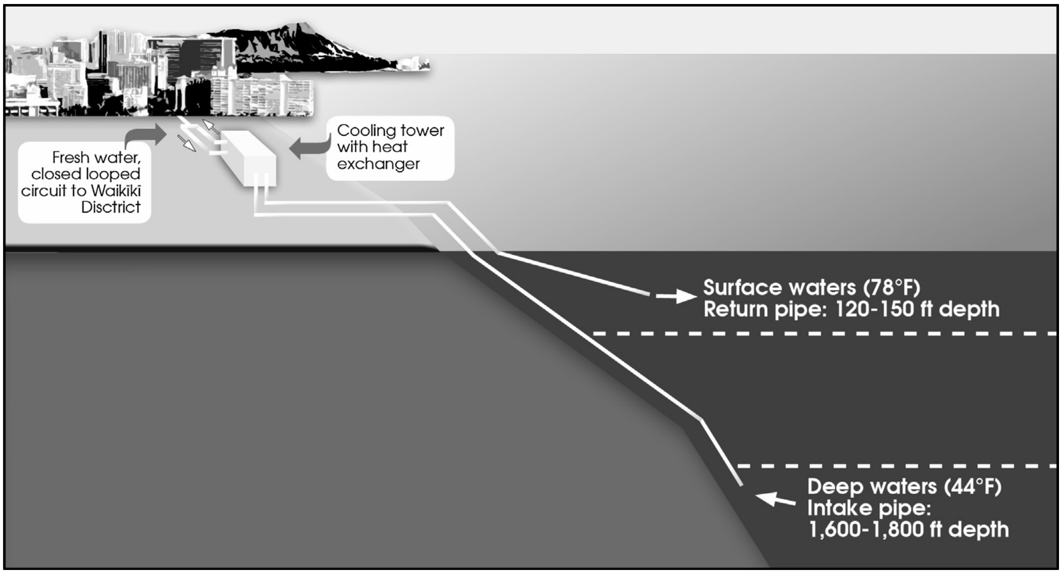

Fig. 1. Seawater air conditioning schematic for Waikīkī.

Some AC systems use cooling towers to improve efficiency. In such cases, rather than using air to transfer heat from the compressor, cold water cools the condenser coils. Inside a cooling tower, water passes over a mesh and is cooled down by air circulation and evaporation. The water in the system must be replenished regularly due to losses through evaporation, and the level of cooling depends on the ambient temperature and relative humidity in the atmosphere. Both chillers and cooling towers have significant resource requirements – electricity for the former and fresh water, often in the form of potable water, for the latter.

By using naturally cold water, SWAC greatly decreases the energy demand from air conditioning; additionally, by not requiring cooling towers, SWAC saves a significant amount of fresh water. It has been estimated that the above-mentioned 25,000 ton SWAC system that has been proposed for downtown Honolulu would reduce AC energy use by 75% (77.5 million kilowatt-hours (kWh) per year) and save approximately 260 million gallons of potable water per year. It would also decrease wastewater production by up to 84 millions gallons per year and cut thermal pollution in the surrounding environment by about 40% [16].

Such a reduction in energy use would eliminate up to 14 megawatts (MW) of new generating capacity (equivalent to one year of load growth on O'ahu). Given the amount of Hawai'i's electricity generated from petroleum products, the proposed project would reduce Hawai'i's oil imports by 178,000 barrels per year, decrease carbon dioxide emissions by 84,000 tons per year, and reduce emissions of a number of air pollutants associated with the burning of fossil fuels [16].

While SWAC has a number of potential advantages over traditional AC, it also has substantial upfront capital costs. For example, the Honolulu project has an estimated price tag of $200–300 million [14,17,18]. In light of these high startup costs, in 2013 Hawai'i's legislature issued two special purpose revenue bonds for proposed projects in Waikīkī on O'ahu and in Kona on the Big Island for $200 million and $40 million, respectively (Senate Bills 23 and 1280 of the 27th Legislature). The state issued a similar, $20 million bond for the downtown project in 2007 (House Bill 870 of the 24th Legislature).

As with any major construction project, the installation of a district cooling system may lead to short-term traffic disruption and congestion in the project area. Other potential negative impacts of SWAC include damage to coral reefs from laying the intake and outflow pipes and the growth of algae due to the higher nutrient content of the outflow water [19] (deep seawater has a higher concentration of phosphorus and nitrogen than surface water). Both of these issues can be avoided by appropriate project design (i.e., by laying the pipes in areas clear of sensitive reef environments and positioning the outflow pipe deep enough so as not to stimulate algae growth).

Currently, there is strong interest from a number of stakeholders in building a seawater air conditioning system for Waikīkī. The recent issuance of the above-mentioned special purpose revenue bond allows for this interest to be further pursued. With a high, year-round tourist population and the same access to deep ocean water as the downtown Honolulu project, Waikīkī appears to be an ideal location for a SWAC system. In 2002, it was estimated that conventional AC for buildings in West Waikīkī consumed 40,614 MWh/yr and that SWAC could reduce that amount to 4,805 MWh/yr – an efficiency improvement of almost 90% [20]. More recently, Kaiuli Energy (a private developer) has proposed a 22,415 ton SWAC system for Waikīkī that has the potential to: reduce electricity demand by 48,000 MWh/yr (saving almost $17 million per year in energy costs); cut water usage and sewer production (by up to 157 million and 69 million gallons a year, respectively); and reduce emissions by up to 50,000 tons per year [21].

3. Public opinion of marine-based energy technologies

Given the fact that there are only a few SWAC projects worldwide, no studies to date have examined public attitudes toward the development and installation of such systems. However, there is an existing literature regarding public opinion of other marine-based energy technologies, such as offshore wind power and wave energy.[4]

For the most part, public opinion of offshore energy is generally positive. General support for offshore wind in the United States has been shown to hover around the 80% mark [22]. When specific, individual projects are at issue, support levels fluctuate more – ranging

[4] Some may argue that SWAC is technically not an offshore technology given that most of the infrastructure is onshore. However, like offshore wind power and wave power, SWAC harnesses the ocean's resources and thus is typically perceived as marine-based.

from 57% in Cape Cod to 80% in Delaware [23]. In Europe, Ladenburg (2010) found that just 27 out of 1,082 respondents in a Danish study had a negative attitude toward existing offshore wind farms, with more than half of the respondents (652) holding a very positive attitude [24]. An earlier study in Denmark, also by Ladenburg (2008), found similar results with just 5% out of 369 respondents having a negative attitude toward further development of offshore wind [25]. In the United Kingdom, a survey of 352 Cornish residents by Bailey et al. (2011) found similar support levels to those seen in the United States, with 79% of survey respondents supportive of offshore wind near their community and 82% in favor of it elsewhere in Cornwall [26]. Smaller-scale, interview-based studies at the local level in Europe have also found high levels of support for offshore wind power [27,28].

Studies that have investigated attitudes toward wave and tidal energy have found similar levels of support. In the above-mentioned study by Bailey et al., a large majority of survey respondents were in favor of both tidal energy (64% near their community, 68% elsewhere in Cornwall) and wave power (86% near their community and 89% elsewhere in Cornwall). In Northern Ireland, Devine-Wright (2011) found mean levels of project acceptance to be positive for residents of villages close to a tidal energy facility in Strangford Lough [29]. In the United States, a study of Oregon residents found lower levels of support for wave energy than in Cornwall although, with 52% in favor, a majority still supported the technology [30]. This lower level of support was likely more due to a lack of awareness of wave energy rather than opposition to it. Thirty-five percent of the 674 survey respondents stated they did not have enough information to form an opinion, whereas just 3% had a negative attitude toward the technology.

Overall, it appears that the public is in favor of utilizing the ocean's resources to generate renewable energy. Where concerns have been raised, they typically relate to: visual impacts [31–33]; environmental impacts [32,33]; impacts on local industry and tourism [32,33]; the cost of renewable energy projects [22]; and the concept of place attachment [29,34–36].

Based on the predominantly positive attitude toward the harnessing of offshore renewable energy, it is expected that most residents of O'ahu will support the development of SWAC in Waikīkī. As the proposed project will have a minor visual impact, it is unlikely that there will be any objections based on aesthetic grounds. Of more relevance are concerns over the cost and potential environmental impacts of SWAC, the concept of place attachment, the idea that the ocean is a special place, and what benefits local residents might gain from the project.

4. Methods

To elicit data regarding public opinion of seawater air conditioning, a mail survey was distributed to O'ahu residents in the summer of 2012 (the survey was limited to O'ahu as that is where large-scale SWAC is economically feasible). Dillman's Tailored Design Method was used as a general guide to conduct the survey [37]. In brief, the Tailored Design Method incorporates five elements for maximizing survey response rates: (1) a clear and easy-to-understand questionnaire; (2) multiple contacts; (3) the inclusion of return envelopes with real stamps; (4) personalized correspondence; and, (5) the inclusion of a token financial incentive with the survey. For this project, the first four steps of Dillman's method were followed. Given financial constraints, it was not possible to include a token monetary incentive with each survey.

After extensive pretesting, the survey was administered to 2,000 O'ahu residents. To ensure coverage across the entire island, and to allow for comparisons between different localities, a balanced stratified random sample was drawn [38]. Stratified random sampling has a number of benefits over simple random sampling. It ensures that important subpopulations are incorporated into the sample and it maximizes the between-group variance and minimizes the within-group variance for the independent variables [39]. It also allows for specific regions to be oversampled to ensure that enough surveys are received from key areas (see below). Data for the sample was provided by Survey Sampling International (SSI) which generates data by combining and crosschecking multiple public records.

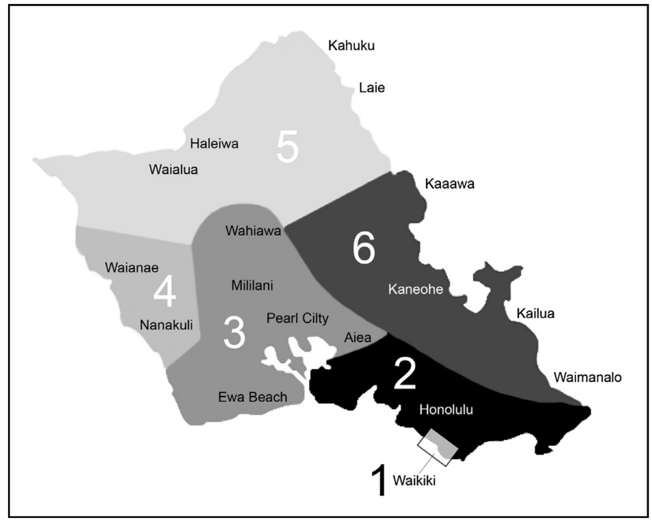

Fig. 2. O'ahu sampling strata.

For the purposes of sampling, O'ahu was split into six regions, or strata (Fig. 2). Table 1 displays the population of each stratum and its proportion of O'ahu's population. As the focus of this project was on SWAC in Waikīkī, it was decided to substantially oversample that region (Stratum 1 in Fig. 2) to ensure that enough data were generated from O'ahu's primary tourist district. As a result, the greater Honolulu and 'Aiea-Pearl City-'Ewa Beach regions (Strata 2 and 3, respectively) were undersampled. Further, given lower population densities in Wai'anae and the North Shore (Strata 4 and 5) those regions were also oversampled in an attempt to obtain a representative sample. Finally, the Kailua-Kāne'ohe region (Stratum 6) was undersampled. By way of comparison, Table 1 also shows how many surveys would have been sent to each stratum had a proportional sample been used.[5]

To administer the survey, up to three mailings (two survey packets and a reminder postcard) were sent to each address. Of the 2,000 surveys distributed, 559 were completed and returned. A further 280 were sent back as undeliverable, resulting in a bad address rate of 14% (the expected bad address rate was 20%). Accounting for these undeliverable questionnaires, the survey had a response rate of 33%. Upon receipt, the survey data were coded and entered into a database. To check the quality of the entered data, every tenth survey was re-examined; five errors were found in the 55 surveys, resulting in a data entry error rate of 0.1%.[6] Lastly, to make certain that oversampling the greater Honolulu area did not skew the results, the data were weighted according to strata, sex, age,

[5] Had the Waikīkī, Wai'anae, and North Shore strata not been oversampled, then very few responses would have been received from these areas. For example, with an overall survey response rate of 33%, one might have expected only 23 responses from Waikīkī (33% of 70 surveys mailed out). Instead, due to the oversampling, 89 responses were received from the Waikīkī district, providing a stronger foundation for our analysis.

[6] Five errors divided by 4,840 data points (55 surveys, each with 88 questions) multiplied by 100.

Table 1
Oʻahu sampling strategy.

Stratum	2011 population	Percentage of Oʻahu (%)	No. of surveys (proportional)	No. of surveys (w/ oversampling)	Change (%)
1) Waikīkī	32,354	3.50	70	350	+400
2) Honolulu	329,176	35.60	712	650	−9
3) ʻAiea-Pearl City-ʻEwa Beach	363,330	39.30	786	500	−36
4) Wai'anae	49,344	5.34	107	150	+41
5) North Shore	31,177	3.37	67	150	+122
6) Kailua-Kāne'ohe	119,186	12.89	258	200	−22
	924,567	100.00	2,000	2,000	

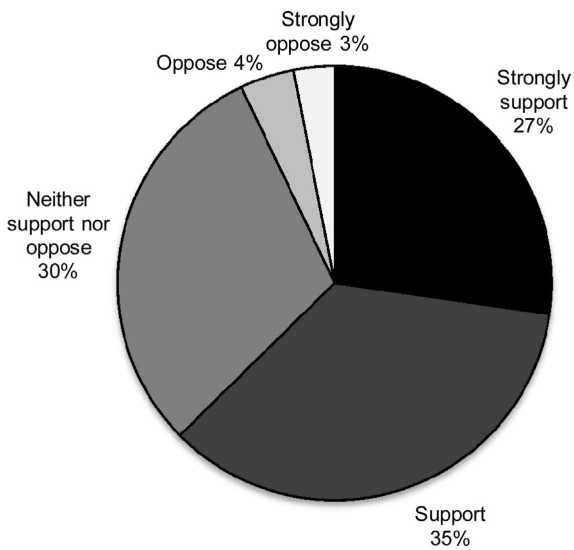

Fig. 3. Public support for the development of a Waikīkī SWAC system.

and income. This ensures that the data accurately represent Oʻahu residents and allows inferences drawn from the responses to be applied to the broader population. The results presented below use the weighted data. The data were analyzed using the statistical program STATA and all significance testing was conducted using Wald tests [40].

5. Results and discussion

5.1. Support for SWAC

To better understand the level of knowledge people have concerning SWAC, survey respondents were first asked whether they had previously heard of using seawater for air conditioning purposes. Fifty-five percent of respondents were aware of SWAC prior to completing the survey and 45% were unaware of the technology. After reading a brief description explaining how SWAC works and being presented with Fig. 1, respondents were asked whether they support or oppose the installation of a SWAC system in Waikīkī.[7] As shown in Fig. 3, 62% of Oʻahu residents support the idea (27% strongly support and 35% support), 30% neither support nor oppose, and only 7% oppose the idea (3% strongly oppose).[8]

To assess whether prior knowledge of SWAC affected attitudes toward its installation in Waikīkī, support levels were compared between people who had previously heard of SWAC and those who had not. Oʻahu residents who had heard of SWAC were more supportive of the technology than those who had not heard of it, with 69% of those previously aware in favor compared to 54% of those previously unaware – a difference significant at the 0.01 level.

5.2. Reasons for support and opposition

After indicating whether they support or oppose the development of SWAC in Waikīkī, survey respondents were asked to briefly state why. As this question was posed in an open-ended manner, a variety of answers were received. To summarize the results, the answer choices were coded and grouped together. Commonly cited reasons for support include: a belief that SWAC will be more cost-effective; a belief that the technology behind SWAC makes inherent sense; the fact that SWAC utilizes a renewable resource; the fact that SWAC will reduce fossil fuel use and save energy; a belief that SWAC will be beneficial for the environment; and the fact that SWAC will help Hawaiʻi become more energy self-sufficient.

Among those opposed to SWAC, the primary issue was the environmental impact SWAC might have on both the ocean and the land environment. A small number of people were also concerned about the potential cost of SWAC development and what impacts SWAC might have on local residents. Respondents who were undecided about whether they support or oppose SWAC in Waikīkī listed similar issues, with potential environmental impacts again cited most often. Cost, the potential impact on local residents, the potential use of public money, and the viability or maintenance of the technology were also listed as concerns. Although no survey respondent explicitly stated that they view the ocean as a special place, three respondents did express concern about developing the ocean and two were concerned about the impact SWAC might have on Hawaiian cultural resources. Two respondents believed we should leave the ocean alone with one stating that SWAC is "not natural."

The survey shows that the potential cost and environmental impacts of using seawater for air conditioning purposes were cited by both supporters and opponents of SWAC alike. Survey respondents were not asked about the rationale behind their answers so we can only speculate as to why cost and environmental impacts are seen in both a positive and a negative light. It might be that SWAC is seen as a cheaper alternative to rising fossil fuel prices by some and as a costly, capital-intensive investment by others. Similarly, SWAC could be viewed as a way to reduce carbon dioxide and other fossil fuel emissions, or as a harmful intrusion into the marine environment. This apparent contradiction is in fact reflective of attitudes toward renewable resources more generally, where environmental factors can fuel both support and opposition depending on whether one has a global or a more local perspective [41]. To tease out these issues, more specific questions would be needed and while there was not space to include such questions in the current survey, they could be incorporated into future research on this subject.

[7] In Fig. 1, the depth of the outflow pipe is given as 120–150 feet (36–46 m) and this information was presented to survey respondents. While this description was based on the best available information at the time, it now seems more likely that the outflow pipe will be at a depth of 300–400 feet (91–122 m).

[8] Percentages do not add to 100 due to rounding.

Table 2
Ranking of energy generation/displacement technologies proposed for Hawai'i.

Technology	Percentage who rank in top-3 choices (%)[a]	Percentage who rank as top choice (%)[a]
Solar rooftop PV	68	39
Wind energy	60	10
Solar water heaters	44	11
Biofuels/biomass	31	18
Wave energy	31	5
Geothermal energy	26	11
OTEC	16	3
SWAC	11	1
Natural gas	8	3

[a] The numbers do not add to 300% for the top-3 choices or to 100% for the top choices due to rounding.

While not listed by any opponents, the use of public money to build a SWAC system was cited by a handful of undecided respondents (those who neither supported nor opposed SWAC) as an area of concern. However, a plurality of O'ahu residents support the use of funds from Hawai'i's Public Benefit Fund (PBF) for SWAC development. In the survey, it was explained that the PBF is funded by a surcharge on electricity bills and that it is used to pay for programs such as rebates for solar water heaters and clean energy appliances. Although fewer people are in favor of this idea than those that support SWAC in general, a plurality (46%) is still in favor of using PBF funding, with 28% unsure and 26% opposed. While it is unlikely that public funds will be provided directly to a private developer of a SWAC system, it is possible that such monies could be used to retrofit buildings to enable them to access a district cooling system.

5.3. SWAC compared to other options

Although a majority of O'ahu residents support SWAC in Waikīkī, when it comes to choosing between various options, SWAC does not fare as well as other energy displacement or renewable energy technologies. Survey respondents were asked to rank nine energy technologies (biofuels/biomass, geothermal energy, natural gas, ocean thermal energy conversion (OTEC), rooftop solar water heaters, SWAC, solar power, wave energy, and wind energy) in the order they thought they should be developed in Hawai'i. As shown in Table 2, only 11% of O'ahu residents rank SWAC in their top-three alternative energy choices and just 1% rank it as their first choice. The low ranking of SWAC may be due to people having more familiarity with some of the other technologies listed. The proposed "Big Wind" project on the island of Lana'i has resulted in wind power receiving a lot of attention in the local media, rooftop solar PV systems are a common sight on O'ahu, and solar water heaters have been required for new single-family dwellings since January 1, 2010 (Hawai'i Revised Statues §196–6.5 (2008)). Not surprisingly, all three of these technologies rank highly among local residents. The fact that survey respondents had just read about both the potential benefits and impacts of SWAC, whereas they may not have been as aware of the negative impacts of the other options, may also have contributed to the low ranking of SWAC, as could the fact that SWAC is more applicable to tourists than to residents.

5.4. Effect of potential benefits and impacts of SWAC on support levels

In an attempt to measure the effect that knowledge of the potential benefits and impacts of SWAC has on support levels, survey respondents were provided with six statements (three positive and three negative) and asked whether each statement made them more or less supportive, more or less opposed, or had no effect on their opinion. The following two tables show the percentage of people whose opinion was influenced by the six statements.[9] The first table (Table 3) shows the percentage of opponents who would be less opposed, as well as the percentage of those undecided who would be more supportive, if they knew about three potential benefits of SWAC.

Table 3
Effect of knowing the benefits of SWAC on the opinion of SWAC opponents and the undecided.

Statement	Opponents % less opposed	Undecided % more supportive
The amount of energy used by buildings connected to a SWAC system would be reduced by 30%	19	63
SWAC would reduce fresh water use by 110 million gallons a year (1% of what O'ahu uses)	25	70
SWAC would reduce CO_2 emissions by 120,000 metric tons (1% of Hawai'i's total CO_2 emissions)	38	69

Table 4
Effect of knowing the impacts of SWAC on the opinion of SWAC supporters and the undecided.

Statement	Supporters % less supportive	Undecided % more opposed
If SWAC caused traffic disruption for up to six months during construction	19	38
If SWAC caused minor damage to Waikīkī's reef during construction	60	73
If SWAC caused algae to form off Waikīkī Beach	72	68

As indicated by Table 3, there is a significant difference in the effect of knowing about the benefits of SWAC between opponents of SWAC and people who are undecided. Knowing that SWAC would reduce the amount of energy used by buildings positively influenced the opinion of 63% of those undecided compared to just 19% of opponents (a difference significant at the 0.01 level). Similarly, 70% of those undecided were more likely to have their opinion positively influenced when hearing about the water savings associated with SWAC, compared to 25% of opponents (significant at the 0.01 level). Lastly, 69% of those undecided were more likely to have their opinion positively influenced when learning of the reduction in CO_2 emissions, compared to 38% of opponents (again significant at the 0.01 level). This implies that simply providing opponents with information about the potential benefits of SWAC will do little to alter their opinion. Conversely, presenting the same information to those undecided appears to increase support levels.

To gauge the effect on public opinion of SWAC's potential negative impacts, a similar analysis was undertaken on supporters of SWAC, along with those undecided. Table 4 shows the percentage of those who support SWAC and those undecided who stated they would be less supportive (or more opposed) to SWAC if the following potential impacts were to occur.

Given that the development of SWAC in Waikīkī is still at a conceptual stage, it is difficult to know what the precise impacts of installing such a system might be. There will, of course, be some temporary disruption to traffic but the likelihood of damage to Waikīkī's reef or the growth of algae off Waikīkī Beach, is not currently known. It should, however, be noted that such negative environmental effects issues are not inevitable and that an

[9] The results of this question might have been influenced by question order as the answer choices were not rotated in the survey instrument.

appropriately designed project should be able to minimize any adverse effects. Given this, these statements were phrased as hypotheticals, for instance, "if SWAC caused minor damage to Waikīkī's reef" and "if SWAC caused algae to form off Waikīkī Beach." Still, the results imply that *should* such impacts occur then support for SWAC in Waikīkī would likely decrease. As Table 4 shows, 60% of supporters and 73% of those undecided would be either less supportive or more opposed to SWAC should reef damage occur. Similarly, 72% of supporters and 68% of those undecided would lose enthusiasm for SWAC if it were to cause an algal bloom off Waikīkī Beach. As with the potential benefits, there are significant differences between, in this case, supporters of SWAC and those undecided. People who have not yet made up there mind about SWAC are significantly more likely than supporters to oppose its development if it were to disrupt traffic or cause reef damage. These differences are significant at the 0.01 and the 0.05 levels, respectively. There is, however, no significant difference between the two groups when it comes to algae formation. Even among supporters of SWAC, the formation of algae off the beaches of Waikīkī would lead to a substantial decrease in support.

When attempting to measure opposition to SWAC, it is worth differentiating between potential short- and long-term negative impacts of the project. Referring once more to the literature into public acceptance of wind power, it has been suggested that local support for new wind projects often follows a 'U' or 'V' shaped pattern. In such cases, a project might have strong public backing in the abstract sense, lose support during construction, and then regain support when it is operational [42–44]. Regarding SWAC, should any negative impacts associated with the project prove to be short-term (e.g., traffic congestion or reef damage during the installation of the pipes), then it might be expected that opposition would decrease after construction, thereby following the 'U' shaped pattern. However, should there be ongoing negative impacts from SWAC (e.g., continued reef degradation or algae growth) then it is likely that opposition to the project would not dissipate but rather continue and potentially increase over time.

5.5. Multivariate analysis of support for SWAC in Waikīkī

To better understand public sentiment, logistic regression was employed to determine which factors influence support for SWAC in Waikīkī. Logistic (or logit) regression is a form of multiple regression analysis used to predict or explain the relationship between a dichotomous dependent variable (in this case, support or opposition to SWAC) and multiple independent variables, which might influence the dependent variable (e.g., age, sex, and education level). The power of multiple regression lies in its ability to analyze the effect that an independent variable has on the dependent variable, while controlling for the effect of the other independent variables in the model.

In the logit model presented in Table 6, the dependent variable (support for SWAC) is a dichotomous variable where 1 = *support SWAC* (those who indicated support or strong support) and 0 = *oppose SWAC* (those who indicated opposition or strong opposition).[10] The model has a pseudo R^2 of 0.487[11] and a p-value of 0.0000.[12] The independent variables are described in Table 5 and represent a mix of demographic and attitudinal measures. Three demographic characteristics (income, political persuasion, and strata) are represented in the model by dummy variables with the excluded categories being low income (less than $35,000 per year), democrat, and Waikīkī, respectively. A fourth demographic category (race) was considered but not included, as none of the categories were significant and there were no theoretical grounds to believe that one race was more, or less, likely to support SWAC than another. The attitudinal variables measure: opinion of renewable energy, the importance of tourism to Hawai'i, the potential effect SWAC might have on tourism, and the relative importance of five issues that affect Hawai'i: the cost of living, the economy, public education, a reliance on imported energy, and the health of the environment. These last five independent variables were generated from a survey question that asked respondents to rank their top five

Table 5
Description of variables used in logistic regression.

Variable	Description
male	1 if male, 0 if female
age	Age of respondent in years
college	1 if have at least a college degree, 0 if no degree
medium_income	Income: 1 if have a medium income ($35,000–$100,000), 0 if not
high_income	Income: 1 if have a high income ($100,000–$200,000), 0 if not
vhigh_income	Income: 1 if have a very high income (over $200,000), 0 if not
independent	Politics: 1 if identified as Independent, 0 if not
republican	Politics: 1 if identified as Republican, 0 if not
other_politics	Politics: 1 if identified as other, 0 if not
honolulu	Strata: 1 if live in Honolulu (excluding Waikīkī), 0 if not
aiea	Strata: 1 if live in the 'Aiea-Pearl City-'Ewa Beach region, 0 if not
waianae	Strata: 1 if live in Wai'anae, 0 if not
north_shore	Strata: 1 if live on the North Shore, 0 if not
kailua	Strata: 1 if live in the Kailua-Kāne'ohe region, 0 if not
swac_aware	1 if aware of SWAC prior to receiving the survey, 0 if not
vpos_renew	1 if have a very positive attitude to renewable energy, 0 if not
tourism	1 if believe tourism is very important to Hawai'i, 0 if not
swac_tourism	3 if believe SWAC will make Waikīkī a more attractive tourist destination, 2 if not sure, 1 if do not believe
cost_living	Hawai'i issues: 1 if the cost of living is a top-five issue of concern, 0 if not
economy	Hawai'i issues: 1 if the economy is a top-five issue of concern, 0 if not
public_ed	Hawai'i issues: 1 if public education is a top-five issue of concern, 0 if not
energy	Hawai'i issues: 1 if a reliance on imported energy is a top-five issue of concern, 0 if not
environment	Hawai'i issues: 1 if the health of the environment is a top-five issue of concern, 0 if not

[10] Survey responses from respondents who were undecided (i.e., those who selected the *neither support nor oppose* option) were not included in the model. Also excluded were responses that were missing data for any of the model's variables. As a result, the model contains 317 observations.

[11] As the maximum likelihood estimates generated by logistic regression models are not calculated to minimize variance, the goodness of fit measure (R^2) used in ordinary least squares (OLS) regression does not apply. Instead, various "pseudo" R^2 measures have been developed to help evaluate the goodness of fit of logistic models. While these pseudo R^2 measures provide an approximate indication of whether a model is adequate, they should not be interpreted in the same way as OLS R^2 values. See [45] for more information regarding how to interpret pseudo R^2 values in logistic regression analysis.

[12] In addition to the dichotomous logit model, the following models were tested: a five-category ordered logit model (*strongly support*, *support*, *neither support nor oppose*, *oppose*, and *strongly oppose*), a three-category ordered logit (*support*, *neither support nor oppose*, and *oppose*), a three-category multinomial logit model (*support*, *neither support nor oppose*, and *oppose*), and a dichotomous logit model in which the *neither support nor oppose* responses were combined with the *oppose* responses. Neither of the ordered logit models fitted the data as well as the logit model and, while seemingly a good fit, the multinomial logit model failed to distinguish adequately between the *oppose* and *neither support nor oppose* categories. Lastly, the model that combined the *neither support not oppose* and *oppose* responses was rejected because: (1) it had a lower pseudo R^2 (0.261); and (2) there was no theoretical basis to aggregate these answer choices.

Table 6
Logistic regression of factors influencing support for SWAC in Waikīkī.

Variable	Coefficient (*b*)	Standard error	Odds ratio	*z*	*p*
male	−0.079	0.600	0.924	−0.13	0.896
age	−0.044	0.022	0.957	−2.02	0.043*
college	0.767	0.665	2.152	1.15	0.249
medium_income	−1.076	0.829	0.341	−1.30	0.194
high_income	−1.496	0.857	0.224	−1.75	0.081
vhigh_income	−1.994	0.989	0.136	−2.02	0.044*
independent	0.291	0.726	1.338	0.40	0.688
republican	1.830	0.916	6.234	2.00	0.046*
other_politics	−0.670	0.769	0.512	−0.87	0.384
honolulu	−1.788	0.831	0.167	−2.15	0.031*
aiea	−0.746	0.853	0.474	−0.87	0.382
waianae	1.716	1.320	5.565	1.30	0.193
north_shore	−3.020	1.086	0.049	−2.78	0.005**
kailua	−0.239	1.079	0.788	−0.22	0.825
swac_aware	2.894	0.818	18.060	3.54	0.000**
vpos_renew	1.498	0.565	4.474	2.65	0.008**
tourism	0.882	0.766	2.415	1.15	0.250
swac_tourism	3.182	0.764	24.106	4.17	0.000**
cost_living	0.328	1.047	1.388	0.31	0.754
economy	1.555	0.661	4.733	2.35	0.019*
public_ed	−0.239	0.561	0.787	−0.43	0.670
energy	−0.643	0.671	0.526	−0.96	0.338
environment	0.604	0.599	1.830	1.01	0.314
constant	−3.140	2.288		−1.37	0.170

No. of observations = 317; log pseudolikelihood = −53.99; Wald χ^2 = 65.85; probability > χ^2 = 0.0000; pseudo R^2 = 0.487.
* Significant at the .05 level.
** Significant at the .01 level.

issues from a list of twelve; the issues selected for the model were the five highest ranked.[13]

The coefficients (*b*) in Table 6 give an indication of how a particular variable affects the likelihood of support for SWAC; positive coefficients imply a greater likelihood of support, negative coefficients imply a greater likelihood of opposition, holding other variables constant. The greater the absolute value of the coefficient, the more pronounced the impact. In most cases, one can directly compare the effect of one variable in the model to another variable by examining their coefficients. All dichotomous variables can be compared in this way. There are however exceptions (e.g., the age variable, where the coefficient refers to a change of one year and the *swac_tourism* variable, which is trichotomous). In the case of age, an increase in age of 30 years (from 25 to 55 or 37 to 67, for example) implies an increase in the likelihood of opposition to SWAC of −1.32 (-0.044×30). The effect of a variable can also be gauged by its odds ratio. An odds ratio greater than one denotes a positive effect on the likelihood of support, whereas an odds ratio of less that one denotes a negative effect.[14] As Table 6 shows, there exists little difference between men and women regarding the likelihood of support. Men are slightly less likely to support SWAC, but the effect is very small and insignificant ($b = 0.079$, $p = 0.896$). As already shown, with a *p*-value of 0.043, age is significant and has a negative effect on the likelihood of support – older O‘ahu residents are more likely to oppose SWAC than younger residents. Having at least a college degree appears to have a positive effect on the likelihood of support for SWAC but in this model the effect is insignificant.

Income is negatively correlated with support for SWAC. As income levels increase from low (less than $35,000 per year) to medium ($35,000–$100,000), high ($100,000–$200,000), and very high (more than $200,000) the less likely a person is to support SWAC. Specifically, the coefficients become larger (in absolute terms) and the *p*-values decrease; *medium_income* has a coefficient of −1.076 and a *p*-value of 0.194, *high_income* has a coefficient of −1.496 and a *p*-value of 0.081, and, with a coefficient of −1.994 and a *p*-value of 0.044, *vhigh_income* has the largest effect on support and is significant at the 0.05 level. Indeed, O‘ahu residents who fall into the highest income bracket are 86% less likely to support SWAC than residents in the lowest income category (less than $35,000 per year).

Regarding political affiliation, both Republicans and Independents are more likely to support SWAC than Democrats, albeit to varying degrees. Republicans are six times more likely to support SWAC than Democrats, a difference significant at the 0.05 level ($b = 1.830$, $p = 0.046$). Independents are also more likely to support, although the difference is much less and not significant ($b = 0.291$, $p = 0.688$). Those who class themselves as being of another political persuasion are less likely to support SWAC than Democrats, although again the difference is not significant ($b = -0.670$, $p = 0.384$). The fact that Republicans are more likely to support SWAC than Democrats is worth noting, as typically it is the latter that favor environmental positions [46]. There could be a number of reasons why our results do not follow this pattern. It may be that Hawai‘i Democrats see SWAC as being more harmful than beneficial to the environment, or that Hawai‘i Republicans place a greater emphasis on the energy savings of SWAC. It may also be the case that Republicans in Hawai‘i are more environmentally minded than their counterparts on the mainland. It should also be noted, however, that in the model there are only a few instances where a person both opposes SWAC and falls into either the very high income or Republican categories (three and

[13] The remaining seven items in the list were: crime; food security (a reliable supply of food); Hawaiian sovereignty; homeland security (the threat of terrorism); homelessness; overdevelopment; and Pacific Islander migration. The top-five variables were assigned points according to their ranking (five points if ranked first, four points if ranked second, etc.). The points were then summed across all survey respondents to determine a weighted rank. The point totals for the top-five issues were: the cost of living (2,042 points); the economy (1,244); public education (910); a reliance on imported energy (671); and the health of the environment (654). As the point totals show, concern over the cost of living dominates all other issues.

[14] For example, a variable with an odds ratio of 2 is interpreted as causing a two-fold increase in the odds (the likelihood) of support. To convert an odds ratio of less than one into a more intuitive measure, first subtract one from the odds ratio and then multiply the resulting number by 100. For example, an odds ratio of 0.2 means that the odds of support change by −80% ($0.2 - 1 = -0.8$; $-0.8 \times 100 = -80$). In other words, the odds of support decrease by 80% [45].

four respondents, respectively). To be able to draw firmer conclusions from these data and to tease out the relationships further, additional research would be needed.

It appears that people living in Waikīkī are generally more supportive of SWAC than those living in other parts of Oʻahu. The only significant differences are found among residents living in greater Honolulu who are 83% less likely to support SWAC than Waikīkī residents ($b = -1.788$, $p = 0.031$) and those living on the North Shore who are 95% less likely to support than Waikīkī residents ($b = -3.020$, $p = 0.005$). It is interesting that Waikīkī residents are more supportive of SWAC that those living on other parts of the island, especially considering that Waikīkī would bear the brunt of any traffic disruptions. Most Waikīkī residents live in high-rise condominium or apartment buildings so it is possible that they could benefit from SWAC if their buildings were connected to the system. Hawaiʻi's North Shore has a well-established surfing community so it is not too surprising that residents of this region are more opposed to a technology that intrudes into the ocean.

The next four variables in the model (*swac_aware*, *vpos_renew*, *tourism*, and *swac_tourism*) all have a positive impact on the likelihood of support and all except *tourism* are significant at the 0.01 level. Given the results of the earlier Wald test, it was expected that people who are aware of SWAC are more likely to support. Indeed the model shows them to be eighteen times as likely to favor SWAC development ($b = 2.894$, $p = 0.000$). Also unsurprisingly, those who have a very positive view of renewable energy are more likely to support ($b = 1.498$, $p = 0.008$). What is more interesting is the connection people draw between SWAC and increased levels of tourism. In the survey, respondents were asked how important they believe tourism is to Hawaiʻi's economy. Eighty-three percent of respondents stated that tourism is very important, 11% important, 5% somewhat important and less than 1% believed it to be not important. Tourism is indeed a key driver of Hawaiʻi's economy, accounting for about a fifth of the state's economic activity [47,48]. In the model, while the variable *tourism* (which compares those who believe tourism to be very important with those who view it as important, somewhat important, or unimportant) is not significant, the variable *swac_tourism* is significant. This three-category variable compares those who do not believe SWAC will make Waikīkī a more attractive tourism destination (32% of respondents), those who are not sure (50%), and those who think SWAC will make Waikīkī more attractive to tourists (18%). With a coefficient of 3.182 and *p*-value of 0.000, the variable is the most influential variable in the model and highly significant. Looking at the odds ratio, it is possible to say that, all else being equal, the odds of a person supporting SWAC who is unsure about its value to tourism are 24 times greater than someone who thinks SWAC has no tourism value. The odds of support are a further 24 times greater for someone who believes SWAC will have a positive impact on tourism in Waikīkī. Of course, without further study, it is hard to know whether the significance of this variable is a result of people supporting SWAC because they believe it will be beneficial for tourism, or whether it is significant because SWAC supporters want to believe the technology will help tourism. It is also unclear at this stage how great an effect SWAC would actually have on Hawaiʻi's visitor industry. It would certainly reduce the environmental footprint of Waikīkī's hotels and could be marketed as such but whether it would increase the attractiveness of what is already a very popular tourist destination is hard to say.

Lastly, the five variables derived from the most commonly cited issues that affect Hawaiʻi (*cost_living*, *economy*, *public_ed*, *energy*, and *environment*) have a mixed, and generally insignificant, effect on the likelihood of support. Of the five variables, only *economy* is significant ($b = 1.555$, $p = 0.019$) with the odds of support among Oʻahu residents who think the economy is important being almost five times greater than among those who are not as concerned about the state of the economy. Although not significant, a similar effect was seen among people who view the cost of living as a top issue of concern ($b = 0.328$, $p = 0.754$). The positive effect of *economy*, and to a lesser extent *cost_living*, implies that, despite the high upfront capital costs, those concerned about economic issues are more likely to support SWAC. Of course, it is not possible to know how informed people are about the cost of SWAC. The survey did not mention the potential cost of a Waikīkī SWAC system, although, as noted above, a figure of $200–300 million has been reported by local media for the similarly-sized downtown Honolulu project.

Although not significant, the variable *environment* has a positive effect on the likelihood of support ($b = 0.604$, $p = 0.314$). This suggests that, regardless of any concern over potential negative environmental impacts, people who are concerned about the health of the environment are more likely to support SWAC than people who are not as concerned about the environment. However, as the *environment* variable is not significant, it is not possible to state this with any degree of certainty. Similarly, the variable *energy* (representing those concerned about Hawaiʻi's reliance on imported energy) has a negative effect on the likelihood of support, but as with *environment*, is not significant ($b = -0.643$, $p = 0.338$). Given SWAC's energy saving potential, it might be expected that people concerned about the amount of energy Hawaiʻi imports would be more likely to support SWAC but this does not appear to be the case. This could be because people do not believe the energy savings of SWAC to be that significant, or possibly because they have not made the connection between Hawaiʻi's importation of oil and the energy demand of air conditioning. Oʻahu residents who are concerned with the status of the state's public education system appear to be slightly less likely to support SWAC, although the effect of the variable *public_ed* is very small and insignificant ($b = -0.239$, $p = 0.670$).

6. Conclusion

With a heavy air conditioning load, high electricity prices, and close proximity to deep ocean water, Waikīkī presents itself as an ideal location for SWAC. There is already one system planned for downtown Honolulu and there exists strong interest in building a similar project for Oʻahu's primary tourist district. Unlike other proposed energy projects in the state – such as the island of Lanaʻi's Big Wind project, which has been the focus of a vocal public opposition campaign – it appears that the public generally supports moving forward with SWAC development.

Logistic regression modeling shows no significant differences in the likelihood of a person supporting SWAC due to their sex or level of education, although age, political affiliation, and locality do affect the likelihood of support. People who believe tourism to be very important to Hawaiʻi and see SWAC as benefiting the tourism industry are more likely to support, along with those who have a very positive opinion of renewable energy, and those who are familiar with the technology. On the other hand, high-income Oʻahu residents are less likely to support SWAC.

Some concern exists among Oʻahu residents about SWAC's possible adverse environmental effects, especially with regard to potential reef damage and algae production. However, these issues are by no means inevitable and an appropriately designed project should be able to minimize environmental impacts. Further, concern over the health of the environment has a positive (albeit insignificant) effect on the likelihood of SWAC support. Lastly, given that the success of such a project depends heavily on its economic viability, it bodes well for SWAC that a plurality of people are in favor of using some amount of public funding to help develop such a system in Waikīkī (at least in the abstract sense).

When compared to other energy displacement or renewable energy technologies, SWAC ranks at the bottom of a list of nine options. SWAC's low rank is possibly due to a lack of familiarity with the technology, especially when compared to solar or wind power. It might also be due to recognition that SWAC requires a high concentration of buildings with a heavy AC demand and is not feasible for single home residences. As such, when given the choice between SWAC and other, wider-reaching options, it is understandable that other technologies are chosen. Still, that should not detract from SWAC's overall popularity among O'ahu residents. If Hawai'i is to achieve its stated goal of a 70% reduction in fossil fuel use, then a range of approaches will be needed and renewable energy projects, energy efficiency measures, and energy displacement technologies, such as SWAC, all have a potential role to play in Hawai'i's energy future.

Finally, regarding the broader questions discussed at the beginning of this article, it appears that the issue of private benefits versus public costs is not of great concern to most of O'ahu's residents. While the use of taxpayer money was mentioned as an area of concern by a few of those who had not made up their minds about SWAC, no opponents listed it as a reason for opposition. Granted, there were not many opponents in this study and presumably, if one tried hard enough, it would be possible to find someone who opposed SWAC on those grounds but, overall, it does not appear to be a prevailing concern. Indeed, when asked directly, a plurality of O'ahu residents support using public funds to subsidize the installation of a SWAC system. Of greater concern are the potential environmental impacts of SWAC for, in the public's mind, any benefits of SWAC would be negated by local environmental costs such as reef damage or algae formation. Minimizing local environmental impacts is therefore imperative to ensure public support for SWAC.

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