Techno-economic analysis of integrating renewable energy and water treatment infrastructure

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RESEARCH PROBLEM

Alaska has the lowest rate of homes without piped water and sewer systems. In-home plumbing rates in 23% of Alaskan communities have had a statistically significant decline between 2011 and 2015 (Brown et al., 2022). While some individuals in Alaskan villages still choose to obtain water directly from local water sources, pollution and climate change have often made this practice unsafe, resulting in possible adverse health impacts. Therefore, the engineering community considers it a failure if the public must resort to collecting water from the environment or alternative sources. Despite challenges, Alaska residents desire piped water infrastructure (Spearing et al., 2022). However, the primary obstacle lies in the associated costs, with energy as a significant cost factor.

The energy requirements to maintain a consistent water supply in the Arctic are distinctive and substantial and come with significant costs (Wu et al., 2018). The energy expenses in remote regions of Alaska are approximately ten times greater than the national average in the United States (Aggarwal, 2022). High energy costs are due to the extreme natural and climate impacts and the remote contexts in which the infrastructure is built. Water distribution systems frequently require heat or continuous water recirculation to prevent freezing.

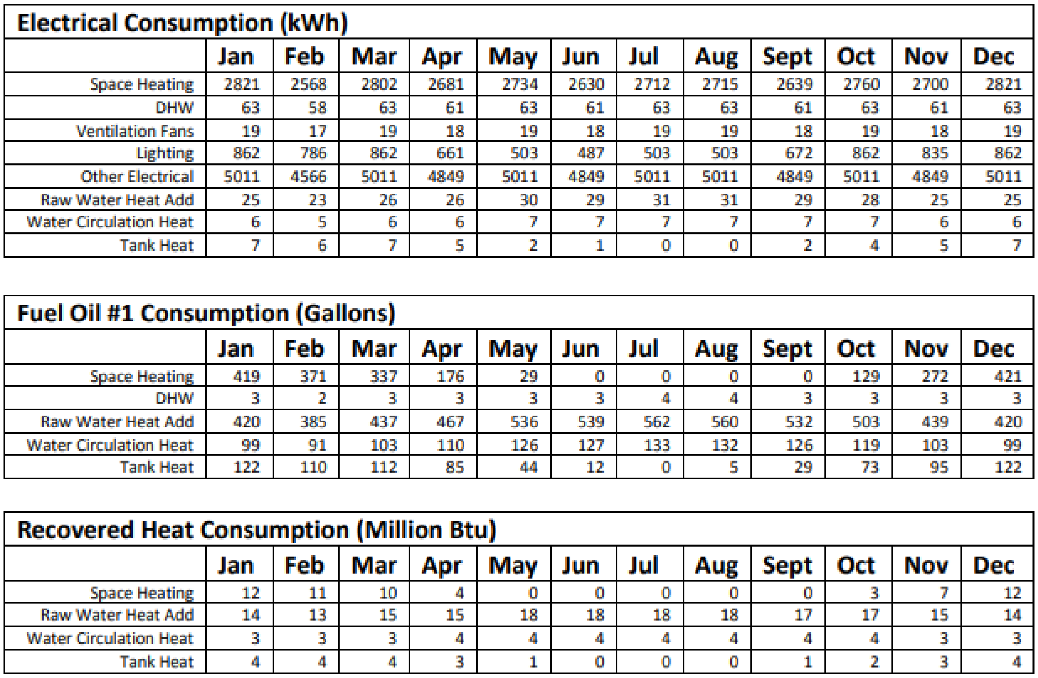
The water-energy nexus refers to the interconnected relationship between water and energy resources, highlighting how they influence and depend on each other. This concept recognizes that the production, distribution, and consumption of energy require water, while the extraction, treatment, and distribution of water necessitate energy. Incorporating the water-energy nexus into the planning, design, and operation of a water supply system ensures the system's sustainability, promotes energy conservation, and minimizes associated greenhouse gas (GHG) emissions. The water industry accounts for 2–3% of global energy consumption (Vakilifard et al., 2018). In the United States, the water supply system represents 13% of total energy usage and contributes 5% to the country's annual GHG emissions (Griffiths-Sattenspiel, 2009). Disregarding the water sector's contributions could lead to an escalation in energy usage and hasten climate change, impacting the sustainability of available water resources. The decreasing costs of renewable energy, which have become more affordable than fossil fuels globally, including their upfront construction costs, make renewables attractive, particularly in lower-income and remote Arctic areas where energy costs can be significantly higher (Feldman et al., 2021; IEA, 2022). Hybrid energy systems, which blend fossil fuel and renewable supply, are a compelling option in remote contexts (Sambor et al., 2022). This approach can significantly benefit water supply systems by reducing electricity costs. Moreover, recent research highlights the high energy intensity of Arctic water infrastructure, with per capita energy consumption being 12-26 times higher than the national U.S. average (Aggarwal, 2022). The integration of renewable electricity can mitigate these energy-related costs.

METHODS

ANTHC Data

We utilized energy audit data from the Alaska Native Tribal Health Consortium (ANTHC), collected from 78 rural communities (ANTHC, 2015). ANTHC conducted surveys to determine the overall energy consumption for water treatment and distribution in rural Alaska communities. These rural communities span Alaska's Northern, Interior, Southwest, Gulf Coast, and Southeast regions. The energy audit surveys provided data on electricity (in kilowatt-hours; kWh), #1 heating fuel oil (in gallons), spruce and birch wood (in cords), and heat recovery system (in million BTUs). Per capita consumption estimates were derived by incorporating population data from the U.S. Census. Heating degree days (HDD), a measure of temperature over a specific time often used to determine heating needs, served as a proxy for ambient temperature. In this study, we chose to examine data in Akiak, Alaska.

Akiak, Alaska, is in the southwest region of Alaska, residing in the Yukon Delta in the Bethel Census area. As of the 2011 audit, they had a population of 356, a mean annual heating degree day of 13109, and an annual energy consumption of 208 kWh per person or 2624 MJ per person. The Akiachak plant serves the community through piped distribution loops and primarily uses electrical, fuel oil, and heat recovery to power the system, as seen in Figure 1. The Akiachak Water Treatment Plant is anticipated to incur a total annual energy cost of $91,894. The predominant component is electricity, accounting for $60,861 annually, of which $25,359 is covered by the community, and $35,502 is subsidized by the Power Cost Equalization (PCE) program through the State of Alaska. The remaining portion, amounting to $30,707 annually, is attributed to fuel oil expenses. The facility benefits from the recovered heat supplied by the neighboring power plant at no cost. Additionally, $325 per year is allocated for maintenance purposes in the energy modeling calculations.



Electrical Consumption (kWh)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Space Heating	2821	2568	2802	2681	2734	2630	2712	2715	2639	2760	2700	2821
DHW	63	58	63	61	63	61	63	63	61	63	61	63
Ventilation Fans	19	17	19	18	19	18	19	19	18	19	18	19
Lighting	862	786	862	661	503	487	503	503	672	862	835	862
Other Electrical	5011	4566	5011	4849	5011	4849	5011	5011	4849	5011	4849	5011
Raw Water Heat Add	25	23	26	26	30	29	31	31	29	28	25	25
Water Circulation Heat	6	5	6	6	7	7	7	7	7	7	6	6
Tank Heat	7	6	7	5	2	1	0	0	2	4	5	7

Fuel Oil #1 Consumption (Gallons)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Space Heating	419	371	337	176	29	0	0	0	0	129	272	421
DHW	3	2	3	3	3	3	4	4	3	3	3	3
Raw Water Heat Add	420	385	437	467	536	539	562	560	532	503	439	420
Water Circulation Heat	99	91	103	110	126	127	133	132	126	119	103	99
Tank Heat	122	110	112	85	44	12	0	5	29	73	95	122

Recovered Heat Consumption (Million Btu)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Space Heating	12	11	10	4	0	0	0	0	0	3	7	12
Raw Water Heat Add	14	13	15	15	18	18	18	18	17	17	15	14
Water Circulation Heat	3	3	3	4	4	4	4	4	4	4	3	3
Tank Heat	4	4	4	3	1	0	0	0	1	2	3	4

Figure 1: Atiak, Alaska Water Treatment Plant's energy consumption by source(ANTHC, 2015)

HOMER Software

The assessment utilizes HOMER, a software package developed by the U.S. National Renewable Energy Laboratory, allowing for comparing various energy systems based on their technical and economic merits (Lambert et al., 2005). HOMER functions as a simulation and optimization tool, modeling the hourly performance of diverse system configurations, allowing users to pinpoint the optimal combination that meets technical constraints at the lowest net present cost. The software is designed to evaluate and design micro-generation systems providing electricity and heat for nearby loads. These systems can operate independently or be connected to the grid, incorporating renewable and conventional technologies and storage options. HOMER is versatile and capable of modeling various micro-generation systems like photovoltaic units, wind turbines, and Combined Heat and Power units.

Data Analysis

We will use the HOMER software's simulation, optimization, and sensitivity analysis features to create an evaluation model of the pumping mechanism in Atiak's water treatment plant. Electricity demand profiles will be derived from technical specifications and operational data from the ANTHC dataset. Utilizing the HOMER software, economically and technically feasible configurations of decentralized renewable energy systems will be designed. The analysis involves sizing configurations based on Akiak's identified renewable resources. Potential configurations may include solar P.V. + battery storage, wind + battery storage, and hybrid fossil fuel-renewables systems like solar P.V. + grid and wind + grid, leveraging Akiak's existing energy systems.

The resulting designs will comprehensively distribute water and energy technologies, revealing performance metrics and tradeoffs among distributed renewable energy and water infrastructure integrations. Our approach involves analyzing load profiles to identify demand peaks and adjusting scenarios to reduce these peaks, ultimately minimizing energy system size and cost. Strategies for peak reduction may involve selecting different water treatment and energy generation technologies, altering infrastructure operational strategies, temporal load shifting, or exploring energy efficiency opportunities.

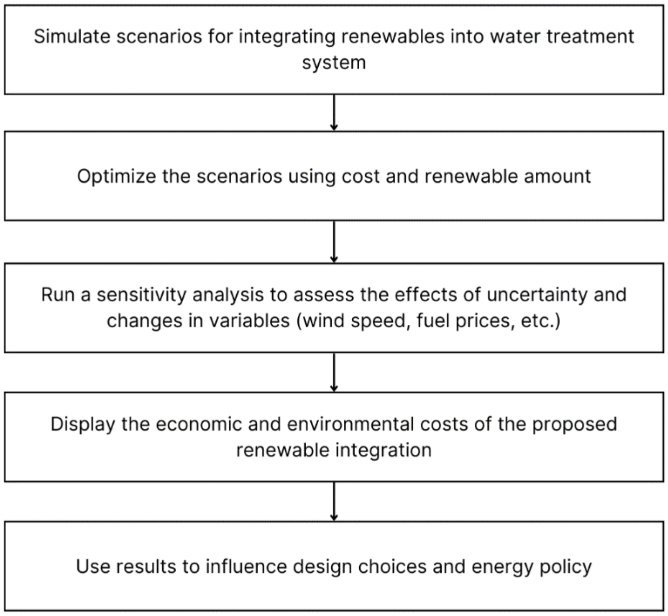


Figure 2: Methods flowchart using HOMER software

FINDINGS

The outcomes of this analysis will encompass estimated costs, optimization scenarios, and sensitivity analysis. The cost breakdown will incorporate capital, operational, maintenance, and fuel and installation expenses associated with the proposed grid. Optimization scenarios will illustrate both cost optimization and the integration of renewable resources based on the required configuration. The sensitivity analysis will offer insights into conditions that could impact the proposed project, such as fluctuations in fuel costs.

IMPLICATIONS

The implications of conducting a paper on utilizing HOMER for designing renewable energy grids in Alaska are substantial and far-reaching. The existing engineering literature lacks comprehensive research on the effective design and operation of integrated water and renewable energy infrastructure systems. This project addresses this gap by generating generalized design guidance from our collected data. The practical significance of this endeavor is noteworthy, considering the myriad social, natural, and built environment factors propelling the adoption of renewable energy. The proposed techno-economic analysis will be used to think about physical and organizational design strategies that can influence how renewables and water infrastructure interact. By formulating theories on integrating renewable energy into water treatment systems, we establish a foundation that can guide others embarking on new projects or seeking to incorporate renewable energy solutions. This contribution extends to offering knowledge on associated costs, identifying suitable types of renewables for implementation, and outlining methods for efficient energy storage within water treatment infrastructure. The theories generated from this study could inform policy decisions promoting resiliency to climate change. Policymakers may also consider incorporating insights from the research into initiatives supporting integrating renewable energy into water treatment systems, potentially leading to developing policies that encourage such environmentally conscious projects. The interdisciplinary nature of this research positions it as a pioneering effort that advances technical design and aligns with the evolving needs and challenges faced by communities globally and in the Arctic, establishing a foundation for continued exploration and innovation in integrated renewable energy infrastructure.

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