INSTITUTE FOR ENERGY INNOVATION
LOUISIANA STATE UNIVERSITY

Utilizing the Sun for a Sustainable Future in Louisiana – a Pilot Solar Deployment Project at LSU
(LSU-2023-IEI-P1-Synthesis-03)

WHITE PAPER

EXPLORING THE TOOLS AND METHODS FOR COMMUNITY-ENGAGED SOLAR DESIGN AND DEVELOPMENT

Arup Bhattacharya*, Department of Construction Management, LSU
Soo J. Jo, School of Architecture, LSU
Zhihong Pang, Department of Construction Management, LSU
Chris Kees, Department of Civil and Environmental Engineering, LSU
Yimin Zhu, Department of Construction Management, LSU

**Corresponding author. Email – arupb@lsu.edu*

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Introduction

Louisiana ranked third in total energy consumption and second in per capita energy consumption among all U.S. states in 2021, with most of its power generated from natural gas-fired plants [1]. Holding one-sixth of the nation's oil refining capacity, the industrial sector used over 70% of Louisiana's energy in 2021. Despite the residential sector only using about 7% of the total energy, Louisiana had the highest residential energy consumption in the nation, primarily due to over 70% electric heating and widespread use of air conditioning [1]. As a result, Louisiana emitted 188.6 million metric tons of CO_2, placing it sixth nationwide. These emissions contribute significantly to climate change, posing multiple threats to the state. The Intergovernmental Panel on Climate Change predicts a 5.85-degree increase in average summertime temperatures by 2100, leading to more frequent and severe superstorms due to warming oceans. Rising sea levels are expected to submerge nearly 70% of Louisiana's salt marshes in the coming centuries. The Gulf Coast, already having lost 1.2 million acres of wetlands, continues to lose 24 square miles annually. This environmental shift threatens the habitat of the state tree, the Bald Cypress, due to increased flooding from hurricanes [2]. A report from the Louisiana Department of Health, reviewing ER data from 2010 to 2020, indicated that over 100 people per year visited the ER for heat-related illnesses, with a peak in the summer months for individuals aged 40-49 [3]. Therefore, managing Louisiana's environment proactively is crucial, particularly by strategically controlling energy production and consumption to reduce greenhouse gas emissions through cleaner energy methods.

According to the International Energy Agency, a 30% increase in global electricity use is forecasted, which causes concern about future energy sources [4]. This concern has brought renewable energy research to the forefront of scientific inquiry. There are several programs by the US Federal Government to boost the integration of renewable energy sources into our existing energy grids. The Justice40 program[1] covers investments in clean energy and energy efficiency to offer affordable housing and sustainable living conditions. Several offices in the US Department of Energy (DoE) have been endeavoring to support specific topics. The Office of Electricity in the US DoE has initiated the Communities Local Energy Action Program (Communities LEAP) to reduce local air pollution, increase energy resilience, lower utility costs and energy burdens, and provide long-term jobs and economic opportunities for disadvantaged communities[2]. The Office of Energy Efficiency and Renewable Energy added new research funding that covers electricity generation from solar, wind, and hydropower, as well as critical testing infrastructure, energy storage, grid integration, and other renewable energy technologies. The Office of Environmental Management supports soil and groundwater remediation research in several national laboratories. Many US

[1] https://www.whitehouse.gov/environmentaljustice/justice40/
[2] https://www.energy.gov/communitiesLEAP/communities-leap

states have set individual targets of acquiring renewable energy from various resources to achieve zero-carbon emissions by the end of 2050. Meeting these goals is a significant deployment challenge that turns partly on effective designs and communication of actual benefits and costs. Currently, renewable energy generates about 20% of all US electricity, and that percentage continues to grow [5]. Solar and wind are expected to add more than 60% of the utility-scale generating capacity to the U.S. power grid (46% from solar). In 2022, the Department of Energy (DoE) assessed that the available clean energy production is 100 times that of the Nation's annual electricity need [6]. The potential is enormous, while the US used only 0.2% of the total available renewable energy in 2020. While ocean and marine energy resources have essential roles to play in respective regions, solar is the most abundant renewable energy resource nationwide. Overall, the advantages of renewable energy are numerous in the economy, environment, and human welfare as it reduces carbon emissions, increases affordability, enhances reliability and resilience, creates job opportunities, and enhances community engagement.

Louisiana, having 216 sunny days per year on average, which is more than the US average, certainly has a lot of untapped potential to use solar energy [7]. A 2022 factsheet by the Solar Industry Association (SEIA) points out that Louisiana has 306 MW of installed solar, which is 0.48% of the state's total electricity production, ranking 38th in the nation, but also projects that the total solar installation can go up to 3482 MW taking the state to 14th position [8]. With prices falling by 54% in the last five years, solar deployment in the state has rapid growth potential. At the same time, it is also important to recognize the challenges associated with large-scale solar deployment.

Currently, the Department of Natural Resources in Louisiana encourages the development of solar energy harvesting. Some industry leaders have developed large solar energy projects and will continue to expand their investment in Louisiana. Entergy, a major power supplier, currently operates a 100-megawatt renewable solar power station near Ruleville in the Mississippi Delta, which is the largest utility-owned solar installation in Mississippi and provides enough energy to power 16,000 homes. Entergy is seeking approval for 175 megawatts from facilities in Iberville Parish, Louisiana, and another 49 megawatts from facilities in Ouachita Parish, Louisiana, which is poised to be the largest renewable power expansion request in state history. Lightsource BP will own and operate the privately funded $300 million, 345 megawatts DC Oxbow solar farm on 1,800 acres of land in Pointe Coupee Parish, Louisiana. BASF, a world-leading energy producer, has entered agreements for 250 megawatts of solar and wind power supply of more than 20 sites across the United States. In addition to inland facilities, BASF has installed an innovative proof-of-concept floating solar system at their manufacturing site in McIntosh, Alabama.

Thus, in light of the developing solar energy scenario in Louisiana, it is crucial to develop research expertise for sustainable growth in the state. This white paper produces a comprehensive overview of the state of the knowledge in solar deployment from peer-reviewed literature and reports, focusing on the fluid-structure interaction (interaction between solar panel mounts and wind), community engagement for renewable energy projects, and renewable energy integration aspects of the project.

Methods:

A systematic literature review process was applied to collect, categorize, analyze, and summarize the current state of the knowledge. Various journals were screened using a set of pre-determined criteria that targeted the primary keywords, year of publication, citation index, and contributions to the broad subject topic. Databases like Google Scholar, Scopus, IEEE Library, and Web of Science (WES) were utilized to find the relevant targeted peer-reviewed articles. In addition, relevant reports from research firms were also screened and added to the body of literature. To avoid the plethora of published data on the broad topics of 'renewable energy' and 'solar energy,' topic-specific keywords were selected for topics discussed in this manuscript. Some previous review paper's references were also checked to find similar topic-related highly cited publications. A total of 125 publications were considered and analyzed by the team, and 73 publications were chosen to gather information on our research focus to provide the summary, which is delineated below.

Solar development in Louisiana

Louisiana is one of the most vulnerable areas in the nation to flood and storm damage because of its unique geographical features. While the petroleum industry in the state is one of the most crucial industrial sectors in the nation, it is widely understood that the transition to clean energy is critical for the future of the state and the nation. Louisiana is ranked 38th in the US for solar deployment, with only 276 megawatts installed [9]. Historically, Louisiana has been less involved in clean energy research projects [10] due to its reliance on the petroleum and derivative chemical industry. Louisiana is uniquely poised to have industry-academia collaboration for applied research to settle strategic plans for the deployment of solar farms and to further expand renewable energy harvesting plans from inland to nearshore and offshore facilities. Louisiana, with abundant sunshine, has been an area of interest for solar energy for decades. However, the initial development of solar farms was slow, primarily due to the state's historical reliance on fossil-fuel industries due to the proximity to the hotbed of oil and gas reserves. The growth of solar farms in Louisiana, like in many states, has been significantly influenced by federal and state incentives, including tax credits and renewable energy policies. While Louisiana does not have as aggressive renewable energy mandates as some other states, the economic viability of solar power continues to drive growth. Initially, solar energy developments in Louisiana were primarily in the residential sector. Homeowners installed rooftop solar panels to take advantage of state and federal tax credits. Over time, as the cost of solar technology decreased and public interest in renewable energy grew, utility-scale solar projects began to emerge. These larger projects are driven by the economics of solar energy and, in some cases, by renewable portfolio standards and corporate renewable energy goals. With the decreasing cost of solar panels and the increasing demand for clean energy, traditional energy companies started investing in solar farm projects, recognizing the potential of renewable energy. The future of solar farms in Louisiana looks promising, particularly as the state and the nation continue to move towards more sustainable energy sources. The solar energy landscape in Louisiana is dynamic and influenced by a combination of technological advancements, policy changes, and economic factors. Solar farms will likely play an increasingly important role in Louisiana's energy mix as solar technology continues to improve and become more cost-effective. The floating solar module emerged as a way to utilize water bodies for solar energy generation without using valuable land space. Such a facility has several advantages, including reduced water evaporation and a cooling effect on the panels, which can increase efficiency. Since their inception, these systems have seen considerable development, especially in countries with limited land areas or competing land use needs. However, solar energy from floating farms remains an untapped resource in Louisiana.

Barriers to ground-mounted solar

There are a couple of predicaments with the construction of solar facilities on land including soil and vegetative cover, potentially modifying drainage, runoff, and infiltration patterns. This can significantly alter vegetation growth and the landscape of native grassland environments and potentially harm natural systems. In arid regions, the increased demand for cooling water can further strain the limited water resources that already exist. Floating solar panels can be another option that could reduce land disturbance and impact terrestrial vegetation while improving solar performance. The impact on aquatic ecosystems and performance in sometimes harsh marine and riverine environments is challenging to assess. The Solar Energy Technologies Office (SETO) is gathering data to assess the performance of floating photovoltaic (PV) and the ecological impacts on aquatic ecosystems through research at the University of Central Florida. Floating solar systems are an untapped market, while the National Renewable Energy Laboratory’s report showed that 27% of water bodies are suitable for solar [11]. Many suitable water bodies, such as reservoirs, lakes, and nearshore areas, face high land acquisition costs and elevated electricity prices. Implementing floating PV modules can strategically enable broader access to solar energy, and reduces costs. In addition, floating platforms and lower operating temperatures for PV panels can mitigate evaporation and algae growth. Such factors can potentially enhance panel performance with accelerating the transition to renewable energy.

Ground-mounted solar installation technology, which might apparently be simple, involves many complications, which drives the installation costs higher. As the solar farm installation is governed by multiscale interactions between vegetation, sediment transport, infiltration, airflow, and surface water flow, it is crucial to investigate their impacts at the design stage. Air-structure and water-structure interactions can easily cause unforeseen damage and structural failure. Angled solar arrays create lift force (just like an airfoil) and alter the wake and turbulence [12]. Engineers should analyze the dynamic wind pressure distribution on the panel to design the load and resistance factor for the supporting structures. However, the existing building code for wind load is not designed for solar panel modules. Additionally, flooding prevention needs to be considered in the design phase through reliable simulation tools. Since the analysis and simulation during the assessment and design phase remain very challenging nowadays, this pilot scale project aims to develop digital twins for solar installations to support design exploration, deployment, and multi-objective optimization for setting best practices and, ultimately, establishing sustainable communities and improving global resiliency. This project is looking into developing novel Computational Fluid Dynamics (CFD) – based simulations to understand the fluid-structure interaction better, aiding in decision-making during the design stage, enhancing the capability for location-specific design, especially in places like Louisiana where extreme weather conditions must be accounted for.

Design tools to overcome implementation barriers

CFD methods

This project aims to provide reliable product evaluation for new design and strategic planning deployment through scalable development of hydrodynamic and structural dynamic modeling for solar energy modules using CFD models. The development of numerical methods and computational toolkits, specifically for multi-physics coastal and geological systems, are essential components of this project. For designing systems with significant components of fluid-structure interactions, collecting field data using experimental methods is difficult and sometimes even impossible. Simulation tools, hence, are used to approximate systems states in reality. For simulations approximating the parameters of fluid flow problems, which are governed by the Navier-Stokes' equation, have assumptions built into the simulation method, and need to be adjusted depending on the desired accuracy and convergence. Researchers have worked to provide innovative simulation methods to increase the accuracy and precision of the simulated systems. Kees et al. (2011) proposed the phase-conservative variational form to build a hybrid VOF-LS method, which can handle complex two-phase Navier-Stokes flow problems without excessive mass loss or smearing of the interface [13]. Quezada de Luna et al. [14] reformulated a monolithic equation for local mass conservation and signed distance property. Quezada de Luna et al. (2019) advanced the monolithic LS method and a semi-implicit high-order projection scheme for variable-density flows [15]. They included an extra step to ensure convergence to the signed distance level set function and to simplify other aspects of the original scheme. Additionally, consistent artificial viscosity was introduced by them considering the project scheme to stabilize the momentum equations. Such a stabilization method is algebraic, parameterfree, and effective for unstructured meshes and varying refinement levels. Meanwhile, Dimakopoulos et al. (2019) developed a numerical wavemaker capable of generating random wave fields (free surface elevation and velocities) by reconstructing them in time and space from a reference time series using window processing [16]. This approach efficiently reproduces long, non-repeating wave sequences with only $O(10^1)$~$O(10^2)$ wave components, as opposed to the $O(10^3)$~$O(10^4)$ components required for direct reconstruction from a single spectrum.

In addition to the Navier-Stokes model, some reduced-order models have also been considered. Conventional models include the dispersive shallow water model and potential flow model. They usually ignore minor physical phenomena and simplify the governing equations to reduce computational costs and obtain simpler numerical algorithms. Guermond et al. (2018) investigated the approximation of shallow water equations with topography. The friction term was explicitly handled to replicate the dry boundary [17]. Guermond et al. (2019) then included the nonlinear term in the Serre-Green-Naghdi (SGN) equations to simulate the dispersion and diffraction of water waves propagating over complex bathymetry [18]. Guermond et al. (2022) expanded the hyperbolic relaxation technique to achieve second-order spatial accuracy, third-order temporal accuracy, and invariant-domain preservation [19]. This method is also well-balanced and does not require adjustable parameters. Another simplified model is the potential theory that assumes the flow to be incompressible, inviscid, and irrotational. The 2D and 3D potential flows were tackled using the finite element method (FEM) [20], [21]. In order to update the Galerkin method was utilized to construct the velocity field for updating the free surface. Employing the S-G filter can effectively eliminate spurious waves [22], [23]. Using cubic spline approximation, Sajedeh et al. (2019) re-meshed the fluid grid in a tank with a curved bottom [24]. New spherical Hankel shape functions were introduced by them to decrease computational load for quadrilateral elements. In order to solve Laplace's equation an alternative approach is transforming it into the boundary integral equation (BIE) using Green's second identity. This technique relocates numerical nodes to the boundary, thereby reducing the order of the linear equation system by one. This method is particularly beneficial for problems requiring re-meshing, such as large wave deformations, because it requires less preparation time and eliminates unnecessary information, focusing on the surface where most engineering problems occur. An appropriate radiation condition can tackle wave propagation and model the behavior of absorptions [25]. This algorithm represented by Grilli et al. (1989) includes Eulerian and Lagrangian approaches to solve the mixed-type boundary value problem (BVP) using the boundary element method (BEM) while tracking free-surface particles via second-order Taylor series expansion. This dual approach is commonly referred to as the mixed Eulerian-Lagrangian (MEL) method [26]. Yung-Hsiang et al. (2017) tackled the sloshing problem using the RBIM combined with the MEL method [27]. The numerical findings represented by them revealed no distorted elements, as the stochastically oscillatory wave naturally minimized large nodal shifts. However, strong nonlinear waves were not clearly observed due to stability issues. Additionally, their resonant experiments did not focus on the wave-bottom effect or fluid-structure interaction. In this study, the ALE (Arbitrary Lagrangian-Eulerian) method is employed to avoid significant distortion of nodal distribution in Lagrangian calculations while retaining the ease of applying free-surface boundary conditions. The method's name indicates that computations, such as fluid velocity or other time derivatives, are managed in a third frame chosen arbitrarily between the Eulerian and Lagrangian frames. Duarte et al. (2004) addressed problems with moving boundaries such as dam breaks and bubbles in fluids, by converting the moving domain into a fixed reference domain using an artificial domain velocity [28]. Ma and Yan (2006) outlined criteria for applying ALE-FEM in potential flows, extending the numerical scheme to analyze the dynamics of a moored floating body in 2D and 3D wave conditions [29][30]. Ozdemir et al. (2010) demonstrated the ALE method's effectiveness in resolving the sloshing response within a tank on an elastic foundation [31]. Recently, the meshless Regularized Boundary Integral Method (RBIM) embedded in the arbitrary Lagrangian-Eulerian frame was employed to capture the wave dispersion in complex topography [32]. They proposed a fast algorithm to implement boundary integrals for solving the Laplace equation through several regularization skills. Compared to the traditional boundary element method, their method reduces the computational cost and improves numerical accuracy and stability. Overall, the reduced-order models enable simple parallel schemes in modern finite element and boundary element methods and achieve high-order spatiotemporal convergence rates. The hydrodynamic effect occurs not only in pure water systems but underground. To calculate a physics-based entropy production rate for linear and nonlinear species transport issues, entropy inequality equations were utilized by Weigand et al. (2021) for porous medium problems [33]. This scheme is attractive for many subsurface problems with irregularly shaped domains. The infiltration in soil and a bioswale were successfully simulated based on the Richards model, representing the infiltration process in variably saturated media [34]. Modified Picard and Newton iterations are proposed to obtain a faster convergence speed when solving nonlinear algebraic systems. Mass lumping and upwind schemes for relative permeability are utilized to develop a method that upholds a local discrete maximum principle which ensures global bound preservation. The Flux Corrected Transport (FCT) method is employed to add an anti-diffusive term to the lower-order solution. This approach enforces the discrete maximum principle similar to the low-order scheme while with significantly lower errors on coarse grids can achieve convergence rates comparable to the standard Galerkin method.

Investigation of fluid-structure interaction

The above numerical methods can solve most critical hydrodynamic and aerodynamic problems. However, some important issues must be addressed in order to calculate the structural dynamics under wave and wind effects. The first is that the coupling algorithm should satisfy the equilibrium on the fluid-structure interface, such as the kinematic and dynamic conditions. To ensure equilibrium conditions, Sen (1993) developed an iterative scheme to mitigate numerical instability at the intersection of fluid and solid surfaces [35]. Van Daalen (1993) integrated the motion equations of the rigid body into the Bernoulli equation applied to the embedded interface [36], resulting in an additional integral equation that simultaneously satisfies continuity. Guerber et al. (2012) and Dombre et al. (2015) evaluated the performance of both iterative and simultaneous schemes for addressing the FSI of a fully submerged body.[37], [38]. Rakhsha et al. (2021) employed the Immersed Boundary Method (IBM) in conjunction with Nitsche's technique to evaluate the deflection of an elastic gate subjected to a hydrostatic force (typical dam break problem) [39]. Tsao et al. (2023) solved the structural vibrational control of a floating platform with a mooring system [40]. In general, the iterative scheme can be helpful when the time interval is small enough, while the simultaneous scheme may cost extra computational resources. The other important issue is the mesh regrinding technique, which avoids cell distortion during large deformations or occurs on complex embedded surfaces. To tackle this challenge, the Cut Finite Element Method (CutFEM) was proposed to solve the multiphase Navier-Stokes flow model involving structures with complex geometry. This method allows arbitrary geometry from the 3D imaging data to be represented as implicit surfaces and retains optimal accuracy of boundary-conforming meshes by using Nitsche's method. Kees et al. (2022) provided a high-order CutFEM for embedded interfaces by applying the equivalent polynomials to calculate the cut cell integrals for Heaviside and Dirac distributions [41]. In their example, the moving boundary of the interface between fluid and a falling particle was well-preserved. This method is robust and accurate for interacting particles. Besides, it is convenient to upgrade legacy FE codes to include CutFEM. More benchmark tests have been conducted to validate the numerical methods. The advantages of this module over the conventional Lagrangian approach structures have been addressed in the published article [39]. Tsao and Kees (2023) analyzed the hydrodynamic drag caused by the mangrove trunk-root system and quantified the damping effect of the mangrove forests, hence evaluating the wave attenuation [42]. Their papers demonstrate the capability of CutFEM for solving multiscale air/water-structure interaction. Tsao et al. (2023) used numerical toolkits to solve the wave attenuation over natural shorelines [43]. The momentum dissipation through artificial mangrove forests can be described more accurately using high-order integration on the embedded surface. In addition to the FEM, Dominguez et al. (2019) evaluated their Smoothed Particle Hydrodynamics (SPH) module for the dynamics of moored systems [44]. The Navier-Stokes solver requires significant computational resources for problems with large fluid domains which normally encounter large-scale simulations challenging. Also, viscous effects are not always crucial in wave simulations. Alternative reduced-order models have been used for fluid-structure interaction simulations. Koo and Kim (2007) employed the Boundary Element Method (BEM) with constant panels to calculate the hydrodynamic force and overturning moment on a stationary, surface-piercing body [45]. Bhattacharjee and

Soares (2010) decomposed the fluid domain to analyze the eigenvalue problem involving a floating box [46]. Nokob and Yeung (2020) applied the fast multipole method to BEM to speed up the numerical process but adhered to linear wave theory [47]. Nevertheless, their numerical solution for the angular motion of a floating body is still questionable due to the inviscid potential flows, which neglect eddy-making damping around the submerged body. Hyo et al. (2006) conducted a wave flume experiment demonstrating that the potential-flow assumption negatively impacts numerical accuracy in predicting the roll motion of a floating body [48]. Instead of viscous models, Lin and Kuang (2008) included a roll-damping term in the motion equation of a ship [49]. Gaeta et al. (2020) calibrated coefficients in their potential model by comparing numerical and experimental results [50]. Tsao et al. (2022) applied the potential-based method to solve the vibration mitigation of a floating structure and an LNG vessel by an improved tuned liquid damper [51]. Both sloshing waves and ambient wave responses were successfully simulated. The results were validated by viscous models [52].

Thus, with the advancement of computing procedures and innovative methods of CFD simulation, it is essential to understand the design problem to be able to obtain reliable results that are accurate, precise, and not computation-intensive. With specific methods being available to provide insights on the system's physical properties under fluid flow at their normal level and during extreme events, the design framework would provide a guideline to use proper tools at the design stage for a reliable and sustainable infrastructure.

Stakeholder Engagement

A significant body of research explores the fundamental mechanisms behind emerging technologies and their applications, such as integrating renewable energy integration. In contrast, some research focuses on practical aspects and approaches to maximizing these energy sources' efficiency, affordability, and scalability. Moving on from engineering and/or technological research, the following sections focus on the literature, identifying key stakeholders, the mechanisms of data collection, and predicting challenges faced during the implementation of renewable energy projects. "Stakeholders" refer to any group or individual who can affect or is affected by the achievement of the project [53], and getting stakeholders involved is the key to the success of the project. When stakeholders are actively involved, projects can be better shaped by the contributors and meet the users' needs, making their participation in project planning critical [54]. This review delves into this crucial research landscape that engages stakeholders, examining the current state of knowledge and identifying key trends shaping the future of renewable energy.

Social acceptance in advancing renewable energy projects

In the past, communities were often excluded in the planning process of large-scale renewable energy projects and did not share the benefits of the project, which caused pushbacks and conflicts. In response, a new participatory design approach is gaining ground, in which communities play a role in the project design process. This approach is employed in smaller projects led by local people with the benefits of staying local [53]. While the implementation process of renewable energy technologies underestimated the importance of social acceptance in the 1980s, social acceptance is considered a significant factor recently, in disseminating renewable energy systems [54]. Social acceptance can be categorized as socio-political, community, and market acceptance. Socio-political acceptance ensures policy and legislative support, community acceptance secures local backing and minimizes resistance, while market acceptance validates the project's economic viability and consumer demand. These three aspects are multifaceted, influencing project design and implementation, and thus, all crucial for the success and sustainability of renewable energy initiatives [54], [55]

Identifying stakeholders and data collection methods

Developing a framework for gathering data from the stakeholders on renewable energy projects in an urban area involves a meticulous approach. The process starts with investigating the existing methods for conducting renewable energy systems projects and analyzing how these practices align with the community's needs. Factors such as rooftop conditions, energy use, and socioeconomic and environmental considerations need a thorough examination. A design framework for an urban area should encompass a detailed plan for collecting and managing data incorporating innovative technologies, as ensuring the accessibility and transparency of collected data to facilitate stakeholder engagement is also fundamental.

Such as the study by Musall and Kuik (2011) utilizing interviews to explore the impact of community co-ownership models on local acceptance of renewable energy [56] and the study by Belmonte et al. (2015) that employed an online survey with a sample size of 3,963 responses [57], the process of collecting data generally has two distinct phases: structured interviews or surveys to gain information on stakeholders' perceptions and the possible influence they carry within the project [58], and the analysis and interpretation of the gathered information. The interviews or surveys should be carefully designed to elicit specific information, ensuring that the data collected is both relevant and comprehensive. In the data collection process, it is necessary to inform the participants about the project and educate them on a basic level. The lack of knowledge on renewable energy systems projects may lead to a lack of social; thus, fostering early deployment projects and further training opportunities for the dissemination of knowledge may help overcome this barrier [58].

Analyzing the data collected from the interviews and surveys may involve coding processes, where the responses are categorized and organized to allow researchers to identify patterns and trends. Coding is a popular qualitative research method that transforms raw interview data into a structured format that can be easily analyzed to draw meaningful conclusions [58]. This method may help the understanding of the dynamics of stakeholder engagement and their impact on projects, providing a clearer picture of how stakeholders perceive their involvement and influence. For a quantitative analysis, statistical methods can be utilized, such as a regression analysis by Roddis et al. (2018), which examined the relationship between the community's acceptance indicators and the planning outcomes [55]. This methodology enables researchers to delve deeper into the complexities of stakeholder dynamics, providing valuable insights that can inform project design and implementation strategies.

Stakeholders' resistance to the implementation of renewable energy systems

Even though renewable energy projects are generally seen as environment-friendly initiatives, they may face resistance from the community [59]. The reasons may include the sensitivity to large-scale projects in local areas, the lack of public information and understanding about the project, and perceived risks or harm to the community, including aesthetics or environmental impact [54]. Cultural factors like traditions, trust in institutions, and openness to new technologies can also affect the resistance [58]. To overcome the local resistance to the projects, understanding the critical role of community acceptance and aesthetic considerations in the implementation of renewable energy projects, developing a harmonious design with the existing landscape, and emphasizing the potential for aesthetic and economic community benefits is the key. Exploring the link between legal ownership and a more subjective "sense of ownership" for these projects can be another strategy to overcome stakeholder resistance [54]. Also, the planning outcomes should address the need for equitable renewable energy development across communities [55]. Finally, a comprehensive examination of the tangible and intangible elements of the projects' aesthetic influence, encompassing both the physical and psychological aspects, would be necessary to develop a successful renewable energy systems project design [60]. However, there is an apparent lack of studies on the visual impact of renewable energy projects on communities, particularly on the relationship between objective factors and the subjective assessment of the observer [61], with a notable study gap in understanding how stakeholders can be motivated to overcome the obstacles and actively engage in the design of renewable energy projects. Filling this gap will ultimately lead to more involvement of stakeholders in project design and make renewable energy projects more inclusive, responsive, and sustainable.

Integration of Renewable Resources in Energy Infrastructures Across Diverse Operations

The process of incorporating renewable energy sources into the electrical grid is referred to as renewable energy integration (REI). The main objective of REI is to integrate renewable energy, distributed generation, energy storage, and demand response into the electric distribution and transmission infrastructure. REI systems are seen to be a practical strategy for boosting the use of renewable resources and enhancing generating efficiency since they may meet energy demands in various ways [62]. Renewable energy currently accounts for more than 20% of the nation's yearly electricity production as it is connected to electric power infrastructure at an accelerating rate [63]. Renewable energy sources (RES) have the potential to produce enough energy to power a clean future by harnessing self-replenishing resources like solar, wind, and water. However, the amount of energy produced by renewable resources, such as solar and wind power, might differ greatly based on the time of day and the location [64]. However, they could improve the resilience of the power infrastructure by supporting distributed energy solutions that reduce cost and the amount of electricity demand on the grid. These benefits can be fully realized only by integrating renewable energy with more farms and businesses [65]. The installed capacity of renewable energy is predicted to rise significantly until 2050 because of the drive to decarbonize economies. The switch to renewable energy sources and economic expansion will result in a sharp rise in the demand for electricity, which will double by 2050 and rise by 40% between 2020 and 2030 [66].

Integrating renewable energy in various applications around the world is important at this point in time. As time goes on, there is a global push to reduce the use of fossil fuels because of their detrimental effects on the environment and to mitigate the effects of climate change. In parallel with this, the requirement for fuel is rising to satisfy the world's expanding population of billions of people. The most promising solution for meeting demand is to include renewable energy sources in the traditional grid. Because of this, a thorough understanding of the potential wide range of effects from the implementations is also needed. The REI has numerous ramifications and difficulties. The crucial point is developing renewable energy sources is not a remedy for all issues. Beyond the power market, action is required to achieve a significant reduction in energy-related emissions. In other industries, the primary means of obtaining energy is still through the burning of fossil fuels [62]. For instance, renewable energy sources only account for 10.3% and 3.4% of the energy supply, respectively, in the transportation and heating sectors, even though these two industries together account for around 80% of the world's total energy demand [62]. More small and medium farms that haven't thought about switching to renewable energy sources should integrate with the RE.

Rahmat et al. (2022) developed a study to identify the optimal combinations of renewable energy technologies for various Malaysian contexts with two specific scenarios [67]. By employing HOMER Pro software investments in renewable energy systems across various scenarios in Johor, Mersing, Pahang, Pekan, and Malaysia were examined. The findings illustrated that the PV-wind hybrid system exhibits a lower net present cost (NPC) compared to other systems in both scenarios. The PV-wind hybrid system has a payback period of 4.86 years in Scenario 1 and 2.98 years in Scenario 2. Additionally, for Syiah Kuala University, situated at the tip of Sumatra Island, a techno-economic performance and optimization analysis was conducted for grid-connected PV, wind turbines, and battery packs. The Hybrid Optimization Model for Electric Renewables (HOMER) was utilized to analyze and optimize the renewable energy required by the university [68]. In their study, they considered the system architecture, daily radiation, clearness index, location, temperature, daily solar PV, and average electric load demand. They also developed a suggestive methodology with two different combinations of solar PV and wind turbine, which contributed 62% and 20%, respectively. The analysis concluded that wind turbines and solar PV systems connected to the local grid may provide up to 82% of the needed electricity at a lower cost of energy (CoE) of $0.0446/kWh as opposed to $0.060/kWh.

The analysis by Mekonnen et al. (2021) provides important information for Ethiopian policymakers implementing alternate energy supply options [69]. To supply the residential load in Mekelle City, Ethiopia, they studied grid-connected and islanded photovoltaic (PV) power systems using PVGIS, PVWatts for the technical viability of the suggested supply option, and HOMER Pro for the analysis of the economic and environmental optimization aspects. They also presented output comparisons and sensitivity analyses between the three renewable energy simulation tools. The findings show that the grid/photovoltaic system's COE is approximately 12% lower than that of the utility grid, with a simple payback period of 7.81 years. Along with describing the effects of the inflation rate, nominal discount rate, and PV capital cost as economic parameters, it also discussed the technical parameters of inverter efficiency and variations in solar radiation while generating 80,485 kWh of energy annually from solar PV, or 57.1% of the location's total load. The payback period of the study seems more realistic than the previous study mentioned above.

Barrera et al. (2021) propose a methodology for integrating residential photovoltaic solar systems in Bogotá, Colombia. Their estimates suggest annual savings between USD 29.72 and USD 293.27 in two distinct regions. As stated in their environmental analysis, this will decarbonize 20.41 and 20.39 tons of CO2, respectively, over the next 25 years [70]. Considering the study location, incentives offered, and bulk purchase of PV cells augmenting faster payback and better ROI, the simulation runs on the PVsyst software indicate that the characteristics of the solar system are feasible and lucrative. Kumar et al. (2020) presented a PV integration study that estimated how an academic department building would fulfill its required load by installing a rooftop PV unit of an off-grid PV framework and accumulating homogeneous strings of PV modules [71]. This resulted in the generation of 1143.6 kWh of energy, compared to the department's total requirement of 1086.24 kWh, with an average performance ratio of 72.8% in a year as determined by computational modeling and PVsyst simulation analysis. In both cases, the researcher suggested the PV module was the most economical and lucrative option of the CoE, lacking a good picture of the usability, maintenance, overall user point of view, and ease of operation.

Eight hybrid renewable energy source configurations that combine solar, wind, diesel, and battery power are shown in a 2020 study by Zhang et al. to meet the electrical needs of a medium-sized workshop in an industrial district of Ardabil, Iran [72]. They analyzed various distribution system configurations using HOMER with two optimization algorithms, the original grid search algorithm and a proprietary derivative-free algorithm, to determine the system's viability and its optimal Net Profit Cost (NPC) given the system's 20-year lifespan, specified investment cost, and operating expenses. A higher percentage of wind energy is used in the simulation study, as the wind turbine produces more energy than a photovoltaic panel due to the local climate. The Levelized Cost of Energy (COE) for the study was USD 0.471 per kWh, signifying a 7.17-year payback period. This study records more convincing data than a few of the others, though the model described is localized, and the effectiveness of the system for generalized use might be questioned. Bagherian and Mehranzamir (2020) tested the integration of single or multiple renewable energies in combined heat and power (CHP) systems [62]. They developed the mechanisms for a solution to reduce CO_2 emissions, increase energy efficiency, and decrease fuel consumption by utilizing cogeneration technologies and incorporating RES as a prime mover unit in CHP. However, the lack of readily available RES, the inconsistent pattern of renewable energy output, and the high maintenance and investment costs restrict this process.

In their 2020 study on hybrid renewable energy microgrids (HREMs), Kumar et al. proposed a modern configuration of photovoltaic solar panels, wind turbines, diesel generators, and battery energy storage systems as a means of ensuring affordable, dependable, and sustainable energy access for all [71]. They also developed a techno-economic and environmental modeling of the grid-independent HREM and optimized it for a remote community in South India to meet the requirements of the community for residential electric load. In the study, nominal discount rates ranging from 5% to 15%, diesel fuel prices between 0.75 and 1.2 $/L, average solar radiation, and wind speeds between 5-7 kWh/m2/day and 2-4 m/s were all considered. The study concluded with a single, sensitive case in which the NPV and COE were $440,039 and $0.416, respectively, meeting the SDG7 requirements. Kumar et al. (2020) illustrated that encouraging renewable energy systems appears to be one way to help achieve SDG7, especially through microgrids (MGs) [71]. RE-based MGs offer a workable way to balance the concerns of environmental preservation, energy access, and the depletion of fossil fuels. Additionally, the energy systems based on REs emit less carbon dioxide and contribute to reducing global warming overall. For a rural village in South India, they suggested grid-independent hybrid renewable energy optimization and techno-economic-environmental modeling using HOMER pro, which represents the net present cost (NPC) and coefficient of efficiency (COEf). In parallel to this, Mekonnen et al. (2021) leveraged 3 simulation tools: PVgyst, PVwatts, and Homer Pro, as their major focus on solar energy. In their study, technical measures included yield and capacity factors, and economic indicators included payback period, NPC, and COEf. This study provides important new information for Ethiopian policymakers looking to develop energy supply options. Rahmat et al. (2022) reproduce another similar research using Homer Pro as a technical and economic analysis assistant while finding the investment viability for a project in Malaysia [67]. Riayatsyah et al. (2022) mentioned that to examine the operational behavior of every conceivable scenario, applying pertinent criteria to on-site location data is frequently necessary to assess renewable energy projects [68]. They used the HOMER grid as a more efficient way to model hybrid energy systems and analyze solutions for lowering electricity costs for a grid-connected system. Ultimately, they concluded that a PV system with batteries would provide economic feasibility and that, given the location's remoteness, a wind turbine could also be integrated with a more practicable zone, albeit at a potentially high initial cost. In the meantime, Tozzi and Jo (2017) reviewed the performances of the tools used for system optimization and modeling and concluded the difference in simulation and optimization of the system [64].

Reviewing the trend challenges and new room for more research in their study unfolds many analytic notions. While looking into the data collection strategies of this research, the way seems more comprehensive. Capital cost variation, efficiency variation, impact of nominal cost variation, and inflation rate variation pose new avenues for a more detailed study of their process [69]. It is common that studies did not include whole-system simulations, indicating that many authors and organizations have not specifically addressed or didn't fully comprehend the difficulty of assuring reliable supply from variable sources [73]. Resources Availability and load profile, annual average of solar GHI, Wind resources, and a sensitivity analysis show the relevancy following the selected strategies. To model and optimize low-cost renewable energy systems and risk-mitigation strategies, this research determines the optimal system design that best fits the island configuration. It also evaluates the technical and economic feasibility of microgrid or distributed energy systems, whether off-grid or connected to an unstable grid. The best probabilities could be revealed by the optimization results for the plant location.

Conclusion:

This white paper reviewed existing reports, publications, and conference proceedings to assess the current state of the knowledge related to three crucial aspects of solar deployment: numerical simulation tools to study the resiliency of ground-mounted solar structures against extreme weather-related wind and water forces, the importance of community engagement for urban design framework development and implementation, and integration of renewable energy in the existing grid for optimal operation. The reviews revealed a wide range of available numerical tools and packages that can be utilized for simulating the fluid-structure interaction study, depending on the design condition being studied. These numerical formulations of dynamic weather-related problems and the exploration of solutions using project-specific boundary conditions are crucial arsenals for designers to develop resilient and sustainable renewable-energy infrastructure that is especially suited for disaster resilience. The explored literature highlights the importance of goal-oriented analysis in focusing on the final objective of utilizing solar PV-generated energy in the existing urban energy grid. Renewable energy system designers and implementers should properly understand the requirements, use patterns, and existing grid conditions to optimally integrate the newly installed solar energy infrastructure into the energy mix. Finally, bringing in the stakeholders from the community by understanding the community priorities through active engagement of end-users in the decision-making process and translating the socio-technical intricacies in a palatable way holds the key to success in community-driven solar installment projects.

Acknowledgement:

This research is supported by the Institute for Energy Innovations at Louisiana State University. The project team is also grateful for the support from our industry partner, BASF.

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