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A Root Cause Analyses of Low Consumer Confidence in Distributed Wind Energy

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Abstract: The distributed wind industry has remained limited in its installation. Since 2012, its installation is generally declining. This paper attempts to gather the factors that are contributing to the declining trend and risks involved in the low installation trend of built-environment wind turbines using data available from existing projects. Initially, four main factors, namely, economic, technical, policies and incentives, social and environmental, and twelve secondary causes were identified based on their contribution level and the failure rate of existing small wind projects. The data available from existing projects were utilized and a questionnaire was designed and disseminated among industry and academic experts to rate each causative factor on a 0-10 scale. A project management approach was adopted to calculate the weight of each risk and prioritize the risks involved. To further investigate the causes, the systematic Root Cause Analysis (RCA) method was applied to investigate the primary and secondary causes. A risk factor for each dimension of causes was calculated using its probability of occurrence and potential impact on the project. The risk factor of all secondary causes is added to generate a hierarchy of primary causes (HPC). The prioritized risk of primary causes indicates that economic causes (40%) carry the highest rank followed by technical causes (34%), lack of policies and incentives (20%), and social and environmental causes (6%). The present study is limited to analyses of causative factors of limited urban turbine installation. The recommended practices to address the identified risks are beyond the scope of this paper.

Key Words: Distributed Wind Energy (DWE) Built-environment Wind Turbines (BEWT), Limited Installation, Root Cause Analyses (RCA), Risk Priority Number (RPN)

1. Introduction

The United States is developing a plan to replace traditional power generation with clean energy entirely. According to the 2021 long-term strategy, the United States has an ambitious plan to reduce greenhouse gas emissions by 50-52% below the 2005 level by 2030 and this will lead to a goal of net zero by 2050. Reaching the net zero goal will require utilizing all available energy resources [13]. According to National Renewable Energy Laboratory [14], distributed wind energy has great potential in the United States, but it is underdeveloped and has not been explored to its maximum potential (1,400 gigawatts). In 2020, 11 states added just 14.7 MW of energy, representing 1,493 turbine units with an investment of $41 million [24]. Comparatively, in 2020, distributed wind turbine installation is 18% less than in 2019 in installation capacity and 39% less in investment funds, and this declining trend is consistent for almost a decade. A similar situation exists globally. In 2021, 40.22MW of small wind was installed globally and out of which 33 MW (83%) was installed in China only. The other countries in Europe have negligible contribution towards small wind installation except for Germany with a 2.5 MW maximum. Surprisingly, Australia add zero MW towards small winds and the United Kingdom has stopped tracking & reporting on small winds

[25]. The diminishing interest of investors and consumers in distributed wind energy can be attributed to the technical, financial, social, and zoning policies involved in its installation. Although distributed turbines have the advantage of the installation location being close to the point of utilization [2] and a significant reduction in transmission cost [7], the barriers distributed wind (DW) encounters are much more robust than large scale wind farms.

There is very limited data about the risk management of distributed wind energy and the literature focusing on the risks involved in DW projects is sparse. [26] listed the barriers and prospects of distributed wind energy and evaluated different technologies in terms of their potential contribution to benefits and challenges. [3] evaluated distributed wind energy from technical, economic, social, and political perspectives. His study discusses different dimensions of distributed wind energy, but the risks involved with distributed are lacking. [23] quantified the risks involved in renewable energy projects. Their study identified, classified, and suggested risk management to help with project evaluation. [6] conducted a failure analysis of collapsed large wind towers under high wind speed and rainfall conditions. His work provides a deep insight into lessons learned from the causes of structural tower failure and a post-disaster inspection based on tower design data. [8] assessed the risk-based cost efficiency of renewable support schemes and compare the effectiveness of the feed-in-tariff and certificate market. [21] reviewed the current status and challenges of the wind power industry concerning the corresponding insurance market. Their correlative study shows that the slow-paced insurance industry is not growing fast enough to control the risk of the rapidly growing wind industry.[22] concentrated on the risk involved during the operation of a wind turbine. His primary focus was on low-capacity factor wind projects. [10], in their case study of onshore and offshore projects, presented the list of risks and offered risk management solutions. Their study showed that regulatory and policy-related issues are the most significant barriers to attracting investors to distributed energy projects. [11] discussed the risk management tools for renewable projects. Their study categorized and prioritized renewable project risks from a decision-making perspective. They applied a different combination of methodologies such as the analytical hierarchy process (AHP), strength, weakness, opportunities, and threats (SWOT) technique to facilitate the decision-making process. [27] conducted a case study in China to study the barrier distributed wind energy is facing and proposed recommendations to overcome these issues. [28] analyzed the possible risks involved in implementing specific wind energy projects. He applied SWOT analyses and the McKinsey matrix for the identification of risks and to determine the project dot location coordinates using matrix analyses. [4] carried out an analyses on low speed wind sites and calculated the annal energy production and capacity factor for distributed wind turbines. They concluded that small scale wind turbines has great potential for low to good wind sites. [16] overviewed the present and future status of distributed generation in Canada and emphasized on the role of these facilities in modern power system power generation. [17] overviewed the technical difficulties with the connection of distributed wind to optimize the efficiency, cost and fluctuations in distribution generation systems. [18] investigated the technical challenges small wind turbines are facing and concluded that lack of testing facilities , inadequate urban wind resource data and absence of performance estimations standard are underlying reasons for low investor confidence in small wind technology.

As the literature review indicates researchers have explored the different aspects of risks involved in distributed projects and each of them has addressed a particular kind of risk. However, there is still a need for more comprehensive research. Therefore, in this paper, a systematic project management approach is adopted to gather data about existing and previously installed projects. The success and failure rates of projects are analyzed, the unsuccessful projects are further explored, and a comprehensive list of risks is compiled and ranked using risk priority numbers. If addressed, the compiled list of risks would be helpful for researchers, industry practitioners, project developers, and investors to focus on prioritized areas (technical, economic, social, and policies) to improve the situation of distributed wind energy. For instance, at Los Alamos National Lab, the authors have already started addressing the technical challenges by developing and validating computer-based models for accurate resource assessment. The model, once developed, would resolve technical and economic issues by avoiding capital-intensive resource assessment campaigns. Furthermore, if all risks are addressed systematically as recommended by this study, it would help individuals, businesses, and communities to have independence over power and would add to grid reliability, grid operation and enhance grid resiliency with backup power. Overall, This research aims to promote the deployment of distributed wind turbines

2. Research Methodology

As shown in Figure 1, a systematic root cause analysis is structured to investigate the true cause of the built environment project's limited installation [1]**.** The data collected by Pacific Northwest National Laboratory (PNNL) from existing projects, project developers, case studies, and National renewable energy laboratories annual reports are utilized in this research endeavor. The data was further analyzed to identify the problem, perceive the level of the cause and ultimately prepare the hierarchy of involved primary and secondary risks.

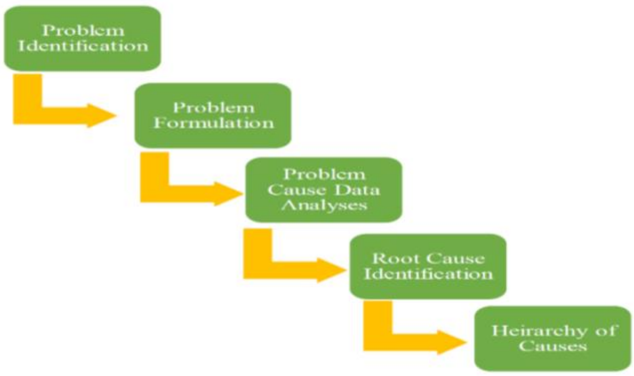

Fig. 1. A systematic application of root cause analyses

The root cause analysis is a collection of tools and techniques that can be applied to reach the cause elimination goal. As the first step in root cause analyses, the flow, and the data collected from different resources are analyzed and categorized as successful and unsuccessful. Although there were no baseline criteria to measure the success of a project, the criteria used in this methodology is the owner's perspective on their project. The projects are installed with multiple purposes including energy generation, building aesthetics, green energy initiative awareness, and as a research facility. If a project meets its installation goals it is declared as successful, otherwise, it is a failure. The failed projects were further analyzed using the cause-and-effect diagram as shown in Figure 3.

2.1 Survey Details

After analyzing the data, two levels of causes are identified: Primary-level causes and Secondary-level causes. To determine the impact of each cause, a survey was designed about the risks involved in the installation of wind turbines in the urban environment. A careful survey sampling technique was developed to get input from all the stakeholders involved. The survey was disseminated among 565 participants from different backgrounds such as project investors, project developers, project installers, turbine manufacturers, National labs' scientists, academic researchers, and customers. A list and demographics of survey participants are provided in Table 1. The survey participants were asked to rate each of the main and sub-cause on a 0-10 scale based on its probability of occurrence and the potential impact on the project's health. The risk level for each cause was calculated and a prioritized list of primary causes was presented. Furthermore, the potential impact of each secondary cause was discussed on their relative primary cause.

Table 1. Occupation, and statistics of respondents

	No. of People
Project Investor	5
Project Developer	5
Project Installer	20
Turbine Manufacturer	5
National Labs' scientists	10
Academic Researcher	20
Costumers	500

3. Results and Discussion: This section of the paper presents and discusses the results.

3.1 A comparison of cumulative Wind Generation and Small Wind Turbines (Problem Identification):

In this research, to identify the problem the installation trend of small-scale wind turbines is quantified from 2000 to 2021. The total number of small wind projects that have been installed across all 50 states in the United States is 2681 having an installed project capacity of 60,836 KW. Most of the projects are single turbine projects and the accumulated number of turbines on these projects is 2899 units. As per field data collected by Pacific Northwest National Laboratory (PNNL), the first small wind turbine was installed in 1997 in Kotzebue city of Alaska state. It was a hybrid (diesel, solar, wind) power system with three wind turbines each of which produced 66kw with a total project capacity of 198KW. As can be seen in Figure 2, the installation generally has an increasing trend from 2003 to 2010, the year 2011 a drop, and a dramatic increase in installation is observed in 2012. Interestingly, Statistical analyses inform that only 2012 has 25% of the total installed capacity. A breakdown of 2012 installed capacity indicates that Nevada Installation projects consist of 44% of the total installed capacity in 2012. The three 6700 KW capacity Nevada projects had an estimated installation cost of $23.85 Million and 70% of the project's total installation cost was funded by Nevada Energy Renewable Generations.

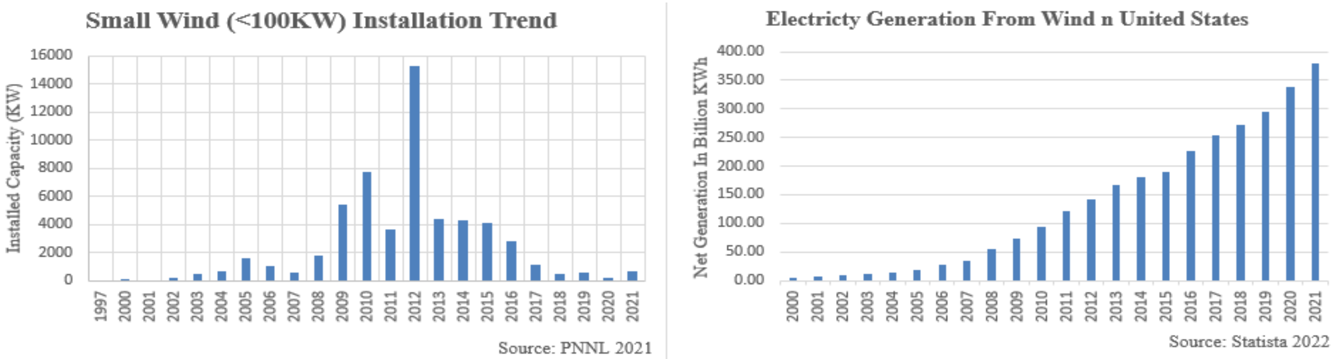

Fig.2. A comparison of net energy generation from wind and Small-scale wind contribution

Figure 2 indicates a comparison of net energy generation from wind turbines in the United States and a contribution made by small-scale wind turbines. It is clear that despite having great potential, the contribution of small-scale wind turbines is significantly less than utility-scale wind turbines. Since 2012, small wind turbine projects are unable to attract investors and they are experiencing a downward trend. Apart from financial factors, in the next sections, all the contributing factors and their subfactors will be explored and discussed.

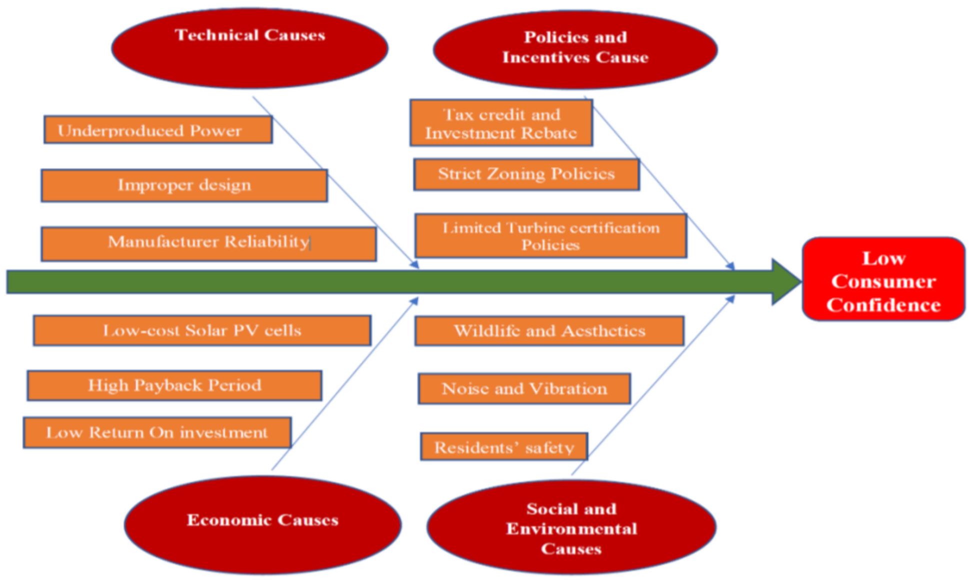

Fig.3. Ishikawa diagram from multiple causes and effects

3.2 Ishikawa Diagram (Problem Formulation)

The Ishikawa diagram (fishbone diagram) is a systematic way of looking into an effect and identifying the potential causes that contribute to that effect. Considering the low installation trend and underperforming wind turbines, a list of potential barriers is identified, and each potential factor is further divided into subfactors.

The diagram depicts four main causes (technical, economic, policy, incentive, social and environmental) of potential project failure main causes, and it has 12 secondary causes three for each main cause. The position of the main causes on the line axis is in the sequence of relevant significance. The factor carrying major importance such as technical and economic are placed at the beginning of the root cause diagram (Left side). Factors of comparatively less significance occupy the right end of the horizontal line. The main causes in the upper zone of the axis are interconnected, meaning that the technical feasibility of a wind project is highly dependent on its local zoning, permitting, and turbine model based on wind speed in that area. The main causes in the lower zone of the line axis are almost disjoint or have a minor interrelation, meaning that economic analyses of small wind turbines are slightly dependent on their social and economic impacts. The placement of sub-causes is according to their level of strength with the main causes. For instance, in economic causes, the competition from low-cost solar PV cells has a stronger connection than limited economic feasibility.

3.3 Main and Sub causes Nomenclature

For the convenient operation and processing of causes, a nomenclature methodology is applied. Table 2 depicts the sequencing of the main and sub-causes in sequential order. The representation of each cause is based on its position on the cause-and-effect diagram (left to right). The codification of sub-causes is based on their close relationship with the main causes.

Table 2, Causes, and Sub causes indexing

Causes No.	**Main Causes**	**Sub Cause**	**Coding**
1	Technical Cause	C1	
1.1	Underproduced power		C1.1
1.2	Improper design		C1.2
1.3	Manufacturer’s reliability		C1.3
2	Economic Cause	C2	
2.1	Low-cost solar PV cells		C2.1
2.2	Low return on investment		C2.2
2.3	High payback period		C2.3
3	Policies and Incentive causes	C3	
3.1	Tax credits and Investment Rebates		C3.1
3.2	Strict Zoning Policies		C3.2
3.3	Limited Turbine certification Policies		C3.3
4	Social and Environmental Causes	C4	
4.1	Residents’ safety		C4.1
4.2	Noise and Vibration		C4.2
4.3	Wildlife and aesthetics		C4.3

3.4 Causes Quantification

To determine the probability of the occurrence and impact of cause on the installation of a small wind project, the results of the survey are compiled as shown in table 3. The survey responses gathered from industry, national research, lab researchers, and academic experts are further processed to calculate the weighted average of each response (Eq.1).

Table 3. Causes Contributing Factor

Sr.#	Primary Cause	Secondary Cause	Probability Of Occurrence	Impact On Project
1.	**Technical Causes**			
1.1		Underproduced Power	0.95	0.80
1.2		Improper design	0.51	0.78
1.3		Manufacturer Reliability	0.38	0.88
2	**Economic Causes**			
2.1		Low-cost Solar PV cells	0.99	1.0
2.2		Low return on investment	0.66	0.77
2.3		High payback period	0.51	0.78
3	**Policies and Incentives Causes**			
3.1		Tax credits and Investment Rebates	0.38	0.77
3.2		Strict Zoning Policies	0.32	0.44
3.3		Limited Turbine certification Policies	0.51	0.65
4	**Social and Environmental Causes**			
4.1		Residents' safety	0.16	0.85
4.2		Noise and Vibration	0.3	0.44
4.3		Wildlife and Aesthetics	0.2	0.2

3.5 Secondary Cause Risk Quantification

The secondary risk is quantified using equation (1) The risk of each secondary cause is the product of the probability of its occurrence and its potential impact on the project.

$$\textbf{\textit{Risk = Probability(P) X Impact(I)}} \qquad \textbf{\textit{Eq. (1)}}$$

$$R_n = P_n \times I_n$$

$$RC_{1.1} = PC_{1.1} \times IC_{1.1}$$

$$= 0.95 \text{ X } 0.8$$

$$= 0.76$$

A similar procedure is followed for all secondary causes and compiled results are presented in Table 4.

Table 4 Risk calculation for secondary causes

Causes No.	Main Causes	Probability(R)	Impact(I)	Risk (P x I)
1.1	C11	0.95	0.80	0.76
1.2	C12	0.62	0.78	0.48
1.3	C13	0.43	0.88	0.38
2.1	C21	0.99	1.00	0.99
2.2	C22	0.66	0.77	0.51
2.3	C23	0.51	0.78	0.40
3.1	C31	0.60	0.77	0.46
3.2	C32	0.32	0.44	0.14
3.3	C33	0.51	0.65	0.33
4.1	C41	0.16	0.85	0.14
4.2	C42	0.30	0.44	0.13
4.3	C43	0.20	0.20	0.04

3.6 Main Cause Risk Quantification

The main causes are quantified using equation (2) which is simply the sum of all secondary causes involved in that category.

$$RC_m = RC_{ii} + RC_{ij} + RC_{ik} \qquad \textbf{Eq.}\ (2)$$

$$RC_1 = RC_{1.1} + RC_{1.2} + RC_{1.3} = 0.76 + 0.48 + 0.38 = 1.62 \qquad \textbf{Eq.}\ (2.1)$$

$$RC_2 = RC_{2.1} + RC_{2.2} + RC_{2.3} = 0.99 + 0.51 + 0.40 = 1.90 \qquad \textbf{Eq.}\ (2.2)$$

$$RC_3 = RC_{31} + RC_{32} + RC_{33} = 0.46 + 0.14 + 0.33 = 0.93 \qquad \textbf{Eq.}\ (2.3)$$

$$RC_4 = RC_{41} + RC_{42} + RC_{43} = 0.14 + 0.13 + 0.04 = 0.31 \qquad \textbf{Eq.}\ (2.4)$$

3.7 Risk Hierarchy of Primary Causes (HPC)

The main cause is prioritized based on the highest value of the sum of its all-secondary causes. The hierarchy of causes indicates that the most critical cause in this list is the economic cause which takes approximately 40% of total contributing factors. The hierarchy depicts that stakeholders believe that built environment wind turbines (BEWT) are not economically viable, and this is the primary reason for their failure. The next on the list is the technical cause which occupies 34% of the overall causes. It implies that project stakeholders also believe that economic cause is highly coupled with technical cause. If a project performs well technically, there is no doubt that it will produce its intended economic number. The next in the list (policies and incentives) has a 20% contribution and it is believed that the underdevelopment of small wind turbines in an urban environment is strongly affiliated with policies and incentives provided by the U.S. government. The last category of causes (social and environmental) has a 6% contribution. Although it seems to be a minor contribution, its subfactors still also are discussed for their impact on the project.

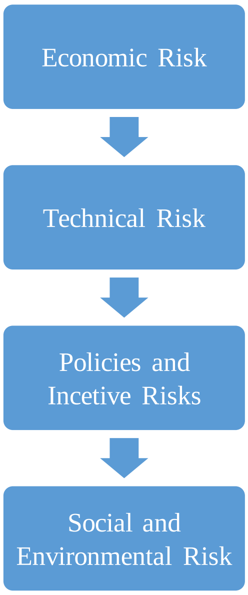

Fig.4. A prioritized Risk hierarchy of Main Causes

Secondary Causes Classification:

The secondary causes are classified according to their relevance to primary causes. Table 5 shows a range of risk that is posed by a secondary cause to its respective primary cause.

Table 5. Risk range for a Secondary Cause

Minor Risks	**Medium Risks**	**Major Risks**
0.00-0.30	0.31-0.70	0.71-1.00

Table 6. Risk factor of Secondary Causes

Causes No.	**Cause Codification**	**Secondary Cause**	**Risk Factor**	**Risk Level**
1.1	C1.1	Underproduced power	0.76	Major
1.2	C1.2	Improper design	0.48	Medium
1.3	C1.3	Manufacturer's reliability	0.38	Medium
2.1	C2.1	Low-cost Solar PV cells	0.99	Major
2.2	C2.2	Low return on investment	0.51	Medium
2.3	C2.3	High payback period	0.40	Medium
3.1	C3.1	Tax credits and Investment Rebates	0.46	Medium
3.2	C3.2	Strict Zoning Policies	0.14	Minor
3.3	C3.3	Limited Turbine certification Policies	0.33	Medium
4.1	C4.1	Wildlife and Aesthetics	0.14	Minor
4.2	C4.2	Noise and Vibration	0.13	Minor
4.3	C4.3	Residents' safety	0.04	Minor

4 Interpretation and Discussion

This section discusses the results obtained in the previous section.

4.1 Economic Risk

According to the respondents of the survey, the biggest risk in the development of small wind projects is their low economic viability. The economic cause carries the highest weight among technical, policy, and environmental factors. Among all the subfactors contributing to the economic factor, the competition from low-cost photovoltaic systems carries the highest weight (52%). Consumers prefer installing low-cost distributed photovoltaic PV cells for all small-scale applications compared to high-cost small wind turbines. A recent study published by Berkeley lab reveals that installed cost for residential PV system ranges between $3-5/W and most of the installed system has a median price of $4/W [5]. In contrast to solar, the installation cost for small, distributed wind projects is significantly higher [24], in her annual report on distributed wind energy, reported that the capacity-weighted average cost for small wind projects ranges between $4/W to $11/w, and most of the solar systems have a flat installation rate of $9.50/W.

The second parameter in economic analyses is the low return on investment, contributing 27% to a project failure as a secondary cause. This is one of the important parameters in assessing the project's economic feasibility. The project investors and customers often compare their return on investment in light of other potential renewable generation sources. The return on investment thoroughly depends on the net income generated and the capital cost of the project, whereas the net income is hugely dependent on the energy generation capability of a wind turbine. [9] in their case study on five projects installed in the built environment, concluded that none of the projects met their economic goals and all the projects were declared economic failures.

According to respondents of the survey, the third most causative factor for small wind projects economic failure is the extremely high payback period on investment. The payback period contribution is 21 % towards economic risks for micro wind projects. The data collected from developers show that NASA building 12 wind turbines were installed with preconstruction and post-construction assessments. The project had an installation cost of $100,000 and developers believe the project will never produce any monetary payback. The literature shows that a 4-turbine project installed on a 23-story building in Portland has an installation cost of $240,000. The estimated payback period is 40 years which seems to be significantly high compared to other renewable energy resources.

While discussing project economic feasibility parameters with project developers, it was realized that the development model applied to urban wind projects is similar to traditional wind projects. However, costs associated with planning, permitting, installation, and maintenance of urban environment turbines are more complex than open field wind projects. For instance, the Boston Museum of Science wind project experienced a dramatic escalation in project initial cost due to the building's structural incompatibility for turbine installation. It was reported that one-quarter of a $350,000 project was spent on a necessary steel structure that ultimately led to project delay and raised its initial and installation cost in later stages.

Therefore, the critical reason behind the low installation of small wind projects is their weak profitability and this low profit is due, in part, to low energy production due to non-consideration of urban complexities during the project technical feasibility phase.

4.2 Technical Risks

In the hierarchy of project risks, the technical causes occupy the second place and account for 34% of the total risk. The crucial reason for unsuccessful projects is that actual energy production is far less than estimated. The data provided by Pacific Northwest National Lab (PNNL) is analyzed to get an in-depth knowledge of turbine performance. The performance of small wind projects is measured using the annual capacity factor. The capacity factor of a wind turbine is the ratio of actual energy produced during a year to energy produced if the turbine operated at its rated power [31]. Figure 5 shows the average capacity factor of 35 wind turbines on 35 different project sites totaling 495KW is 12%. The capacity factor for micro wind projects is significantly low, whereas the capacity factor for other distributed wind turbines is 20% for mid-size and 29% for large-scale distributed wind energy [24]. In the U.S. land-based wind turbine capacity factor ranges between 0.26-.52. In 2020, the capacity factor for projects installed between 2014-2019 remained was 41% [30]. The low-capacity factor implies that turbines in urban environments are underperforming and are unable to meet their financial goal. Among the several technical factors that contribute to a turbine's poor performance, energy forecasting is the primary causative factor. Energy forecasting stems from the wind resource potential at a specific site. In most cases, the turbines are installed without conducting proper resource assessment and wind maps available for open flow-field purposes are considered sufficient for an urban environment.

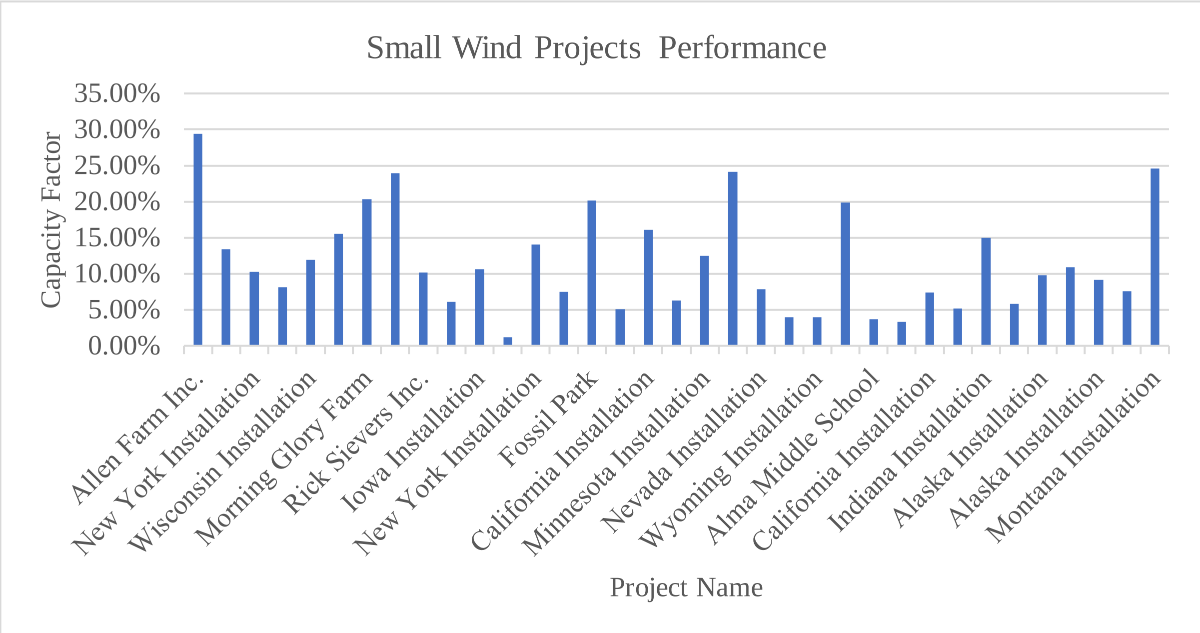

Figure 2. *Project performance*

The second technical parameter that combines with poor resource assessment to cause the technical failure of urban wind projects is the utilization of improper turbine design and siting. This causative factor has a contribution of 30% toward the projects' technical failure. Based on the turbine performance data collected over a multiyear period it can be deduced that turbines are not producing as much as they were designed for. It could be interpreted in two ways; the installed turbines were not suitable for the urban environment because most of the turbine testing is performed in a simulated atmosphere, or they are tested in wind tunnels. Whereas when the turbines are exposed to a real-world urban atmosphere that is more highly complicated than the wind tunnel or simulation condition, the turbine underproduces. Secondly, the turbine design was available, but the site conditions were miscomputed, and the wrong design was installed.

The third technical parameter that caused the wind projects to fail is manufacturer reliability. This factor has a 23% contribution to the overall failure causes which is still a significant contribution. Many of the projects failed due to the non-availability of spare parts which makes small wind projects' reliability questionable. For instance, when NASA's building 12 project was designed, the project developer had to choose an alternative turbine model because the original turbine manufacturer was out of business. In another case, in Minnesota, the owner of the wind farm filed for bankruptcy, and it is reported that a major turbine component was required to repair, and the company was unable to maintain the turbines [15], because a certain turbine component failed and when the manufacturer was contacted, they had gone bankrupt. Consequently, this resulted in project failure. Another technical report [29] found that three of the six wind turbines installed at Detroit Metro Airport stopped production due to maintenance issues and the non-availability of parts. The airport administration reported that the project never met its production goals, and they are planning to proceed with the rest of the three turbines by borrowing parts from other wind turbines.

4.3 Policies and Incentives

The respondents of the survey pointed out that policies and incentives contribute 20% of the total risk involved in small-scale wind projects' low installation trends.

Tax credit and rebate policies are the first and considerably higher factor in the category of policies and incentives. For small wind turbines, there are many incentives available at the federal and state level such as clean energy production tax credits, state-based incentives, investment tax credits, USDA Rural Energy for America Program (REAP), and research to promote installation in an urban environment. For many of the projects that are investigated in this research, there was a significant contribution by USDA (REAP) ranging from 1% to 100% of the total installation cost. According to [19], for any wind turbine that has a nameplate capacity of below 100 kW, there are federal tax credits in place from 22% to 30% based on the year (2019 to 2024) the system was placed in service. The [20] reported that many states such as California, Illinois, Massachusetts, Minnesota, and New York have rebate programs for small turbines, and the number of programs is increasing with funding from the American Recovery and Reinvestment Act of 2009. Although credit and incentive policies do contribute (15%) as a secondary cause to low-level business practices of micro wind turbines, it can be concluded that lack of federal funding is not a significant factor in the slow-paced growth of small wind turbines.

Strict zoning policies are another complicated secondary factor under the policy category that hinders the development of small wind projects. Zoning and permitting are two different things: zoning is about whether an installation is allowed or not allowed in an urban environment and permitting is about granting permission with specific guidelines under the local city and town planning office. Zoning regulations are different from state to state and from one local jurisdiction to another [12]. The permitting is generally obtained from local governing bodies, and it is a time, capital, and energy-consuming process. According to U.S standard zoning act (USDC 1926), most jurisdictions limit the height of structures for wind turbines in residential areas to up to 35 feet. It is a well-known principle that energy produced from a wind turbine is a function of height. In other research, the author conducted a real-world field study and recommended that for a wind turbine to extract maximum available power in wind, the hub height of the turbine should be at least 2.5-3 times the height of the obstacle. In this study, the participants of the survey have placed great stress (50%) on the limited zoning policies as a prominent barrier to the development of urban wind energy. Among the 21,262 turbines that are installed as distributed (Residential or Non-residential) facilities, 30% of them have an average installed height of 58.9 feet. The effective use of urban wind energy requires this obstacle to be addressed.

Limited Turbine certification: Currently there are eight certified turbine models [24]. Two standards take care of turbine certification standards: the international standard IEC-61400-2 and U.S. national standard AWEA's small wind turbine standard 9.1-2009. Both standards consider urban environment complexities such as low wind speed and high turbulent intensity in their turbine certification approach, but there are still parameters that are beyond standard criteria. For example, the values set for turbulent intensity are quite low (18%) whereas in real-field conditions TI values are much higher than that covered in turbine certification. This exposes the turbine to enhanced fatigue and offsets vertical loads that increase the probability of reduced turbine reliability. In the present study, the limited turbine certification carries a 35% weightage as a secondary cause. To verify this, we traced turbine power production data for 25 projects and compared it with manufacturers' turbine-rated power data, Surprisingly, all of the wind turbines underproduced, and none of the turbine's performance curves matched the actual production.

4.4 Social and Environmental Causes

The respondents of the survey did not give high weight to social and environmental causes. They are just 6% of the total cause involved in the low installation trend. Socially, there exist too many misconceptions about the installation and operation of wind turbines in an urban environment. Among the social concerns, the cause of the highest ranking is residents' safety, and it carries a high value of 44%. The misinformation about potential tower collapse, turbine blades burning, brake system breakdown and potential loss to the property has turned into an inevitable obstacle in urban installations. In the year 2001, Bob Loebelenz in Massachusetts succeed to get approval to install a small wind turbine on his farm, before installation, the permit was revoked due to a complaint lodged by his neighbor. There was a huge amount of misinformation discussed and clarified by Bob's lawyer in the public hearing. Ultimately, the permit was re-issued after a continuous effort of 13 months and the legal process cost him around $13,000. Among the projects analyzed in this study, not a single event of tower collapse or blade burning is reported.

The second cause in this category is the noise produced by turbines and the vibration induced by the building structure due to turbine operation. It has a significantly high value (43%). There are two types of sounds/ vibrations that are produced by a wind turbine, 1), the mechanical sound/ vibration that is produced by running machine parts such as a gearbox and generator, and 2) the aerodynamic sound/vibration that is generated when air interacts with turbine blades. Generally, the turbine manufacturers furnish the turbines operating noise/vibration level in their sales brochure. Again, the approving and planning authorities have no fair basis to determine the acoustic and vibrational impact of wind turbines on the residents or neighborhood. It is simply decided on a case-by-case basis by the planning authority or sometimes the neighbor complains about turbine installation. In another example [12], Douglas Stockman from New York applied for a small wind turbine and was opposed by his neighbors. The request was forwarded to the planning board and Mr. Stockman had to refute his request after four months of follow-up. Whereas, in actual practice, the sound level produced by a small wind system(43dB) is less than that produced by an air conditioning unit and slightly higher than that produced by a domestic refrigerator (attainable home report, 2022).

The third causative factor in this category is the turbine's effect on local wildlife and urban aesthetics. It has a minor value (13%). Based on our research, it did not contribute effectively to project failure. Even in some cases, it added to the building's aesthetic and attracts visitors. There was just one case when a bird hit the turbine.

5. Conclusion

The causative factors of the low installation trend are analyzed in this study. It is realized that small-scale wind projects are implemented without prior economic and technical feasibility analyses. If analyses were conducted, the projects' economic parameters were not baselined following project management principles, and the projects' technical feasibility analyses were not conducted according to project management rules and guidelines. The proper project planning and performance are measured without proper attention to urban atmosphere complexities. Urban wind projects are cost intensive as compared to other onshore and offshore wind energy. From a post-project perspective, the project performance data is not traced regularly. Out of 3000 installed wind turbines, only 36 of them have performance data.

A root cause analysis applied to contributing factors depicts that competition from solar PV cells is the biggest barrier to the installation of small wind turbines. The second root cause is project performance which has many undermining factors, which include a lack of understanding or analysis of complex flow structures in an urban environment. The flow modeling in urban environments required special treatment and more in-depth analyses. Thirdly, there is a general lack of turbine certification and zoning policies. The permitting process seems to be arduous and labor-intensive. Lastly, there are environmental and social challenges, but most of them are not scientific and most of them are assumed based on misconception and unnecessary fear. The authors would like to identify two factors as limitations in this research; (1) the limited availability of project performance data (2) respondents' limited technical knowledge about distributed wind.

Future Work

Risk treatment recommendations:

The future work would include a remedial measure approach for identified causes and risks to enhance installation practices in the urban environment. The two highly ranked (Economical and Technical) causative factors will be addressed specifically. Technically a resource assessment campaign would be carried out with real-world data and a technical model can be developed to compare the simulation results with field data. Economically hybrid wind-solar projects can be developed to harness maximum energy from both resources. Moreover, an economic model can be developed to set the project baselines that would improve the project's performance through net present value (NPV), return on investment (ROI), and simple payback time (SPT) analyses.

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