Optimization for Renewable Energy Resource Allocation Using Linear Programming (A case Study)

By: Marwan Othman Ghabban[1*], Abdulmajeed Hussain Marzouq[2], Yazeed Abdalrhman Alsughayyir[3], Ahmed Mohammed Alesayi[4]

Ph.D. researcher in Business Administration at Effat University, Kingdom of Saudi Arabia [1-4]

[*]Email: moghabban@effat.edu.sa

Abstract:

This case study aims to examines using a linear programming technique on how to distribute a scarce €500,000 on four projects in renewable energy. The goal here is the overall energy production with some constraints that include but are not limited to financial capacity, minimum threshold in single project investment, and environmental impact. This analysis presents the resource allocation and energy output derived from the solution of this linear programming problem by Excel Solver, the effects of constraints involved, the ensuing financial scores and the sustainability analysis, to reach the outcome of identifying efficient resource distribution that would allow maximum energy production, given the budget constraint.

The output efficient decision of this case study was of course aimed to correspond to the capabilities of the sources in regard to the used Euro in order to produce as much energy as possible but also in terms of ecology the proper use of Solar and Wind energy was the best option, Theoretical optimal investments in hydropower were excluded mainly because of their high costs and low densities of energy. This approach can therefore be used as a reference by other company and industries especially those with many objectives when undertaking renewable energy investments or any other Multi-objective decision problems.

Keywords: Renewable Energy, Resource Allocation, Linear Programming, Optimization

1. Introduction

Renewable energy is one of the key sectors of the current global society strategy owing to the pressing problem of climate change, depletion of resources, and the detrimental effects of traditional energy sources to the general environment. Given the growing need for clean, safe, and efficient energy, players in the industry are always confronted with challenging choices on how to deploy their capital assets with a view of achieving the highest energy returns within the confines of fixed budgets, environmental standards and legal requirements. This paper describes a real life problem in a renewable energy production and supply organization covering an operational area of resource allocation between different renewable energy projects such as solar, wind, hydro energy, and biomass energy. The industry and firm-specific scenario successfully illustrates the strategic management decisions that may rise to recur when investing in renewable energy for the firm’s operations and sustainability.

The firm in question is expected to determine how to distribute a restricted cash of €500, 000 between four renewable energy systems, each associated with its investment price together with the energy created. Some of these projects encompass a solar power project, a wind power project, a hydro power project and a bio mass power project. A critical goal involves summing up the total rating of energy produced from the available capital The company has several constraints in its operations; it has to minimize the cost of investment; the projects it undertakes must be independent or dependent on other projects, and the final projects must be sustainable. The constraints include the following; the project can only spend at least 30% of the budget in wind energy because a vendor has already contracted the technology, only 20% of the budget can be spent on hydropower to reduce impact on the environment and finally, at least 15% of the budget can be spent on solar energy because the region has favorable solar conditions.

This problem forms a well-defined category of an optimization problem whereby the company has to aims to reach an optimal solution within the set limitations. Portfolio decisions include decisions on how much to commit to each project given the capacity in terms of output per unit of investment, cost of project and sustainability mandates. Furthermore, the problem indicates that it is challenging to address the questions of resource management at the present degree of innovative development, linking it to the search for solutions to the global environmental and social problem of reducing carbon emissions and improving the quality of life. Renewable energy sector is especially appropriate to consider such optimization problems because of the wide range of offered energy sources and different costs and produces connected with each type of energy.

Solar, wind, hydropower and biomass energy sources are different in that each has different strength and some weaknesses. This is because the sources may be rich but they are intermittent, e.g., Solar energy is widely available and quite easy to capture particularly in countries that enjoy high Solar irradiation but depending with the time of the day or the season, it may not be available. Wind energy, in contrast, can produce large quantities of electricity, especially in regions where the wind is persistent, however, costs much of money to establish large wind power plant and also to maintain it. Hydropower has been identified as a dependable renewable energy source; however, the subsequent effects on ecosystem and water supply are not always good. Technological resources of biomass energy are flexible and renewable, but care must be taken when choosing and applying available technologies and resources.

However, the company is to undertake technical and financial analyses alongside various global sustainability objectives and guidelines. Continues globalization, especially the last decade's tendency towards the acknowledgement of the problems of sustainability on the level of single companies and the governments' actions, put extra pressure on organizations to make environmental decisions. The reality is captured in the case study, where the company must meet certain sustainability thresholds, for instance, in relation to the investment in hydropower, it cannot spend more because of the ecological effects and in terms of the investment in solar energy, it has to invest more because of the regional opportunity. Such constraints bring to light an appreciation for a systems approach to decision making that recognizes financial returns, but also outside concerns in environmental and social costs of an energy endeavor. Given this interdependent resource allocation problem, the company can always turn to optimization instruments such as LP, which is a powerful technique of solving a problem as much complicated as it has numerous constraints on it. Here, the decision variable of the given linear programming model is represented in its objective function as the total energy to be generated from the investment while bounded by the available budget and other sustainable goals. The decision variables are the investment proportions of the four renewable energy projects Selected and the constraints ensure the company does not violate the financial and environmental conditions given by the problem. Linear programming will help the company to decide on each of the €500, 000 budget on which the four projects it will go on to achieve the greatest energy output possible given the various constraints that come with the projects.

The optimization approach, apart from its apparent and convincing manner of decision-making, allows the company to consider the impact of various factors and make justified choices.

For instance, the company can get to know how best they would manage in the circumstance where the budget or the constraints are changed. This kind of analysis is especially relevant for the renewable energy industry because publicly available information influences the success of the project by affecting financial incentives, available technologies, regulations, and market conditions. Also, it should be emphasized that optimization model can be refined with additional data or constraints at any time and thus it can be used for long term make span planning. Overall, the case of renewable energy resource allocation suggested that managing investment in renewable energy resources requires optimization techniques to understand specificities of decision making in this field. Optimally selecting financial, environmental and regulatory attributes of resources can help the companies to achieve the greatest energy within the sustainable frameworks of the global community. Thus, the linear programming and other optimization tools used in the paper give a logical and effective basis to solve such problems and to make rational and reasonable decisions about investments into renewable energy projects. Since the role of clean energy is ever increasing, the issue of resource survival becomes a critical success factor to the firms to gain competitive advantage and operate sustainably. So, this case study aims to how to linear programming deploy the capital assets with a view of achieving the highest energy returns within the confines of fixed budgets, environmental standards and legal requirements, and make informed decisions.

2. Literature Review

2.1. Renewable Energy Allocation: An Overview

The distribution of resources in renewable energy sources has become a subject of discussion for the last few years as the world has shifted from fossil fuels to sustainable energy. Solar energy source, wind energy source, hydropower, and biomass energy are the important sources of energy in the future energy systems. But all differing types of renewable energy have unique characteristics related to cost, performance, environmental effects, and practical applicability. Consequently, effective deployment of financial and technological resources across the varied renewable power projects has emerged as an area of research. The challenges of decision-making in renewable energy investments have been the subject of a great many publications. More often than not, these decisions are most likely going to be strategic management decisions since decision makers are likely to be faced with tasks that require an optimal blend of two or more objectives such as energy output, cost reduction, and sustainability. The incorporation of multiple RE sources in energy systems entails formulation of right strategies in investment to balance energy and resource supply, as posited by (Zhang, Zheng, & Sun, 2020). That is, in addition to the variability of the supply cost, energy prices, demand and the utility of the intermittent renewable energy supplies such as wind and solar power (Ghofrani, Arabali, Etezadi-Amoli, & Fadali, 2013).

2.2. Optimization Methods for Determining the Distribution of Renewable Electricity Resources

The use of optimization approaches to solve resource allocation challenges in the renewable energy industry has been widely applied. Four of the most basic models of approaches are linear programming (LP), Mixed Integer programming (MIP), Dynamic programming, and Evolutionary algorithms especially genetic algorithms (GA). These methods assist decision makers in arriving at the most suitable or almost the most suitable decision that satisfies a number of physical constraints or goals. It has been applied in the past because of its simplicity and applicability in scenarios where resource constraints form linear models. In the area of renewable energy funding, LP models have been used to determine the correct distribution of the funding resources needed to fund the various energy projects so as to achieve a given maximum production level subject to certain restrictions (Wu, Xia, & Cheng, 2017). For instance, Li, Ma, & Feng (2018) used LP models to propose investment strategies for solar and wind energy projects with regard to installation costs, energy yield, and project area in a particular region. From their results, the authors note that LP can provide real solutions for optimizing resource investments in large energy systems for the purpose of attaining maximum energy yield.

Another technique used conveniently in renewable energy planning is the Mixed Integer Programming (MIP). MIP models are an extension of LP models that permits some decision variables to assume integer values; this option is relevant in contexts where investments are also integer, such as Solar or Wind energy. Work by Zeng, Zhao, & Wang (2014) confirms that MIP models may be employed in the context of the capacity of renewable energy systems, in view of the stochastic nature of renewable energy sources. The same type of application has also involved MIP models for assaying the solution to combination problems of both energy sources and storage systems and connection to the grid (Bahramara, Moghaddam, & Haghifam, 2016).

Dynamic programming is another optimization power tool that is quite helpful in situations, which involve multiple stages of decisions making. It has been employed in the management of the renewable energy resources to simulate the lifelong investment plans that grow with time (Sáenz, Piacentini, & Ubierna, 2013). For example, in the dynamic programming models, people optimally plan the investment schedule for renewable energy projects given energy prices volatility and the development of technology (Harsha & Dahleh, 2016). Other optimization technique includes the evolutionary algorithms which includes genetic algorithms (GA) and particle swarm optimization (PSO) have also been used to solve renewable energy allocation problems when the objective function is non-linear or complicated.

GAs have been used in hybrid renewable energy systems sizing optimization based on a criterion of lowest possible cost while fulfilling utility requirements (Mahmoudimehr & Sadeh, 2016). Likewise, PSO has application in determination of the control parameters for energy storage systems to improve reliability in conjunction with RE projects (Mohammadi, et al., 2016).

2.3. Sustainability and Environmental Concern

Substitutability is equally an essential consideration in renewable energy distribution as these projects are developed with climate change considerations and an aim of attaining lowest carbon footprints. In the current studies, literature on the allocation of renewable energy focuses on combining economic-related goals with environmental and social factors. Some of the researchers have applied sustainability measures in optimization models for allocation of renewable energy. For instance, Krishan and Suhag (2019) indicated that they have developed an optimization model that embraced economic and environmental objectives for resource portfolio of wind and solar. Their direct costs fundamentally expanded their model to cover things like greenhouse gas emissions, land use, water consumption, and many others, as well as the financial ones. This type of multimodal optimization is critical when attempting to match investment in the renewable energy domain with the ideals of sustainability. In a similar fashion, Wang et al. (2018) have intention to explain about the application of LCA in improving the investment in renewable energy. When using LCA in modelling optimization the authors were able to evaluate the environmental load of the various RE technologies across their life cycle phases including construction, operation and dismantling. This indicates that whilst constructing solar and wind energy they emit far much lesser emissions during lifetime emissions than the conventional energy projects.

Another new development is the involvement of social and ecological aspects in renewable energy configuration. To this end, Boie et al. (2016) examined how deployment of re- newable energy technologies may be made to have least negative effect on ecosystems and people. In their study, they found that there is a need for proper engagement with the public to ensure that such projects are supported, and implemented successfully. Moreover, Gielen et al. (2019) pointed that the existing renewable energy allocation models have to address the potential socio ecological effects of energy projects for biodiversity, water use and the availability of land particularly when implemented in ecologically sensitive areas.

2.4. Limitations of Investing in Renewable Energy

Financial management is one of the most critical barriers in renewable energy allocation because most of the renewable energy projects require plenty of capital investments in most of their projects. This paper aims to reveal various approaches of financing in renewable energy with certain restriction on investment in renewable energy projects. Economic models in renewable energy distribution usually mean to achieve a least cost of energy or leveled cost of energy (LCOE), the price per unit of energy produced over the entire life span of a project. Appropriate distribution of cash flows across various renewable energy technologies is central in driving down the LCOE and therefore increasing returns on the investment made. It could be seen from the study of Shrimali et al. (2013) that the US wind and solar energy systems financing option, LCOE is equivalent with that of fossil power plants when financed optimally.

The budget concerns of investment and financing are more critical in those areas since other conditions such as government support in form of incentives or subsidies for the renewable energy may not be favorable. In these circumstances, however, private sector has to be sensitive on the money needed for the financing of renewable energy sources by putting the buck sensibly. As noted by (IRENA, 2016), innovative financing structures like green bond, public private partnership and crowd funding has progressively been employed to mobilize funds for renewable energy projects. These mechanisms assist to manage the high capital costs involved in renewable energy technologies, again within the context of developing countries. Further, some research has examined the application of financial risk management of renewable energy distribution. Business risks include cost volatility hence energy prices, different policies and technologies that can profoundly impact the assessment of RE projects. Labordena et al. (2017) suggest introduction of financial risk measures to assess the optimal and non-optimal risks approximation models. According to them it may be seen that risk averse investors may wish to invest more in stable renewable resources like hydropower or biomasses which may not be greatly influenced by the market externalities.

3. Methodology

This study uses linear programming (LP) to do the following in the context of renewable energy resource allocation. The goal is to maximize the total energy output by optimally distributing a €500,000 budget across four renewable energy projects: renewable resources included solar, wind, hydropower and biomass energy. Every project is different and so is its cost and energy generation potential which must also be compatible with constraints which are of financial, contractual and sustainability in nature.

3.1. Problem Definition

The decision variables $x_1 + x_2 + x_3 + x_4$ represent the investment amounts in solar, wind, hydropower and biomass energy projects respectively. The objective of the company is to find a solution that will allow the maximum of the total energy without violating the constraints. Each project has specific costs and energy outputs: Solar generated at €1000, 150 MWh per year, while wind at € 2500 300 MWh per year, hydropower at € 5000 500 MWh per year, biomass power at € 3000, 200 MWh per year. The objective function is to maximize total energy output:

$$E = 0.15x_1 + 0.12x_2 + 0.10x_3 + 0.066x_4$$

3.2. Constraints

Several constraints guide the allocation:

Budget constraint: RC for the control or management of a business must not exceed €500,000.

$$x_1 + x_2 + x_3 + x_4 \leq 500{,}000$$

Wind energy: At least 30 % of the total determined budget should be allocated for the wind energy.

$$x_2 \geq 150{,}000$$

Hydropower limit: Specifically, it has been established that a maximum of 20 percent of the overall budget for the development of energy can be made available for hydropower development.

$$x_3 \geq 100{,}000$$

Solar energy: The minimum that needs to be invested in solar is 15% of the planned budget:

$$x_1 \geq 75{,}000$$

Furthermore, all decision variables should be non-negative.

3.3. Solution Approach

Linear programming problem is solved using **Excel Solver or Python SciPy** optimization. Solver to decide as to how much should be invested in each of the investments. $x_1 + x_2 + x_3 + x_4$ Which must meet certain constraints and whose goal is to achieve maximum energy from the given restrictions. The availability of purchase capital determines the best allocation involving not only financial result but also sustainability targets applying the Simplex algorithm.

This methodology applies sets of linear equations to ensure optimum resource utilization with a view of maximizing the output of energy within the set limits of expenditure. Solver tools are useful instruments to apply practice for the effective investment choice among renewable energies.

4. Case Study Analysis and Discussion

This particular case study examines using a linear programming technique on how to distribute a scarce €500,000 on four projects in renewable energy. The goal here is the overall energy production with some constraints that include but are not limited to financial capacity, minimum threshold in single project investment, and environmental impact. This analysis presents the resource allocation and energy output derived from the solution of this linear programming problem by Excel Solver, the effects of constraints involved, the ensuing financial scores and the sustainability analysis.

4.1. Optimization Solution: Allocation of Budget

The company has a total budget of €500,000 to invest in four renewable energy projects: solar power, wind power, hydropower and bio mass energy. The constraints of the optimization include such factors as the total energy that can be generated by a specific fossil fuel. After solving the linear programming problem using Excel Solver, the budget was allocated as follows:

Solar Power: €350,000

Wind Turbines: €150,000

Hydropower: €0

Biomass Energy: €0

This allocation makes it quite clear that a preponderant share of the total has been spent on solar way of power while the rest was spent on wind mills. There was no investment made in hydropower or biomass energy. It increased allocation of the solar power budget because it is cheap in terms of cost per unit investment (€ 1,000 per unit) and very effective because it generates 150MWh per unit. This makes solar power a unique solution as far as the cost of generating energy per invested euro is concerned. Likewise, the capacity factor of wind turbines also has a fairly high energy rating (300 MWh/unit) for a relatively high unit price of € 2,500 it has the second best score for the energy output within the constraint.

There was no capital provided for hydropower or biomass energy because they are relatively expensive with low unit energy supply as compared to solar and wind power. Hydropower energy at a cost of 5, 000EU per unit and energy production of 500 MWh per unit were omitted probably due to the high cost of setting up this type of IPP and the condition that hydropower had to be developed at a cost of no more than 100, 000EU. That biomass energy cost € 3,000 per unit and provided energy of 200 MWh per unit was considered less efficient than solar and wind energy.

4.2. Energy Output Results

The solution indicated that a total energy output of 70, 500 MWh can be realised when investment was made solely in the renewable energy source such as solar power and wind turbines. The breakdown of energy generation is as follows:

Solar Power: 52,500 MWh

Wind Turbines: 18,000 MWh

Hydropower: 0 MWh

Biomass Energy: 0 MWh

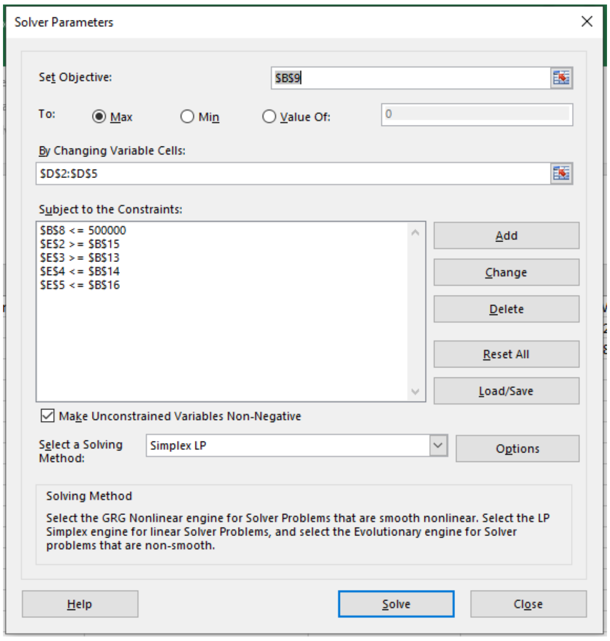

Figure 1: Parameters for Excel Solver

The absolute potential is the condition in which all the financial resources are invested in the project that yields the highest energy per Euro. In this case therefore, €1,000 investment in solar power yields 150 MWh, which diversified to give per euro yields 0.15 MWh. If the entire €500,000 were invested in solar power, the theoretical maximum energy output would be:

$$Maximum\ Theoretical\ Output = \frac{500{,}000}{1000} \times 150 = 75{,}000MWh$$

Surprisingly, the actual amount of energy produced from the optimal solution, 70,500 MWh, is near this theoretical maximum. This difference stems for the fact that the investment in wind turbines has to be not less than €150 000. Because wind turbines produce less energy per euro than solar electricity, the constraint provides some wind electricity investment, lowering the total electricity produced.

4.3. Constraint Analysis

The optimization problem was subject to several constraints, which significantly influenced the outcome:

Total Budget Constraint: Total investment of a project could not be over € 500000 which is available capital for the company. This constraint was met exactly as the optimal solution provided the best solution to the solar power and wind turbines with a total budget requirement meeting the total budget constraint.

Minimum Investment in Wind Turbines: An important constraint indicated that there must be an absolute investment of greater than €150,000 in wind turbines, and this was observed in the optimal location. Wind turbines produce 300 MWh per investment per unit, although it costs

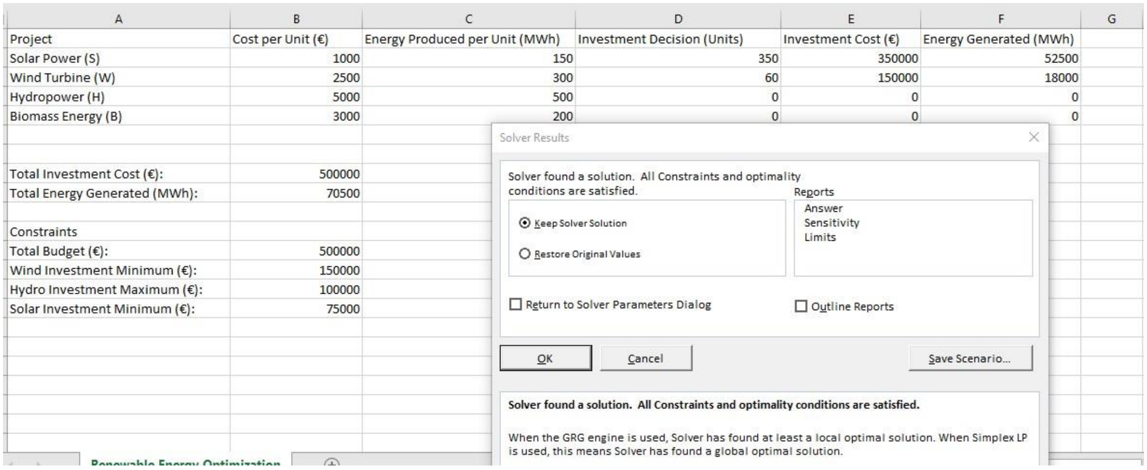

Figure 2: Feasible Solution

€2,500 per unit which is quite expensive. That being said, they are less efficient as cheap as solar energy which produces 150 MWh per € 1000 investment. The limitation in wind turbines caused the total available power to be lower and if more capital were to be placed in solar power the reward would be more energy. However, wind turbines were incorporated into the equations in order to meet this criterion.

Maximum Investment in Hydropower: In another case, hydropower was limited to an investment limit of €100.000 based on the sustainable environment issues.

Interestingly, no fund was allocated towards the hydropower generation in the identified optima. This should be so when we consider the fact that hydropower produces the highest energy output per unit (500 MWH), but costs so much per unit of energy produced (€5000). Hydropower did not make the list of projects and, therefore, proved that the model favored cost and disregarded different types of projects.

Minimum Investment in Solar Power: The last constraint that at least €75,000 has to be spent on the solar power was also satisfied in the optimal solution, in fact €350,000 has been spent for the solar. This is very much true and explains why solar power, which is the cheapest source of power, was bound to attract the biggest investment even without this consideration. This implies that the minimum solar investment constraint did not influence the result since the model would even have allocated a huge share of the cost on solar energy.

Trade-offs Between Projects

The forced constraints are majorly oriented towards such aspects of project organization as trade-offs between projects. The most inexpensive source, solar power, was awarded the largest allocation of the total budget. However, the measure laying down the provisions that wind turbines are to be put into operation with investments of at least € 150000 has brought about the total energy yield low as this sum could have been farther utilized to the installation the solar systems. However, there was no investment in hydropower and biomass as its costs were high and energy yield was lower than solar and wind energy investments. This exclusion suggests that hydropower or biomass if invested under the same conditions in the given constraints would have been suboptimal from an energy generation point of view.

They also still into the environmental and contractual factors that have capped them. For instance, the cap on wind turbines might be due to previous commitments with a supplier while on the side of hydropower, there might be risks associated with large scale hydropower implementation. These constraints bring practical concerns that are typical for business: how much they can earn, and how far they agree to go to gain extra revenues forgetting about sustainable development and their contracts with partners.

4.4. Sustainable and financial factors.

The optimization solution to the model has the following implications for the company's financial performance and sustainability objectives. Financially, the solution guarantees that the firm gets through the most optimum level of energy in the given financial capability. By orientating toward solar power generation as well as wind turbines, the company ensures the optimal energy generation which proves to be economically beneficial for the company as it generates up-to-the-max return on the investments used in generation of energy. This makes the solution to be highly efficient in terms of cost since it directs funds to the most profitable activities. From a sustainability point of view, the solution fits into the company's overall objective of promoting generation of clean renewable energy. Energy both from the sun and wind are well known renewable sources of energy with little environmental damage when compared to fossil energy sources. By making those two projects take most of the budget, the company can be in a position to cut down its carbon emission and therefore it will be contributing to the fight against climate change.

Depending on the particularities of the case, the exclusion of hydropower and biomass energy from the optimal solution may be considered as the major disadvantage of the approach. Nevertheless, the lack of investment in these projects may be explained by the need to achieve the maximum generation of energy possible within a given financial envelope. Hydropower has great advantages as a form of renewable energy but the environmental effects may also be high especially when developing an installation such as dams affects the natural flow of water. These environmental issues have been put into consideration by the company when choosing to invest a maximum of €100,000 on hydropower. It also follows trends of the modern renewable energy crisis with an emphasis on solar and wind energies. Wind and solar have shown improvements in the last few years with regard to cost reduction and enhanced efficacy. Leaning heavily on these technologies helps the company to cycle with the continuous enhancement of renewable energy technologies as well as growing appetite for clean power.

As a result, the optimization solution helps the company to achieve both the financial profitability and sustainability aims adequately. Most of the budget is being focused on solar and wind energy which gives efficient results of energy with least harm to the environment. The constraints incurred present practical aspects that solve real-world problems including contractual duties and sustainable issues and the solution achieved pays attention to the conviction that resources should be allocated efficiently in the renewable energy industry. This way the company is positioned to achieve its energy production objectives as is the rest of the world in a bid to embrace more sustainable energy production.

5. Conclusion and Recommendations

The positions in the renewable energy segment are very important as it relates to bringing positive change in the society today. With energy demand progressively increasing and the available fossil fuel recourses decreasing, there is no better time that today to invest in renewable energy.

This research analyzed the distribution of a specific investment capital to four types of renewable energy sources; solar power, wind turbines, hydropower, and biomass energy with specific constraints in terms of finance and sustainability measured by linear programming on the total amount of energy that can be generated. Excel Solver was used to solve the model with the outcome of identifying efficient resource distribution that would allow maximum energy production, given the budget constraint.

The efficient solution provided was €350 000 for solar energy, €150 000 for wind energy, and none for hydropower or biomass energy. This decision was of course aimed to correspond to the capabilities of the sources in regard to the used Euro in order to produce as much energy as possible but also in terms of ecology the proper use of Solar and Wind energy was the best option. Solar power with cost € 000 per unit and energy output of 150 MWh per unit had the highest specific energy indicating that it has received a suggestively big share of the total budget. Even though wind turbines are more costly than a simple photovoltaic cell or some other types of generators, wind turbines nevertheless were still an important component of total energy production because more than €150,000 was needed to be spent on wind energy. Theoretical optimal investments in hydropower were excluded mainly because of their high costs and low densities of energy and thus implying that these projects were less efficient in the attainment of the target of generating the highest possible energy within the stated budget.

95,875,000 persons total energy generated by the optimal solution was 70500 MWh, which is slightly lower than the theoretical 75000 which would have been generated if the entire budget was used to source power from solar. The small deviation is as a result of the WHO guideline that demands a minimum capital investment of € 150000 in wind turbines which though a constructive power source, produced less energy per euro invested than the solar power did. Still this constraint is realistic based on contractual relationships at a certain point depicting that the theoretical efficiency of the allocations of resources can be influenced by practicalities.

The solution also considered the problem sustainability goals that were laid down in the problem. Both solar and wind energy sources do not pollute the environment and recourses from them are inexhaustible, so they should represent interests that can be invested on a large scale. The exclusion of hydropower is consistent with the controversies surrounding effects on the environment and the availability of water occasioned by large hydropower for instance, where construction of dams is involved. Likewise for biomass, it stated that the efficiency of biomass energy per unit of the area is smaller than that of solar and wind energy; moreover, biomass production results in alteration of land use, which is disadvantageous to the environment. Ever since there are optimal strategies that exist in a solution space, this case exposed the strategic role of optimization in a decision-making process especially in organizations where there are scarcity of resources and reacts of objectives. Application of linear programming helped the management of the company to determine on how the available budget will provide maximum returns in terms of generating energy without compromising any aspect of the financial restrictions and environmental conservationist measures. This approach can therefore be used as a reference by other company and industries especially those with many objectives when undertaking renewable energy investments or any other Multi-objective decision problems.

Conclusion

Therefore, it can be stated that application of linear programming to define the optimal allocation of the company resources on renewable energy investments is beneficial to generate the necessary insights. Solar and Wind energy have been accorded topmost priority with the company achieving its highest energy production within the set budgets and while still practicing the principles of sustainability. In the future, the company should remain committed to cost-efficient renewable resources; at the same time, the company needs to remain quite responsive to changes in technology, market, and environmental trends. If the company follows the below-mentioned recommendations it will be able to improve its financial position, advance its efforts toward contribution to global sustainability and can be regarded as a key player in the renewable energy sector.

Recommendations

Based on the analysis and results of this case study, several key recommendations can be made for the company as it moves forward with its renewable energy investments:

1. Promote the Most Economic Forms of Renewable Power

There is an evidence of increases of costs of other types of renewable energy sources as derived from the results of the optimization, but solar power remains to be the cheapest among the type of renewable energy sources accessible to the firm. Due to a low cost per unit of investment and high energy return, solar energy should be one of the priorities for the future. The company should keep on investing a large portion of its financial capital on the solar energy, especially when the technology keeps on increasing the efficiency and bring down the costs. Over the years, solar power costs significantly reduce; thus, the company will produce more energy with little capital outlay, resulting in better profitability and environmental impact.

2. There should be unrelenting support for wind energy investment

While onshore wind has higher costs compared to onshore solar it is still important in the development of the company's renewable energy power mix. The binding that maintains a minimum investment in wind energy may be due to a long-term contractual commitment, and windmills also supply a predictable and stable energy source, especially in locations where wind is predictable. Investing in wind power should be sustained as technology enhancement in the composition of Wind turbines increases the energy yield of Wind power projects. Further, wind energy can create synergy with solar energy generating electricity during time that solar power production maybe low (e.g. at night or during rainy conditions).

3. Assess the Position and Significance of Hydropower and Biomass Energy

The omission of Hydropower and biomass energy in the optimal solution indicated that these are sub-optimal in the context of MW populated per euro invested. But hydropower and biomass energy should still be considered in the company energy mix especially if other circumstances change. For example, if the cost is reduced a little or if the problems associated with the large-scale hydropower are solved, that is by embracing the small-scale hydropower technologies, then the company may consider reviewing its investment ratios and bidding for opportunities to invest in hydropower in the next investment rounds. Likewise, biomass energy is somewhat less efficient than solar or wind power but biomass energy could be a feasible solution for a place having biomass resources. The company should regularly review these energy sources for possible changes in technology and availabilities of markets.

4. Management of Technological Changes and the Environment

The renewable energy industry is continually growing and developing, and there are novel technologies that could greatly change the effectiveness of resource utilization. For instance, progress in the field of batteries could help decrease the output of energy from solar and wind by less generation, this just offer backup energy from less efficient technologies. The company should be able to regularly update on the new technologies in the renewable energy industry so that it can be able to be on the lookout in case there are changes that it needs to pick and invest on. This way, the company can remain at the technological vanguard and, therefore, sustain the most yields at lowest costs and minimal adverse effects on the environment.

6. Explore Government Incentives and Partnerships

Taxes credits, grants, and subsidies are commonly used instruments used by many governments to encourage investments in renewable energy sources. The company should research ways of leveraging on these incentives as the overall returns on renewable energy projects could be boosted by the cutting of upfront costs. Also, collaborations with state authorities, non-governmental organizations, and other renewable energy companies may grant the required resources and knowledge as well as contribute to the company's possible evolution of the existing renewable energy portfolio.

6. References

Zhang, D., Zheng, Y., & Sun, Y. (2020). Optimal planning of integrated energy systems: Review and future research directions. *Applied Energy*, *262*, 114497.

Ghofrani, M., Arabali, A., Etezadi-Amoli, M., & Fadali, M. S. (2013). Smart grid demand response: Outage management strategy for hybrid renewable energy systems. *Electric Power Systems Research*, *95*, 206-213.

Wu, J., Xia, Q., & Cheng, S. (2017). Energy optimization in the industrial sector using linear programming techniques. *Renewable Energy*, *114*, 1064-1073.

Li, H., Ma, T., & Feng, K. (2018). Optimal allocation of wind and solar power in energy systems using a multi-objective linear programming approach. *Journal of Cleaner Production, 182*, 114-126.

Zeng, Q., Zhao, X., & Wang, Y. (2014). Mixed-integer linear programming for renewable energy systems: A review. *Energy Reports*, *4*, 199-208.

Bahramara, S., Moghaddam, P., & Haghifam, M. R. (2016). Optimal planning of hybrid renewable energy systems using HOMER: A review. *Renewable and Sustainable Energy Reviews, 62*, 609-620.

Sáenz, J. R., Piacentini, R. D., & Ubierna, A. F. (2013). Dynamic programming for long-term investment in hybrid renewable energy systems. *Renewable Energy*, *60*, 615-621.

Harsha, P., & Dahleh, M. A. (2016). Optimal management and sizing of energy storage under dynamic pricing for the efficient integration of renewable energy. *IEEE Transactions on Power Systems, 31*(3), 2202-2211.

Mahmoudimehr, J., & Sadeh, J. (2016). Risk-based optimal planning of renewable distributed generation considering reliability and power quality. *International Journal of Electrical Power & Energy Systems*, *76*, 35-44.

Mohammadi, M., Noorollahi, Y., Mohammadi-Ivatloo, B., & Hosseinzadeh, M. (2016). Optimal planning of hybrid renewable energy systems using HOMER: A review. *Renewable and Sustainable Energy Reviews*, *62*, 609-620.

Krishan, O., & Suhag, S. (2019). A review on energy economics and planning in India: Renewable energy perspectives. *Renewable and Sustainable Energy Reviews*, *81*, 2278-2290.

Wang, J., Zhang, Y., Li, J., & Zhao, Z. (2018). A multi-objective optimization model for life-cycle environmental impact minimization of wind and solar energy systems. *Journal of Cleaner Production*, *199*, 1032-1043.

Boie, I., Bohn, S., Götz, M., & Schneider, G. (2016). Regional socio-economic impacts of renewable energies—A case study from Shandong Province, China. *Renewable Energy*, *99*, 40-49.

Gielen, D., Boshell, F., Saygin, D., Bazilian, M. D., Wagner, N., & Gorini, R. (2019). The role of renewable energy in the global energy transformation. *Energy Strategy Reviews*, *24*, 38-50.

Shrimali, G., Konda, C., & Farooquee, A. (2013). Renewable energy deployment in India: Financing issues and policy interventions. *Energy Policy*, *62*, 28-43.

International Renewable Energy Agency (IRENA). (2016). Unlocking renewable energy investment: The role of risk mitigation and structured finance. *IRENA*. Available at: https://www.irena.org/

Labordena, M., Lilliestam, J., Patt, A., & Pfenninger, S. (2017). Impact of national-level grid development on the European electricity sector transition. *Nature Energy*, *2*(5), 342-350.

Doi: doi.org/10.52132/Ajrsp.e.2024.67.4