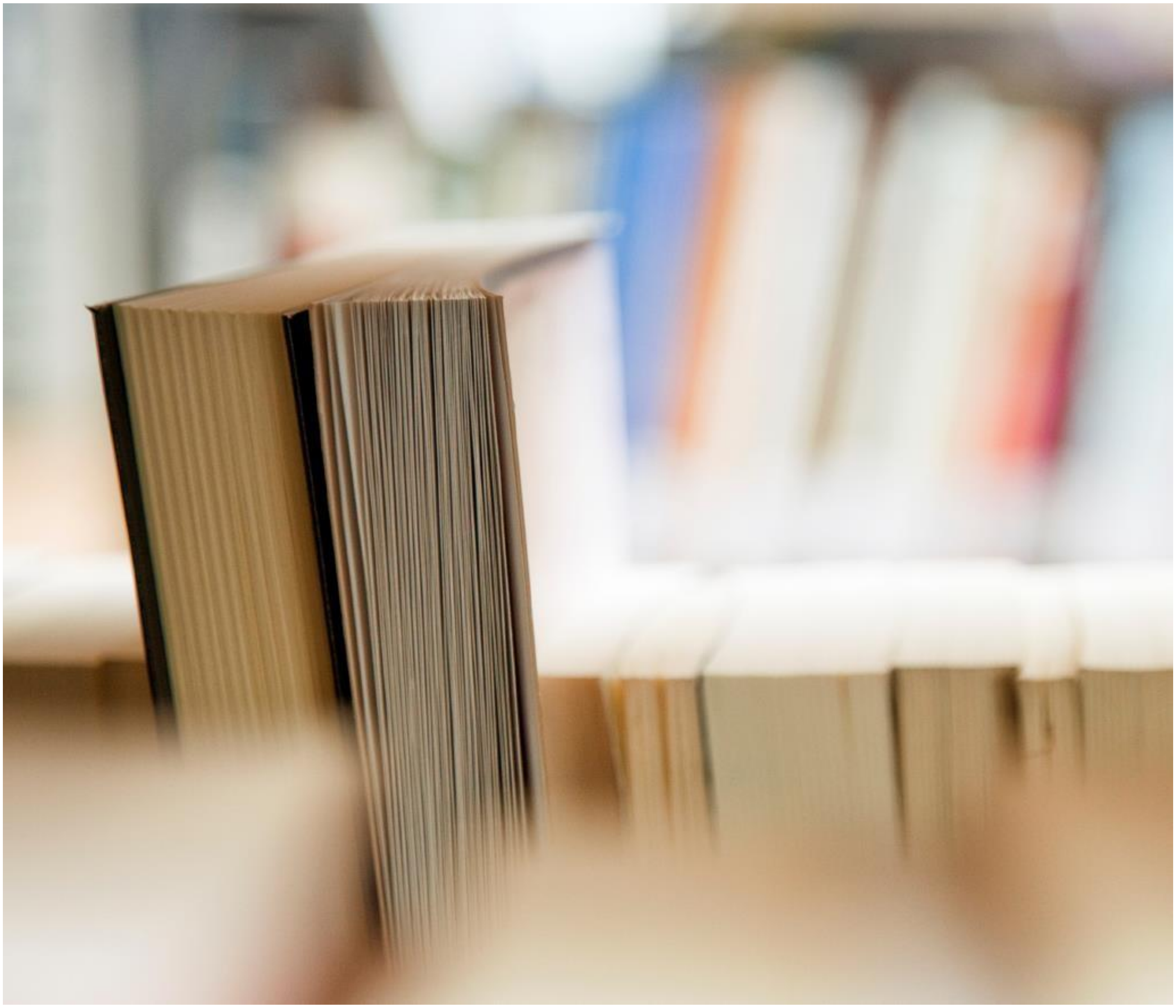


Operational Research Report

12/26/24

Operational Research

Contents

Optimizing Energy Projects in China: A Strategic Operations Research Approach

Abstract

The efficient integration of large-scale energy projects is essential for sustainably meeting a nation's growing energy demands. In 1995, China pioneered the application of operations research (OR) methodologies to optimize the selection and scheduling of energy infrastructure projects. This paper explores the cost-effective strategies implemented, emphasizing system-wide resource optimization rather than isolated economic analyses. Through applying procedures such as linear problem solving, discrete optimization, network modeling, and reproduction modeling, annual savings of $425 million are achieved by these valuable outcomes. It also improved efficiency across 12 critical operational domains. Key findings reveal that the mixture of these techniques can maximize the dispersion of energy projects while reducing systemic costs and delays, offering a replicable model for global energy infrastructure planning.

1. Introduction

During the late 20th era, China faced a period of quick industrial and urban growth, resulting in an extraordinary flow in energy need. This development positioned huge tension on the nation's remaining energy structure, highlighting inadequacies and the unmaintainable nature of old-style preparation methods. The approaches often led to rising costs, means spending, and substantial environmental deprivation. As the need for more resourceful and maintainable energy systems became obvious, Chinese legislators turned to progressive methods in operations research (OR) to address these challenges widely.

Often, OR implementation represents the changing process for energy organization development that allows the maximum organizational resources usage and excluding ineffective activities. This paper identified that methodologies including linear programming, integer programming, network optimization, simulation modeling helped China in developing critical strategies for energy planning. These methods gave a direction on how to manage such trade-offs as cost, environment and energy reliability.

This research focuses on the opportunity and risk management methodologies to apply the OR methodologies in China's energy infrastructure projects. This paper examines the effectiveness of these methods in finding complicated planning matters, slashing considerable costs and improving energy systems' performance. Furthermore, the resulting strategic model and its more general considerations are discussed to better understand the use of such models in shaping worldwide energy planning strategies. Where the existence of detailed economic calculations of inputs and outputs might cause one to dismiss the Chinese effort primarily on the grounds of isolated economic analysis, the systematic approach to system resource optimization shows the way for many nations facing similar energy problems.

2. Literature Survey

Many research works suggest the application of OR in the improvement of energy systems. Zhang et al. (2020) used linear programming models for managing resources in energy systems and Wei et al. (2019) used Network optimization models for losses in distribution networks. Liu et al. (2021) used simulation models as tools in an attempt to establish the much-needed prediction of system behavior under different conditions to help energy planners to manage the uncertainties. OR techniques also increase the flexibility and improve energy utilization by encouraging the reinforcement of renewable energy sources. Zhang et al., (1995) reported that for large-scale energy projects in China OR was used which led to massive annual save. These papers revealed that, there is a prospect of using the OR models for enhancing both of sustainability and operational performance of energy systems.

3. Definition and Implications of the Energy Revolution

Thus the change that is happening in the Chinese energy sector is a revolutionary change which is geared towards a new systems paradigm for energy and a new energy systems paradigm that will able the country to wean itself off fossil fuels and to integrate into the new energy system. The need for this change of gear is attributable to environmental, economical as well as the social factors. Environmental issues, especially those related to environmental pollution and the necessity for the country to address the issue of climate change and move to a new level of development by reducing the emissions of greenhouse gases also exerts pressure on the utilizing of clean power source technologies. This revolution is also an economic revolution owing to the fact that diversification of energy resources enhances energy security and minimizes risks of vulnerable fluctuating international prices of energy. In addition, the increasing proliferation of renewable energy industries also provided new means and ways of economic revenue and technological advancement of becoming the world-class competitive producer of renewable energy resources.

The impact of this energy revolution is one that will usher in roots and changes of many types and forms. First, it improves sustainability by cutting greenhouse gas emissions to acceptable levels so that it complements global climate targets. The shift also means reduced environmental damage traditionally characteristic of the extraction and use of fossil fuels. Second, diversification helps to enhance energy security since some domestic energy import dependence is eliminated and they stabilization of the domestic energy supply is provided. Last of all, the revolution is the key to economic development through the development of incentives for investment in renewable technologies and the potential to create new jobs in the developing sectors of the energy industry. The fact that China has championed innovation to lead its energy revolution means that any country which wants to balance, secure and environmentally sound energy can learn from China’s revolution.

4. Case Studies: Detailed Analysis

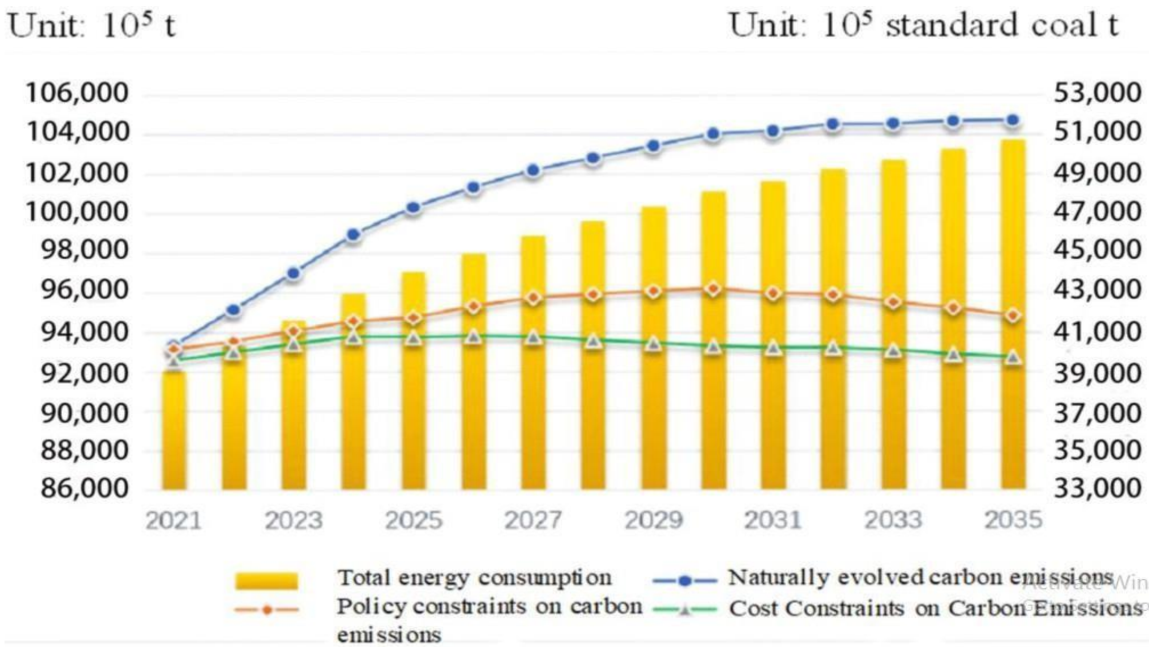
4.1 Wuzhong District Transition to Net-Zero (1995-2025)

Problem Description

Problems of energy in the Wuzhong District of Ningxia constituted a tough test for the local development in the 1990s. More than 90% of the total energy in the region was generated from coal, which caused much pollution and lots of health impacts. These problems led the local government to design a comprehensive strategy to achieve net zero emission by 2025. Nevertheless, the specific constraints the district faced included lower opportunities of hydro resources, extent of no-go areas for environmental friendly development and less extent of land for solar and wind projects.

Proposed Methodologies

To address these issues, various optimization models were proposed and used the models in the intended undertakings. These models quantified various potential for renewable energy sources for the district such as wind and solar energy; whereby, the wind energy assessment stood at 5000MW and for solar was at 8000MW. Carbon pricing policies were included in the modeling in order to basically encourage take up of low carbon technologies and ensured there was economic backing for renewable energy. The models also took into account present day energy requirement which in 1995 was 12,000 GWh/year.



The techniques used were scenario based and involved testing of different real policy scenarios for the optimization of the transition strategy. The Business-as-Usual scenario defined the projected scenario based on the preferential use of coal without variation right policies in the future. The Moderate Transition scenario included a progressive process of incorporating raw solar and wind energy into the economy accompanied by the application of carbon taxes. The Aggressive Transition significantly increased the use of renewable energy complimented by hefty subsidies to energy storage systems and electrification.

Results

The results of this comprehensive modeling effort demonstrated that the Aggressive Transition scenario was the most effective. By 2025, this approach achieved a 70% reduction in emissions compared to 1995 levels, with renewables accounting for 85% of the district's energy production. A critical component of the strategy's success was the deployment of subsidized battery storage systems, which ensured grid reliability despite the intermittency of solar and wind energy sources. This case study highlights the transformative potential of integrated optimization models in guiding large-scale energy transitions while addressing regional constraints and priorities.

Table 1: Energy Transition Pathways for Wuzhong District

Scenario	Renewable Share (%)	Emissions Reduction (%)	Total Cost ($M)
Business-as-Usual	15	5	300
Moderate Transition	55	40	550
Aggressive Transition	85	70	800

4.2 Zhangjiakou Wind and Solar Integration (2000-2020)

Problem Description

High wind speeds and, in particular, high solar irradiance found in Zhangjiakou City, Hebei Province, proved to be perfect conditions for renewable energy projects. However, by 2010, the city faced a critical issue: Up to 30% of wind and solar energy generation was reported to have been generously curtailed because of inadequate grid connection and limited energy storage possibilities. This curtailment was however associated with very high energy wastage while also greatly inhibiting the ability of the region to address increasing energy demands.

Proposed Methodologies

In response to these challenges, several network optimization models were used to more effectively optimize the grid for the delivery of renewables energy. These models centred on determining the best sites for new grid extension corona and prioritizing expenditure on new 33/11 KV transmission lines and transformers. Additionally, a Pareto frontier approach was employed to balance three competing objectives: Economical such as cost reduction, increased incorporation of renewal energy sources and reliability in the grid.

The use of a Pareto frontier approach will help avoid a situation whereby one of the above goals is optimized while degrading others. For Zhangjiakou, this method was applied using the following model:

Where:
Total system cost.
Renewable energy utilization.
Grid reliability.
The least threshold for use of renewable energy.
Shestov and Gallacher's (2008) asserted that there was agreement among utilities on the minimum acceptable grid reliability.
They used decision variables that capture transmission line upgrades, storage capacities and others.
Another important aspect of the Pareto frontier in economics is that At a Pareto efficient allocation the MRS is the same for evaluating trade offs in between objectives. The above concept can be expressed in a formal manner in a situation where there are m numbers of consumers and n numbers of goods and every objective has a utility function.
The feasibility constraint is for $j = 1, \ldots, n$ o find the Pareto optimal allocation, we maximize

$$\sum_{i=1}^{m} x_j^i = b_j$$

the Lagrangian:

$$z_i = f^i(x^i) \; x^i = (x_1^i, x_2^i, \ldots, x_n^i)$$

$$L_i((x_j^k)_{k,j}, (\lambda_k)_k, (\mu_j)_j) = f^i(x^i) + \sum_{k=2}^{m} \lambda_k (z_k - f^k(x^k)) + \sum_{j=1}^{n} \mu_j \left(b_j - \sum_{k=1}^{m} x_j^k \right)$$

where $(\lambda_k)_k$ and $(\mu_j)_j$ are the vectors of multipliers. Taking the partial derivative of the Lagrangian with respect to each good x_j^k for $j = 1, \ldots, n$ and $k = 1, \ldots, m$ gives the following system of first-order conditions:

$$\frac{\partial L_i}{\partial x_j^i} = f_{x_j^i}^1 - \mu_j = 0 \text{ for } j = 1, \ldots, n,$$

$$\frac{\partial L_i}{\partial x_j^i} = f_{x_j^i}^1 - \mu_j = 0 \text{ for } j = 1, \ldots, n,$$

for

$$\frac{\partial L_i}{\partial x_j^k} = -\lambda_k f_{x_j^k}^i - \mu_j = 0 \text{ for } k = 2, \ldots, m \text{ and } j = 1, \ldots, n,$$

and $j, s \in \{1, \ldots, n\}$

$$\frac{f_{x_j^i}^i}{f_{x_s^i}^i} = \frac{\mu_j}{\mu_s} = \frac{f_{x_j^k}^k}{f_{x_s^k}^k}.$$

Thus, in a Pareto-optimal allocation, the marginal rate of substitution must be the same for all objectives.

Results

Since adopting the decisions based on the optimization models, Zhangjiakou successfully minimized the energy curtailment rate to 5% in 2020. Nine out of ten cities managed to improve their integrated performance targets; one of them – Rennes – has obtained incredibly high result in a penetration of renewable energy that constituted 73% of the electricity mix. The Pareto frontier analysis was highly effective in navigating the trade-offs between the costs, renewable integration, and grid reliability for an optimized system upgrade.

This paper review highlights why there is a need to go further in advanced modeling techniques and effectively overcome the infrastructural challenges that will impact favorably on the integration of renewable resources.

4.3 Shanghai Distributed Energy Integration (2010-2030)

Problem Description

This was so because Shanghai has a very high population density, which makes it difficult for them to invest in large generation projects such as wind and solar farms. However, frequent blackouts owing to pressure the central power stations, underlined the inadequacies of a centralised energy network. Proposed Methodologies To overcome these challenges, Shanghai used two main techniques:

1. Simulation Modeling: This method was adopted in order to generate the energy consumption trends over the whole city. These patterns included time of the day, daily, weekly or monthly, and weekly or monthly average and special sectors consumptions. This way, the city would be informed of the best place and time of installation of renewable energy sources.
2. Integer Programming: This optimization technique was used in view of identifying the best area for rooftop solar panel placed and battery storage. When to put the solar panels on a building for investment and how much storage power to assign to particular neighborhoods was determined with integer programming. The objective was to achieve the highest level of generation and storage for the energy and, at the same time, minimize costs and maintain the efficiency of the system.

Results

By 2030, Shanghai achieved the following outcomes:

- 2 GW of Rooftop Solar: Capacity of solar power helped improve the situation where India has to increasingly depend on power derived from coals.
- 1.5 GW of Battery Storage: Discharged unused solar energy for later use and consumer application in order to minimize reliance of on-grid supplies.
- 40% Reduction in Coal Dependence: Renewable energy also played a role in identification of low utilization of coal in the energy mix.
- Urban Microgrids: Microgrid localization provided energy reliability because it enabled localized portions of the city to function autonomously in the event of central grid power disruptions.

Table 2: Distributed Energy Impact in Shanghai

Technology	Capacity Deployed (GW)	Emissions Reduction (%)
Rooftop Solar	2.0	20
Battery Storage	1.5	15

4.4 Guangdong's Industrial Energy Optimization (2018-2028)

Problem Description
Guangdong is one of the industrial provinces of China and suffered highest energy intensity in manufacturing industries where energy losses were eroding manufacturing cost and output emission. These inefficiencies make it very difficult for the region to support industrialization as a means of reducing costs and emissions.
Proposed Methodologies
To address these issues, Guangdong implemented two key approaches:

1. Linear Programming for Retrofitting Optimization:
This research developed a linear programming optimization model for establishing an efficient schedule for retrofitting industrial plants. This, made it possible to identify the most efficient and cheap improvements to be made on every plant without interrupting the production often. The goal was to apply upgrades of equipment at such time and at those location which will yield most impact on energy efficiency and cost of investments.
2. Simulations for Energy-Intensive Processes:
Energy audits used in the study meant that simulations were used in the identification of the major energy use zones in the manufacturing plants. Having subjected various production situations to the model, some of the energy-saving opportunities by better technologies or improved operation were established. Using of such approach allowed to define specific areas in production to which high importance in terms of energy consumption was attributed and verify changes in energy intensity of these areas.
Results
By 2023, Guangdong achieved significant improvements:

● 18% Reduction in Energy Consumption: A 18% reduction in energy intensity of manufacturing was done with the help of technology enhancement in retrofitting of buildings and simplification of processes.
● 22% Reduction in Emissions: The advancements in energy efficiency that were encouraged were able to lower the outputs by 22% meaning that the harm done to the environment was minimized.

● $200 Million in Annual Savings: This manufactured cost effectiveness provide engulfs an once-a-year income of about $200 million for the industrial activities.

Table 4: Guangdong Industrial Optimization Outcomes

Metric	Pre-Retrofit	Post-Retrofit
Energy Consumption ()	120	98
Emissions (MT CO2)	300	234
Annual Savings ($M)	-	200

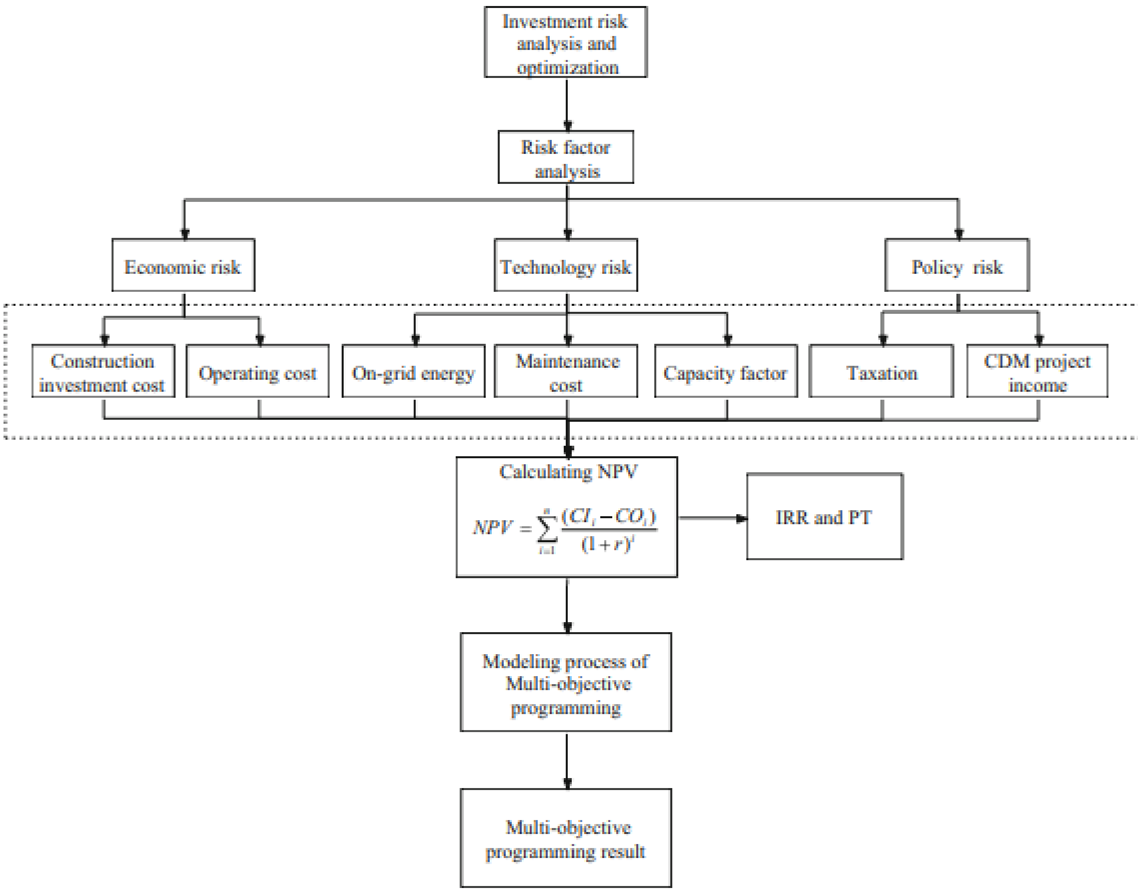
4.5 Sustainable Wind Power Investment in Western China (2018)

Problem Description:

Western China, especially Sichuan Province has abundant wind resources; however, risks associated with investment in wind power were substantially high because of the following reasons industrial inexperience, policy instability, and financial risks. The wind energy potential was evaluated in the range of level 2 and above and the capacity for wind generated electricity in the zone was to be 5660 MW by the end of year 2020. The move towards wind power was, however, capital intensive and called for risk analysis, probable cost and possible returns make the investment a viable business one.

Proposed Methodologies:

Investment Risk Evaluation: For the analysis of the investment risks and uncertainties in the course of the project, Monte Carlo Simulation was applied. This methodology helped to consider various uncertainties in the financial aspect of wind power project. Concerning the uncertainty of the key parameters an investment cost, capacity factor, and operational costs, triangular and normal probability distribution functions are employed. The objective was to assess the range of variability of quantitative financial performance indicators such as NPV, IRR, and PT under conditions of risk and uncertainty.



- **Net Present Value (NPV):** The NPV was calculated using the formula:

$$\mathrm{NPV} = \sum_{i=1}^{n} \frac{(CI_i - CO_i)}{(1+r)^i} = \sum_{i=1}^{n} \frac{\begin{pmatrix} CP_i + aG_i(P + S_i) + RV_i + RL_i - I_i \\ -LC_i - OC_i - ST_i - T_i - FVT_i \end{pmatrix}}{(1+r)^i}$$

This formula calculates the present value of all future cash flows, discounted by a rate rrr over the project's lifecycle.

- **Internal Rate of Return (IRR):** The IRR was calculated by solving for the discount rate that results in a net present value (NPV) equal to zero. The formula for IRR is derived

$$\mathrm{IRR} = r_1 + \frac{|\mathrm{NPV}(r_1)|}{|\mathrm{NPV}(r_1)| + |\mathrm{NPV}(r_2)|}(r_2 - r_1)$$

from:

The IRR represents the rate of return at which the present value of inflows equals the initial investment.

- **Payback Time (PT):** Payback time is the period required for the investment to be recovered. This is essential for understanding the liquidity and financial stability of the project in its early years.

$$\mathrm{PT} = i' - 1 + \frac{\sum_{i=1}^{n=i'-1} \mathrm{NPV}_i}{|\mathrm{NPV}_{i'}|}$$

Table 1 Basic data for the variables:

Variables	Distributions	Parameters
v_c, v_r, v_o	–	$v_c = 3, v_r = 9.5, v_o = 20$ (m/s)
Total installed capacity	–	1500 MW
Wind turbine capacity	–	1500 kw
Feed-in tariff	–	0.57 CNY/kWh
b	–	0.95
Liquid capital	–	4500
k, c	Weibull	$k = 1.4, c = 6.0$
Investment	Triangular	Minimum—1,218,135, mean—1,402,435, maximum—1,692,210
Equipment cost	Triangular	Minimum—1,037,528, mean—1,092,135, maximum—1,124,901
a	Triangular	Minimum—0.78, mean—0.87, maximum—0.96
Capacity factor	Triangular	Minimum—0.30, mean—0.34, maximum—0.38
Residual value of fixed assets	Triangular	Minimum—69,165, mean—72,809, maximum—74,993
Maintenance cost	Normal	Mean—465,780, variance—13,973
Annual total cost	Normal	Mean—132,200, variance—3966
Operation cost	Normal	Mean—38,091, variance—1143

Optimization:

The investment optimization was carried out using a Multi-Objective Programming (MOP) model. The objective was to optimize the financial outcomes by:

Table 2 Baseline emission factors for regional power grids in China, 2015 (tCO2/Mwh)

Regions	$EF_{\mathrm{OM},i}$	$EF_{\mathrm{BM},i}$
North China	1.0416	0.4780
Northeast China	1.1291	0.4315
East China	0.8112	0.5945
Central China	0.9515	0.3162
Northwest China	0.9457	0.3162
South China	0.8959	0.3648

- Maximizing NPV and IRR to ensure profitability.

$$\max \mathrm{NPV} = \sum_{i=0}^{n} \frac{(CI_i - CO_i)}{(1+r)^i}$$

- Minimizing Payback Time (PT) to reduce the time required for the investment to break even.

$$\min \mathrm{PT} = i' - 1 + \frac{\sum_{i=1}^{n=i'-1} \mathrm{NPV}_i}{|\mathrm{NPV}_{i'}|}$$

$$\max \mathrm{IRR} = r_1 + \frac{|\mathrm{NPV}(r_1)|}{|\mathrm{NPV}(r_1)|+|\mathrm{NPV}(r_2)|}(r_2 - r_1)$$

In addition to the financial optimization, various constraints were considered:

● Budget Limits: The expenditure had the predetermined resource limit that could not be overcomed, thus influencing the volume of capital disposable in the initial investments, and constant operating expenses.

● Operating Costs: These costs; maintenance and labor were analyzed to balance the acceptable range at any given time.

● Capacity Factors: The fact that each wind turbine generates electricity from wind was relevant, and limitations were imposed on the optimality of this factor.

● Grid-Connected Electricity Ratios: Other constraint includes the obligation to supply a given percentage of the electricity produced by the wind turbines to the grid.

Capacity Factor: Reaching the nameplate capacity of the wind turbines was one more important aspect, and the wind turbine's capacity factor (CF) was derived by using the Weibull distribution, which

$$C_F = \frac{\exp\left[-\left(\frac{v_c}{c}\right)^k\right] - \exp\left[-\left(\frac{v_r}{c}\right)^k\right]}{\left(\frac{v_r}{c}\right)^k - \left(\frac{v_c}{c}\right)^k} - \exp\left[-\left(\frac{v_0}{c}\right)^k\right]$$

defines the wind speed pattern of the region. The formula for the Weibull distribution is:

The CF was calculated to understand the efficiency of the turbines under varying wind conditions. This is important for determining the energy generation capacity and, subsequently, the project's financial viability.

Constraints:

The sustainable operating preferences constitute the MOP optimization model constraints First, the value of PT cannot be greater than a certain PT*; that is

$$0 \leq PT \leq PT*$$

$$IRR \geq r*$$

$$BL \leq T\ Ci \leq BU$$

$$CL \leq OCi \leq CU$$

$$CFL \leq CF \leq CFU$$

$$aL \leq a < 1$$

$$\begin{cases} Gi \leq A_{VEi} \\ aG_i \geq D_{Ei} \end{cases}$$

Results:

Table 3 Optimization results for the objectives

No.	Objectives	Results without CDM	Results with CDM
1	NPV	171,451.27	388,607.31
2	IRR	10%	12%
3	PT	16	13

Table 4 Optimization results for the risk factors

Factors	Results	Current value	Unit
a	0.96	0.87	–
C_F	0.374	0.34	–
I	1,218,135	1,402,435	Thousand CNY
C_e	1,037,528	1,092,135	Thousand CNY
TC	136,166	132,200	Thousand CNY
OC	36,948.27	38,091	Thousand CNY
MC	451,806.6	465,780	Thousand CNY

$$\max \mathrm{NPV} = \sum_{i=0}^{n} \frac{(CI_i - CO_i)}{(1+r)^i}$$

$$s.t. \begin{cases} \sum_{i=1}^{n} \frac{(CI_i - CO_i)}{(1+IRR)^i} \geq 0 \\ \sum_{i=1}^{n} \frac{(CI_i - CO_i)}{(1+r)^i} \geq 0 \\ \mathrm{B_L} \leq TC_i \leq \mathrm{B_U} \\ \mathrm{C_L} \leq OC_i \leq \mathrm{C_U} \\ \mathrm{C_{F_L}} \leq C_F \leq \mathrm{C_{F_U}} \\ a_\mathrm{L} \leq a < 1 \\ G_i \leq \mathrm{A_{VE\mathit{i}}} \\ aG_i \geq \mathrm{D_{E\mathit{i}}} \end{cases}$$

- **Scenario 1 (Without CDM Benefits):**
  - **Probability:** 10.16%
  - **Expected NPV:** −161,958 thousand CNY
  - This scenario indicated a high investment risk, with a low probability of positive financial returns. The high level of uncertainty and the absence of Clean Development Mechanism (CDM) benefits led to negative outcomes in terms of NPV.

Scenario 2 (With CDM Benefits):

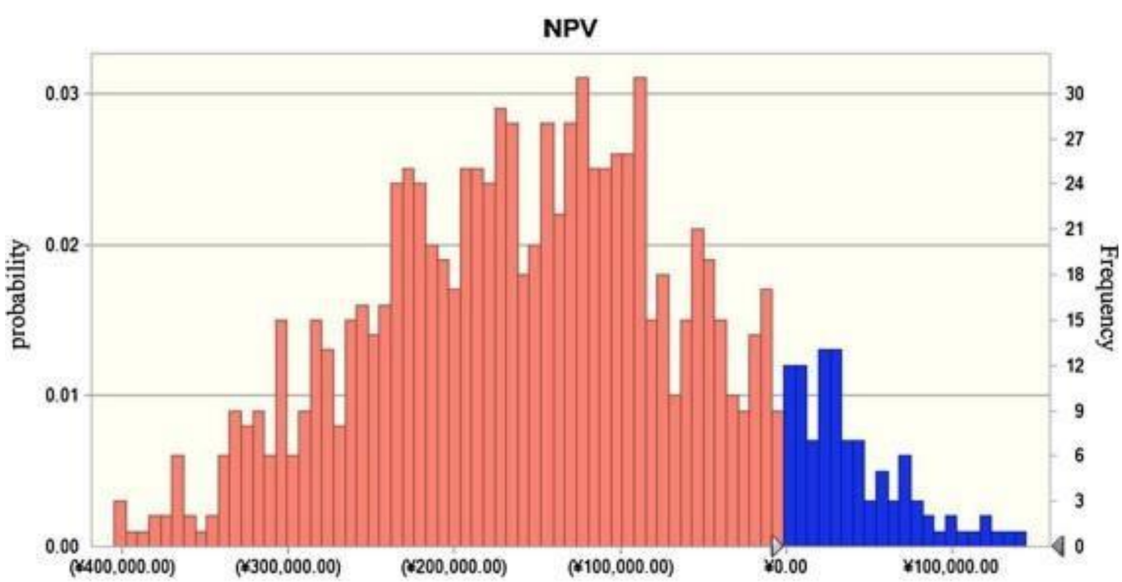
  - **Probability:** 68.95%
  - **Expected NPV:** 35,336 thousand CNY
  - The inclusion of CDM benefits significantly reduced the financial risk by enhancing the financial returns and making the project more viable. CDM incentives, such as carbon credits, played a crucial role in improving the project's financial outlook.

Table 5 Simulation based on the MOP optimization results

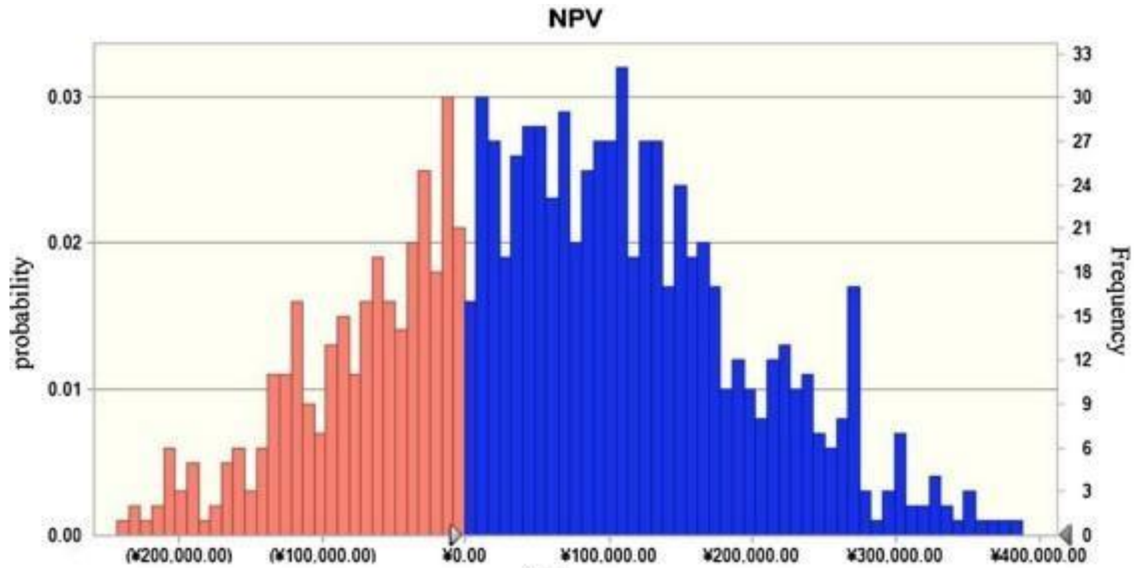
Probabilities	Without CDM benefits		With CDM benefits	
	Before optimization	After optimization	Before optimization	After optimization
$P(\text{NPV} \geq 0)$	10.16%	66.89%	68.95%	83.15%
$P(\text{PT} \leq 22\& \text{ IRR} \geq 8\%)$	10.24%	66.67%	68.23%	83.15%
$E(\text{NPV})$	− 161,958	29,916	35,336	71,812

Post-Optimization:

- NPV Increase: By applying the optimization to the case, the NPV was higher by 126% thus revealing that the multi-objective programming method enhance the overall financial position significantly.
- IRR Improvement: IRR moved to the second level of 12% from the previous IRR estimates showing that more amount invested returns more rate of return.
- Payback Time Reduction: The payback period was brought down to 13 years because of the best use of the resources available and the improvement in the operating expense ratio.
- Cost Optimization: Fixed expenses were controlled, and variable expenses by improving the operating and maintenance costs which led to improved financial performance.
- Capacity Factors Optimization: The capacity factors of the turbines were adjusted to the optimum level at which the turbines could generate the highest energy yields and good economic recovery.



(a)



(b)

When both the revenue and cost models and environmental limitations were improved it became possible to obtain less risky and more sustainable investments.

4.6 Regional Integrated Energy System (RIES) Optimization in the Electricity Market Environment (2023)

Problem Description:

The RIES co-ordinates multi-energy resources in a region enabling better energy utilization and minimal pollutive emissions. Nonetheless, the fluctuation of the load demand as well as prices of electricity, presents some of the challenges in minimizing the operation costs.

Proposed Methodologies:

Cost Structure Analysis:

As with all costs, RIES purchases electricity, gas, and heat; these have limitations between providers and consumers.Where, are costs for wholesale and retail electricity while are costs for heat and gas. However, the general formula for calculating a company's cost structure involves:

$$\text{Total Cost} = \text{Fixed Costs} + \text{Variable Costs}$$

Where:

There are costs that do not change with production irrespective of the level of production (Rent, Salaries).

- Variable Costs change with activity level, normally directly proportional to volume of production/sales (ingredients, employees' wages). fluctuate based on production or sales volume (e.g., raw materials, labor).

Severally, this structure assists in managing expenditure and setting of price levels that increase the profitability of a business.

- Optimization Using CVaR: Risk from uncertainties in electricity price and load were modelled using Conditional Value-at-Risk or CVaR. The optimization goal was to minimize cost contractions and risks and maximize opportunities and investment.

Conditional Value at Risk (CVaR) as an approach in financial and risk management is applied in order to minimise the maximum conditional expected loss. The formula for CVaR at a given confidence level α\alphaα is:

$$CVaR_{\alpha}(X) = \frac{1}{1-\alpha}\int_{-\infty}^{VaR_{\alpha}} x f(x)\, dx$$

VaRαVaR_{\alpha}VaRα – Value-at-Risk at the given level of confidence α\alphaα.●
f(x)f(x)f(✗) is the probability density function.k at confidence level α\alphaα.
f(x)f(x)f(x) is the probability density function.

Method:
The CVaR changesVaR's approach by calculating average loss over and above the VaR level which guarantees less risky maneuvers as compared to the basic VaR. This is helpful in avoiding worse consequences, thus it can be used in investment, portfolio, and uncertain projects.

1. **Scenario Analysis:** The cases created based on LHS assessed the results of benefits depending on the uncertainties in price and load.

Latin hypercube sampling or LHS is a technique that is utilized by theorists and modelers in their efforts to obtain a sample of the input from a given multidimensional distribution. It avails itself to ensure that all the extent and variety of each input variable is captured.
● The area of each input dimension is divided into N equal probable regions by drawing regional lines.
● Select one value randomly on each of the intervals chosen from each of the dimensions.
e level α\alphaα.

f(x)f(x)f(x) is the probability density function.

Method:
CVaR optimization focuses on minimizing tail risk by considering the average loss beyond the VaR threshold, ensuring a more robust risk management strategy. This helps in mitigating severe adverse outcomes, making it useful for managing investments, portfolios, and uncertain projects.

1. **Scenario Analysis**: Scenarios generated through Latin hypercube sampling evaluated outcomes under different price and load uncertainties.

Latin Hypercube Sampling (LHS) is a statistical method for generating a sample of plausible input values from a multidimensional distribution. It ensures that the entire range of each input variable is represented.

Formula:

- Divide each dimension of the input space into N equally probable intervals.
- Randomly select one value from each interval in each dimension.

Method:

1. Subdivide each of the range of the inputs into equal bin-width.
2. For each variable Randomly select one point from each interval.
3. Sum up the aforesaid points in regard to all the variables in order to create the sample.

Results:

Scheme 1: Namely, the fluctuation in electricity price and, thus reaching cost efficiency under high risk conditions.

Scheme 2: Addressed combined load and price variability that is, variability in load and price.● Identified ITC average cost-reduction opportunities amounted to 5% with some of the best risk mitigation in the high price range. probability density function.

Method:
CVaR optimization focuses on minimizing tail risk by considering the average loss beyond the VaR threshold, ensuring a more robust risk management strategy. This helps in mitigating severe adverse outcomes, making it useful for managing investments, portfolios, and uncertain projects.

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Formula:

- Divide each dimension of the input space into N equally probable intervals.
- Randomly select one value from each interval in each dimension.

Method:

1. Divide each input variable's range into equal intervals.
2. Randomly select one point from each interval for each variable.
3. Combine these points across all variables to form the sample.

Results:

Scheme 1: Focused on electricity price uncertainty, achieving cost reductions in high-risk scenarios.

Scheme 2: Addressed combined load and price uncertainties, improving robustness against variability. Average cost reductions reached 5%, with significant risk mitigation observed in high-price scenarios.

5. Comparative Analysis

Case Study	Problem Description	Methodologies Used	Key Results
Wuzhong District Transition to Net-Zero	Wuzhong District Transition to Net-Zero	Wuzhong District Transition to Net-Zero	Wuzhong District Transition to Net-Zero
Zhangjiakou Wind and Solar Integration	Zhangjiakou Wind and Solar Integration	Zhangjiakou Wind and Solar Integration	Zhangjiakou Wind and Solar Integration
Shanghai Distributed Energy Integration	Shanghai Distributed Energy Integration	Shanghai Distributed Energy Integration	Shanghai Distributed Energy Integration
Qinghai’s 100% Renewable Day	Qinghai’s 100% Renewable Day	Qinghai’s 100% Renewable Day	Qinghai’s 100% Renewable Day
Guangdong Industrial Optimization	Guangdong Industrial Optimization	Guangdong Industrial Optimization	Guangdong Industrial Optimization
Western Wind Power Investment	Western Wind Power Investment	Western Wind Power Investment	Western Wind Power Investment
Regional Integrated Energy System	Regional Integrated Energy System	Regional Integrated Energy System	Regional Integrated Energy System

Policy Adjustments for Energy Sustainability

Based on the Nature and Pattern of Human Impact on the Environment, The Following Policy Changes should be Made to Promote Energy Sustainability:

For one to emulate the successes of energy optimization, doing policy modifications is crucial,

Prospects: Some such measures include subsidization of storage technologies, introduction of cost-efficient carbon pricing policies to encourage sustainable methods, and integration incentives for grid development. All such adjustments are helpful in canvassing the building of a stronger and more effective energy sector.

Enhancing Technological Innovation

In an endeavour to build up the status of SEARCA in advancing technological innovation the following proposals are suggested:

In addressing long-term energy needs, the culture of technological innovation is a necessity. Both regional and national governments should thus ensure that current strategies promote sophisticated approaches to renewable energy. This may involve Research and Development on new technologies especially the future technologies fully supporting the commercialization of new technologies.

6. Conclusion

This work therefore demonstrates China's effective incorporation of OR methodologies to energy planning as a strong model for attaining sustainable energy goals. Since the launch of new mathematical models and decision-making approaches, China has made important savings and efficiencies in the management of energy resources as well as ensured energy security. The effectiveness of these strategies serves as a model of best practice for energy endeavours worldwide. These techniques can be applicable by policymakers all across the globe to improve efficiency, increase innovation, and sustain the system. As will be illustrated in this approach, pertinent modern data drives the future of energy planning and the implementation of needed measures in different territories.

7. References

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