SYSTEM MODELING FOR SECURITY AND SUSTAINABILITY IN INDIAN ENERGY SECTOR: SELECT ISSUES

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SYSTEM MODELING FOR SECURITY AND SUSTAINABILITY IN INDIAN ENERGY SECTOR: SELECT ISSUES

by

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सत्यमेव जयते

सत्यमेव जयते नानृतं	Truth alone triumphs; not falsehood.
सत्येन पन्था विततो देवयानः ।	Through truth the divine path is spread out
येनाक्रमन्त्यृषयो ह्याप्तकामा	by which the sages whose desires have been completely fulfilled,
यत्र तत् सत्यस्य परमं निधानम् ॥६॥	reach where that supreme treasure of Truth resides.

On very personal and heart touching note,

This Ph.D. dissertation is dedicated to my parents, Shri Genda Lal Soni and Smt. Ram Dulari Soni who have faith and admiration for whatever I did and took great pain to show their affections.

All elder sisters, especially younger loving sister, Arti Soni, who spent her childhood love in my absence at hometown, felt unsheltered, unprotected and unknowingly forced me every time to go back to this Institute to complete the research work. All persons of my family including my wife Mrs. Rashmi Anand, their strong mental support, encouragement, and constant love have sustained me throughout Ph.D programme and without their positive attitude, this Ph.D. work was impossible.

While on the professional fronts, both Indian energy and power sectors are felt as ocean of inspiration, need for their proper management have given many challenges to instigate for conduct of this study. I would like to thank to set aside this work for all the academicians, experts and the stakeholders.

"*But that's not enough: To maintain energy security, one needs a supply system that provides a buffer against shocks. It needs large, flexible markets. And it's important to acknowledge the fact that the entire energy supply chain needs to be protected*". Daniel Yergin

CERTIFICATE

This is to certify that the thesis entitled **“System Modeling for Security and Sustainability in Indian Energy Sector: Select Issues**” being submitted by **Mr. Vivek Soni** to the Department of Management Studies, Indian Institute of Technology Delhi for the award of the **Doctor of Philosophy** (Ph.D.) is a bonafide record of original work carried out by him. He has worked under our guidance and supervision and has fulfilled the requirements for the submission of the thesis, which has attained the requisite standard for a Ph.D. degree of the Institute. The research work and the results represented in this thesis have not been submitted to any other university or institute for the award of any Degree or Diploma.

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(**Vivek Soni**)

ABSTRACT

Energy security and sustainability in energy sector has become an essential supportive base for economy of almost all the nations including India. Meeting energy demand, and bridging gap between demand and supply through its planned capacity additions from various sources of energy, has become more critical and complex to provide adequate capacity infrastructure development in the country. Both side of energy security i.e. energy demand and energy supply need proper management where security ensures demand by effective fuel utilization, large scale capacity addition through execution of energy projects in the Indian energy sector. In the context of energy security, minimizing the gap between demand and supply side of issues is found as situation to deal with. After extensive literature review, the research study addresses the demand side issues using cointegration and causality analysis and is used to measure the sustainability in demand side. The analysis is addressing long term Causality between energy consumption and GDP. On applying co-integration test, it is found that two variables energy consumption and gross domestic product (GDP) are cointegrated of the order of one (i.e. $I\sim 1$). In Causality analysis (Johansen, 1988 and Klein, 1997), sustainability is shown to have a long run relationship between driving variables of energy demand (energy consumption *kWh*) with infrastructure development variable of GDP. Thereby, sustainability in the sector supports current deficit accounts of the country in a larger perspective.

Literature reviews show that there is need of optimal utilization of energy resources allocations. Effective decision making has become very important to prioritize capacity addition by various conventional sources like coal, gas, hydro, nuclear and non- conventional renewable energy. Each of these energy projects is very complex in nature and is becoming more multifaceted. Due to various reforms adopted in the energy sector where adverse situations of climate change phenomenon have been impacted by type of energy resources and environmental degradation linkages. Firstly, these projects are assessed based on a sustainable thinking approach of life cycle costing (LCC) (Dhillon, 1989). This cradle to grave approach of LCC gives decision makers, investors and policy makers not only a system level framework, but also opportunities to choosing sensitive variables for effective capacity addition. These variables impact each phase of life cycle of projects where all major cost components are converted in present value of the time. LCC provides system level holistic approach considering various costs which a decision maker can omit while performing decision analyses. The cost incurred against Renovation and Modernization (R&M) plan, (As per R&M Plan of CEA, Ministry of Power, Govt. of India, 2009) and costs incurred against measure for environmental protection (in lieu of EP Act, Govt. of India, 1986) are such investment components. It is found that LCC has been emerged as critical in analyses and has widely applications used in research for sustainable development.

Based on LCC analysis, comprehensive list of criteria influencing projects investment decision are identified and few of them have been considered for multi criteria decision making (MCDM) framework development. Few MCDM techniques such as AHP, ANP have been used in the

Indian context. In this research, contemporary MCDM techniques such as preference ranking organization method for enrichment (PROMETHEE) (Brans *et al.*, 1984) and with its hybrid applications with others MCDM approaches have been used. As noted, energy sector of the Indian economy is complex in nature and in order to deal with the subjectivity and to have more precise evolutions, the fuzzy set theory (FST) and fuzzy scale (Zadeh, 1977) are used. These are more specifically used for outranking the various energy projects and later compared with the energy options analysis of LCC. This study presents specific gaps between analyzing traditional approach of NPV versus LCC analysis identifying R&M, investment for environment protection etc. This comparison supports decision making as compared to the traditional approaches of project evaluation i.e. by using the net present value (NPV) concept. Myers (1984) pointed out that NPV modeling ignores the value of flexibility of real asset investment. Moreover, the study also considers investment decisions to add Coal based capacity addition based on Real Option Analysis (RoA) integrated with LCC financial modeling.

Issues such as preferences on alternatives or on the criteria of energy projects are often uncertain where investment decision becomes more difficult to assess correctly are dealt with application of grey system theory (GST) (Julong, 1982). The GST methodology is used to deal with uncertain information for investment purposes. In this research study, MCDM technique complex proportional assessment (COPRAS) is also used for comparison of energy project alternatives (Zavadskas *et al*., 1994) in the Indian energy sector. COPRAS method assumes direct and proportional dependence of significance and priority of alternatives on a system of criteria (Ustinovichius *et al.*, 2007). While based on PROMETHEE outranking method for assessment of various projects such as Coal, Solar based projects should be continued. But in the precise scenarios of comparison with GST based COPRAS method (i.e. COPRAS-G), capacity addition based on renewable must be given priority to help in become country as a strong emerging nation over crossing the GDP. In additional, energy efficiency is studied as part of energy security and it is felt as back bone of Standards and Labeling (S&L) Scheme which promotes star rated energy efficient appliances to reduce the overall energy consumption. The research work is also focused on measuring the effectiveness of the S&L Scheme identifying enablers and ranking of various check tests laboratories which are engaged in testing of various energy efficient equipments and appliances as per the Indian and ISO Standards. This part of work is assessed using Interpretive Structure Modeling (ISM) and Analytical Hierarchy Process (AHP) approaches. In the later part of the research work, Indian energy sector has been also enquired and analyzed using development of SAP-LAP (Sushil, 2001) model for presenting situation of energy security and considering issues of sustainability.

This Ph.D. thesis is an attempt to improve the functionality of both Indian energy and power sectors and also to support decision making on investments issues related to various capital intensive energy projects. Thereby, the results from research work can synergies with pro-actions of investors, policy makers towards the present need to consider sustainable practices and also to help in adoption of effective measures to improve efficiency of the sector and thereby, Indian economy at large.

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ABBREVIATIONS

ADF	Augmented Dickey Fuller
AERB	Atomic Energy Regulatory Board
AHP	Analytical Hierarchy Process
ANP	Analytical Network Process
BARC	Bhabha Atomic Research Centre
BEE	Bureau of Energy Efficiency
CEA	Central Electricity Authority
CERC	Central Electricity Regulatory Commission
CIM	Cross Interaction Matrix
COPRAS	Complex PRroportional Assessment
COPRAS-G	Grey Set Theory Based COPRAS
CPRI	Central Power Research Institute
CV	Calorific Value
DAE	Department of Atomic Energy, GOI
DCF	Discounted Cash Flow
EATWOS	Efficiency Analysis Technique with Output Satisfying
EE	Energy Efficiency
ELECTRE	ELimination and Choice Expressing Reality
F-AHP	Fuzzy Analytical Hierarchy Process
FDI	Foreign Direct Investment
F-PROMETHEE	Fuzzy PROMTEHEE
F-TISM	Fuzzy TISM
FY	Financial Year
GAIA	Graphical Analysis for Interactive Aid
GDM	Grey Decision Making
GDP	Gross Domestic Product
GHG	Green House Gases
GNP	Gross National Products
GOI	Government of India
GST	Grey System Theory
IEA	International Energy Agency
IEA	International Energy Agency
ISM	Interpretive Structural Modeling
LAP	Learning- Suggested Actions and Performance
LCC	Life Cycle Costing

LCM	Life Cycle Management
MCDM	Multicriteria Decision Making
MNRE	Ministry of New and Renewable Energy, GOI
MoC	Ministry of Coal, GOI
MoP	Ministry of Power, GOI
MoP	Ministry of Coal, GOI
MoPNG	Ministry of Petroleum and Natural Gas, GOI
MTOE	Million Tonnes of Oil Equivalent
MW	Megawatt
NCF	Net Cash Flow
NITI Aayog	National Institution for Transforming India, GOI
NPTI	National Power Training Institute
NPV	Net Present Value
O&M Cost	Operations and Maintenance Cost
OPEC	Organization of Petroleum Exporting Countries
PAT	Perform Achieve and Trade
PEST	Political, Economic, Social and Technological Factors
PP	Phillips Perron
PROMETHEE	Preference Ranking Organization METHod for Enrichment Evaluation
R&M Cost	Renovation and Modernization Cost
SAP	Situation, Actor and Process
SEB	State Electricity Boards
SIM	Self Interaction Matrices
SWOT	Strengths, Weaknesses, Opportunities and Threats
TFN	Triangular Fuzzy Number
TISM	Total Interpretive Structural Modeling
TISM	Total Interpretive Structural Modeling
TISM	Total Interpretive Structural Modeling
UN	United Nations
YoY	Year on Year

TECHNICAL ABBREVIATIONS

AT&C	Aggregate Technical & Commercial Losses
CC	Cooling Capacity
CEC	Comparative Energy Consumption
DC	Designated Consumers
EC	Energy Consumption
EE	Energy Efficiency
EER	Energy Efficiency Ratio (W/W)
EI	Energy Intensity
HVAC	Heating Ventilation & Air Conditioning Systems
J	Joules
kWh	Kilo Watt Hours
L	Litres
MT	Metric Tonnes
MTOE	Million Tonnes of Oil Equivalent
MW	Mega Watt
R&M	Renovation and Modernization
SHR	Station Heat Rate
TR	Tons of Refrigeration
VAR	Vector Auto-Regression
VECM	Vector Error Correction Model
W	Watts

UNIT OF MEASUREMENT

1 Lac	=	100 Thousand
10 Lac	=	1 Million
1 Crore	=	10 Million
100 Crore	=	1 Billion
1000 Crore	=	10 Billion
1 Percent	=	100 Basis Points
1kWh	=	3600 kilojoules