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INDEPENDENT POWER PRODUCERS' EFFICIENCY PERFORMANCE USING FUZZY DATA ENVELOPMENT ANALYSIS (FDEA) MODEL

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Abstract:
The purpose of this study is to evaluate and investigate the efficiency performance of nine (9) selected Independent Power Producer (IPP) firms using the Fuzzy Data Envelopment Analysis (FDEA) Model. The data were drawn from a database of 7 panel firms in the Luzon Area, Philippines, over the period 2000-2006. The efficiency performance evaluations were done first from 63 pooled panel data prior to cross-sectional analysis in three stages (**CVSTE 1, UCVRSTE 2** and **UCVRSTE 3**). The input controllable variables were (X1) Total Number of Employees, (X2) Depreciation, input uncontrollable variable (X3) ISO Certification. The output controllable variables were (Y1) Total Operating Revenue, (Y2) Total MWH- Sales, output uncontrollable variable (Y3) Age of Technology. Empirically, this study suggested that: (1) ISO Certification and Age of Technology entry into the IPP firm study implies enhanced fuzzification, thus connoting the possible loss of precision; (2) Input and output orientation via UCVRSTE (Stages 2 & 3) manifests deficiencies through *inappropriate use of scale transformation*; (3) slacks occurrence exhibited in three stages implies *mismanagement of variable alternatives*; (4) an average of 1.33 percent yearly for ISO Certification compliance is required for the IPP's relative technical efficiency and continuous deterrence yields *non-compliance of quality standards;* (5) average reduction of 1.22 percent yearly for refurbishment of old technologies is tantamount to an IPP firms' efficient score, otherwise, non-adherence

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means *disregard of technology rehabilitation and upgrading*. This study provides the theoretical, comparative empirical models, and robust evidence of how the **DEA-CVRSTE** Model (Stage 1) justified the enhanced discriminating power of **FDEA-UCVRSTE** (Stage 2) Model. The methodology tackles handling information that contains controllable (precise, exact) and uncontrollable (imprecise, uncertain, missing, unclear, vague, fuzzy) values. Hence, this study is an aid for strategic multi-criteria decision making and risk management.

Keywords: Fuzzy DEA; correlation; slacks; technical efficiency performance; Independent Power Producer Industry

1. Introduction

The majority of the countries around the world have signified their solidarity to coalesce for global economic growth and development through the important contribution of the power and energy sector, specifically electricity implementation and readiness (Mallillin *et al.*, 2020). It is indisputable that electricity contributes to development, being a prime necessity for modern living (Vivoda, 2025). Electricity speeds up numerous trade projects and technologies for the countless sectors of society, synergizing globalization during this technological era. One of the distinguishing factors of the power and energy sector is its efficiency performance through the generation of electricity service to distribution utilities like the regional electric cooperatives (Farr *et al.*, 2025). The study of the efficiency performance has been recognized worldwide in various industries, not only dealing with investigation or assessment on non-parametric models focusing on traditional frontier analysis but also those research works narrowing with ambiguities, uncertainties or randomness alone (Mallillin *et al.*, 2020). This particular study found its niche on the significant gap of recent studies that rely on known data via the traditional Data Envelopment Analysis, and it explored deeper into a combination of imprecision, randomness, uncertainties variables, which we were anticipating based on the citations below citations that it could affect/ break through the core of the system (Ackenhusen, *et al.* 2025).

In the Philippines scenario, a study of regional electric cooperatives shows that the government has launched multiple electricity generation services around the country by setting up electric power and operating the generation plant facilities, but with limited coverage. During the Ramos Administration, a power and energy crisis was responded to by expanding the generation and transmission by the government- owned National Power Corporation (NPC), also by assigning demand loads to independent power producers (IPPs), the National Transmission Company (TransCo), and Various distribution utilities (electric cooperatives). The NPC has full autonomy over the mentioned power producers via the regulating EPIRA 9136 law. But apart from exercising its regulatory role, the government encouraged private industry participants to join in the continuous electric power industry restructuring and privatization program.

The government, however, did not rest on its laurels, as it continuously implement cohesive and effective electric power program in the country (Invest, 2025). During the early 1989, the Philippine Government offered portfolios to IPPs through various arrangements such as the Build-On-Operate (BOT), Build- Transfer Operate (BTO), Build-Rehabilitate-Maintain (ROM) and Rehabilitate-Operate-Transfer (ROT) in the case of the old facilities of NPC (Wang *et al.*, 2025).

The IPPs serve strategic areas. Their performance and generation system are under the supervision, control, policy direction and coordination of the Power Sector Assets and Liabilities Management Corporation (PSALM), an agency under the Department of Energy (DOE). Since June 8, 2001, PSALM corporation has been responsible for the formulation and implementation of a program for the sale and privatization of the NPC assets and IPP contracts and the electric power industry reforms acts (EPIRA), policies and regulations as mandated by Republic Act No. 9136 under a power restructuring scheme program (Gao *et al.*, 2025). This program calls for the separation of the industry into generation, transmission, distribution and supply sectors nationwide. As a private sector in a strategic area coverage, independent power producers are for profit or stock entity, with the purpose of raising money to finance itself, managing its business, distributing its revenue to those who have contributed to its activity and sustaining operations for effective electricity generation to distribution utilities and to various clientele (Ahmed, *et al.* 2025, pp. 5323-5351).

Based on empirical factual knowledge of electricity generation/ production service, the World Bank evaluated the IPP firms' efficiency performance as well as its generation system. Results of the evaluation reflected inefficiency and substantial losses of a minimum of 18-22 percent in 1989. This would eventually double by the end of the century, at the range of 44-50 percent in 1989. This represented an astounding approximation at a minimum of $ 30 billion to a high of $60-70 billion over a decade. All in all, the efficiency performance of most IPPs was below standard, and their generation service reliability was low (Hamilton-Tshangela, 2025).

In line with this report on IPPs' inefficient performance, this paper attempts to investigate and verify the recent efficiency performance of IPPs in strategic locations in Luzon, Philippines. This present investigation will attempt to apply the modern and up-to-date multi- dimensional approaches to efficiency evaluation by employing the conventional Non-Fuzzy Data Envelopment Analysis (DEA) and unconventional Fuzzy Envelopment (FDEA) Model (Kannan *et al.*, 2024, p.55).

1.1 Statement of the Problem

In spite of the plant classification and their aggregate performance over the test period for previous studies conducted for IPPs, there have been a handful of issues concerning the inefficiency performance of various independent power producers (IPPs), especially those located in Luzon geographical areas in the Philippines.

As it was and where it had been observed and evaluated in the local setting, these independent power producers could have exhibited the same characteristic, whether operating in different geographical areas outside the Philippine Territory or outside of the country. Primarily, the uncertainties and issues it possesses could be addressed and rectified with proper resolutions. In these contexts, it needs to pursue the evaluations for these IPPs if slackness in terms of controllable and uncontrollable variables could affect the inefficient performance of the cited existing plants. Objectively, this study introduces the conventional and non-conventional/ non-parametric method of analyzing the efficiency performance of various IPPs as DMUs through the use of the Fuzzy Data Envelopment Analysis Model and helps accommodate, layer by layer, through cross-sectional analysis of controllable/uncontrollable variables under stages 1, 2 & 3 methodology out of the 63 pooled panel data.

Even though, these studies had seen the significant gap in the research previously conducted merely for Luzon Area IPPs. It would purposely find its initiatives that these studies would somehow be a connecting link and validate the correlation for other IPPs strategically & geographically operated in Visayas and Mindanao Areas, despite its robust restructuring of the electric industries and constraints issues on the deregulation made by the ERC, which has affected the economic policy, especially in the Philippines business ecosystem landscape.

1.2 Hypotheses

1) There is no proof of total efficiency performance on Independent Power Producers (IPPs) as to their classification of plant and their aggregate performance over the test period.
2) There are no controllable or uncontrollable variables (in terms of slack) that can affect the technical efficiency of this independent power producers' industry using Fuzzy DEA.
3) There is no significant correlation on total technical efficiency performance of industries using Non-Fuzzy DEA and Fuzzy DEA Models.

2. Theoretical Framework

The theoretical framework for this study consists of theories relating to the measurement of fuzzy sets, technical performance, efficiency, and production function. The brief descriptions of these theories are as follows:

2.1 The Concept of Fuzzy Sets

The foundation of these sets basically started through understanding the common function of conventional crisp sets and how they are related to fuzzy sets. Conventional, crisp sets allow only two mutually exclusive states: membership and non-membership functions. It identifies crisp sets which could establish distinctions for an issue that is wholly qualitative in nature. Whereas fuzzy sets refer to a group or team which is a conventional (or "crisp") set that is divided into two parts. Fuzzy sets specifically extend crisp sets by permitting membership scores in the interval between 0 and 1. This gives an idea behind fuzzy sets to permit the scaling of membership scores and thus, allow partial or fuzzy membership (Nwokoro & Ejegwa, 2025, pp. 145-164).

2.2 Types of Fuzzy Sets

The type of fuzzy sets indicates objects that are neither in nor fully out of the set. *Five-value fuzzy set* will use what is known as a "crossover point" (a fuzzy membership score of 0.5) to separate cases that are "more in" from those that are "more out." It also distinguishes between cases that are "mostly in" versus "fully in" and between cases that are more "Mostly out" versus "fully out". This *Seven-Value Fuzzy Set* utilizes two qualitative states ("fully out" and "fully in") and the 0.5 crossover point. However, the *Seven-Value Fuzzy Set* inserts two more intermediate levels between "full out" and the crossover point ("mostly out" and "more or less out") and two intermediate levels between the crossover point and "fully in" ("more or less in" and "mostly in"). Finally, *"Continuous" Fuzzy Set* permits cases to take values anywhere in the interval from 0 to 1(inclusive), as shown in Table 3.5. The *Continuous Fuzzy Set*, like all fuzzy sets, utilises the two qualitative states (fully out and fully in), and it also uses the crossover point to distinguish between cases that are more out from those that are more in (Fujita & Smarandache, 2025).

2.3 Operation of Fuzzy Set

In evaluating the problem, any researcher or scholar needs to have a general view of the issue or case, then trim it down for analysis. A theoretical or empirical analysis would need a set of operations prior to going to detailed processes. In dealing with uncontrollable variables, imprecise or fuzzy sets, it should be determined primarily and considered during the decision-making cycle. This condition normally creates some effects if not complied with fully. It is believed to reduce the efficiency of the decision-making unit (DMU) or increase its efficiency performance when applied properly. Their imprecision or being an uncontrollable state could be resolved by using an appropriate fuzzy set operation approach (Gul & Sarfraz, 2025, pp. 126-146).

2.4 Production Efficiency Theory

In any form of organization, production is a factor which plays a pivotal role in technology by helping the company produce the required products. Usually, it molds the company's reputation and takes it to the next level of efficiency and productivity. Progress manifestation would be the transformation of a firm's sufficient level of input, such as raw materials, labor and capital, in order to produce the required outputs, as this will help define the production function. *Production function* is defined as a technical relationship between the "best" and optimal output from every set of inputs. Production function requires how much outputs are produced from a combination of inputs, e.i labor and land. In other words, the production function is how an organisation chooses the lowest cost combination of inputs for a given technology. Efficiency, then, is a summary of the functional relationship between maximum quantities of output produced which form a given combination of inputs (Wahyuanto, 2025, pp. 211-219).

3. Conceptual Framework

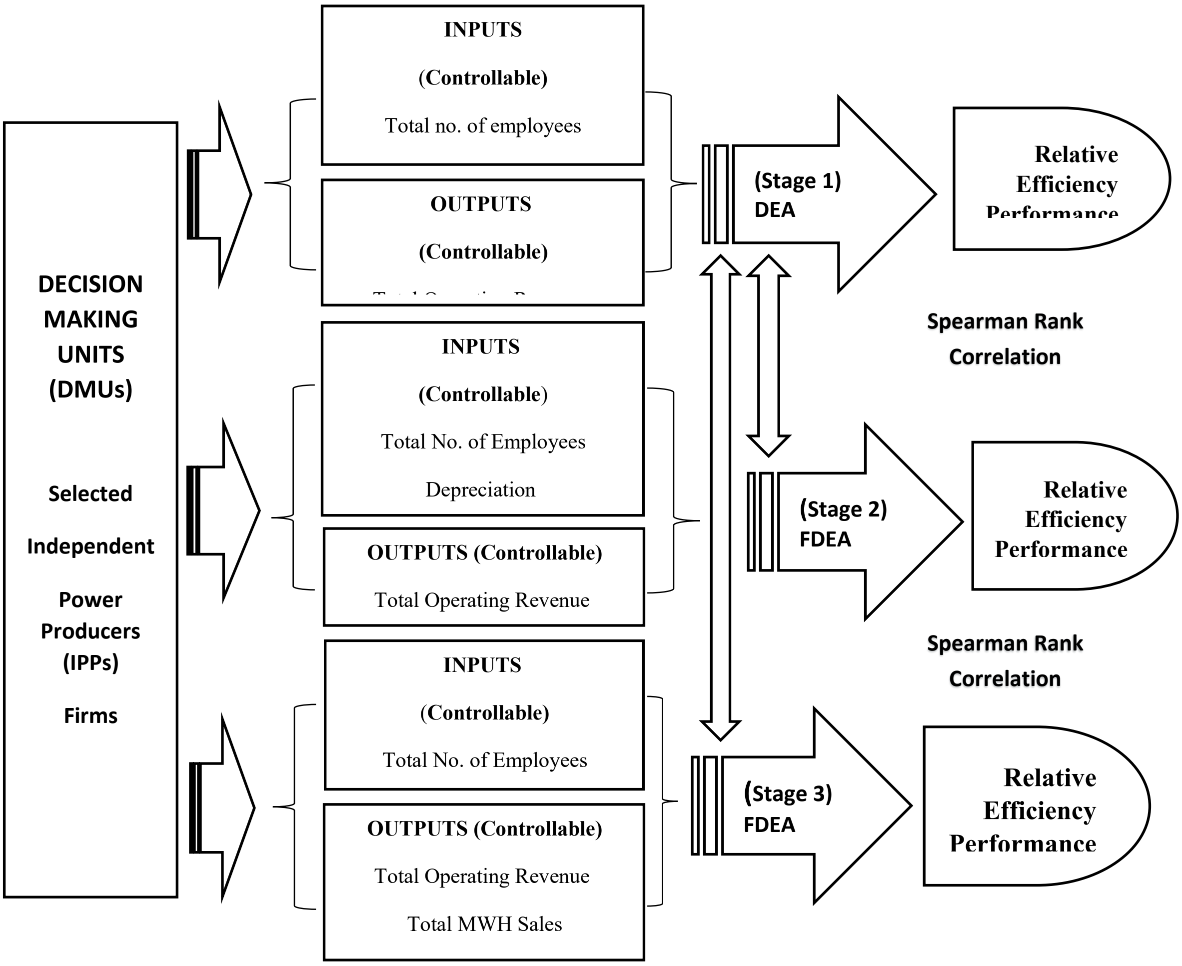

Figure 1: Conceptual Framework Model

The efficiency performance evaluation of the business's operation of selected IPPs is measured using the three-stage DEA approaches through the input-oriented DEA Model under the VRS assumption for the cross-sectional analyses of 9 pooled data from the DMUs. The DMUs are represented by the selected 9 IPPs, which are in existing operation and geographically located in the Luzon area. Collectively, they are the former NPC Generating Plants, which were awarded by PSALM Corporation to IPPs at the agreed contract offer (refer to Chapter 1, Section 1.1 elaboration). This study covers the period of 2000 to 2006 and was analysed by adopting the conventional DEA and unconventional FDEA Methods, which deal with controllable and uncontrollable variables (Ahmed, 2023).

Methodology shows the detailed analysis of the results regarding the efficiency scores performance of the 9 selected IPPs, which are subjected in this study.

Subsequently, Methodology, Results and Discussions depict the relative efficiency or inefficiency of these IPPs on an industry- and year-by-year basis. Furthermore, these relationships with controllable and uncontrollable variables are thoroughly scrutinized as per the results gathered and tabulated. This brings us to the discussion of the input-uncontrollable variables can affect other controllable variables in terms of scales and slack variation; likewise, with the output, uncontrollable variables are influential factors with controllable variables to the output performance results. This is the effect pointed out by the uncontrollable input variable represented by the ISO Certification operation in each firm/industry mentioned. IPPs should be able to comply with the requirements of this ISO; if not, then their efficiency performance also deteriorates (Sun *et al.*, 2025).

Moreover, when the particular plant has been certified by ISO a year later, it means that the remaining 8 DMUs could probably show better results than the former stage. A probability that it is not an assurance that a number of them have been constructed in different years, and the application of ISO certification is also different. Consequently, it does affect the controllable inputs given, which eventually will become part of a systematic and standardized system where quality is a top priority. A continuous application of input probably can increase an efficient rate in proportion to the controlled output, similar to stage 2 application; whereas, the stage 3 uncontrollable variable emphasized on technology application could bring a favorable factor if technology is upgraded regularly. Input-controlled variables, in fact, can probably decrease the effort applied by just reducing the number of employees assigned to a particular plant location and then transferring some of them to areas lacking in manpower supply in order to get the expected performance level. This clearly illustrates stage 3 operation while stage 1 shows the normal level efficiency performance since uncontrolled input and uncontrolled output do not apply to these considerations (Tsolas, 2023).

4. Methodology

This approach discussed the overall purpose of how the research is conducted. This includes the research design where models imply the variable used (exact, imprecise values) and the sources of data. This design conveys the method used and period covered by this study. The data and variables show the approaches used for the analysis where anSN: MP2R86H7, PN: 83JC00GEPH, BIOS: PQCN24WWd, and how the data are collected. The research models illustrate the Data Envelopment Analysis (DEA) Input Oriented Model and the Fuzzy Sets Theory Fusion in evaluating the efficiency performance of selected IPP firms.

A. Up-to-date Multidimensional Approaches

1. Conventional Non-Fuzzy DEA

a. DEA-Stage 1 (CVRSTE)

DEA conventional or traditional type is a common non-parametric linear programming-based technique that converts multiple input and output measures into a single comprehensive measure of productivity efficiency. This model provides a performance-based measurement of one DMU in relation to other firms. It describes his concepts using a simple example involving firms, which use two inputs (x_1 and x_2) to produce a single output (y), under the assumption of constant returns to scale (CRS). Understanding of the unit isoquant of the fully efficient firm represented by curve SS" in Figure 3.1 permits the calibration of technical efficiency. If a given IPP uses quantities of inputs, it is defined by the point P, to produce a unit of output, the technical inefficiency of that firm is presented by the distance *QP*, which is the amount by which all input is proportionally reduced without a reduction in output. This is commonly expressed as the ratio QP/OP, which represents the percentage by which all inputs could feasibly be reduced (Mo & Zeng, 2025). The technical efficiency (*TE)* of a firm is most commonly measured by a ratio:

$TE = OQ/OP$

Which is equal to one minus *QP/OP.* This takes a value between zero and one, henceforth, provides a sign for the degree of technical efficiency of the firm. The value of one illustrates that the firm (*IPP)* is fully technically efficient. As a sample, point *Q* is technically efficient because it lies on the efficient isoquant.

$AE = OR/OQ$

Since the distance *RQ* represents the reduction in production cost which occurs if production is occurring at the allocative efficient point *Q'*, instead of at the technically efficient, but allocative inefficient, point *Q*. The total economic efficiency (EE) is defined as the ratio

$EE = OR/OP$

It shows where the distance *RP* is interpreted in terms of a cost reduction. It shows the product of technical and allocative efficiency that provides the overall economic efficiency as:

$TE \times AE = (OQ/OP) \times (OR/OQ) = OR/OP = EE$

Furthermore, the DEA (Input–Orientated) model is where a sequence of radial Linear Programming is conducted to identify the efficient projected point. The benefits of using this model are that it is able to determine efficient projected points which have input and output mixes which are similar to those of the inefficient points and are also invariant to units of measurement. Importantly, this model involves slack that can be taken as allocative inefficiency or input excess. Therefore, the model is able to report the Farrell measure of technical efficiency and any non-zero input and output slacks to provide an accurate illustration of the technical efficiency of a DMU.

2. Input and Output Slacks

Slacks would mean input excess, or there is surplus use of input resources. These input slacks occur in DEA analysis when the projection of an efficient plane occurs in such a manner that the further reduction of one or more inputs is feasible.

Output slacks on the other hand mean a surplus or excess of output resources. It shows that its output variables' equivalent percentage or quantity exhibited has a need to "catch up" in order to reach the best practice frontier (efficiency level), a need to improve or strengthen the output resources just to reduce the output slacks and arrive at the efficiency level (Kyshakevych *et al.*, 2025, pp. 46-73).

B. Up-to-date Multidimensional Approaches

1. Unconventional Non – Fuzzy DEA

a. FDEA-Stage 2 (UCVRSTE)

Data Envelopment Analysis Model (Conventional Type)

DEA conventional or traditional type is a common non-parametric linear programming-based technique which converts multiple input and output measures into a single comprehensive measure of productivity efficiency. This model provides a measure which one firm can have vivid comparison with itself against the other firms relatively on the performance base (Luhaniwal *et al*., 2025, p. 838).

2. Fuzzy Sets Theory Operation

2.1 Fuzzy Sets

Fuzzy Sets refer to a group that is a conventional (or "crisp") set which is dichotomized. These sets extend crisp sets by permitting membership scores in the interval between 0 and 1. The basic idea behind fuzzy sets is to permit the scaling of membership scores and, henceforth, allow partial or fuzzy membership. Fuzzy Set is much more than the transformation of a binary variable into a continuous variable due to the reason that it is much more infused with theoretical and substantive knowledge. Meaning, the set does not stop into something else but rather goes into a continuous form; one of its functions has been calibrating the degree of membership (Fujita & Smarandache, 2025).

2.2 Fuzzy Membership Measurement/Assessment

Fuzzy membership scores indicate the degree to which relevant cases belong to the sets that scholars use to describe and analyze. The strength of fuzzy-set analysis stems from the close relationship with the corresponding content and theoretical concepts on one hand, and the assessment of fuzzy membership scores on the other hand. It is important to view the measurement of fuzzy membership as neither a fundamentally interpretive act nor a merely mechanical exercise:

1) Specify the relevant domain of the assessment.
2) Define the fuzzy sets that follow from the concepts guiding the investigation.
3) Determine the type of fuzzy set that is feasible for each concept.
4) Determine the likely range of membership scores.
5) Identify empirical evidence that is appropriate for indexing fuzzy membership scores.

2.3 Variable Alterations (Ordinal and Fuzzy Data Rank Modeling)

The data that could be handled easily by means of transforming the linear programming equivalent two (2) stages process. These by means of manipulating or altering the variable, then subjecting it to the required transformation operation. Alteration of variable would be assigning or converting three exact data to ordinal; ordinal data to bounded data, or vice versa. This current study involved a lot of conversion operations from ordinal data to fuzzy set values. This would entail the manipulation of ordinal data to fuzzy data rank modelling (Kong *et al.*, 2025).

The study discusses a portion of problems and applications of ordinal data ranking and the issue of applicability in the DMU performance measurement. Ordinal data naturally deals with input/output data; this is going to be done through assigning a specific designation. When it comes to management competence assessment examples, certainly, the information available is sufficient to put each DMU into L categories or groups (i.e., "high"," medium", and "Low" competence). Likewise, by considering such factor, it could provide a complete rank ordering of the DMUs. This is done through assigning a 5-point scale commonly applied when a particular project is rated for its development status, which could be given importance. These alternative evaluations in terms of qualitative data are often accompanied by interpretations such as: 1 = Extremely important; 2 = Very important; 3 = Important; 4 = Low in importance; 5 = Not important, which could be easily understood by management. Similarly, this principle described earlier has the same application and interpretation as fuzzy set theory regarding its input and output data fuzzy membership operations (Dadmand & Yaghoubi, 2025).

2.4 Scale Transformation (Fuzzy Efficiency Measurement)

The scale transformation via fuzzy efficiency measurement used an algorithm that requires a set of special computational codes for each evaluation. These are due to different objective functions and constraints, with a new set of variables for each unit under evaluation. In the case where all factors are quantitative, such as stage 1 operations for controllable inputs and outputs data, the conventional radial projection model for measuring DMU efficiency is expressed as the ratio of weighted outputs to weighted inputs (Miliauskaitė & Kalibatiene, 2025, pp. 589-624).

2.5 Comparative Strengths, weaknesses and Limitations of the DEA & FDEA Model

Table 1: Definition, Strengths, Weaknesses, and Limitations of the DEA & FDEA Model

1.1 Model Definition and Strengths				
	DEA	**Reference**	**FDEA**	**Reference**
Definition	Data Envelopment Analysis is a linear programming-based technique from measuring the performance efficiency of organizational units which are termed Decision-Making Units (DMUs), wherein, it uses the resources available to generated a set of outputs.	Charnes *et al.* (1978)	An advanced non parametric linear programming model use in measuring or determining efficiency frontier for peer decision-making units and also, for benchmarking purposes. It characterizes to adapt multi stages variables such as controllable and uncontrollable input/output and under a fuzzy environment.	Nadhila *et al.* (2025); Cooper *et al.* (1994)
Strengths	DEA can handle efficiency, productivity, performance assessment and benchmarking of peers DMUs under VRS and CRS, input/ output or multi-stage orientation.	Charnes and Cooper (1984)	FDEA can handle efficiency, productivity performance assessment and benchmarking of peer DMUs under VRS and CRS, input/output or multi-stage orientation with ordinal and imprecise values consideration.	Xu *et al.* (2020); Cook and Zhu (2005)
	DEA provides efficiency ratings based on numerical data, and not by using subjective opinion of people.	Ramanathan (2003)	It can handle triangular fuzzy membership numbers (0,0,0.30), (0,0.25,0.5), (0,2.5,0.5), (0,0.25,0.5), (0.3,0.5,0.7), (0.5,0.75,1)	Efstathio and Rajkovic (1979), Chen *et al.* (1992)
	DEA can handle multiple input and multiple outputs, and they can be measured in very different units.	Ramanathan (2003)	Project performance model predictions where fuzzy time series and data envelopment analysis was used for the assessment matrix. Using Fuzzy DEA -considering Undesirable outputs with ideal points.	Ebrahimnejad & Amani (2021); Salari *et al.* (2016); Gou and Tanaka (2001)
	DEA is non-parametric in the sense that it does not need an assumption of a functional form relating inputs to outputs, which differs from statistical methods of performance analysis.	Ramanathan (2003)	Uses the concept of linear programming to fuzzify the objective function and the constraints of CCR model under the condition of imprecise data.	Sengupta (1992)
	DEA has linkages with MCDM, as a tool for multi-criteria decision making.	Stewart (1996); Agrell and Tind (1998); Belton and Stewart (1999).	As a decision-making tool, FDEA is extended its MCDM criterion through the use of fuzzy multiple objective programming, Analytic Hierarchy Process (AHP) and among others.	Hsiang-Yu and Kuei-Hu (2022); Yu *et al.* (2004)

	DEA can handle efficiency, productivity, performance assessment and benchmarking of peers DMUs under VRS and CRS, input /output or multi-stage orientation.	Charnes and Cooper (1984)	FDE can handle efficiency, productivity performance assessment and benchmarking of peer DMUs under VRS and CRS, input/output or multi-stage orientation with ordinal and imprecise values consideration.	Cook and Zhu (2005); Kim *et al.* (1999); Cook *et al.* (1993); Cooper *et al.* (1999).
	It can handle crisp data 0 and 1.	Charnes, Cooper and Seiford (1978)	It can handle continuous values within 0 and 1, like 0.25; 0.50; 0.75).	Zadeh (1965)

1.2 Model Weaknesses				
	DEA	**Reference**	**FDEA**	**Reference**
Weaknesses	DEA efficiencies are very sensitive to even small errors, making sensitivity analysis an important component of the post-DEA procedure. Errors in measurement can cause a significant problem.	Ramanathan (2003)	With the development of the FDEA Methodology, one can obtain valuable insight into the DMUs efficiencies if exact values are not known. Since this fuzzy model provide only best- and worst-case analysis, it does not assume that.	Goksen *et al.* (2015); Kao and Liu (2005); Liu (2008).
	It weakens when one or more inputs/ outputs are missing. Its methodology has no flexibility to allow for one or more or nil outputs or inputs for performance evaluation.	Ramanathan (2003)	Fuzzy Set Theory allows "Principle of Incompatibility" application eliciting ability on arriving decisions based on qualitative data & Linguistic information.	Sengupta (1992)
	The values of weights of inputs and outputs are chosen (by the methodology) as the optimal value of a linear program for each DMU, wherein it weakens DEA on a way in which efficiencies are calculated.	Ramanathan (2003)	For modeling the uncertainty in weight, bounds values, fuzzy set theory introduction as a replacement of crisp values on weight bounds representation with fuzzy numbers justified the process requirements. Unrealistic…	Yuan and Khim (1995)
	In conventional LP, the decision variables are non-negative; they can be either zero or positive, it reinforces through using weights multiplier in the DEA programs to be strictly positive. Thus, it cannot handle negative constraints.	Charnes *et al*. (1979)	Fuzzy Set Theory lends itself to incorporating LP Models. A few adjustments in incorporating conditions of uncertainty into the methods of fuzzy mathematical programming.	Sengupta (1992)

1.3 Model Definition and Strengths			
DEA	**Reference**	**FDEA**	**Reference**
DEA is non-parametric in the sense that it does not need an assumption of a functional form relating inputs to outputs, which differs from statistical methods of performance analysis.	Ramanathan (2003)	Uses the concept of linear programming to fuzzify the objective function and the constraints of the CCR model under the condition of imprecise data.	Sengupta (1992)
DEA has linkages with MCDM, as a tool for multi-criteria decision making.	Stewart (1996); Agrell and Tind (1998); Belton and Stewart (1999).	As a decision-making tool, FDEA is extended its MCDM criterion through the use of fuzzy multiple objective programming, Analytic Hierarchy Process (AHP) and others.	Hsiang-Yu and Kuei-Hu (2022); Yu *et al.* (2004)
DEA can handle efficiency, productivity, performance	Charnes and Cooper (1984)	FDEA can handle efficiency, productivity performance assessment	Amirteimoori and Allahviranhoo (2025);

assessment and benchmarking of peers DMUs under VRS and CRS, input /output or multi-stage orientation.		and benchmarking of peer DMUs under VRS and CRS, input/output or multi-stage orientation with ordinal and imprecise values consideration.	Cook and Zhu (2005); Kim *et al.* (1999); Cook *et al.* (1993); Cooper *et al.* (1999).
It can handle crisp data 0 and 1.	Charnes, Cooper and Seiford (1978)	Solving FuzzyDEA condition using Z-numbers. It can handle continuous values within 0 and 1, like 0.25, 0.50; 0.75).	Namakin *et al.*(2018); Zadeh (1965)

All the abovementioned variables are subject to the three-stage operation, which considers the controllable and uncontrollable variables that deal with the conventional DEA and unconventional FDEA Models.

First stage is the operation of controllable input and output variables as to (Inputs 1 & 2 versus Outputs 1 & 2) by using the conventional DEA (crisp numbers).

The second stage is the mixture of controllable and uncontrollable variables as (Inputs 1 & 2-Controllable) + (Input 3-Uncontrollable) versus (Outputs 1 & 2). These mixed variables are operated through the Fuzzy DEA Method (Unconventional1 Type).

The third stage is the mixture of uncontrollable and controllable data. Uncontrollable input is not considered at this time; only the controllable input variables against the output variables that combine the controllable and uncontrollable variables.

Explanation regarding the appearance of uncontrollable variables for the two stages (FDEA Stages 2 & 3) is not redundant because the variables used are not the same (Input 3-ISO Certification; Output 3-Age of Technology).

It is expected that slacks can or cannot exhibit equivalent values that can affect the efficiency performance of DMUs. These are accomplished by means of using all the aggregate data and running it in three stages. In decision-making under conditions of uncertainty by using the uncontrollable variables cited, the current researcher in this study does not know the probability of the occurrence of each possible outcome. The current researcher has sufficient knowledge after the actual plant visits and assigned the ordinal numbers to two uncontrollable variables, then altered them to fuzzy set membership scores via scale transformation manipulation on productivity style (Mallillin *et al.*, 2024).

These variables are run in the DEA Software Program, which deals with controllable and uncontrollable data (precise and imprecise data). Moreover, the reference studies indicated in the explanations are the guidelines for choosing the said variables. This is expressed in crisp values (0, 1) or similar ordinal/cardinal ranking (1,2,3….n.) values, but a quantitative data ready for interpretation to fuzzy membership scores which range from 0, 0.25,0.5…1. These are described in tables and figures indicated per topic allocated prior to integrating the same to the detailed processes.

Table 2: Descriptive Summary of all Variables used in the DEA and FDEA Methods in the Efficiency Evaluation of Selected Independent Power Producer in Luzon Philippines

DEA (Stage 1) CVRS-TE

DMU	Input 1	Input 2	Output1	Output 2
1	100	519	20429	287
2	38	24	601	652
3	39	24	601	57
4	20	20	1750	404
5	29	22	4200	8
6	102	3	1180	2584
7	209	570654	1686239	5052
8	383	1945	7572	5049
9	440	1311	104	3935
10	100	322	8444	374
11	40	378	7096	635
12	40	366	6867	63
13	20	195	3663	1083
14	24	281	5265	6
15	106	6	624	4385
16	203	663	3431	5509
17	387	1981	8924	5357
18	427	1083	12035	3555
19	100	44	3266	279
20	44	378	8256	574
21	44	366	8256	70
22	17	195	4386	56
23	26	281	4902	10
24	105	987	2416	3958
25	194	577	3285	5199
26	391	1966	13658727	4861
27	425	1028	12158615	2439
28	100	173	4024	205
29	43	483	14034	495
30	43	483	14034	428
31	16	207	5212	83
32	23	207	6816	38
33	110	1903	3665	6424
34	186	578	3670	5527
35	380	1915	14377088	4211
36	427	1073	13171137	2330
37	80	252	1533	228
38	49	55	9712	548
39	48	55	9712	421
40	15	23	3999	83
41	26	29	5142	38
42	115	1946	3849	5500
43	182	575	3596	5450
44	377	1962	13575431	4916
45	421	1093	12447092	1997
46	80	252	1795	50
47	49	20	9712	444
48	49	20	9712	394

49	16	6	3999	80
50	25	11	5142	35
51	107	1494134	6608644	7657
52	162	442	4059	5385
53	373	109319	11976046	3956
54	421	66363	11324230	2468
55	80	252	977	69
56	49	46	31768	476
57	49	45	30886	371
58	17	14	9707	78
59	24	23	15884	30
60	93	1617607	6078215	7566
61	155	442	3538	5231
62	365	97169	10034325	2507
63	407	61791	10517295	3135

FDEA (Stage 2) UCVRS-TE					
DMU	**Input 1**	**Input 2**	**Input 3**	**Output1**	**Output 2**
1	100	519	0.5	20429	287
2	38	24	0.3	601	652
3	39	24	0.3	601	57
4	20	20	0.3	1750	404
5	29	22	0.3	4200	8
6	102	3	0.2	1180	2584
7	209	570654	0.2	1686239	5052
8	383	1945	0.2	7572	5049
9	440	1311	0.3	104	3935
10	100	322	0.5	8444	374
11	40	378	0.3	7096	635
12	40	366	0.3	6867	63
13	20	195	0.3	3663	1083
14	24	281	0.3	5265	6
15	106	6	0.2	624	4385
16	203	663	0.2	3431	5509
17	387	1981	0.3	8924	5357
18	427	1083	0.3	12035	3555
19	100	44	0.2	3266	279
20	44	378	0.3	8256	574
21	44	366	0.3	8256	70
22	17	195	0.3	4386	56
23	26	281	0.3	4902	10
24	105	987	0.2	2416	3958
25	194	577	0.2	3285	5199
26	391	1966	0.5	13658727	4861
27	425	1028	0.5	12158615	2439
28	100	173	0.2	4024	205
29	43	483	0.3	14034	495
30	43	483	0.3	14034	428
31	16	207	0.3	5212	83

32	23	207	0.3	6816	38
33	110	1903	0.2	3665	6424
34	186	578	0.2	3670	5527
35	380	1915	0.5	14377088	4211
36	427	1073	0.5	13171137	2330
37	80	252	0.2	1533	228
38	49	55	1.0	9712	548
39	48	55	1.0	9712	421
40	15	23	0.7	3999	83
41	26	29	0.7	5142	38
42	115	1946	0.2	3849	5500
43	182	575	0.2	3596	5450
44	377	1962	0.5	13575431	4916
45	421	1093	0.5	12447092	1997
46	80	252	0.2	1795	50
47	49	20	1.0	9712	444
48	49	20	1.0	9712	394
49	16	6	0.7	3999	80
50	25	11	0.7	5142	35
51	107	1494134	0.2	6608644	7657
52	162	442	0.2	4059	5385
53	373	109319	0.5	11976046	3956
54	421	66363	0.5	11324230	2468
55	80	252	0.2	977	69
56	49	46	1.0	31768	476
57	49	45	1.0	30886	371
58	17	14	0.7	9707	78
59	24	23	0.7	15884	30
60	93	1617607	0.3	6078215	7566
61	155	442	0.3	3538	5231
62	365	97169	0.5	10034325	2507
63	407	61791	0.5	10517295	3135

FDEA (Stage 3) UCVRS-TE					
DMU	**Input 1**	**Input 2**	**Output1**	**Output 2**	**Output 3**
1	100	519	20429	287	0.83
2	38	24	601	652	1.00
3	39	24	601	57	0.83
4	20	20	1750	404	1.00
5	29	22	4200	8	0.83
6	102	3	1180	2584	1.00
7	209	570654	1686239	5052	0.83
8	383	1945	7572	5049	1.00
9	440	1311	104	3935	0.83
10	100	322	8444	374	0.67
11	40	378	7096	635	1.00
12	40	366	6867	63	0.83
13	20	195	3663	1083	0.83
14	24	281	5265	6	1.00

15	106	6	624	4385	0.67
16	203	663	3431	5509	0.83
17	387	1981	8924	5357	1.00
18	427	1083	12035	3555	0.83
19	100	44	3266	279	0.67
20	44	378	8256	574	1.00
21	44	366	8256	70	1.00
22	17	195	4386	56	0.83
23	26	281	4902	10	0.83
24	105	987	2416	3958	1.00
25	194	577	3285	5199	0.67
26	391	1966	13658727	4861	0.83
27	425	1028	12158615	2439	0.83
28	100	173	4024	205	0.67
29	43	483	14034	495	1.00
30	43	483	14034	428	1.00
31	16	207	5212	83	1.00
32	23	207	6816	38	0.83
33	110	1903	3665	6424	1.00
34	186	578	3670	5527	0.67
35	380	1915	14377088	4211	0.83
36	427	1073	13171137	2330	0.67
37	80	252	1533	228	0.50
38	49	55	9712	548	1.00
39	48	55	9712	421	1.00
40	15	23	3999	83	1.00
41	26	29	5142	38	1.00
42	115	1946	3849	5500	1.00
43	182	575	3596	5450	0.67
44	377	1962	13575431	4916	0.83
45	421	1093	12447092	1997	0.67
46	80	252	1795	50	0.50
47	49	20	9712	444	0.83
48	49	20	9712	394	1.00
49	16	6	3999	80	1.00
50	25	11	5142	35	1.00
51	107	1494134	6608644	7657	0.83
52	162	442	4059	5385	0.50
53	373	109319	11976046	3956	0.83
54	421	66363	11324230	2468	0.67
55	80	252	977	69	0.50
56	49	46	31768	476	0.83
57	49	45	30886	371	1.00
58	17	14	9707	78	0.83
59	24	23	15884	30	1.00
60	93	1617607	6078215	7566	0.83
61	155	442	3538	5231	0.50
62	365	97169	10034325	2507	0.67
63	407	61791	10517295	3135	0.50

Table 3: Various Studies conducted identifying input and output variables

Studies	Methods	Country	Input	Output
Hattori (2002)	SFA	U.S. and Japan	Labor, fuel, capital	Electricity generated
Lavado and Hua (2004)	Averch-Johnson (AJ) Effect Empirical Analysis	Philippines	Capital, labor, fuel	Electricity generated in MWH
Xu *et al.* (2020)	DEA	China	Various industries data (Refer the literature review of this research)	Various industries data (Refer the literature review of this research)
Delmas and Tokat (2005)	DEA	U.S.	Labor cost, plant value, production expenses, transmission expenses, distribution expenses, sales, administrative and general expenses, electricity purchased form other sources	Quantities of low-voltage sales (residential and commercial), high voltage sales (industrial, interchanges out, and wheeling delivered), sales for resale to other utilities in MGW-Hrs (megawatt-Hrs)
Cherchye and Post (2003)	DEA	The Netherlands	Controllable operational costs	GWh, Number of large customers, Number of small customers, Peak demand> 110kv, Peak demand < 110 kv, Length of network, Number of transformers
Hirschhausen *et al.* (2006)	DEA/SFA	Germany	Labor, capital, Peak load capacity	Units sold, Number of customers
Korhonen and Syrjanen (2003)	DEA	Finland	Operational expenditure, cost of capital	Distributed energy, quality
Nemoto and Goto (2003)	DEA	Japan	Fuel, labor	Electricity for commercial use, electricity for industrial use, electricity for residential use
Hattori *et al.* (2005)	DEA	Japan, U.K.	operating expenditures (OPEX), total expenditure (TOTEX)[sum of operating and capital expenditures (CAPEX)]	Electricity units delivered in megawatt-hours (MGW-Hrs.)
Bagdadioglu *et al.* (2007)	DEA	Turkey	Number of employees, transformer capacity, network length	Customer service, electricity distributed

Hollas *et al.* (2002)	DEA	U.S.	Purchase gas, Labor, Capital	Annual qty. of gas sold to (Residential., Commercial, Industrial) Customers
Posadas and Cabanda (2007)	DEA	Philippines	Number of employees, power cost, Depreciation expenses, administration and general expenses	Total operating revenue, MWH Sales, MWH generated / pur-chased, Number of Consumers, Total Assets
Nadhila *et al.* (2025)	Fuzzy DEA, Triangular Fuzzy Numbers (TFN), Fuzzification	Indonesia	Accessibility, Drainage, Facility Commercial	Environmental Management and Cleanliness, Availability and Quality of Green Spaces.
Amirteimoori and Allahviranhoo (2025)	Fuzzy DEA	Turkey	Interest Expense (IE), Other Operating Expenses (OOE)	Net Interest Revenue (NIR), Operating Revenue (OR)
Zuluaga *et al.* (2023)	Fuzzy DEA	Columbia	Saber 11: Math, Critical Readings, Citizenship, Biology, English	Saber Pro: Quantitative Reasoning, Critical Reading, Citizenship Skills, English, Writing Communication, Formulation of Engineering Academic Program
Kao and Liu (2002)	Fuzzy DEA	Taiwan	Patronage	Collections, Personnel, Expenditures, Buildings, Services
Kao and Liu (2005)	Fuzzy DEA (FDEA)	Taiwan	Automation Technology, Production Management	Productivity
Liu (2008)	Fuzzy DEA/AR, FMS, (FDEA/AR)	China	Capital and Operating costs, Floor space needed	Qualitative, WIP, No. of Tardy, Yield
Yu *et al.* (2004)	Imprecise DEA (IDEA), FMOP	Taiwan	Exact Cost, Interval Judgment	Exact Revenue, Ordinal Satisfaction
Amirteimoori and Allahviranhoo (2025)	Fuzzy DEA	Turkey	Interest Expense (IE), Other Operating Expenses (OOE)	Net Interest Revenue (NIR), Operating Revenue (OR)
Zuluaga *et al.* (2023)	Fuzzy DEA	Columbia	Saber 11: Math, Critical Readings, Citizenship, Biology, English	Saber Pro: Quantitative Reasoning, Critical Reading, Citizenship Skills, English, Writing Communication, Formulation of

				Engineering Academic Program
Kao and Liu (2002)	Fuzzy DEA	Taiwan	Patronage	Collections, Personnel, Expenditures, Buildings, Services
Kao and Liu (2005)	Fuzzy DEA (FDEA)	Taiwan	Automation Technology, Production Management	Productivity
Liu (2008)	Fuzzy DEA/AR, FMS, (FDEA/AR)	China	Capital and Operating costs, Floor space needed	Qualitative, WIP, No. of Tardy, Yield
Yu *et al.* (2004)	Imprecise DEA (IDEA), FMOP	Taiwan	Exact Cost, Interval Judgment	Exact Revenue, Ordinal Satisfaction
Zhu (2004)	Imprecise DEA (IDEA), MPI	Korea	Manpower, Operating cost, Management level	Revenue, Facility success, Fuzzy Output 3
Cooper *et al.* (1999)	Assurance Region (AR)-Imprecise DEA (IDEA)	U.S.	Fuzzy Input 1, Fuzzy Input 2	Fuzzy Output 1, Fuzzy Output 2
Dia (2004)	FDEA, MCDM	Canada	Fuzzy Input 1, Fuzzy Input 2, Fuzzy Input 3	Fuzzy Output 1, Fuzzy Output 2
Guo and Tanaka (2001)	FDEA	Japan	Fuzzy Input 1, Fuzzy Input 2	Fuzzy Output 1, Fuzzy Output 2, Fuzzy Output 3
Guh (2001)	FDEA	China	Fuzzy Input 1, Fuzzy Input 2	Fuzzy Output 1, Fuzzy Output 2

The third input and output uncontrollable variables are subjected to fuzzy membership score transformations prior to processing them for the two-stage 2 & 3 operation. The different range of sets by which the data taken from respective DMUs can be converted by the researcher to the average range fuzzy set classifications in accordance with the total number of decision-making units within the organization (Paraiso & Mallillin, 2025).

Finally, it should be noted that there is no specific rule in determining the procedure for selecting inputs and outputs; however, some rule of thumb, such as sample size, should be at least 2 or 3 times larger than the sum of the number of inputs and outputs. Similarly, the larger of DMUs is expected to be larger than the product of the number of inputs and outputs, thus, to discriminate effectively between efficient and inefficient DMUs (Hoang & Viharos, 2025).

Table 4: Crisp versus Fuzzy Sets

Crisp Set (1)	**Three-Value Fuzzy Set (2)**	**Five-Value Fuzzy Set (3)**	**Seven-Value Fuzzy Set (4)**	**"Continuous" Fuzzy Set (5)**
1 = fully in	1 = fully in	1 = fully in	1 = fully in	1 = fully in
		0.75 = more in than out	0.83 = mostly but not fully in 0.67 = more or less in	Numerical scores indicating that the degree of membership is more "in" than "out" (0.5< Xi <1)
	0.5 = not fully out or fully in	0.50 = crossover: neither in nor out	0.50 = crossover: neither in nor out 0.33 = more or less out	0.50 = crossover: neither in nor out
		0.25 = more out than in	0.17 = mostly but not fully out	Numerical scores indicating that the degree of membership is more "out" than "in" (0<Xi<0.5)
0 = fully out	0 = fully out	0 = fully out	0 = fully out	0 = fully out

Table 5: Translating from Raw Scores to Verbal Labels to Fuzzy Membership Scores

Raw Scores of Population Size	Verbal Labels	Fuzzy Membership Score
≤ 100,000	Fully out	0.000
100,001-250,000	Mostly out	0.001-0.250
250,001-400,000	More or less out	0.251-0.499
400,001-600,000	Neither out nor in	0.500
600,001-800,000	More or less in	0.501-0.750
800,001-1,000,000	Mostly in	0.751-0.999
≥ 1,000,001	Fully in	1.000

5. Results and Discussion

Based on the table below, this portion concentrates on the derived findings for the technical efficiency performance evaluation of selected Independent Power Producers (IPPs) in the Luzon Area, Philippines.

Table 6: Selected Independent Power Producers (IPPs) in the Luzon Area

Decision-Making Units (DMUs)	Acronym	IPP Firms
1	SDPP	Subic Diesel Power Plant
2	KPSS-I	Kalayaan Pumping Storage Power Plant-I
3	KPSS-II	Kalayaan Pumping Storage Power Plant-II
4	CHEPP	Caliraya Hydro Electric Power Plant
5	BHEPP	Botocan Hydro Electric Power Plant
6	ICCPP	Ilijan Combined Cycle Power Plant
7	MOTPP 1 & 2	Malaya Oil Thermal Power Plant 1 & 2
8	SCPP	Sual Coal Power Plant
9	PCPP	Pagbilao Coal Power Plant
Total = 9		

The conventional non parametric approach (DEA) and the unconventional non-parametric approach (FDEA) were used to measure the efficiency score performance of selected IPPs, where a value greater than one (>1) indicates a positive improvement while a value lesser than one (< 1) indicates a decline in a firm's efficiency score performance over the 7 -year period from 2000 to 2006. To evaluate the impact of uncontrollable variables in a fuzzy data envelopment analysis (stages 2 and 3) model, data were incorporated into the operation system. Subsequently, these imprecise data (uncontrollable variables) are handled by transforming them via linear programming for equivalent to two (2) stages operations.

Furthermore, for specification's sake, the said variables were being manipulated or altered from logical to ordinal number form. It was then converted to fuzzy set form prior to subjecting it for scale transformation operation. These priories required the conversion into suitable variable -fuzzy data and were subjected to the mentioned controllable data for advanced linear programming methodology.

Table 7: DEA- Stage 1 Technical Efficiency Analysis (%)

CVRS-TE (Stage 1) Model								
IPP Industry	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**MEAN**
SDPP	16.41	17.57	19.64	16.53	19.66	18.75	18.75	18.19
KPSPP-I	68.17	44.59	39.9	40.23	46.62	47.35	45.07	47.42
KPSPP-II	40.45	37.67	34.32	39.44	42.36	45.37	42.34	40.28
CHEPP	100	100	88.26	93.89	100	100	92.81	96.42
BHEPP	54	62.6	57.75	65.5	59.16	63.91	66.05	61.28
ICCPP	100	100	74.09	100	82.26	100	100	93.8
MOTPP 1 & 2	45.21	86.72	74.31	100	90.59	100	95.59	84.63
SCPP	29.49	34.4	100	100	100	84.42	72.93	74.46
PCPP	20.14	18.95	96.39	100	95.32	71.3	68.77	67.27
MEAN	52.65	55.83	64.96	72.84	70.66	70.12	66.92	64.86

The technical efficiency of 18 utilities for the Dutch electricity Sector- the Netherlands utilized DEA models through CCR and BCC Models. They found that the average efficiency via the CCR model was 50 percent and under the BCC model, 77 percent. Similarly, The Finish Electricity Distribution Utilities, Nemoto and Goto (2003) of Japanese Electricity Utilities, evaluated the technical efficiencies of their respective firms. They also used DEA models in measuring cost, environmental, economic and production efficiency performance. Their results pointed to average efficiency scores of 76.9 percent, 92 percent and 34.14 percent.

The use of DEA applications for measuring efficiency of the university department used the DEA models in measuring the productivity performance of Regional Electric Cooperatives (RECs) in the Philippines. Results revealed that out of 15 regional grouping of electric cooperatives (RECs), 11 regions were found in efficient score level. Specifically, there was a percentage level of 73.3 percent RECs that were performing very well, while 26.67 percent belonged to the inefficient level. It was recommended that these RECs should be able to benchmark the efficient peers for the required improvement.

Table 8: DEA -Stage 1 IPP Industry Comparative Technical Efficiency Analysis (2000-2006)

IPP Industry	**2000**	**2006**	**% Change**
SDPP	0.1641	0.1875	14.26
KPSPP-I	0.6801	0.4507	-33.73
KPSPP-II	0.4045	0.4234	4.67
CHEPP	1.000	0.9281	-7.19
BHEPP	0.5400	0.6605	22.32
ICCPP	1.000	1.000	0
MOTPP 1 & 2	0.4521	0.9559	111.44
SCPP	0.2949	0.7293	147.30
PCPP	0.2014	0.6877	241.46
MEAN	0.5263	0.6692	27.15

Considering the technical efficiency improvement per industry for 2000 and 2006, the results revealed that PCPP IPP firm topped the highest percentage as the most improved IPP industry compared with other IPPs over the test period from 20.14 percent in 2000 to 68.77 percent in 2006: a 241. 46 percent growth change.

SCPP got the highest percentage for the improved industry from 29.49 percent in 2000 to 72.93 percent in 2006 or 147.30 percent growth, and the third highest percentage as improved IPP firm is MOTPP 1 and 2 from 45.21 percent in 2000 to 95.59 percent in 2006 or 111.44 percent growth. The BHEPP industry got the fourth highest percentage for the improved efficiency performance from 54.00 percent in 2000 to 66.05 percent in 2006 or 22.32 percent growth. The ICPP industry has a zero percent growth.

The remaining two (2) IPP firms, KPSPP-I and CHEPP, showed a declining efficiency performance. Although these particular IPPs had plant rehabilitation and expansion projects in the last quarter of 2006, the management involved had perhaps mismanaged the total number of employees' budget allocation, which might have caused a huge deficit in total MWH Sales and total operating revenue. Thus, the IPPs posted a 64.86 percent score performance.

Table 9: FDEA – Stage 2 Technical Efficiency Analysis per IPP Industry (%) (2000- 2006)

UCVRS-TE (Stage 2) Model								
Plants	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**MEAN**
SDPP	16.41	17.57	19.64	16.53	19.66	18.75	18.75	18.19
KPSPP-I	68.17	44.59	39.9	40.23	46.62	47.35	46.07	47.56
KPSPP-II	40.45	37.67	34.32	39.44	42.36	45.37	42.34	40.28
CHEPP	100	100	88.26	93.89	100	100	92.81	96.42
BHEPP	54	62.6	57.75	65.5	59.16	63.91	66.05	61.28
ICCPP	100	100	74.09	100	82.3	100	100	93.8
MOTPP 1 & 2	45.21	86.72	74.31	100	90.59	100	95.59	84.63
SCPP	29.49	34.4	100	100	100	84.42	72.93	74.46
PCPP	20.14	18.95	96.39	100	95.329	71.3	68.77	67.27
MEAN	52.65	55.83	64.96	72.84	70.67	70.12	67.03	64.87

The table pointed out an annual average of 1.13 percent (ISO Certification), 3 percent (Depreciation) and 4.22 percent (Total Number of Employees) while strategically monitoring to balance the output deficit of Total Operating Revenue (24 percent) and Total MWH Sales (196 percent). These prerequisites were a necessary improvement in the transformation of resource inputs to achieve the desired maximum level. So, the IPP industry could reach its optimal relative technical efficiency performance (Kusz *et al.*, 2025).

In this application, the assessment/findings regarding the technical efficiency scores imply that the data contained imprecision and fuzziness. It then recalled that the fusion of Fuzzy sets theory and linear programming operation dealt a lot with the fuzzy membership measurement/ assessment, variable alteration (ordinal and fuzzy data rank modelling) and scale transformation (fuzzy efficiency measurement). It revealed that the first stage results posted a lower efficiency rating than the second stage results. Using the balanced scorecard and FDEA Model were validated and strengthened by the current study's results, which did not limit merely to declining results but also possibly improving percentage.

Observably, there existed flexibility in the results, either increasing or decreasing trend below the efficiency scores which an FDEA model should have attributed. Logically, a decision maker should therefore look thoroughly while expecting the result conveyed that ISO Certification as the uncontrollable factor for input 3 allocation in this Stage 2 model had a very minimal advantage value (64.87 percent) over the Stage 1 model result (64.86 percent) for the comparative efficiency performance of IPP for the year 2000 to 2006. The IPP industry, which perhaps disregards the ISO Certification compliance suffer inefficiency performance, although it could optimize the industry efficiency once they yield to the compliance requirement.

Overall, the current researcher draws the implication that the fuzzy DEA model had increased its discriminating power in terms of handling imprecision, uncontrollable, fuzzy factors as compared with the traditional or conventional DEA approach. Zhu (2004) stressed in his study that this methodology greatly enhanced the applicability of imprecise or fuzzy DEA in applications, which no longer limit the approach totally to obtaining efficiency scores alone. However, it also finds possible ways on how imprecision can be handled thoroughly, together with the exact data needed or gets it done in the opposite direction. He added that the decision maker should be wise enough to determine or assess the best choice selection of efficiency scores that truly represent the fuzzy DEA approach objective. This development helped in the enhancement of imprecise or fuzzy data management via advanced linear programming methodology.

Table 10: Comparative Technical Efficiency Score (DEA-1 and FDEA – 2) Analysis (2000- 2006)

IPP Industry	DEA- Stage 1 (CVRSTE)	FDEA- Stage 2 (CVRSTE)
SDPP	18.19	18.19
KPSPP-I	47.42	47.42
KPSPP-II	40.28	40.28
CHEPP	96.42	96.42
BHEPP	61.28	61.28
ICCPP	93.8	93.8
MOTPP 1 & 2	84.63	84.63
SCPP	74.46	74.46
PCPP	67.27	67.27
MEAN	64.8611	64.8611

The findings of this research study are not merely validated, but solidify previous studies made under this model in a broader perspective. The current study shows the mean 64.86 percent (Stage 1), 64.87 percent (Stage 2), and actual score of 10.0 (Stage 3), which implies the fluctuating /varying characteristic of the technical efficiency performance scores of IPP firms at three stages in seven years period. The mentioned results do not follow the direct descending and majority pattern as shown by the previous studies of Cooper *et al.* (1999), Liu (2008), etc. However, the current study confirmed the validation of the previous result of Hsu's (2008) study, which is in an ascending pattern. This pointed to the current study (second stage), which resulted in 64.87 percent from the earlier 64.86 percent, then it went to a lower unbalanced actual score of 10 (third stage). This is what it takes in associating the uncontrollable variables- ISO Certification in the second stage (Input emphasis) and Age of Technology in the third stage (output emphasis).

For elaboration purposes, it stressed that the U.S. pertained to five (5) DMUs, which showed three (3) different model results for the decision maker to choose from. Firstly, the IDEA model showed efficiency scores which ranges of 70 -100 percent with a mean of 91.5 percent. Secondly, the AR-Model showed an efficiency score range from 69.99 -100 percent with a mean of 91.49 percent. Thirdly, Cone Ratio envelopment concepts showed efficiency scores range from 53.54 -100 percent mean of 73 percent. The difference among these three (3) models was that the DMUs' respective results were subjected to refinement processes. These processes' operation started from the first model results, where a crisp value of 1 and other numerical values less than (<) 1. We're undergoing two stages via scale transformation and variable alterations (exact data, ordinal data, bounded data). Then, it passed through the second model results, and finally, the third model results reflected the redefined values of each DMU.

The results deal with the selection of a flexible manufacturing system (FMS) by the use of the Fuzzy DEA / Assurance Region (AR) Approach. The results revealed the fuzzy ranking indices to be similar to efficiency scores and to the ranking of alternatives as the scores of DMUs reached 48.52- 91.66 percent with a mean of 76.24 percent. The results of FMS alternatives signified that manufacturing firms needed to increase the quality and responsiveness to customization, while lower costs were an edge to compete in the global marketplace. The benefit obtained from this model might be balanced by a possible loss in precision since fuzzy models provided only the best- and worst-case analysis and did not assume that errors compensate. The study also deals with Multinational R and D Project Performance Assessment by the use of Balanced Scorecard and Fuzzy DEA. He sampled three (3) departments as decision-making units (DMUs) for the mentioned approach. Results revealed that the selection option for the two solutions had improved mean results. CCR's Solution showed an indicator range of 57.62- 100 percent with a mean of 79.89 percent, while BCC's Solution had an indicator range of 83.32 -100 percent with a mean of 89.4 percent.

Table 11: FDEA -Stage 2 IPP Industry Comparative Technical Efficiency Analysis (2000-2006)

IPP Industry	2000	2006	% Change
SDPP	0.1641	0.1875	14.26
KPSPP-I	0.6817	0.4607	-32.42
KPSPP-II	0.4045	0.4234	4.67
CHEPP	1.0000	0.9281	-7.20
BHEPP	0.5400	0.6605	22.32
ICCPP	1.0000	1.0000	0
MOTPP 1 & 2	0.4521	0.9559	111.44
SCPP	0.2949	0.7293	147.30
PCPP	0.2014	0.6877	241.46
MEAN	0.5265	0.6703	27.31

With regard to the technical efficiency improvement per IPP industry using the FDEA Stage 2 model, Table 4.5 above shows that PCPP topped the list as the most improved IPP compared with other IPPs over the test period from 20.14 percent in 2000 to 68.77 percent in 2006: a 241.46 percent growth change. SCPP got the second-highest percentage for the improved industry from 29.49 percent in the year 2000 to 72.93 percent in the year 2006, or 147.30 percent growth; and the third-highest percentage of most improved IPP is MOTPP 1 and 2, which moved from 45.21 percent in the year 2000 to 95.59 percent in the year 2006, with 111.44 percent growth. BHEPP got the fourth highest percentage with 54.00 percent in the year 2000 to 66.05 percent in the year 2006, with 22.32 percent growth. ICCPP got a zero percent growth rate due to its consistent efficient performance (efficient frontier score) on mentioned years.

Table 12: FDEA- Stage 3 Technical Efficiency Analysis per IPP Industry (2000-2006)

UVRS-0-TE (Stage 3) Model								
IPP Industry	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**MEAN**
SDPP	15.22	11.67	14.82	20.64	15.59	69.24	51.15	28.00
KPSPP-I	1.94	3.24	3.85	4.54	3.39	3.86	3.58	3.00
KPSPP-II	22.7	29.83	28.74	5.23	4.27	4.32	4.49	14.00
CHEPP	1	1	6.54	2.82	1	1	1.92	2.00
BHEPP	48.2	60.98	68.77	24.08	15.88	12.36	9.98	34.00
ICCPP	1	1	1.34	1	1.2	1	1.00	1.00
MOTPP 1 & 2	1.36	1.01	1.06	1	1.01	1	1.02	1.00
SCPP	1.27	1.2	1	1	1	1.16	1.39	1.00

PCPP	1.53	1.65	1.02	1	1.05	1.27	1.36	1.00
MEAN	10.47	12.40	14.13	6.81	4.93	10.58	8.43	10

Table 12 shows the comparative efficiency performance per IPP industry sector over the test period. The result showed that the performance of these selected IPP Industries from 2000 to 2006 had not reached the efficiency score level. The overall efficiency scores of the 9 selected IPP firms had an average actual score of 10. The null hypothesis (H1) mentioned that there are no selected IPP firms which are totally efficient is accepted. Observably, the average technical efficiency of these selected IPP firms over the test period (2000-2006) is far from the normal conventional DEA (CVRS-TE) Stage 1 and Unconventional FDEA (UCVRS-TE) Stage 2 desired efficiency level of 100 percent.

While ISO Certification puts more emphasis on the compliance requirement, it does not include the initiatives for new methods, devices, tools, machines, automation, and facilities for investment allocation. However, technology cannot be reduced to machines. It has to do with certain kinds of knowledge which allow the adaptation of means to ends. Part of this knowledge is embodied in machines, but most of it is not. It lies elsewhere in the skills of people, in behavioral patterns and in organization structures and procedures. For purposes of clarification, innovative behavior comes from a firm that adopts innovation for its organization. Innovation refers to processes by which firms master and implement the design and production of goods and services that are new to them, irrespective of whether or not they are new to their competitors' generation plants. Most of the time, and in most industries (not only in the IPP industry), innovation is also based on the continuous and incremental upgrading of existing technologies or on a new combination of them (Mallillin *et al.*, 2024).

Looking at the aspect of how this uncontrollable age of technology affects the output association with operating revenues and total MWH-Sales versus the input resources in the respective IPP firm. The firm needs a variety of knowledge and skills to acquire, assimilate, use, adapt, change and create technology. This is achieved by means of exercising technological capabilities that a firm has (Mallillin *et al.*, 2025).

Technological capabilities are classified as: *production; investment; minor change; strategic marketing; linkage; major change. Production capabilities* relate to the knowledge and skills used in plant operation, where shop floor experience and 'learning by doing' continue to play an important role, despite the growing scientific intensity of the IPP firm. *Investment capabilities* refer to the knowledge and skills used in the identification, preparation, design, setting up and commissioning of a new IPP (generation plant) project or the expansion and/ or modernization of the existing ones.

Minor change capability is a firm's ability to improve and adapt its products and processes continuously. It refers to the vast area of adaptive engineering and organizational adjustments involved in the incremental upgrading of product design and performance features and of technology. *Strategic marketing capability* is defined as the knowledge and skills required by an IPP firm for collecting market intelligence, the development of new markets, the establishment of distribution channels and the provision of customer requirements. *Linkage capabilities* relate to the knowledge, skills and organizational competence associated with the transfer of technology at three different levels: within a firm, from one enterprise to another, and between the firm and the domestic science and technology infrastructure. Major change capability is defined as the knowledge and skills required for the creation of new technology (Mallillin, 2025, pp. 152-166).

As part of technological capabilities emphasize by the age of technology, investment capabilities emphasize by the age of technology, and investment. The work evaluated the application of the option value-investment theory, which she found out that in the context of investment of new technologies, rather than the traditional equipment which is obsolete, the above concerns are particularly significant. This is to emphasize that machines/equipment/automation are required, as validated also by the study. The value of investment in a new technology is strongly affected by the typically high degree of uncertainty surrounding both the value and the pace of improvement, upgrading, and rehabilitating of the technology. Moreover, investment reversibility becomes especially valuable when uncertainty is high since the plant will have a chance to recoup some of the initial investment in case of a downturn.

With regards on the justification/qualification of ISO certification as a means of fostering technological advancement, several studies can attest to this assertion. It has proof that the firm technological status and ISO certification are linked to each other. Considering their study hypothesis pointed out that a positive relationship exists between a firm's technological status and its satisfaction with the certification, the higher the technological status of a firm, the more likely it is to advance towards Total Quality once it has become certified. Empirical results have made it clear that the reasons that have led the surveyed companies to adopt certification are the firm's improvement in all areas and its adaptation to the environment, as opposed to others that are traditionally considered more important (Mallillin, 2022, pp. 8-24).

The results are classified into three groups. The first group is integrated by the companies that claim to possess a technological level that is superior to that of their competitors. The second group is made up of those who qualify their status as medium, and the third by those who report a low technological status. This gives more than half of the certified companies in the Spanish sample consider that their technological level is high. As opposed to them, it is hardly 3% estimate that they are beneath their rivals technologically speaking. Using a Likert scale (1-5), I would indicate that the firm was satisfied with the certification, while 5 would reveal a very satisfactory experience.

This conveys that the majority of the companies surveyed declare themselves to be satisfied (44%) or very satisfied (17.3%) with the certification. The percentage of those who consider that their expectations had not been met was much reduced. Nevertheless, it is worthy of note that a high number of companies (30.4%) showed their indifference. Perhaps the attainment of fewer benefits than desired, or the newness of their certificates, may be among the reasons justifying this option. Thus, in practice, the ISO Certification helped to boost efficiency by fostering technological advancement to increase IPP industry performance (Zhang & Xu, 2025, pp. 1-7).

Looking at the output-oriented UCVRS-TE FDEA Stage 3, points to the consideration that selected IPP firms have to optimize their input usages (raw materials, total manpower, depreciation) while working to reduce their output resources: total operating revenue, total MWH Sales and confronting all issues of the age of technology (uncontrollable factor) on their overall system. It must be stressed that the stage 3 model scores exhibited a unique feature of fuzzy DEA approaches, namely that the output is too high or imbalanced relative to the given inputs, as evidenced by the slacks occurrence. Moreover, the justification taken from aggregate results run through FDEA operation really confirmed that the virtual output needed is different from the actual output gathered.

Since Stage 3 emphasized the output-oriented approach operation, the table pointed out an annual average of slack in the output resource reduction: 1.22 percent (Age of Technology), 7594 percent (Total MWH-Sales), 177 percent (Total Number of Employees), 22 percent (depreciation). Overcoming these slacks is a necessary prerequisite for the transformation of resource outputs to achieve the desired optimal level, ensuring the IPP industry's reaching its relative technical efficiency performance (Mavrommati & Pliakoura, 2025

Table 13: Comparative Technical Efficiency Score
(FDEA- Stage 2 and FDEA -Stage 3) Analysis (2000-2006)

IPP Industry	FDEA- Stage 2 (UCVRSTE) Model	FDEA- Stage 3 (UCVRSTE) Model
SDPP	18.19	28
KPSPP-I	47.42	3.8
KPSPP-II	40.28	14
CHEPP	96.42	2
BHEPP	61.28	34
ICCPP	93.87	1
MOTPP 1 & 2	84.63	1
SCPP	74.46	1
PCPP	67.27	1
MEAN	64.87	10

The assessment shows that the technical efficiency scores are shown in the table. The above contained an imprecision and fuzziness, the same as with FDEA stage 2 models. The situation calls for an approach merging the Fuzzy sets theory and linear programming operation to effectively handle the uncertainty inherent in the environment of the IPP industry. Meanwhile, the FDEA-Stage 3 model performed similarly with the FDEA-Stage 2 model in terms of dealing with a lot of fuzzy membership /assessment, variable alteration (ordinal and fuzzy data rank modeling) and scale transformation (fuzzy efficiency measurement).

On a year-to-year basis is shown from 2000 to 2006 that there were a lot of inconsistencies in effective decision-making that the IPP industry had committed. However, they had shown improvement in the years 2003 and 2006, with efficiency soaring up, while budget spending allocation declined due to manpower resources requirements. Similarly, in the FDEA -Stage 2 model approach, inconsistencies with efficiency are obvious due to ISO certification non-compliance. But for the sake of comparison between FDEA- Stage 2 and FDEA -Stage 3, the inefficient IPP firms are determined as scores that vary less than or greater than the actual score of 1.0. In sum, the fuzzy DEA model has increased its discriminating power in terms of handling imprecision, uncontrollable, fuzzy factors as compared with the traditional or conventional DEA approach.

The results of this study, as discussed earlier are not follow the descending pattern of efficiency scores as recalled from previously mentioned fuzzy authors' uncovered results, but also in a descending pattern. The discriminating characteristic shown by the current study further solidified the previous studies' results in terms of refining the efficiency scores, thereby validating the scores' implication, which is presently adjusted to the lowest and extreme percentage value (third stage- actual score of 10).

Although some studies were already discussed in FDEA – Stage 2, there was an elucidation on FDEA- Stage 3 approaches, thus giving a balanced treatment of this study. This study made a sample from nine (9) departments in a newly established YZU University as the decision-making units (DMUs). Results revealed four (4) model illustrations for comparison, and this gives the decision maker the opportunity to choose the best presentation. Firstly, the non-fuzzy DEA model showed an average efficiency score from nine (9) DMUs of 64.69 percent. Secondly, the *Left a plus Coordinate Model* showed an average efficiency score of 87.9 percent. Thirdly, the *Right a minus Coordinate Model* showed an average efficiency score of 31.7 percent, and the *Centroid Index Model* gave an average efficiency score of 74.4 percent.

Regarding the imprecise DEA (IDEA) approach and its application to the machinery firms, he pointed out that automation technology and production management are components of productivity improvement. They were employing triangular fuzzy numbers transformed to linguistic terms by putting in input variables, while assigning crisp values to fuzzy observations for the output variable.

This study revealed an interesting development of how imprecision should be dealt with, particularly for industrial firm applications. With fifteen (15) firms evaluated, an average efficiency of 57.82 percent was manifested. An additional 42.18 percent is needed so that the firm can reach the efficient frontier of 100 percent. The remaining 12 firms had an efficiency score that ranged from 31.3 percent to 76.2 percent. The remaining 12 firms had an efficiency score that ranged from 31.3 percent that 76.2 percent. The efficiency scores were tabulated from conventional DEA-Stage 1, Fuzzy DEA- Stage 2 and the last model, Fuzzy DEA -Stage 3.

The current study shows the backdrop trend of the average efficiency scores for nine (9) selected IPP firms. Fuzzy DEA – Stage 2 and 3 Model efficiency characteristics validated or strengthened the previous fuzzy study. Meanwhile, the study revealed a diversified solution and results in dealing with imprecision. They used fuzzy multiple objective programming to DEA with imprecise data by scale transformation and variable alteration. In fact, the discriminating power of IDEA is enhanced by the portion that both DMUs 1 and 3, which have crisp values of 1, should be made by fuzzy numbers to make the exact values known. These studies cited the firm's top management task of evaluating the best decisions. In addition, they came up with more conservative results derived from the conventional DEA model where crisp values had been assigned to fuzzy observations as discussed in previous statements.

Table 14: FDEA- Stage 3 IPP Industry
Comparative Technical Efficiency Analysis (2000-2006)

UCVRSTE_0 (3rd Stage) Model			
IPP Industry	**2000**	**2006**	**% Change**
SDPP	15.22	51.15	236.07
KPSPP-I	1.94	3.58	-80.22
KPSPP-II	22.7	4.49	-80.22
CHEPP	1.00	1.92	92.00
BHEPP	48.20	9.98	-79.29
ICCPP	1.00	1.00	0
MOTPP 1 & 2	1.36	1.02	-25.00
SCPP	1.27	1.39	9.45
PCPP	1.53	1.36	-11.11
MEAN	10.47	8.43	-19.48

As far as the technical improvement per industry for the years 2000 and 2006 is concerned, the table above shows that CHEPP got the highest percentage on the list as the most improved IPP compared with other IPPs over the test period from 100 percent in 2000 to 192 percent in 2006; a 92 percent growth change. The KPSPP-I got the second highest percentage for the improved IPP from 194 percent in 2000 to 358 percent or 84.54 ~ 85 percent growth. The third most improved percentage growth in 2006.

The imbalanced actual value of IPP industry efficiency indicates a loss of precision which triggers inefficient performance. Four (4) out of nine (9) IPPs (KPSPP-II, BHEPP, MOTPP 1 and 2 and PCPP) showed a declining efficiency. One (1) IPP (ICCPP) did not need improvement because it was able to maintain 100 percent for the years that is being considered. The other one (1) IPP (SDPP) got an imbalanced (abnormal) efficiency, which still has an inefficient value due to the uncontrollable value/fuzziness effect in the output variable. Technology tends to be an obsolescent as it ages. It continues to deteriorate, affecting the output produced; hence, it also affects the slowing down or imbalance of the respective IPP industry technical efficiency score performance.

Possible loss of precision suggests an entry of uncontrollable factor such as ISO Certification and Age of Technology (imprecision/ fuzziness), that occurred in FDEA operations as exhibited. IPP performance results. The uncontrollable factors for input and output UCVRS-TE orientation bounds inappropriately, as shown in the Tables cited. The value of the efficiency score is smaller than the conventional method efficiency score results. The content imprecision and the need for enhanced discrimination are implied.

Inappropriate use of scale transformation points to the failure of recognizing the proper consideration of input and output orientation for the CVRS TE assumption. It illustrates how the actual scores vary at a non-significant level with slacks occurrence at a disappointing trend. Normally, by yielding to the correlation results between each stage and the orientation familiarization, the scale transformation deficiency is minimized.

Mismanagement of variable alternatives conveys improper management and a misconception of various variable input and output resources. As depicted in the table, input and output slacks could be reduced and minimized as long as the IPP decision makers are able to use their managerial skills wisely. DEA Stage 1, FDEA Stage 2 and FDEA Stage 3 approaches manifested comparative results of how industries can, in fact, respond to an obscure situation. It does not show that poor variable alternative management is no exception for such industries which obtained inefficient score performances.

Non-compliance with quality standards suggest total disregard of standard quality system requirements for each industry to comply. The table signifies the impact of the lack of ISO Certification (annual average reduction of 1.13 percent) on the efficiency performance of the nine (9) IPP firms, lessening or reducing the average output deficit of total operating revenue (29 percent) and total MWH Sales (196 percent) within the relative efficiency performance.

Disregard of Technology rehabilitation/upgrading implies total ignorance of technology requirements. A reduction of 1.22 percent for old machineries and facilities that need to be rehabilitated, along with the use of updated technologies, is tantamount to an efficient score on the mentioned IPP industries. With an astounding Total MWH Sales (7594 percent) deduction effort for output resources, the input deficits of 8 percent (Total Number of Employees) and the 22 percent estimate for depreciation expenses of retaining the old machinery/facilities and operation personnel budget could have been minimized.

Table 15: The Summary of Input and Output Slacks (DEA Stage 1 Model)

DEA- Stage 1 Model				
Industry/ IPP Firms	**Input and Output Slacks (%) Average Summary (2000-2006)**			
	Input		**Output**	
	Total Number of Employees	**Depreciation Capital/ Eqp.**	**Total Operating Revenue**	**Total MWH Sales**
SDPP	-	3	89	12
KPSPP-I	-	-	35	-
KPSPP-II	-	-	81	14
CHEPP	-	4	-	8
BHEPP	-	-	-	500
ICCPP	-	-	2	-
MOTPP 1 &2	-	-	3	-

SCPP	-	-	-	4
PCPP	0.3	-	206	9
Mean	0.1	0.4	46	61

Table 15 shows the input-output slacks of the 9 selected independent power producers (IPP) firms. For an IPP industry to be efficient, a zero slack must be accomplished in any of the input and output variables. As exhibited in the table, IPP firms SDPP, CHEPP and PCPP fell short of satisfying zero slack in the input variables on depreciation expenses, as they posted 3 percent (SDPP) and 4 percent (CHEPP) excesses on capital in their input utilization. Average yearly reduction in depreciation required for the IPPs should amount to 0.4 percent within 2000-2006. PCPP needs to reduce an average of 0.3 percent in its total number of employees for efficient performance. Similarly, the average number of total employees per year for the IPPs to be efficient requires a minimal reduction of 0.1 percent. Although the remaining 6 firms have zero input slacks, they still accumulated a huge amount of output slacks deficit, which made the firms deficient.

Meanwhile, the output slacks exhibited a number of IPP firms with deficiencies in the total operating revenues, wherein KPSPP-I with 35 percent, KPSPP-II with 81 percent, ICCPP with 2 percent, MOTPP 1 and 2 with 3 percent and SDPP posting the biggest deficiency with 89 percent. Table 2 above shows the average yearly improvement of the whole IPPs, which requires 46 percent in total operating revenues to be efficient. Moreover, some of the aforementioned and remaining IPP firms posted deficiencies in Total MWH Sales, SDPP (12 percent); KPSPP-II (14 percent); CHEPP (8 percent); BHEPP (500 percent); SCPP (4 percent); and PCPP (9 percent). An improvement of 61 percent per year is needed in the use of resource inputs.

Table 16: The Summary of Input and Output Slacks (FDEA Stage 2 Model)

FDEA- Stage 2 Model					
Industry/ IPP Firms	**Input And Output Slacks (%) Average Summary (2000-2006)**				
	Input			**Output**	
	Total Number of Employees	**Depreciation Capital/ Eqp.**	**ISO Certification**	**Total Operating Revenue**	**Total MWH Sales**
SDPP	-	-	-	11	10
KPSPP-I	-	-	4	25	3
KPSPP-II	-	-	2	25	189
CHEPP	-	-	-	2	18
BHEPP	-	1	-	-	1526
ICCPP	2	2	-	0.3	-
MOTPP 1 &2	10	12	4	3	-
SCPP	12	5	-	-	4
PCPP	14	6	0.14	149	11
Mean	4.22	3	1.13	24	196

Note: none or zero slack.

On average, the table exhibits the input-output slacks of 9 selected IPPs, as mentioned majority of seven (7) IPPs are not efficient in their technical performance due to both input and output slacks considerations. The IPPs ICCPP, MOTPP 1 and 2, SCPP and PCPP had a slack in the input variables as to the total number of employees with 2 percent, 10 percent, 12 percent, and 14 percent, respectively. The IPP industry needed to reduce its total employees' expenses by 4.22 percent to be efficient. Depreciation, or the wear and tear in the use of capital and plant stocks of the IPPs, must be considered. The average reduction needed in the use of capital (depreciation) of BHEPP, ICCPP, MOTPP 1 and 2, SCPP and PCPP stood at 1 percent, 2 percent, 12 percent, 5 percent and 6 percent, respectively. In contrast, the average annual reduction in depreciation required for the IPPs was 3 percent within 2000 to 2006. The investment in machine and equipment of IPPs helped in their application for ISO certification. ISO certification made the majority (1 out of 9) of the IPPs efficient within the 7-year period. Only IPP (KPSPP-I, KPSPP-II, MOTPP 1 and 2 and PCPP) showed a decline in efficiency at 4 percent, 2 percent, 4 percent, 0.14 percent and 1.13 percent annually due to lack of ISO certification.

Meanwhile, the output slacks were exhibited by the most numbers of IPP firms with deficiencies for Total operating Revenue and Total MWH Sales, tallied by SDPP with 11 percent and 10 percent; KPSPP-I with 25 percent and 3 percent; KPSPP-II with 25 percent and 189 percent; CHEPP with 2 percent and 18 percent and PCPP with 149 percent and 11 percent; BHEPP with 1526 percent (Total MWH Sales); ICCPP with 0.3 percent (Total Operating Revenue); MOTPP 1 and 2 with 3 percent (Total Operating Revenue) and SCPP with 4 percent (Total MWH Sales) respectively. Table 4.10 shows the average yearly improvement of the whole IPP firms, which required 24 percent (Total Operating Revenue) and 196 percent (Total MWH Sales) to be efficient.

In sum, the IPPs should their input usage (total number of employees, depreciation and ISO Certification) by 35.13 percent (100-64.87) to achieve overall efficiency of 100 percent.

Table 17: The Summary of Input and Output Slacks (FDEA Stage 3 Model)

FDEA- Stage 3 Model					
Industry/ IPP Firms	**Input and Output Slacks (%) Average Summary (2000-2006)**				
	Input		**Output**		
	Total Number of Employees	**Depreciation Capital/ Eqp.**	**Total Operating Revenue**	**Total MWH Sales**	**Age of Technology**
SDPP	22	15	737	7246	-
KPSPP-I	2	10	71	730	-
KPSPP-II	2	35	264	10375	-
CHEPP	4	25	4	295	-
BHEPP	4	38	114	49681	-
ICCPP	2	1	4	3	-
MOTPP 1 &2	4	14	19	0.4	7
SCPP	14	28	1	2	-
PCPP	15	28	380	10	4
Mean	8	22	177	7594	1.22

Note: - none or zero slack.

Table 18: Comparative Technical Efficiency Performance Analysis of IPPs (%) (DEA-Stage 1, FDEA-Stage 2 & FDEA-Stage 3) (2000-2006)

DMU	Industry	DEA	FDEA	FDEA
	IPP Firms	**CVRS-TE (Stage 1)**	**UCVRS-TE (Stage 1)**	**UCVRS-TE (Stage 3)**
1	SDPP	18.9	18.9	28
2	KPSPP-I	47.42	47.42	3
3	KPSPP-II	40.28	40.28	14
4	CHEPP	96.42	96.42	2
5	BHEPP	61.28	61.28	34
6	ICCPP	93.8	93.8	1
7	MOTPP 1&2	84.63	84.63	1
8	SCPP	74.46	74.46	1
9	PCPP	67.27	67.27	1
Mean		64.86	64.87	10

Table 19: Spearman Rank Correlation Coefficient between DEA-Stage 1 versus FDEA-Stage 2 and DEA- Stage 1 versus FDEA – Stage 3

Method	Correlation Coefficient	Significance
CVRS (Stage 1) and UCVRS_I (Stage 2)	1.000**	0.000
CVRS (Stage 1) and UCVRS_O (Stage 3)	*-0.805***	0.000

Note: **. Correlation is significant at the 0.01 level (2-tailed); a. Listwise N = 63

The result of the study shows that the perfect correlation between CVRS Stage 1 an UCVRS- Stage 1 versus FDEA – Stage 2 is r = 1.000 as illustrated in the table above. Using the two tailed test at 0.01, the result illustrates that there is agreement between the two approaches, with one approach being alternatively used in place of the other. This implies that the investment in machines and equipment of IPPs as controllable input resources is of great help in their application for ISO Certification (uncontrollable resource). This ISO Certification made the majority (1 out of 9) of the IPPs efficient within the period of 2000-2006. The early application of the IPP firm is to be efficient. Thus, there is a real direct correlation of stage 1 with respect to the stage 2 approach, particularly on how this ISO Certification really affects other controllable values to produce the expected output via using the input-oriented VRS scale assumption.

The null hypothesis (H3) rejected that there is a significant inverse correlation on total technical efficiency performance of IPP firms using non-fuzzy DEA and fuzzy DEA Models. Subsequently, CVRS-Stage 1 and UCVRS–Stage 3 approaches revealed that the correlation between them is r =-0.805, as shown in the table by the use of two tailed test at 0.01, which signifies an inverse correlation between the two approaches. This means that when IPPs' efficiencies are being measured and show good performance within two years, Age of Technology will affect the IPPs efficiency performance in the succeeding years if concerns on new machine investment in lieu of old machinery/equipment are disregarded.

Referring further to the results and analysis found in the table manifested that there is an output annual average reduction of 7594 percent (Total MWH Sales) and 177 percent (Total Operating Revenue) for the IPPs. This showed proof that old technology caused a decline in the technical efficiency of IPPs during the test period (2000-2006).

The Age of Technology has made the IPPs technically inefficient in their operation. Inputs usage results in Stage 3 Model and Stage 1 Model showed proofs that the Age of Technology diminishes the technical efficiency performance of IPP using non-fuzzy DEA and Fuzzy DEA Model.

Table 20: Stages 1, 2 and 3 Technical Efficiency (%) Performance Ranking Summary of Independent Power Producers (IPP)

DMU	Industry IPP Firms	DEA CVRS-TE (Stage 1)	Rank	FDEA UCVRS-TE (Stage 1)	Rank	FDEA UCVRS-TE (Stage 3)	Rank
1	SDPP	18.9	**9**	18.9	**9**	28	**8**
2	KPSPP-I	47.42	**7**	47.42	**7**	3	**6**
3	KPSPP-II	40.28	**8**	40.28	**8**	14	**7**
4	CHEPP	96.42	**1**	96.42	**1**	2	**5**
5	BHEPP	61.28	**6**	61.28	**6**	34	**9**
6	ICCPP	93.8	**2**	93.8	**2**	1	**1**
7	MOTPP 1&2	84.63	**3**	84.63	**3**	1	**1**
8	SCPP	74.46	**4**	74.46	**4**	1	**1**
9	PCPP	67.27	**5**	67.27	**5**	1	**1**
Mean		64.86		64.87		10	

The table shows that nine (9) selected independent power producers and their respective ranks and technical efficiency scores. Based on the results, Stage 1 had a slight difference (0.01 percent) with a total technical efficiency score of 64.86 percent than Stage 2, which was only 64.87 percent. Statistically, they are perfectly correlated with each. Considering the Stage 3 approach, those which tallied an imbalanced score of 10 and inversely correlated with Stage 2, diminished in the technical efficiency due to technology age. But through the introduction of ISO Certification for Standard Quality System, the IPP firm's technical efficiency performance improved. A yearly average of 1.13 percent deduction in ISO Certification is an initiative effort that the IPP is efficient in machine and equipment investment allocation.

FDEA – Stage 2 is recommended because it is empirically tested compared to DEA-Stage 1. The justification for this recommendation is due to the analysis and discussion. Therefore, IPP technical efficiency within the unconventional FDEA Approach could not be expected to be higher than the conventional DEA approach results. However, as previously mentioned, scholars have discovered that the technical efficiency scores are lower and far from the efficient frontier.

This implies that there is a possible loss of precision and the discriminating power of this FDEA Model. Moreover, this particular model has a unique characteristic to handle these empirical discoveries surrounding the current study, such as: *the inappropriate use of scale transformation, mismanagement of variable alternatives, non-*

compliance of quality standards (ISO Certification) and disregards of technology rehabilitation/upgrading.

6. Conclusions

The study shows that **ISO Certification & Age of Technology** entry into the IPP firm study characterizes enhanced discriminating power in spite of dropping efficiency score values, connotes the *possible loss of precision.*

The study shows that **input and output orientation via UCVRSTE** (Stages 2 &3) manifested inefficient results, signifying *inappropriate use of scale transformation*.

The study shows that **misallocation of input/output resources as evidence of slacks occurrence** presented in three stages implies *mismanagement of variable alternatives.*

The study shows that **an annual average of 1.13 percent yearly for ISO** Certification compliance is required for the IPP firms' relative technical efficiency, and continuous deterrence yields *non-compliance of quality standards.*

The study shows that **an annual average reduction of 1.22 percent** also for old machineries/ facilities refurbishment + updated technologies utilization, a prerequisite for IPP efficiency score. Thus, non-adherence means *disregard of technology rehabilitation/ upgrading.*

The study is observed that there is a clumsy technical efficiency performance of IPP firms needs an immediate institutional/ restructuring reform, deregulation, full implementation of EPIRA 9136 and other applicable power laws, create further energy enhancement and sustainable development, empowers on continuous research program for electricity technology based on new innovations as to **i**mprecision caused by inefficient managerial capabilities invigorates enormous slacks, proper utilization of input /output mixes put stoppage on mentioned deficiencies to ensure compliance of ISO Certification and full rehabilitation of deteriorating technologies of IPP industry**,** apparently, alleviates its huge substantial losses (not proportionate energy production & escalating capital expenditure) and fragile condition.

Conflict of Interest Statement

The authors declare no conflict of interest in this research.

About the Authors

Engr. Rene Daclan Olamit joined the University of Caloocan City in 2026 and currently serves as the Associate Professor 1 in the Electrical Engineering Department. Prior to his appointment at the College of Engineering, from 2022 to 2025, he served as the Assistant Professorial Lecturer III, Assistant Professorial Lecturer IV, Lecturer: Pamantasan Ng Lungsod ng Maynila (PLM); Universidad De Manila (UDM); Quezon City University (QCU), respectively. His research paper Title: Efficiency of Independent Power Producers: A Fuzzy DEA Approach, co-authored by Dr. Emilyn C. Cabanda, was selected as one of the excellent submissions, which eventually presented, during the *7th International Data Envelopment Analysis Conference* held on July 10-12, 2009 in the Alter Hall, *The Richard J. Fox School of Business and Management,* Temple University, 1801 Liacouras Walk, Philadelphia, PA 19122, United States of America. A native of Camp James McNiel Crawford, Del Monte, Phillips, Bukidnon, Philippines, Engr. Olamit earned his bachelor's and masteral degrees in engineering in the City of Cagayan De Oro and Manila. A recipient of *PECCUI/ DERBCI Scholarship*, where he obtained his Bachelor of Science in Electrical Engineering, *College of Engineering and Architecture*- Cagayan De Oro College, Philippines (1990). He also obtained his *Master of Science in Management Engineering* (Meritus Latin Honour) in the *Graduate School Program* in the Royal and Pontifical University of Santo Tomas, Philippines (2008). with a *Monetary Grant Recipient for Best Thesis Research* from the University of Santo Tomas Graduate School Alumni Association Inc. (USTGSAAI). He is currently pursuing his Doctor of Philosophy Major in Commerce Program at the same university (2026). He is also a competent *Electrical & Instrumentation Manager /Superintendent / Engineer* with a total of 28 Years experiences in various Industries / Sectors from countries: Republic of the Sudan, Negara Brunei Darussalam, Federal Republic of Nigeria, Kingdom of Saudi Arabia and the Philippines. He just recently recognized and awarded as one of the *ASEAN Engineer* with specialization in *Diversified Project Management* at the CAFEO 43- Philippines (2025).

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