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SUSTAINABILITY-ORIENTED SUPPORT MECHANISMS FOR PROMOTION OF RENEWABLE ENERGY SYSTEMS

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Abstract

This paper presents a comprehensive approach for Generation Expansion Planning (GEP) problem in the presence of Distributed Energy Resources (DER). Different support schemes for DER investors are considered and their impacts on sustainable development are modeled. Regarding this matter, several indicators are presented for evaluating different aspects of sustainable development achievements. Moreover, a decision making framework is proposed using a combined fuzzy Analytic Hierarchy Process (AHP) and Technique for Order Performance by Similarity to Ideal Solution (TOPSIS). The effectiveness of the proposed framework is assessed by a numerical study on a test system.

Keywords: Sustainable development; Generation expansion planning (GEP); Distributed energy resources (DER); Support scheme; Sustainability indicator.

1. INTRODUCTION

1.1. \Motivation and incitement

Traditionally, power system planning problem focuses on finding the least-cost generation resources including typical conventional fossil fuel based units without paying attention to a complete set of available generation portfolio alternatives. The predominant share of conventional fossil fuel units in power generation sector has increased concerns on climate changes, energy security, and price volatility [1]. Having these challenges in mind, many power systems have started changing their generation portfolio including significant amounts of renewable energy resources toward a sustainable energy development. The most important aim of sustainable energy development programs is energy generation and consumption in a way which human lives and ecologic balance are guaranteed in long term. Under this perspective, an efficient energy resource planning problem must consider the entire supply-side and demand-side potential resources. However, the high investment costs as well as the inherent stochastic nature of renewable energy resources in power generation are the main obstacles for these energy resources to being fully competitive with conventional units [2]. On this basis, power market regulators attempt to design appropriate support schemes to increase investment in Distributed Energy Resources (DERs) with the aim of achieving a sustainable energy development. The electricity market incentives, government regulation and popular support for research and expansion are the essential factors for expansion of DERs which are expected to motivate the investors by increasing their profits and reduce their risks [3].

1.2. Literature review

The Brundtland Commission's report defined the sustainable development as "development which meets the needs of current generations without compromising the ability of future generations to meet their own needs" [4]. The sustainable development issue contains three main basics including environmental, economic and social aspects [5] efficient utilization of the system is evaluated by considering the whole aspects. There are several researches about sustainable development which are accomplished in all over the world. Reference [6] investigates the situation of energy generation and energy consumption in Indonesia. In addition, the situation of the country in utilization of renewable energy resources such as wind, PV and biomass is reviewed. Ref. [7] outlines a multicriteria analysis framework to assess a country's sustainable energy transition readiness level, drawing from four pillars—social, political/regulatory, economic and technological—comprising a consistent set of eight evaluation criteria. Ref. [8] generates an energy and environmental model using LEAP to forecast energy demand, supply, emissions for Chile by 2030 and create scenarios considering different policies motivated by current policy as well as national and international commitments from Chile. In [9], the power supply and demand have been studied, modelled, analyzed, and foresighted as one of the most important energy carriers. The Business as usual (BAU) scenario was compared based on continuing the status quo with seven other proposed possible scenarios up to the horizon 2050. Ref. [10] investigates several sustainable hybrid renewable systems for electricity production in Iran. In this regard, critical indicators that have the strongest impact on the environment and energy sustainability are presented in this study. After a comprehensive review of environmental issues, data was collected from the meteorological organization and a techno-economic assessment was performed using HOMER software. In [11], a brief energy profile and renewable energy potential in Algeria have been reviewed. The Algerian territory is characterized by abundant renewable energy resources such as solar, wind, hydro, biomass, and geothermal energy. Ref. [12] deals with site selection problems for wind hydrogen production and aims to propose a structural procedure for determining the suitable sites. The study area is Algeria. The methodology focuses on the combined use of geographic information systems (GIS) and multi-criteria decision making (MCDM), aiming to provide a decision tool for wind hydrogen production sites. Ref. [13] develops an integrated framework to evaluate land suitability for hydrogen production from solar energy site selection that combines multi-criteria decision making (MCDM) with geographical information systems (GIS); an application of the proposed framework for Algerian country. Ref. [14] develops an energy forecasting model with renewable energy technologies on which policy can be based, using the Korean energy policy as a case study. Deep learning-based models forecast fluctuating variation in electricity demand and generation, which are necessary in renewable energy system but not possible with conventional models. Ref. [15] proposes a novel approach for distributed energy resource (DER) expansion planning from investors' viewpoint based on a combination of dynamic programming algorithm and game theory.

In most of the above works the role of policy intervention and the way of designing support schemes for achieving sustainable development are not considered.

1.3. Contributions and organization

This paper aims to design various support schemes for distributed energy resources in the generation expansion planning problem towards a sustainable energy development and select the best one according to the sustainable development indicators considering different stakeholder’s goals. For this purpose, three interdependent fundamentals of sustainable development including social, economic and environment objectives which are related to each other by effective government institutions have been accounted. It is worth noting that the current paper aims to propose a comprehensive framework considering versatile stakeholders and their own specific considerations. The stakeholders such as administrative entities, investors and consumers are taken into account to achieve a sustainable development, whereas the past studies took a look at the problem from just one point of view. Finally, to provide a guideline for the power market regulator, an appropriate Multi Attribute Decision Making (MADM) method has been selected for handling such optimization problem. The proposed approach combines fuzzy Analytic Hierarchy Process (AHP) and the Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) methods. In this context, the uncertainty in decision makers’ preferences which depends on the ambiguity in human being’s subjective judgment are modeled through Fuzzy set theory and then, prioritizing of different support schemes is realized by means of TOPSIS. This comprehensive model is vital as it reveals an interpretation of how power market regulators can design various support schemes to increase the share of distributed energy resources in order to achieve a sustainable energy development.

The rest of the paper is organized in the following order. Section 2 describes the problem formulation. Section 3 represents the application of the proposed model. The numerical study is presented in section 4. Finally, the conclusions are given in section 5.

2. PROBLEM FORMULATION

The goals of sustainable development are very wide; therefore, governments and regulators need a set of measurable indicators to measure and monitor the main changes towards these goals. In the following, three bases of sustainable development indicators are discussed to measure the progress towards sustainability. In this paper, seven indicators which cover economic, social and environmental aspects are presented in order to measure the sustainability achievement.

2.1. Social indicators

- **Fairness**

In the context of energy resource expansion, fairness for each consumer is introduced as the price paid for the electricity less than or equal to the electricity value. In order to indicate the electricity value, willingness to pay function is applied which shows the willingness cost of consumers for electricity consumption without any interruption. In this paper, in order to evaluate the fairness indicator, the cost which consumers should pay contrary to the fairness as follows [3]:

$$Cost^{unfair} = \sum_{k\in K} [\lambda\text{-}V(k)] \times d(k) \times t(k) \qquad (1)$$

- **Power reliability**

Reliability is one of the important indicators in power delivery. Since the horizon study is long term, Loss of Load Expectation (LOLE) is used as an indicator for reliability measure as follows [3]:

$$LOLE = \sum_{o\in O} \rho(o) \times t(o) \qquad (2)$$

- **Job opportunities**

The resource expansion should lead more job opportunities. In order to compare various studies on an equal footing, we adopt two simple normalizations to calculate lifetime average employment per unit of energy. First, ''one-time'' employment factors such as construction and installation are averaged over plant lifetime to obtain an average employment number that can be directly added to ongoing employment factors such as operations and maintenance. Next, to allow for comparison between technologies with different capacity factors, we calculate employment per unit of energy or per unit of average-MW of power output.

- **Portfolio risk**

Portfolio risk represents the degree of variability in power generation in order to ensure a balance between the various primary fuels. In the energy resource expansion planning, some resources that have long term security should expand. The portfolio risk is a useful indicator for measuring the long term security of resources. We have to consider a portfolio Ω compounded by different securities. The risk of a portfolio is defined as the standard deviation is given:

$$\sigma_\Omega^2 = \sum_{i\in N}\sum_{j\in N} \omega(i) \times \omega(j) \times \sigma(i,j) \qquad (3)$$

$$\sigma(i,j) = \varphi(i,j) \times \sigma(i) \times \sigma(j) \quad \forall i,j \in N \qquad (4)$$

$$\sigma^2(l) = \omega^I(l) \times \sigma^I(l) + \omega^F(l) \times \sigma^F(l) + \omega^{OM}(l) \times \sigma^{OM}(l) \quad \forall l \in L \qquad (5)$$

- ✓ **Technology cost risks**

Technology cost risk is the year-to-year variability of the generation cost for a certain technology, measured as the standard deviation of historical records on a yearly basis. This paper uses data of [3] that can characterize historical distributions of risk parameters with a normal distribution, averages and standard deviations. To estimate technology risks, we have to take into account that the cost of different technologies is compounded in different ways for investment, fuel and operation and maintenance costs. It could be expected that technologies based on fossil fuels be riskier than those technologies using renewable sources of energy, mainly as a consequence of high volatility of fossil fuel prices.

- ✓ **Fuel cost risks**

Variations parameters, i.e. fossil fuel resources depression, regulatory interventions, highly affect the fuel price.

- ✓ **Operation and maintenance cost risk**

The operation and maintenance cost risk is modeled as follows:

$$\sigma^{OM}(l) = \left[\omega^{Inf}(l) \times \sigma^{Inf}(l) + \omega^{Oth}(l) \times \sigma^{Oth}(l)\right]^2 \quad \forall l \in L \qquad (6)$$

The first term addresses the standard deviation of inflation rate that represents the variation of plants' maintenance costs during the time. The second term represents the extra costs of dependent technologies.

- **Technology costs correlation coefficients**

Resource diversification benefits are function of correlation coefficients. Less the correlation between the two resources, more benefit comes from diversification. In probability theory and statistics, the correlation coefficient is a dimensionless measure between -1 and 1 of the strength and direction of a linear relationship between two random variables [16].

2.2. Environmental indicator

Environmental indicator should be studied during the life cycle of each unit. Fig. 1 shows the life cycle of various resources. The life cycle assessment is an accepted tool for environmental impact assessment of each element in the entire life cycle of a product, process or activity. The emissions come from generation units affected by parameters such as efficiency, fuel consumption, fuel type and technology.

In this paper, a life-cycle greenhouse gas emissions indicator has been used as an environmental indicator.

2.3. Economical indicators

In this paper, two indicators are considered for this aspect as follows:

- **Cost**

Levelized cost of energy is an appropriate parameter to compare the costs of different types of power source [17].The levelized cost indicates annual present value of construction and operation cost of a plant in its lifetime. The investment and operation cost of a power plant over its useful life and is given:

$$\mathrm{SLCOE} = \frac{\mathrm{IC} \times \mathrm{CRF} + \mathrm{C}_{\mathrm{fix}}^{\mathrm{OM}}}{8.76 \times \mathrm{CF}} + \mathrm{C}_{\mathrm{var}}^{\mathrm{OM}} \times \mathrm{P}^{\mathrm{out}} \quad (7)$$

If only the economic indicators be used for energy resource expansion, given the low cost of fossil fuel-based technologies, penetration rate of these resources would increase sharply. However, issues such as the risk of fuel costs or generated pollution will not lead this expansion to sustainable.

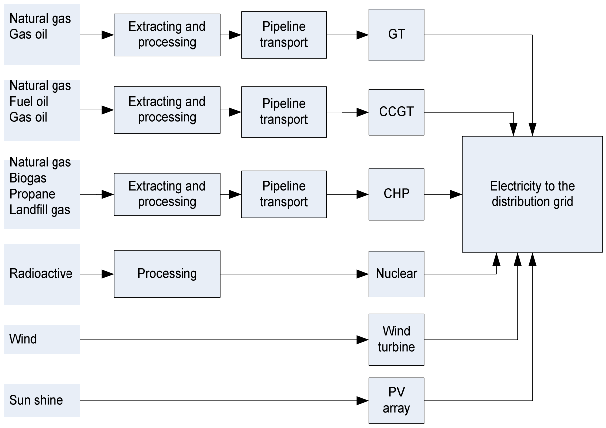

Fig. 1. LIFE CYCLE OF THE ENERGY RESOURCES.

- **Market participation**

Another economic indicator considered in this paper is the market participation indicator. From the perspective of each investor, the market participation is important and tries to have a greater share of market. However, from the regulation point of view, the diversity in the resource portfolio is too important. Ref. [3] considers three characteristic for diversity index: number of resources, balance between resources and difference between resources. Two first characteristics known as dual concept and Shanon index can represent them as follows:

$$\mathrm{H} = -\sum_{\mathrm{m}\in\mathrm{M}} \mathrm{P(m)} \times \ln(\mathrm{P(m)}) \quad (8)$$

3. APPLICATION OF THE PROPOSED MODEL

The sustainable development framework is based on three pillars: social, economic and environmental. To achieve a sustainable development, energy policies orient the goals of these three variables. The AHP is a quantitative technique that structures a multi-attribute problem hierarchically so that solutions are facilitated. One of the main advantages of this method is the relative effectiveness with which it handles multiple criteria. Even though the aim of AHP is to capture the expert's knowledge, the conventional AHP still cannot reflect the uncertainty in human thinking style. Therefore, fuzzy AHP was developed to solve the hierarchical fuzzy problems. The main flowchart of the approach is illustrated in Fig. 2. The TOPSIS method is utilized to rank the scenarios.

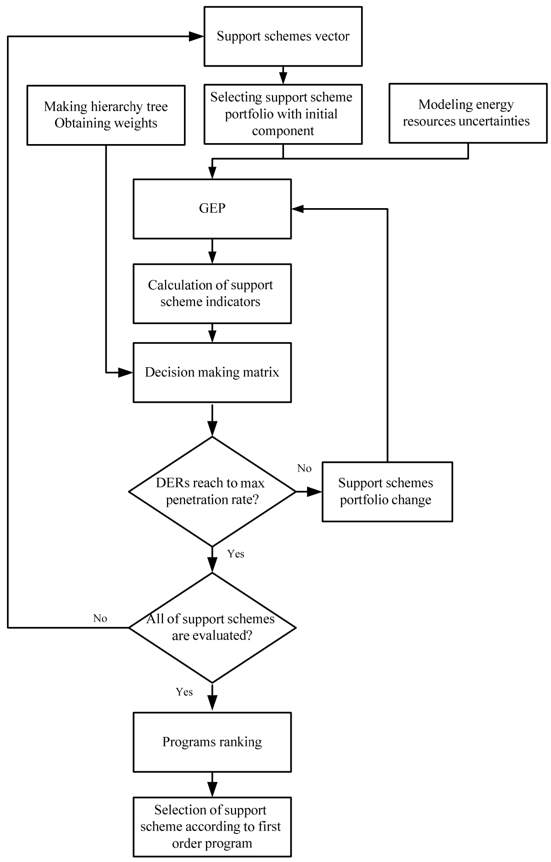

Fig. 2. FLOWCHART OF DECISION MAKING APPROACH

4. NUMERICAL STUDY

In this section, support schemes for some DERs are investigated to achieve sustainable development.

4.1. Under study system

In order to show the effectiveness of the proposed approach, the IEEE 39 bus test system is selected in the horizon study of 10 years. The yearly load of the system is divided into 3 periods, base, medium, and peak load. The seasonal factors are considered to be 1, 1.1, 1.2, and 0.9, respectively with 7044 MW peak load. The annual growth rate of the load and the interest rate are assumed to be 5% and 12%, respectively. The stochastic generations of wind and PV resources are modeled using scenario generation technique for every season. The uncertainty related to demand response resources are also modeled by scenario. The energy resources include: bulk generation such as combined cycle and nuclear resources and DERs such as gas engine, wind turbine, photovoltaic (PV), combined heat and power (CHP) and DR. In order to achieve a sustainable development, some support schemes are designed which is investigated in numerical studies. The simulation results indicate the expansion strategy and penetration rate of generation technologies over the horizon study. Furthermore, the value of each indicator and the amount of sustainability are reported. In this paper, eight support scheme strategies are considered. The first one is non market based support scheme Type 1 (FIT1) and is constant during the time horizon. The second non market based support scheme decrease with descending slope and even in some years the support is lower than the electricity price (FIT5). Third support scheme is market based Type 1 and the support is in proportion to the electricity price (FIT2). The fourth support is also market based but, in some studied years, there isn't any support (FIT3). The fifth support scheme is market based but, the amount of FIT is controlled and in the case of high electricity price, there isn't any support (FIT4). The sixth support scheme is “green certificate tariff”. The seven one is the quota and certain amount of investments are considered for the resources and finally, the eighth support is “interest rate reduction”. The FIT support schemes are shown in the Figs. 3-7.

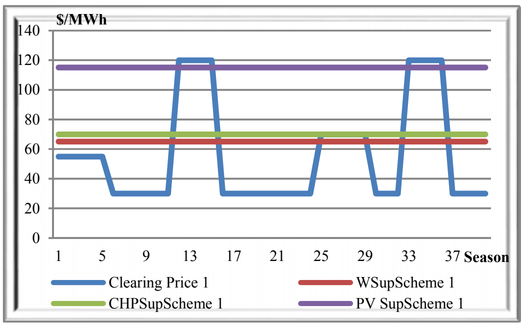

Fig. 3. SUPPORT SCHEME FIT1

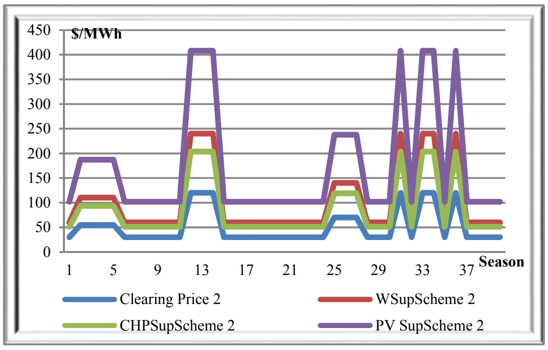

Fig. 4. SUPPORT SCHEME FIT2

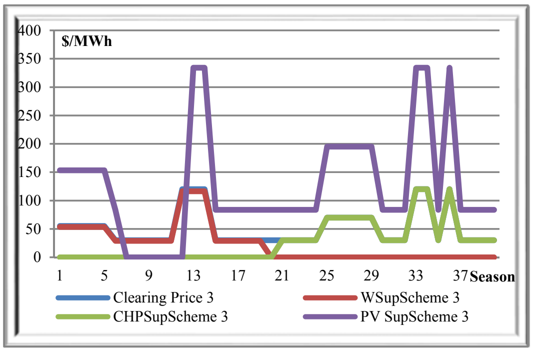

Fig. 5. SUPPORT SCHEME FIT3

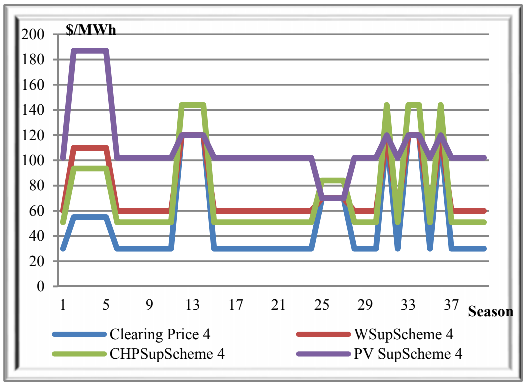

Fig. 6. SUPPORT SCHEME FIT4

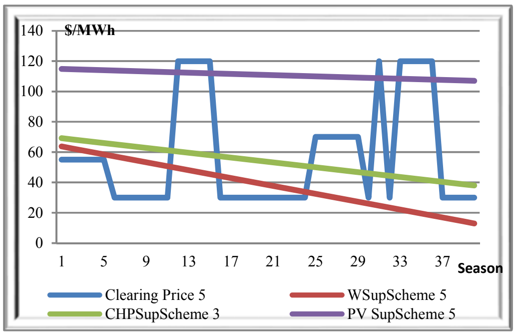

Fig. 7. SUPPORT SCHEME FIT5

Table 1 and 2 show the weights of indicators and pills respectively. Table 3 shows the final weight of indicators. These weights are obtained using questionnaires filled by experts and by means of AHP method.

TABLE. 1. THE WEIGHT OF EACH INDICATOR

Pillar	Indicator	Weight
Economical	Cost	0.86
	Market participation	0.14
Social	Risk	0.54
	Occupation	0.26
	Reliability	0.20

TABLE. 2. THE WEIGHT OF EACH PILLAR

Pillar	Economical	Social	Environmental
Weight	o.3	0.4	0.3

TABLE. 3. THE INITIAL WEIGHT OF INDICATORS

Indicator	Emission	Occupation	Reliability
Weight	0.3	0.104	0.08
Indicator	Risk	Market participation	Cost
Weight	0.216	0.042	0.258

4.2. Results and discussions

Table 4 shows each indicator rang of variation. Columns 2 and 4 demonstrate the minimum and maximum values of each indicator and the last column depicts its total variation. As it can be seen in the table, some indicators have considerable variations, e.g. fairness, while the difference between the maximum and minimum amount of some other indicators are less, e.g. greenhouse gas. This criterion addresses the level of that specific indicator's sensitiveness regarding different policies. Indeed, for enabling sustainable development all indicators should be near their individual optimum amounts, simultaneously. Table 5 addresses the policies that have the most positive and negative impacts on each indicator. This analysis is appropriate for single objective decision making. Table 5 lists the policies that have the most and the least impacts on each resource expansion. This analysis is suitable for the planner of the system to predict the impacts of each single resource support scheme.

TABLE. 4. OPPORTUNITIES AND CHALLENGES

Indicator	Positive effect	Negative effect
Fairness	FIT1, FIT2, FIT4, Quota, Interest rate reduction	Green certificate tariff
Reliability	Green certificate tariff	FIT3
Job opportunities	Interest	Green certificate tariff
Portfolio risk	Interest rate reduction	FIT2
Cost	Green certificate	Interest rate reduction
Market participation	Interest rate reduction	FIT1
greenhouse gas	Green certificate tariff	FIT1

TABLE. 5. IMPACTS OF THE POLICIES

Resource	Least effect policy	Greatest effect policy
Wind	FIT1	Interest rate reduction
PV	Green certificate tariff	FIT3
CHP	FIT4	Quota
DR	Quota	Interest rate reduction
Gas	FIT1,FIT2,Green certificate tariff, Quota, Interest rate reduction	FIT5
Comb cycle	Interest rate reduction	FIT2
Nuclear	Green certificate tariff	Quota

In the case of multi criteria decision making, the results for 10-year period are ranked in Table 6. The best support scheme which has greatest impact on enabling sustainable development is the "interest rate reduction" policy.

The FIT4 support scheme is the best policy among different FIT policies. Because, in the most studies time intervals, its profitability function is greater than the others. However, all of its indices are not better than indices' of other FIT policies (e.g. job opportunity indicator). Comparison between FIT2 and FIT4 shows that adding more supports in high electricity price periods will not lead to better sustainability solution.

Although the FIT5, is decreasing year by year, but it shows that this support has better profitability function in compare with the fixed support and it is demonstrated that adding more supports will not necessarily lead to more sustainability. Comparison between FIT5 with "green certificate tariff" shows in the first half of the study period, the FIT5 has the best performance. However, the profitability function of the green certificate tariff policy is better in the second half period. Table. 7 shows the ranges of the indicators.

It can be concluded, although the "interest rate reduction" support scheme has not the greatest impacts on all mentioned indicators, it is the best option from the sustainable development viewpoint.

TABLE. 6. SCENARIOS RANKING.

Policy	Mean
Interest rate reduction	0.18571
FIT4	0.17996
FIT5	0.17202
Green certificate tariff	0.17017
FIT2	0.17006
Quota	0.1666
FIT3	0.16625
FIT1	0.16596

TABLE. 7. RANGES OF THE INDICATORS

Indicator	Max	
		State
Fairness	1147.445	FIT5,Year5
Reliability	0.000135	FIT3,Year2
Job opportunities	1702.7	FIT3,Year10
Portfolio risk	0.3408	FIT5,Year1
Cost	941878	FIT5,Year10
Market participation	1.37	FIT5,Year10
Greenhouse gas	32833233	FIT1,Year10
Indicator	Min	
	Value	State
Fairness	0	FIT1,FIT2,FIT4, Quota, Interest rate
Reliability	2.24E-06	FIT3,Year8
Job opportunities	816.24	FIT5,Year1
Portfolio risk	0.2026	Interest rate,Year10
Cost	548907	Green certificate,Year1
Market participation	0.91	FIT1,FIT4, Year1
Greenhouse gas	23905076	Green certificate,Year1
Indicator	Mean	Total variation (%)
Fairness	101.1852	100
Reliability	9.24E-06	98
Job opportunities	1164.967	53
Portfolio risk	0.27436	41
Cost	728895.3	42
Market participation	1.11965	34
Greenhouse gas	27656964	27

5. CONCLUSIONS

In this paper, a decision making framework was proposed to evaluate a set of support scheme portfolio in order to move toward the sustainable energy development. Regarding this matter, seven indicators are suggested to cover all aspects of sustainable development. Moreover, eight support scheme policies were considered to evaluate impacts of their implementation on expansion planning studies. Therefore, two simulations are conducted, the first one evaluates the policies that have the most positive and negative impacts on each indicator. The second one addresses the policies that have the most and the least impacts on each resource expansion. It can be concluded, although the best support scheme was not the best for all mentioned individual indicators, it was the best option from the sustainable development viewpoint, i.e. profitability function.

6. NOMENCLATURE

Sets

K	Set of the consumes.
O	Set of the outages.
N	Set of the securities.
L	Set of the technologies.
M	Set of the resources.

Variables and parameters

$Cost^{unfa}$	Unfair Cost of the customers ($).
$V(k)$	Willingness to pay price for consumer k ($/kWh).
$d(k)$	Demand of the consumer k (kWh).
$t(k)$	Duration to pay electricity price for consumer k (h).
LOLE	loss of load expectation (h).
$t(o)$	Number of hours a loss of load for outage o.
$\rho(o)$	Probability of the capacity outage state o.
λ	Electricity price ($/kWh).
σ_{Ω}^{2}	Expected return of the portfolio.
$\omega(i)$	fractional weight for security i.
$\sigma(i,j)$	Covariance of the securities i and j.
$\sigma(i)$	Standard deviation for security i.
$\sigma^2(l)$	Technology variance l.
$\omega^I(l)$	Proportion of investment cost in the total technology cost of technology l.
$\sigma^I(l)$	Standard deviation of the historical investment costs of technology l.
$\omega^F(l)$	Proportion of fuel cost in the total technology cost of technology l.
$\sigma^F(l)$	Standard deviation of the historical fuel costs of technology l.
$\omega^{OM}(l)$	Proportion of O&M cost in the total technology cost of technology l.
$\sigma^{OM}(l)$	standard deviation of the historical O&M costs of technology l.
$\omega^{Inf}(l)$	Proportion of inflation rate of technology l.
$\sigma^{Inf}(l)$	Inflation risk of technology l.
$\omega^{Oth}(l)$	Proportion of dependent technologies risk in the total maintenance risk of technology l.
$\sigma^{Oth}(l)$	Dependent technologies risk of technology l.
SLCOE	Investment and operation cost of a power plant
IC	Investment cost
CRF	Capacity recovery factor
C_{fix}^{OM}	Fix cost of the operation and maintenance.
CF	Capacity factor.

C_{var}^{OM}	Variable cost of the operation and maintenance.
P^{out}	Output power of the power plant.
H	Shanon index
$P(m)$	Market participation of resource m.

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