Evaluation of the energy system through data envelopment analysis: Assessment tool for Paris Agreement

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Abstract

various energy related studies use the data envelopment analysis (DEA) approach to measure the efficiency of decision making units (DMUs). However, heterogenous DMUs and either inappropriate input or output-oriented DEA model lead to unreasonable results. K-Mean clustering method was applied to select homogenous countries from energy data perspective. The input oriented DEA model was performed for power stations (PS) under renewables. The PS under non-renewables and refineiries as well as demand side were analyzed via the output-oriented model. The energy related quality of life (QoL) was the output of the demand efficiency analysis. The overall energy efficiency was calculated by multiplying the efficiency of both sides of energy. The results of the paper specified that the highest potential energy saving (PES) source in the supply side belongs to the non-renewables in power stations, followed by refineries, and finally deployment of renewables. Demand side analysis identified that the highest PES belongs to countries with high population, and high-income economy. In conclusion, the results of overall energy efficiency relying on QoL, suggested an allowance for non-renewables deployment in countries with low economic and low population. The allowance was proposed to support energy poverty, health improvement, and promotion of education.

Keywords: Energy consumption, Data envelopment analysis, Overall efficiency, Quality of life.

Nomenclature

BCC	Banker, Charnes and Cooper	IMR	Infant Mortality Rate
CCR	Charnes, Cooper, and Rhodes	IWA	Improved Water Access
CHP	Combined Heat and Power plant	(In)Eff.$_{P\ NRE.}$	(In)Efficiency of power stations under NRE resources
CHP	Combined Heat and Power	(In)Eff.$_{R.}$	(In)Efficiency of refineries
CRS	Constant Return to Scale	(In)Eff.$_{RE.}$	(In)Efficiency of power stations under RE resources
DEA	Data Envelopment Analysis	LEB	Life Expectancy at Birth
DMU	Decision Making Unit	MYS	Mean Years of Schooling
FEC	Final Energy Consumption	NRE	Non-renewable energies
FECpc	Final Energy Consumption per capita	OECD	Organisation for Economic Co-operation and Development
GDP	Gross Domestic Product	P_NRE	Input resources from NRE for Power stations
GEA	Global Energy Assessment	QoL	Quality of Life
GNI	Gross National Income	R_NRE	Input resources from NRE for Refinery
HDI	Human Development Index	RE	Renewable Energies
IEA	International Energy Agency	TPES	Total Primary Energy Supply
IHR	Infant Health Rate	VRS	Variable Return to Scale

1. Introduction

Energy is an economic good [1] which influences on economic, environment, and human development [2]. One of the purposes of the energy policy is to improve the energy efficiency in all its life cycle. Energy cycle consists of supply and demand technologies, institutions, energy resources, energy consumption pattern, energy policies, and regulations [3]. Investigation on overall energy efficiency targets the energy

life cycle from the cradle to grave [4]. It explore the potential ways to reduce energy consumption in both sides of energy system.

Analysis of energy efficiency from consumer perspective specifies how much resource extraction in the supply side is required to satisfy the human needs [4] in the demand side. Human needs analysis and its relation with energy consumption identifies the social value of energy [5], [6] to reduce energy poverty and CO_2 emissions as well as improve human development [7] in the society.

However, applying the DEA technique on heterogeneous countries from economic, and population provides impractical results, to evaluate and calculate the potential energy saving. This study conducts K-Mean clustering approach to find homogenous countries from economic and population, which are influential factors on energy consumption within country [1]. Then, the DEA technique is used for each group of homogenous countries to measure the reasonable potential energy saving within country. In other words, this study employs an analytical approach to answer the following research question:

I) How much potential energy saving is available in the energy system of a country relying on QoL?

The first contribution of the current paper is to conduct the K-Mean clustering method to homogeneity of the DMUs (here, energy consumption of countries). The second contribution of the paper includes the combination of the supply and demand side's efficiency by concentration on QoL to measure the overall efficiency. Applying the de-commoditization strategy to separate the efficiency analysis of renewables from non-renewables by two different orientation models, is the third contribution of this article.

2. Methodology

Equation (1) illustrates the overall efficiency definition as a ratio of satisfaction to eco-sacrifice [4]. Decomposition of the ratio in terms of the service and commodities, extracts three strategies for enhancing environmental sustainability [8].

$$Overall - Efficiency = \frac{Satisfaction}{Eco-Sacrifice} = \frac{Satisfaction}{Service} \times \frac{Service}{Commodities} \times \frac{Commodities}{Eco-Sacrifice} \quad (1)$$

The last ratio from right in equation (1), points out eco-efficiency strategy, and the next term addresses de-commoditization strategy, and the final one specifies eco-sufficiency strategy. Eco-sufficiency strategy limits the excessive use of natural resources, which brings about a little change in human development. Assume that the TPES of a country flows into power stations, refineries, or directly flows into end-use consumption[1], equation (1) is rewritten as follows:

$$Overall - Efficiency = \frac{FEC}{TPES} \times \frac{Satisfaction}{FEC} = \frac{FEC}{(RE+NRE)} \times \frac{Satisfaction}{FECpc} \times \frac{1}{Population} \quad (2)$$

Two last terms in the right-hand side of equation (2) identify the efficiency of demand side in the energy system. Dividing satisfaction of a community into its population results in per capita satisfaction. This paper applies a QoL index as a proxy for per capita satisfaction, by assuming the strong relationship between human satisfaction and QoL [9], [10]. The third term measures the efficiency of the supply side in the energy production system, in which the RE resources in the denominator indicates the de-commoditization of the energy resources. The NRE resources equals to the sum of the P_NRE and R_NRE resources.

[1] "Other transformation" energy is also supposed as part of end-use energy, which obtains without conversion in the energy balance flows (Sankey Diagram).

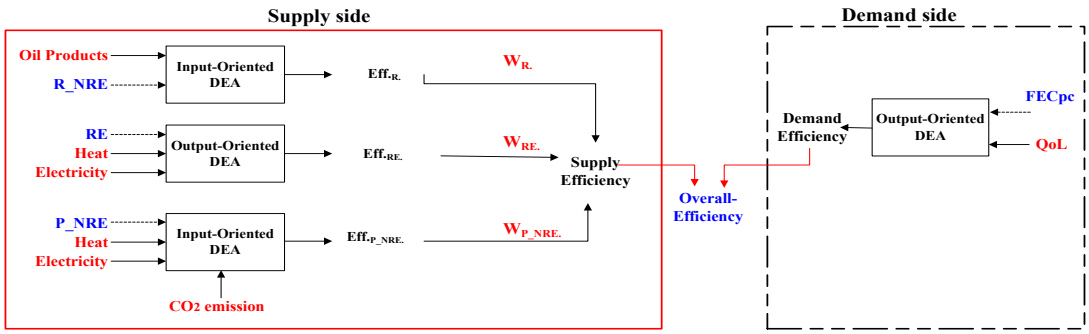


Figure 1: Framework of the energy related overall efficiency

Figure 1 demonstrates the framework of the overall efficiency associated to the demand and supply side of the energy system. The framework takes into account the social aspects of energy consumption through QoL indicator in the demand side. The DEA method [11] is applied to measure the efficiency of supply and demand side separately, which their multiplication calculates the overall efficiency.

2.1 DEA Model and technical efficiency

The CCR [11] and BCC [12] models are two famous approaches of the DEA to measure the technical (global) and pure technical (local) efficiency scores, respectively. Thus, considering scale inefficiency for the energy system of countries as a phenomenon is somewhat unfair [13], and hence, the rest parts study BCC models. Generally, DEA models maximize the ratio of output(s) to input(s) subjected to some constraints. The maximization process is obtained either minimizing the input variables (input-oriented model) or maximizing the output variables (output-oriented model). The output and input-oriented BCC models with input variables' $\mathbf{X}=(X_1, X_2,\ldots,X_m)$, desired output variables' $\mathbf{Y}=(Y_1, Y_2,\ldots,Y_k)$, with n decision making units are presented in equation (3) and (4), respectively.

$$\boldsymbol{Max}\ \alpha$$
$$\sum_{j=1}^{n} \lambda_j x_{ij} \le x_{ijo}\ ; i = 1, \ldots, m$$
$$\sum_{j=1}^{n} \lambda_j y_{rj} \ge \alpha y_{rjo}\ ; r = 1, \ldots, k \qquad (3)$$
$$\sum_{j=1}^{n} \lambda_j = 1\ ;$$
$$\lambda_j \ge 0\ ; j = 1, \ldots, n$$

$$\boldsymbol{Min}\ \beta$$
$$\sum_{j=1}^{n} \lambda_j x_{ij} \le \beta x_{ijo}\ ; i = 1, \ldots, m$$
$$\sum_{j=1}^{n} \lambda_j y_{rj} \ge y_{rjo}\ ; r = 1, \ldots, k \qquad (4)$$
$$\sum_{j=1}^{n} \lambda_j = 1\ ;$$
$$\lambda_j \ge 0\ ; j = 1, \ldots, n$$

However, the following transformation is carried out to change each undesired output, $y_{sj}^{undesired}$ (in case of this study, CO_2 emission), to desired output, $y_{sj}^{desired}$:

$$y_{sj}^{desired} = y_{sj}^{max} - y_{sj}^{undesired} \qquad (5)$$

Implementation of the DEA models to calculate the efficiency is affected by inconvenient data. Countries with low population and developed economy usually gain a higher efficiency score. Considering that energy consumption is heavily influenced by the population and the economy of a country. Therefore, this study categorizes 112 countries based on two aforementioned factors. Then, the DEA models are carried out for each category to provide benchmarking and efficiency information as close to practical as possible.

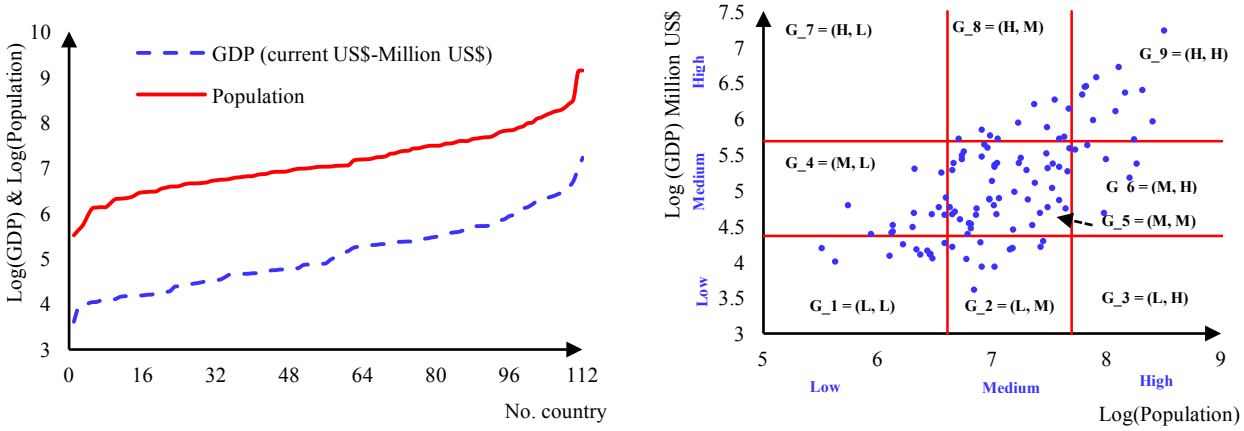


Figure 2: country categorization based on sorted GDP and population data (year 2013)

To cluster 112 countries (Figure 2) based on their economy and population, K-Mean clustering approach is used [14].

2.2 Potential energy saving

Potential energy saving in both supply and demand side, is measured by technical inefficiency. In supply side, technical inefficiency data are multiplied by input (output) of the corresponding DEA model to measure the potential energy saving as follows.

Potential energy saving at refinery= $\text{Ineff.}_{\text{R.}} \times$ R_NRE (6)

Potential energy saving at power stations under P_NRE resources= $\text{Ineff.}_{\text{P_NRE.}} \times$ P_NRE (7)

Potential RE deployment at power stations under RE resources = $\text{Ineff.}_{\text{RE.}} \times (\text{Electricity} + \text{Heat})_{\text{RE}}$ (8)

To measure the potential energy saving in the demand side, the QoL value of each country is obtained through the following formula:

$$QoL_j^t = \sum_{j=1}^{n} v_i^t . z_{i,j}^t \qquad i = 1, \dots, 6; \;\; t = 2005, \dots, 2013. \tag{9}$$

Where $z_{i,j}^t$ implies to i^{th} variable out of six variables of the QoL function in j^{th} country at time t. The v_i^t points out the coefficient corresponding the i^{th} variable at time t. The coefficients are obtained by factor analysis method (for more information please see [15]). The QoL value in equation (9) is normalized as follows:

$$QoL_j^t = \frac{QoL_j^t - \min(QoL^t)}{\max(QoL^t) - \min(QoL^t)} \qquad j = 1, \dots, n; \;\; t = 2005, \dots, 2013. \tag{10}$$

According to [15], the relationship between the results of equation (10) and FECpc has been modeled as follows:

$$QoL_j^t = \alpha^t / (\alpha^t + e^{\frac{-(FECpc)_j}{\beta^t}}), \tag{11}$$

Where α^t and β^t identify the shape and scale parameters for QoL against FECpc at time t, respectively. However, demand side analysis in the output-oriented model of DEA demonstrates the efficient country from QoL perspective with given FECpc. In other hands, the technical inefficiency value in the output-oriented DEA model suggests how much output (QoL value) should be increased to attain the efficient level,

while maintaining input(s). To calculate the potential energy saving related to the demand side, the impact of population should be considered as follows:

$$\text{Potential energy saving related to the QoL} = (FECpc_b - FECpc_a)*\text{Population} \quad (12)$$

Where $FECpc_b$ and $FECpc_a$ specify the FECpc before and after considering inefficiency, corresponding to the QoL_b and QoL_a, respectively. In other words, if the QoL_b determines the current QoL value in a desired country, then the $FECpc_b$ value is calculated by (11). The following calculations are required to obtain the $FECpc_a$ and QoL_a values for the year, *t*:

$$QoL_a^t = QoL_b^t + \frac{QoL_b^t \times Technical\ Inefficiency}{\max(QoL_{j,b}^t) - \min(QoL_{j,b}^t)} \quad j = 1, \dots, n. \quad (13)$$

Where *max* or *min* ($QoL_{j,b}^t$) characterizes the maximum or minimum QoL_j^t among 112 countries data, before considering inefficiency, which obtained through equation (10). By replacing the result of equation (13) into equation (11), the $FECpc_a$ is calculated. The key point here is that the above calculation measures just differentiation of FECP and QoL through the equation (11). This differentiation is used to calculate the potential energy saving in the demand side. However, the potential energy saving associated to the de-commoditization is measured as follows:

$$\text{Potential energy saving related to de-commoditization} = \text{Potential RE deployment at power stations under RE resources} / \eta \quad (14)$$

Where η is the efficiency of power stations under NRE resources, which is calculated by dividing the output $(\text{Heat+Electricity})_{P_NRE}$ to the input (P_NRE). The numerator of equation (14) is obtained by equation (8). In fact, this study assumes the overflow of energy production through RE resources can reduce the energy production by NRE resources.

2.3 Variables and data sources

This section defines all variables required to calculate the overall efficiency attributable to the energy system in 112 countries for nine years as Table 1.

Table 1: Overall efficiency variables

Variables	Unit	Variable	Unit	Variable	Unit
CO_2 emission	tonne CO_2	IMR**	Deaths (0-1 year)/ 1000 live births	Population	Million
Electricity	GWh	IWA	%	QoL	%
FEC	Ktoe*	LEB	Year	RE	Ktoe
GDP	Current Million US$	MYS	Years	R_NRE	Ktoe
GNI per capita	Current US $	Oil Products	Ktoe		
Heat	Terajoule (TJ)	P_NRE	Ktoe		

*Thousand tonnes of oil equivalent ** IHR=1-IMR

The RE consists of wind, solar, hydro (tide, wave, and ocean), geothermal, and biomass. In contrast, the P_NRE includes coal, crude oil, oil products (if applied for power plants[2]), natural gas, and nuclear. All data are collected through IEA website [16], except QoL data, which are measurable through reference [15]. The GDP, GNI, IMR, LEB, IWA, and MYS data, which required to calculate the QoL indicator, are obtained from the websites of the World Bank and Barro & Lee [17], [18], [19]. The normalizing process, equation (10), brings all QoL data into the range of [0, 1]. Thus, the FECpc data in equation (11) are transformed into the 10-base logarithm function to close the data range to each other.

3. Results

2 Power plant, combined heat and power plant (CHP), and heat plant.

This section includes the analysis of supply and demand side of energy separately, and finally multiplying the efficiency of both sides to obtain overall efficiency. Before proceeding with the DEA models, the K-Mean clustering method is conducted to categorize all countries into nine groups.

3.1 Country categorization

Different boundaries for both population and GDP values corresponding with each year are obtained (Table 2). Figure 2 represents the position of the G_1 to G_9 groups for data belong the year 2013. During a nine-year period, a country can be placed on different groups. The most frequently occurring, or repetitive, value in a group array of a country is considered as a rule to decide which country belongs to which group. It should be noted that the G_3 and G_7 are empty groups which excluded from the group list.

Table 2: Boundaries of country classification in terms of GDP and population

Year		2005	2006	2007	2008	2009	2010	2011	2012	2013
Log (GDP*)	Lower boundary	4.18	4.2273	4.3078	4.3747	4.3611	4.4123	4.4528	4.4684	4.4955
	Upper boundary	5.5443	5.5697	5.6417	5.6878	5.653	5.7204	5.7666	5.772	5.7885
Log (Population)	Lower boundary	6.5974	6.5859	6.5928	6.5906	6.6054	6.6181	6.6149	6.6197	6.6241
	Upper boundary	7.6844	7.6694	7.6753	7.6711	7.6885	7.7077	7.7022	7.7058	7.7117

*GDP (current US$-Million US$)

After categorizing 112 countries, the DEA models are performed to evaluate the efficiency of the energy system in a country compared with its group members.

3.2 Supply analysis results

Supply efficiency analysis includes two parts: 1) Electricity and heat generation through power stations 2) Oil products via refineries. Import of oil products, electricity, or heat does not consider in the supply efficiency analysis, because their influences are measured through QoL calculation by GDP and/or GNI indicators.

3.2.1 Electricity and Heat generation system

The output and input-oriented models of DEA were implemented for the electricity and heat generated through RE and P_NRE resources, respectively. To separate the electricity and heat generated by renewables, this paper gathered all outputs of power plants consist of electricity, CHP, and heat plants. The amount of electricity and heat generated through renewables were fixed, and subtraction of the both was assigned for non-renewables. In some cases, data obtained from "Renewables and Waste" of a country did not consistent with the output of power station in the balance sheet of the country such as Luxembourg. Table 3 specifies the efficiency scores for power stations in terms of their resource types (RE, and P_NRE) as well as total power stations, for G_9 countries. Brazil, China, France, Russia, and Turkey are identified as an efficient country from electricity and heat generation. Indonesia obtained the lowest level of efficiency between 13 countries. In other words, its technical inefficiency in P_NRE and RE are 0.1211 and 0.8543, respectively. Although, the inefficiency value for Indonesia is too high, the percentage of RE in the energy mix program of the country is so low. Thus, the total power stations efficiency for the country is 0.6610.

3.2.2 Oil refinery

Oil refineries convert crude oil into more useful products. The input-oriented model of DEA was carried out for the refinery system to measure the efficiency. According to the Table 3, France, Italy, Japan, Turkey, and United States are efficient countries in the refinery industry from DEA model. Indonesia with 0.9424 efficiency score obtained the lowest level of efficiency among G_9 countries.

3.3 Demand analysis results

The output-oriented DEA model is used for the demand analysis to consider how much QoL value can increase in a country, while keeping FECpc (or FEC). Table 3 depicts the efficiency results, in which UK, Mexico, India, and Germany were identified as an efficient country. Russia, and China are two countries with the lowest level of efficiency in the demand side based on QoL output.

3.4 Overall efficiency results

The results of the overall efficiency (Table 3) illustrate that the highest level of overall energy efficiency among G_9 countries, belongs to the US, followed by Japan, and France. In contrast, Indonesia, Russia, and China gained the lowest level of overall efficiency respectively.

Table 3: Supply, demand, and overall efficiency data (G_9 category, year 2013)

Country Name	$W_{R.}$	$W_{RE.}$	$W_{P_NRE.}$	$Eff._{R.}$	$Eff._{RE.}$	$Eff._{P_NR.}$	Total Power stations	Supply	Demand	Overall
Brazil	0.617	0.228	0.155	0.989	1.000	1.000	1.000	0.993	0.924	0.918
China	0.282	0.065	0.653	0.976	1.000	1.000	1.000	0.993	0.837	0.831
France	0.304	0.061	0.635	1.000	1.000	1.000	1.000	1.000	0.979	0.979
Germany	0.431	0.100	0.470	0.984	0.856	0.926	0.914	0.944	1.000	0.944
India	0.458	0.055	0.488	0.993	0.701	0.780	0.772	0.873	1.000	0.873
Indonesia	0.450	0.163	0.386	0.942	0.146	0.879	0.661	0.788	0.992	0.782
Italy	0.562	0.151	0.287	1.000	0.642	1.000	0.877	0.946	0.970	0.918
Japan	0.472	0.048	0.480	1.000	0.763	1.000	0.979	0.989	0.991	0.980
Mexico	0.553	0.054	0.394	0.946	1.000	0.943	0.950	0.948	1.000	0.948
Russia	0.422	0.030	0.548	0.972	1.000	1.000	1.000	0.988	0.835	0.825
Turkey	0.385	0.110	0.505	1.000	1.000	1.000	1.000	1.000	0.948	0.948
United Kingdom	0.476	0.056	0.468	0.987	0.753	0.877	0.864	0.922	1.000	0.922
United States	0.480	0.040	0.479	1.000	0.809	1.000	0.985	0.992	0.994	0.986

3.5 Potential energy saving results

Table 4 shows the amount of potential energy saving based on the supply (Primary energy) and demand (Final energy) side, among G_9 countries in the year 2013. In the refinery industries, China, Russia, and Mexico are three countries with the highest potential to reduce energy consumption. Indonesia, Germany, India, Brazil, and UK are next potential countries to energy saving in the refinery industries.

Table 4: Potential energy saving for the G_9 category, year 2013

Country Name	**Primary Energy (Ktoe)**				**Final Energy (Ktoe)**
	Refinery	Power station (NRE)	Power stations (RE)	De-commoditization	Demand side (QoL)
Brazil	1205.74	0.00	0.00	0.00	23.66
China	11055.38	0.00	0.00	0.00	348.99
France	0.00	0.00	0.00	0.00	8.00
Germany	1592.25	8193.09	2364.67	5273.28	0.00
India	1560.98	55275.76	5331.25	15777.99	0.00
Indonesia	2635.60	5081.55	1948.61	5030.49	2.10
Italy	0.00	0.00	3903.91	7320.71	8.31
Japan	0.00	0.00	2859.97	6475.45	7.50
Mexico	3823.40	3057.07	0.00	0.00	0.00
Russia	7733.66	0.00	0.00	0.00	66.78
Turkey	0.00	0.00	0.00	0.00	6.35
United Kingdom	874.44	8233.48	1240.26	3054.30	0.00
United States	0.00	0.00	9616.02	24139.20	14.81
Total	**30481.46**	**79840.95**	**27264.69**	**67071.42**	**486.51**

In terms of power stations under NRE resources, India, UK, Germany, Indonesia, and Mexico gained the highest potential of energy saving. Finally, in the renewable energy production system, the US, India, Italy, Japan, Germany, Indonesia, and UK can increase their renewable energy outputs by benchmarking from

other countries in this group such as Russia, and Brazil. Total potential energy saving in the refinery, and power stations in G_9 is 137587 ktoe for the year 2013. The highest potential of energy saving is for the power stations under NRE resources, followed by refinery and the last one is renewables development. Table 4 shows the US, India, Italy, Japan, and Germany have obtained the highest potential energy saving by de-commoditization among the G_9 countries. The last column of Table 4 represents the results of potential energy saving through QoL improvement. China, Russia, and Brazil are three countries with the highest potential to increase their QoL with current FEC (or FECpc). Table 5 illustrates total potential energy saving in the demand and supply side for the seven groups. Group nine has the highest potential to reduce energy consumption in both sides, followed by the G_5 countries. Additionally, power stations with P_NRE resources have the highest potential to save natural energy resources, especially by increasing technical efficiency of related technologies.

Table 5: Potential energy saving for all nine groups, year 2013

Group Name	Primary Energy (Ktoe)				Final Energy (Ktoe)
	Refinery	Power station (NRE)	Power stations (RE)	De-commoditization	Demand side (QoL)
Group_1	14.75	1306.34	64.50	194.20	5.38
Group_2	101.56	1347.68	594.10	1459.98	56.72
Group_4	335.27	826.03	91.54	153.09	6.71
Group_5	9616.18	47883.66	7073.97	16791.61	227.43
Group_6	202.10	3595.18	1352.71	3281.43	181.16
Group_8	2970.95	275.23	1835.85	4659.97	61.09
Group_9	30481.46	79840.95	27264.69	67071.42	486.51
Total	**43722**	**135075**	**38277**	**93612**	**1025**

The potential energy saving in the demand side has the lowest level because of output oriented assumption in the DEA model. Indeed, the output oriented assumption considers an improvement in QoL, while maintaining FECpc. Therefore, effective energy policy brings about 1025 ktoe energy saving in the final energy, which its corresponding primary energy value changes based on different types of feedstock as well as conversion technology efficiency. The potential energy saving in the demand side for the G_9 countries in the year 2013, are greater than the potential energy saving in refinery in G_1, G_2, G_4, or G_6 countries. Additionally, it is higher than the potential energy deployment by RE in G_1, and G_4 countries, together (same results for de-commoditization).

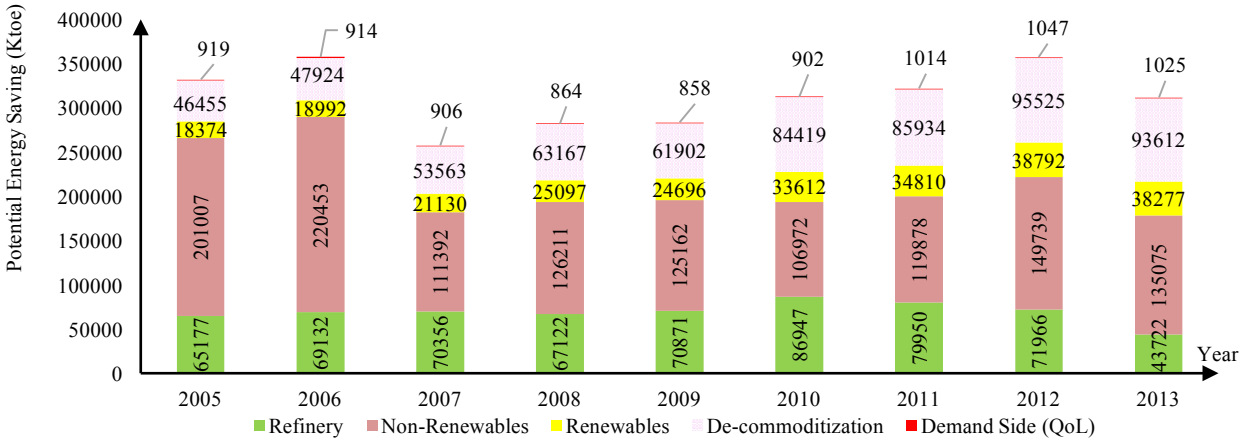


Figure 3: Potential energy saving during nine years (2005-2013)

Figure 3 represents the potential energy saving values during nine years (2005-2013). It presents that potential energy saving at power stations under P_NRE as well as refineries is decreasing. One of the reasons is to the increment of technology efficiency in non-renewable's power stations and refineries, which

has reduced the potential energy saving in these areas. In contrast, the potential energy saving is increasing for power stations under RE resources and demand side.

4. Discussion and Conclusion

In contrast to wide application of the DEA model to measure the potential energy saving in the energy system, heterogeneous DMUs and either inappropriate input or output-oriented DEA model bring about unreasonable results. This research used the K-Mean clustering approach to find homogenous countries from energy consumption factors. De-commoditization strategy was used to separate the input-oriented DEA model under non-renewables from output-oriented DEA model under renewables. Furthermore, the concept of overall efficiency was applied to combine the supply efficiency with demand efficiency by focusing on energy-related QoL. The proposed systematic way was used to answer the following question:

I- *How much potential energy saving is available in the energy system of a country relying on QoL*?

The results demonstrated that the highest potential energy saving belonged to the supply side. The results of the year 2013 showed that power stations under NRE resources with 135075 Ktoe had the highest potential part in energy saving, followed by de-commoditization, refineries, and renewables with 93612, 43722, and 38277 Ktoe, respectively. The results of the analysis showed that the demand side by considering QoL aspect has less than one percent (0.32%) of energy reduction. The outcomes of the year 2013 indicate that the G_9 countries had the highest potential to reduce energy consumption. The shares of G_9 compared with total potential energy saving at refineries, power stations with NRE resources, renewables, de-commoditization, and demand side (QoL) were obtained 69.72%, 59.11%, 71.23%, 71.65%, and 47.47%, respectively (Table 5). The lowest level of potential energy saving belonged to the group one (G_1), which their corresponding values were 0.03%, 0.97%, 0.17%, 0.21%, and 0.52%, respectively. Group four (G_4), group 2 (G_2), and group 6 (G_6) were the next lowest potential energy saving. The results of the country classification and homogeneity can be used to track the Paris Agreement. It recommends different level of threshold for different countries in energy consumption and CO_2 emission. This recommendation is to prevent of economic recession, especially in majority of G_9 countries.

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