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How to improve the regulatory performance of the provincial administrations of coal mine safety in China: a grey clustering assessment based on centre-point mixed triangular whitenisation weight function

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Abstract: The vertical-management system of coal mine safety regulation in China has played an important role in improving coal mine safety. In this study, the performances of coal mine safety regulation in the provincial Administrations of Coal Mine Safety (ACMS) are evaluated and analysed by a grey clustering method using centre-point mixed triangular whitenisation weight function. The results show that the provincial ACMS could be divided into four categories, and the clustering results are highly consistent with the actual situation. Overall, regulatory performance of provincial ACMS is on the low side since 21 provincial ACMS belong to the lowest and lower grey performance classes. Causes of diversified performances could be attributed to the number of per capita regulatory times, rather than per capita working days. From a policy perspective, it is essential for the State ACMS to strengthen regulation and management.

Keywords: coal mine safety; regulatory performance; evaluation; grey clustering; China.

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1 Introduction

Coal mine safety in China has experienced significant changes since 1970s. From 1975 to 2006, coal mining accidents claimed the lives of more than 4700 people. In the 54 years from 1949 to 2002, the death rate per million tons (DRPMT) of coal mine was higher than 4.40 persons. In 1999, China's coal mining deaths still reached 6469, and the DRPMT reached 5.30 persons (State Administration of Coal Mine Safety (SACMS), 2010). Since 2000, China began to develop a vertical regulatory system for coal mine safety which is independent of local government in order to improve coal mine safety and reduce accidents and deaths. Over the past decade, a vertical management system is being constructed in China and is composed of the SACMS, 27 provincial Administrations of Coal Mine Safety (ACMS) and 76 coal mine inspection branches. Since then, the management mechanism in China's coal mining industry, namely "National Supervision, Local Regulation, Enterprise's Responsibility", has been gradually implemented. Meanwhile, coal mining deaths and DRPMT gradually decreased to 1067 persons and 0.288 persons per million tons in 2013, a decrease of 83.51% and 94.57% respectively.

The establishment of a vertical regulatory system for coal mine safety played an important role in improving China's coal mine safety. In this system, it is important for provincial ACMS to supervise and regulate local coal mine safety, while it is also evaluating the performances of the provincial ACMS. However, the current regulatory performance levels in these provincial ACMS are still mixed, and it is essential to distinguish them and accordingly improve the regulatory performances based on the scientific performance assessment.

Currently, there are numerous studies discussing the performance of implementing mine safety regulations by safety regulatory and supervisory agencies. In essence, coal mine safety regulation is the activity of the provincial ACMS to implement coal mine safety regulations, such as the Law of Production Safety, Coal Law, Regulations on Coal Mine Safety and other regulations. Take the United States as an example, Shi (2009) summarised two opposing opinions. One opinion, proposed by Andrews and Christenson (1974, 1975), Bartel and Thomas (1987), McCaffrey (1983), Ruser and Smith (1991) and Viscusi (1979, 1986), is that implementing the Occupational Safety and Health Act has no significant effect on mining safety; the other opinion, proposed by Lewis-Beck and Alford (1980), Boden (1985), Gray and Jones (1991) and Lanoie (1992) is that implementing the Occupational Safety and Health Act has a significant positive impact on coal mine safety. To explain the contradiction, Shi (2009) verified that asynchronous effects of implementing regulations could reduce the number of major accidents in the short term and reduce the mortality representing the overall security situation in the long term. Tan et al. (2011) and Chen et al. (2011) investigated the security role of "three laws and one regulation" (PRC Mine Safety Law, PRC Coal Law, PRC Safety Production Law and the Regulation of Reporting and Investigating Production Accident) on coal mine safety production in China through a dummy variable model. The results show that implementing the former two laws makes coal mine death rate increased, while implementing the latter two laws (or regulation) makes coal mine death rate decreased.

In China, many studies discussed the performance improvement of China's coal mine safety regulation from different perspectives. Xiao and Han (2009) used a vector autoregressive model to analyse the effects of coal mine safety regulations from the perspective of property rights in China. Song and Mu (2013) proposed that coal mine safety regulation requires effective incentives and authorisation for miners from the perspective of a stakeholder theory. Huang (2012) used a regression model to discuss effects of main factors on the performance of coal mine safety regulation.

There are many studies exploring the ways to improve the performance of China's coal mine safety regulation by comparing China and other countries in order to learn from the advanced experience of other countries. Homer (2009) compared coal mine safety regulation and regulation between China and the US in terms of statistics, legislature, and the executive and judicial aspects and analysed the reasons for the participation gap between the two countries regarding regulatory performance from the perspective of the corruption associated with illegal coal mines, the labour, organisation and its safety regulation. Wei (2011) compared coal mine accident data between the two countries, analysed the reasons for China's coal mining accidents, introduced the regulatory experience of the US, and proposed some ways to improve the performance of China's coal mine safety regulation. Guo and Wu (2011) analysed the differences between the two countries' coal mine safety regulation from a security point of view, and advanced some proposals to improve China's coal mine safety. Huang (2013) compared Chinese and foreign coal mine safety regulation mode, and proposed rationalising supervisory functions and regulatory functions of coal mine safety and improving the efficiency in the background of the Changes of Big Ministries System.

In the vertical regulatory system, one of the key and most difficult points is the SACMS's ability to carry out a scientific evaluation on the regulatory performances of a large number of provincial ACMS, and to improve the regulatory performance of coal mine safety by classified regulation. The regulatory performance can reflect whether coal mine safety regulations are effectively implemented, and it is an indicator to assess the ACMS's administrative level degree. In practice, the method of objective assessment is usually used to evaluate the overall work of provincial ACMS in China, but it is not suitable for evaluating regulatory performance alone.

The purpose of this paper is to evaluate the performance of 26 provincial ACMS coal mine safety regulation based on centre-point mixed triangular whitenisation weight function (TWWF), to find a key way to improve regulatory performance and to further explore a classification management mechanism of provincial ACMS standing in the position of the SACMS.

The paper is organised as follows. Section 2 introduces the indicator system, assessment method and data sources; Section 3 and Section 4 contain the results and the discussion of the findings. The main conclusions and suggestions regarding feasible improvements to current regulatory performance are provided in Section 5.

2 Methodology

2.1 Indicator system

An indicator system is established according to the practical work of provincial ACMS. Regulatory work of provincial ACMS is mainly composed of implementing "three regulation" (focus regulation, special regulation, regular regulation) plans, supervising local regulators' work and other regulatory work. In the "three regulation" institutions, focus regulation means the ACMS supervise the key coal mines and the key coal mining areas (Lin, 2006). For example, accident-prone coal mines are the key coal mines so that Shanxi provincial ACMS draws up a focus regulation plan to regulate these coal mines. Special regulation means the ACMS supervises a certain aspect of coal mine safety. For example, safety training is a certain aspect of coal mine safety and Henan provincial ACMS draws up a special plan to supervise safety training of all coal mine enterprises. Regular regulation means the ACMS supervises overall safety work of coal mines at regular intervals. For example, Shandong provincial ACMS supervises each coal mine once every two years. Supervising local regulators' work means that the ACMS supervises the work of local regulation department of coal mine safety. For example, Shandong Provincial ACMS supervises safety regulation work of Zaozhuang Municipal Administration of Work Safety. Other regulatory work refers to the safety work except the "three regulation" work and supervising local regulator's work.

Therefore, six indicators are selected to form an indicator system in order to evaluate regulatory performance of provincial ACMS (see Table 1). These indicators include the main work of provincial ACMS. The number of human resources of provincial ACMS varies greatly, so it is most efficient to use per capita indicators to evaluate regulatory performance.

Table 1 An indicator system for evaluating the regulatory performance

Variables	*Evaluation indicators*	*Unit*
x_1	per capita working days for implementing three regulation plans	days/person
x_2	per capita working days for supervising local regulators' work	days/person
x_3	per capita working days for other regulatory work	days/person
x_4	per capita times of focus regulation on coal mines	times/person
x_5	per capita times of special regulation on coal mines	times/person
x_6	per capita times of regular regulation on coal mines	times/person

2.2 Data sources

The data of working days and times for coal mine safety regulation are from the Notification on the Completion of the Regulation and Law Enforcement Plan of ACMS in 2010 announced by the central government portal site. The data of human resources for law enforcement come from law enforcement work plan of provincial ACMS in 2007. All data are shown in Table 2.

Table 2 Regulatory data of provincial ACMS

Provincial ACMS	x_1 *(days/ person)*	x_2 *(days/ person)*	x_3 *(days/ person)*	x_4 *(times/ person)*	x_5 *(times/ person)*	x_6 *(times/ person)*
Beijing coal mine inspection branch	36.11	4.33	168.00	0.67	6.33	3.22
Hebei ACMS	25.92	11.77	100.87	0.21	3.49	1.74
Shanxi ACMS	21.96	18.21	99.90	0.00	2.85	0.00
Inner Mongolia ACMS	46.00	15.30	131.25	0.65	3.65	1.45
Liaoning ACMS	44.23	13.70	98.90	4.20	3.05	0.70
Jilin ACMS	37.50	12.80	152.70	0.33	1.80	0.00
Heilongjiang ACMS	18.36	8.18	83.64	2.18	2.89	0.00
Jiangsu ACMS	65.42	10.58	107.75	2.00	12.42	5.08
Anhui ACMS	34.14	10.34	143.45	1.07	1.55	1.66
Fujian ACMS	48.42	32.92	110.00	0.83	4.25	1.83
Jiangxi ACMS	40.20	7.77	93.53	2.00	4.93	0.77
Shandong ACMS	44.69	14.00	82.11	1.57	4.09	0.86
Henan ACMS	34.05	8.86	123.78	0.32	5.30	1.24
Hubei ACMS	58.00	32.67	150.92	2.42	3.08	1.33
Hunan ACMS	27.19	17.41	101.22	0.37	3.56	0.37
Guangxi ACMS	44.00	26.70	148.10	3.20	3.50	0.80
Chongqing ACMS	22.71	10.86	120.69	0.54	2.77	0.34
Sichuan ACMS	30.29	34.12	146.47	1.41	4.71	1.12
Guizhou ACMS	22.12	6.79	136.19	1.52	0.93	0.29
Yunnan ACMS	38.74	19.52	138.30	1.11	1.15	1.04

Table 2 Regulatory data of provincial ACMS (continued)

Provincial ACMS	x_1 (days/ person)	x_2 (days/ person)	x_3 (days/ person)	x_4 (times/ person)	x_5 (times/ person)	x_6 (times/ person)
Shaanxi ACMS	44.10	10.67	128.20	0.87	4.43	1.93
Gansu ACMS	16.53	3.62	81.98	1.38	2.24	1.13
Qinghai ACMS	48.89	13.22	104.22	1.67	2.22	2.44
Ningxia ACMS	26.70	14.00	143.53	0.53	4.67	0.00
Xinjiang ACMS	24.14	13.04	122.36	0.89	1.29	0.61
Xinjiang Production and Construction Corps coal mine inspection branch	72.80	46.90	158.10	10.80	8.50	4.40

2.3 Evaluation model

The grey clustering model based on centre-point mixed TWWF which has made significant improvement on the centre-point TWWF is a grey clustering method of grey system theory proposed by Liu and Xie (2014). Clustering criteria is the amount of regulatory activities of each provincial ACMS. The more regulatory activities provincial ACMS did, the higher class it would be. There are two reasons for choosing this model to evaluate regulatory performance. First, general clustering methods cannot rank all classes. For example, we have used the Predictive Analytics Software statistical software to make a system clustering with inter-group connection and the Euclidean distance. It can be divided into four classes (see Table 3). However, this method cannot sort the four categories. The grey clustering model based on TWWF can divide objects into multiple categories according to data characteristics of clustering object indicators and sort these categories. Second, if evaluation indicators vary greatly in dimension and number, the grey clustering model with TWWF has a better clustering effect.

Table 3 The clustering results with the statistical software of PASW

Classes	*Provincial ACMS*	*Number*
1st class	Beijing	1
2nd class	Shanxi, Hebei, Liaoning, Jiangsu, Heilongjiang, Fujian, Shandong, Jiangxi, Hunan, Gansu, Qinghai	11
3rd class	Inner Mongolia, Jilin, Anhui, Sichuan, Chongqing, Guangxi, Shaanxi, Yunnan, Guizhou, Hubei, Henan, Ningxia, Xinjiang	13
4th class	Xinjiang Corps	1

The evaluation process is briefly described as follows.

Step 1: The performance of coal mine safety regulation is divided into five grey classes; namely, the lowest performance grey class, the lower grey performance class, the middle grey performance class, the higher grey performance class, the highest grey performance class. As for the indicator x_j, its value interval is $[a_j, b_j]$. $\lambda_j^1, \lambda_j^2, \lambda_j^3, \lambda_j^4, \lambda_j^5$, are selected as centre points (midpoint or not) which have the largest possibility of belonging to the five grey classes respectively (see Figure 1). Therefore the five grey performance classes of x_j correspond to the intervals $[a_j, \lambda_j^2],[\lambda_j^1, \lambda_j^3],[\lambda_j^2, \lambda_j^4],[\lambda_j^3, \lambda_j^5],[\lambda_j^4, b_j]$. Five centre points and their connotations, as well as intervals of each indicator, are shown in Table 4.

Figure 1 A diagram of centre-point mixed triangular whitenisation weight function.

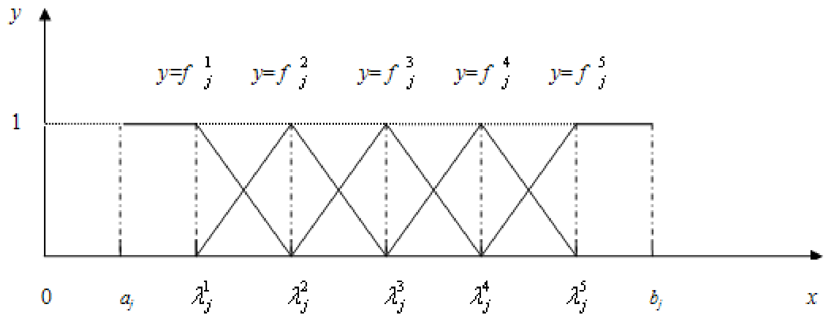

Table 4 Centre points and its connotations and intervals of each indicator

Indicators	*Centre points*	*Connotations of centre points*	*Intervals*
x_1	10, 20, 40, 60, 80	The centre points of x_1 which have the largest possibility of belonging to the three grey classes are 10 days, 20 days, 40 days, 60 days, 80 days	[a_1, 20], [10, 40], [20, 60], [40, 80], [60, b_1]
x_2	5, 15, 30, 45, 60	The centre points of x_2 which have the largest possibility belong to the three grey classes are 5days, 15 days, 30 days, 45 days, 60 days	[a_2, 15], [5, 30], [15, 45], [30, 60] , [45, b_2]
x_3	60, 90, 120, 150, 180	The centre points of x_3 which have the largest possibility belong to the three grey classes are 60 days, 90 days, 120 days, 150 days, 180 days	[a_3, 90], [60, 120], [90, 150], [120, 180], [150, b_3]
x_4	1, 3, 6, 9, 12	The centre points of x_4 which have the largest possibility belong to the three grey classes are 1 time, 3 times, 6 times, 9 times, 12 times	[a_4, 3], [1, 6], [3, 9], [6, 12], [9, b_4]
x_5	1, 3.5, 7, 10.5, 14	The centre points of x_5 which have the largest possibility belong to the three grey classes are 1 time, 3.5 times, 7 times, 10.5 times, 14 times	[a_5, 3.5], [1, 7], [3.5, 10.5], [7, 14] , [10.5, b_5]
x_6	0.5, 1.5, 3, 4.5, 6	The centre points of x_6 which have the largest possibility belong to the three grey classes are 0.5 time, 1.5 times, 3 times, 4.5 times, 6 times	[a_6, 1.5], [0.5, 3], [1.5, 4.5], [3, 6] , [4.5, b_6]

Step 2: As for the lowest grey performance class, a lower measure whitenisation weight function is constructed as $f_j^1[-,-,\lambda_j^1,\lambda_j^2]$ (see Figure 1). For observation x of x_j indicator, the following formula can be used to calculate its membership in the lowest grey performance class:

$$f_j^1(x)=\begin{cases}0, & x\notin[a_{j,}\ \lambda_j^2]\\ 1, & x\in[a_{j,}\ \lambda_j^1]\\ \left(\lambda_j^2-x\right)/(\lambda_j^2-\lambda_j^1), & x\in[\lambda_j^1\ \lambda_j^2]\end{cases} \quad (1)$$

Step 3: As for the lower grey performance class, the middle grey performance class, the higher grey performance class, after connecting the points $(\lambda_j^k,1),(\lambda_j^{k-1},0)$ and $(\lambda_j^{k+1},0)$, the centre-point TWWF $f_j^k[\lambda_j^{k-1},\lambda_j^k,-,\lambda_j^{k+1}]$ (see Figure 1) can be constructed for the grey class k (k = 2, 3, 4) and the indicator x_j (j = 1, 2, …, 6).

For observation x of x_j indicator, the following formula can be used to calculate its membership in grey class k:

$$f_j^k(x)=\begin{cases}0, & x\notin[\lambda_j^{k-1},\lambda_j^{k+1}]\\ (x-\lambda_j^{k-1})/(\lambda_j^k-\lambda_j^{k-1}), & x\in[\lambda_j^{k-1},\lambda_j^k]\\ (\lambda_j^{k+1}-x)/(\lambda_j^{k+1}-\lambda_j^k), & x\in[\lambda_j^k,\lambda_j^{k+1}]\end{cases} \tag{2}$$

Step 4: As for the highest grey performance class, an upper measure whitenisation weight function is constructed as $f_j^5[\lambda_j^4,\lambda_j^5,-,-]$ (see Figure 1). For observation x of x_j indicator, the following formula can be used to calculate its membership in grey class k:

$$f_j^5(x)=\begin{cases}0, & x\notin[\lambda_j^4\ b_j]\\ (x-\lambda_j^4)/(\lambda_j^5-\lambda_j^4) & x\in[\lambda_j^4\ \lambda_j^5]\\ 1, & x\in[\lambda_j^5\ b_j]\end{cases} \tag{3}$$

Taking indicator x_1 as an example, centre-point mixed TWWF of the five grey classes are constructed as follows:

$$f_1^1(x_1)=\begin{cases}0, & x_1\notin[a_1,20]\\ 1, & x_1\in[a_1,10]\\ (20-x_1)/(20-10), & x_1\in[10,20]\end{cases}=\begin{cases}0, & x_1\notin[a_1,20]\\ 1, & x_1\in[a_1,10]\\ (20-x_1)/10, & x_1\in[10,20]\end{cases}$$

$$f_1^2(x_1)=\begin{cases}0, & x_1\notin[10,40]\\ (x_1-10)/(20-10). & x_1\in[10,20]\\ (40-x_1)/(40-20), & x_1\in[20,40]\end{cases}=\begin{cases}0, & x_1\notin[10,40]\\ (x_1-10)/10, & x_1\in[10,20]\\ (40-x_1)/20, & x_1\in[20,40]\end{cases}$$

$$f_1^3(x_1)=\begin{cases}0, & x_1\notin[20,60]\\ (x_1-20)/(40-20), & x_1\in[20,40]\\ (60-x_1)/(60-40), & x_1\in[40,60]\end{cases}=\begin{cases}0, & x_1\notin[20,60]\\ (x_1-20)/20, & x_1\in[20,40]\\ (60-x_1)/20, & x_1\in[40,60]\end{cases}$$

$$f_1^4(x_1)=\begin{cases}0, & x_1\notin[40,80]\\ (x_1-40)/(60-40), & x_1\in[40,60]\\ (80-x_1)/(80-60), & x_1\in[60,80]\end{cases}=\begin{cases}0, & x_1\notin[40,80]\\ (x_1-40)/20, & x_1\in[40,60]\\ (80-x_1)/20, & x_1\in[60,80]\end{cases}$$

$$f_1^5(x_1)=\begin{cases}0, & x_1\notin[60,b_1]\\ (x_1-60)/(80-60), & x_1\in[60,80]\\ 1, & x_1\in[80,b_1]\end{cases}=\begin{cases}0, & x_1\notin[60,b_1]\\ (x_1-60)/20, & x_1\in[60,80]\\ 1, & x_1\in[80,b_1]\end{cases}$$

Step 5: To determine the weights of 6 indicators. The data in Table 2 are standardised. Then weights are determined using the principal component analysis method. The weights of six indicators are got as 0.237012, 0.194335, 0.09973, 0.082222, 0.092025, and 0.294676, respectively.

Step 6: $\sigma_i^k = \sum_{j=1}^{6} f_j^k \left(x_{ij} \right) \cdot \eta_j$ is calculated as comprehensive clustering coefficient of the grey class k (k = 0, 1, …, 4) of the provincial ACMS i (i = 1, 2, …, 26). Among the formula, $f_j^k(x_{ij})$ is the whitenisation weight function of the grey class k of indicator x_j. And η_j is the weight of indicator x_j in comprehensive clustering.

Taking Beijing coal mine inspection branch as an example, we calculate the clustering coefficients. Details are shown in Table 5. Clustering coefficients of other provincial ACMS, which can be calculated by the same methods, are omitted.

Table 5 Clustering coefficients of centre-point mixed triangular whitenisation weight function of Beijing coal mine inspection branch

Grey class	x_1	x_2	x_3	x_4	x_5	x_6	x
The lowest grey performance class	0	0.19434	0	0.08222	0	0	0.2766
The lower grey performance class	0.04610	0	0	0	0.01762	0	0.0637
The middle grey performance class	0.19091	0	0	0	0.07441	0.25146	0.5168
The higher grey performance class	0	0	0.03989	0	0	0.04322	0.0831
The highest grey performance class	0	0	0.05984	0	0	0	0.0598

Step 7: For $1 \le k \le 5$, we can conclude that the provincial ACMS i belongs to the grey class k with max $\{\sigma_i^k\} = \sigma_i^{k^*}$. If there are multiple provincial ACMS belonging to the grey class k, it also can rank these institutions which belong to the same class according to the size of the comprehensive clustering coefficient. From Table 5, we can see that 0.35168 is the largest comprehensive clustering coefficient in the column of x. That is to say, Beijing coal mine inspection branch has the largest possibility belong to the middle grey performance class. Therefore, Beijing coal mine inspection branch is correspondingly judged to belong to the middle grey performance class.

3 Results

Similarly, we can calculate the comprehensive clustering coefficients of other provincial ACMS and classify these provincial ACMS into the corresponding classes. Clustering results of all provincial ACMS are shown in Table 6.

Table 6 Clustering results of all provincial ACMS

Classes	*Provincial ACMS*	*Number*
The lowest grey performance class	Guizhou, Jilin, Heilongjiang, Jiangxi, Chongqing, Yunnan, Gansu, Qinghai	8
The lower grey performance class	Ningxia, Xinjiang, Shaanxi, Sichuan, Hunan, Hubei, Henan, Shandong, Anhui, Hebei, Liaoning, Inner Mongolia, Shanxi	13
The middle grey performance class	Fujian, Guangxi and Beijing	3
The higher grey performance class	Jiangsu, Xinjiang Production and Construction Corps	2
The highest grey performance class	None	0

4 Discussion

Results show that 26 provincial ACMS can be classified to four classes; namely the lowest grey performance class, the lower grey performance class, the middle grey performance class, the higher grey performance class. Jiangsu ACMS and Xinjiang Production and Construction Corps coal mine inspection branch belong to the higher grey performance class. Fujian ACMS and Beijing coal mine inspection branch belong to the middle grey performance class. Guizhou ACMS and Jilin ACMS belong to the lowest grey performance class. Other provincial ACMS belong to the lower grey performance classes. None of the provincial ACMS belong to the highest grey performance class.

The clustering results are highly consistent with the actual situation. Chen and Zhao (2012) ranked Chinese provinces by the total amount of coal mine accidents during the period of 2001–2010 from greatest to least (see Table 7). The former 16 provinces, many more accidents occur in, all belong to the lower grey performance class and the lowest grey performance class. Yao (2015) ranked Chinese 25 provinces by the total amount of coal mine accidents and deaths during the period of 2009–2013 from greatest to least (see Table 8). It is found that the four provincial ACMS belong to the higher grey performance class and the middle grey performance class (except Xinjiang Production and Construction Corps due to the absence of data) are in the front rank, while 19 provincial ACMS belong to the lower grey performance class and the lowest grey performance class (except Qinghai ACMS and Ningxia ACMS) are at the back. The two statistical ranking results are highly consistent with the clustering results in this paper. That is, the clustering results by using a grey clustering method based on centre-point mixed TWWF are very effective.

Overall, regulatory performance of all provincial ACMS is on the low side. The number of provincial ACMS belonging to the lowest grey performance class or the lower grey performance class equals 21 (with the only exceptions being Fujian ACMS, Guangxi ACMS, Beijing coal mine inspection branch, Jiangsu ACMS, Xinjiang Production and Construction Corps coal mine inspection branch). This accounts for 80.77% of all provincial ACMS. The lowest and lower regulatory performance is closely related to the content and condition of the coal mine safety regulatory work. First, coal mine safety regulation needs safety supervisors to descend into coal mines frequently. There is a certain degree of risk that deters the inspectors from taking the initiative to be underground. Second, coal mines generally have an unpleasant environment, which makes safety supervisors less willing to descend into coal mines. Third, the provincial ACMS generally are set in provincial capital cities, generally far from coal mines. Rugged terrain and bumpy roads leading to the mine increase the difficulty of travelling to coal mines.

Table 7 Coal mine accidents in most Chinese provinces from 2001 to 2010

Rank	*Provinces*	*The amount of accidents*	*Rank*	*Provinces*	*The amount of accidents*
1	Sichuan	1583	10	Liaoning	231
2	Hunan	1271	11	Gansu	200
3	Chongqing	933	12	Yunnan	189
4	Guizhou	703	13	Fujian	148
5	Shanxi	362	14	Henan	140
6	Guilin	360	15	Anhui	130
7	Heilongjiang	357	16	Jiangxi	123
8	Hebei	258	17	Other provinces	639
9	Shaanxi	257			

Table 8 Coal mine accidents in most Chinese provinces from 2009 to 2013

Rank	*Provinces*	*Amount of accidents*	*Deaths*	*Rank*	*Provinces*	*Amount of accidents*	*Deaths*
1	Guizhou	81	466	14	Inner Mongolia	16	92
2	Hunan	62	397	15	Shaanxi	16	103
3	Yunnan	52	200	16	Gansu	14	76
4	Shanxi	38	318	17	Hebei	9	26
5	Sichuan	37	265	18	Anhui	8	24
6	Chongqing	31	145	19	Shandong	6	24
7	Heilongjiang	25	261	20	Fujian	5	15
8	Liaoning	24	110	21	Guangxi	4	20
9	Xinjiang	22	116	22	Qinghai	3	12
10	Henan	22	386	23	Ningxia	3	18
11	Jilin	19	150	24	Beijing	1	3
12	Hubei	16	58	25	Jiangsu	1	4
13	Jiangxi	16	91				

The different performances could be attributed to the number of per capita regulatory times, rather than per capita working days. Eight provincial ACMS in the lowest grey performance class and two provincial ACMS in the higher grey performance class should be analysed and discussed in more detail, especially because they represent the extremes of classes (Table 9). Through a comparative analysis, the work engagement of the lowest grey performance class is far lower than the higher grey performance class in per capita times of focus regulation on coal mines (x_4), per capita times of special regulation on coal mines (x_5) and per capita times of regular regulation on coal mines (x_6). In addition, the sum of per capita regulatory times ($x_4 + x_5 + x_6$) of the lowest grey performance class is only 20.65% (= 4.46/21.60) of the higher grey performance class. The sum of per capita working days ($x_1 + x_2 + x_3$) of the lowest grey performance class is 67.11% (= 154.88/ 230.78) of the higher grey performance class. Thus, the reason that eight provincial ACMS in the lowest grey performance class had lower coal mine safety regulatory performance is mainly attributed to fewer per capita regulatory times rather than per capita working days.

Table 9 Regulatory data of provincial ACMS at the extremes of classes

Provincial ACMS	x_1	x_2	x_3	x_4	x_5	x_6
Jilin ACMS	37.50	12.80	152.70	0.33	1.80	0.00
Guizhou ACMS	22.12	6.79	136.19	1.52	0.93	0.29
Heilongjiang ACMS	18.36	8.18	83.64	2.18	2.89	0.00
Jiangxi ACMS	40.20	7.77	93.53	2.00	4.93	0.77
Chongqin ACMS	22.71	10.86	120.69	0.54	2.77	0.34
Yunnan ACMS	38.74	19.52	138.30	1.11	1.15	1.04
Gansu ACMS	16.53	3.62	81.98	1.38	2.24	1.13
Qinghai ACMS	48.89	13.22	104.22	1.67	2.22	2.44
Jiangsu ACMS	65.42	10.58	107.75	2.00	12.42	5.08
Xinjiang Production and Construction Corps Coal Mine Inspection Branch	72.80	46.90	158.10	10.80	8.50	4.40

For most provincial ACMS with lower or lowest performance, they can increase their regulatory performance. Except for a few provincial ACMS such as Heilongjiang ACMS, Jilin ACMS and Liaoning ACMS in colder areas, provincial ACMS can reach the higher grey performance class through increasing the number of regulatory times and working days. From the end of the last century, China began to implement the “close small coal mines movement”. The provincial ACMS can put limited human resources into the shrinking number of coal mines so that safety regulation of a single coal mine can be enhanced. With the decline in coal prices from June 2012, a rapid increase of coal production will not be expected in the short term. This situation is also conducive to improving the regulatory performance of provincial ACMS.

5 Conclusions and suggestions

The paper evaluated provincial ACMS coal mine safety regulatory performance based on centre-point mixed TWWF. Results show that 26 provincial ACMS can be divided into four classes: the lowest grey performance class, the lower grey performance class, the middle grey performance class and the higher grey performance class. There isn’t a provincial ACMS belonging to the highest grey performance class. Regulatory performance of provincial ACMS is on the low side overall. The major difference among provincial ACMS regulatory performance exists in the number of per capita regulatory times rather than per capita working days. Therefore, one of the key ways to improve the regulatory performance is to raise per capita regulatory times on coal mines.

In order to improve the regulatory performance, reduce coal mine accidents and improve coal mine safety, the SACMS can take the following three measures as policy suggestions.

1 *Database construction and data utilisation.* The first measure is to develop a database. Evaluating regulatory performance based on centre-point TWWF needs related regulatory data. If there are no specific data, the evaluation is only qualitative and would be quite subjective. Therefore, the SACMS should pay attention to data acquisition of the subordinate administrations and develop a scientific regulatory database. Moreover, the data acquisition should be primarily based on the actual safety regulatory cases rather than the law enforcement plans.

   The second measure is to expand the scale of the database reasonably. In fact, the SACMS owns related information of administrative punishment implemented by provincial ACMS, such as the investigation and punishment number of general potential accidents, the investigation and punishment number of serious potential accidents, the number of coal mines ordered to stop production, the implementation number of administrative punishments and the economic punishment amount. These data should be recorded in the database.

2 *Institution construction*. We advise developing an internal institution; for example, an information office. Its main job may consist of four aspects. The first is to develop and maintain the database. The second is to design the uniform data reports which could make provincial ACMS gather and report regulatory data according to the uniform format and requirements. The third is to evaluate the performance of coal mine safety regulation according to the collected data. The fourth is to require provincial ACMS to raise their regulatory performance.

3 *Classification management*. For the superior department, classification management of provincial ACMS could be mainly carried out by four aspects: (1) Scientific classification. So many provincial ACMS should be classified according to the results of the evaluation which will facilitate the SACMS to take further measures. And clustering results should be announced so that these provincial ACMS can know their own regulatory performance level clearly. (2) Focus on those provincial ACMS that have poor regulatory performance. The SACMS need to focus on these provincial ACMS belonging to the lower performance grey class. According to this study, the SACMS should focus regulation on Guizhou ACMS and Jilin ACMS. The SACMS needs to review their law enforcement program, improve the appraisal target and supervise the implementation in practice. (3) Set the forefront honour. The honour is granted to the provincial ACMS belonging to the higher grey performance class. According to this study, the honour should be awarded to Xinjiang Production and Construction Corps coal mine inspection branch, Jiangsu ACMS, Beijing coal mine inspection branch, Guangxi ACMS, and Fujian ACMS. (4) Distribute year-end bonuses according to the grey classes. The SACMS should set up five classes of year-end bonuses. The first-class bonus is vacant due to the absence of the highest grey performance class. The second-class bonus is awarded to Jiangsu ACMS and Xinjiang Production and Construction Corps coal mine inspection branch. The third-class bonus is awarded to Fujian ACMS, Guangxi ACMS and Beijing coal mine inspection branch. The fourth-class bonus is awarded to the thirteen provincial

ACMS, for example, Qinghai ACMS, Ningxia ACMS. The fifth-class bonus is awarded to the eight provincial ACMS, for example, Guizhou ACMS and Jilin ACMS, or cancelled as a penalty

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The impact of expectations of returns and investment time scales on carbon price: findings from EU ETS

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Abstract: Carbon price fluctuations affect the carbon market's efficiency and CO_2 emission reductions. In this paper, Zipf analysis technology is used to analyse the impact of expectations of returns and time scales on carbon price in the European Union Emissions Trading Scheme (EU ETS). Results show the probability of prices declining becomes greater than the probability of prices increasing at longer time scales. Traders with different expectations of returns have different price perceptions. For traders with low expectations of returns, carbon prices are affected by market mechanisms, seasonal weather variations and other heterogeneous events, and carbon price fluctuations are relatively well perceived. Carbon prices are more volatile and higher risks and uncertainties are more characteristic for high expectations of returns.

Keywords: carbon price; emissions trading; price volatility; expectations of return; investment time scales.

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1 Introduction

With greenhouse gas emissions having become a scarce resource, the international greenhouse gas emissions trading market (the carbon market) has developed rapidly. The trading volume under the European Union Emissions Trading Scheme (EU ETS) grew from 8.49 million tons in 2004 to 1030 million tons in 2011, and the trading value increased from US$8.2 billion in 2005 to US$176 billion in 2011 (Capoor and Ambrosi, 2006; Kossoy and Guigon, 2012).

Great attention is being paid to carbon emissions and the emerging carbon market (Zhang and Wei, 2010; Benz and Trück, 2008). Carbon price fluctuations play a significant role in the carbon market. The carbon market is affected by market mechanisms (e.g. traders' behaviours, etc.), and also by the market environment such as international politics, negotiations, weather and financial crises. Alberola and Chevallier (2009) analysed the reasons for the carbon price decline in 2007 during the first phase. Chevallier et al. (2009) evaluated the impact of the 2006 compliance event on changes in investor' risk aversion in EU ETS with option prices. The results showed evidence of a dramatic change in the market perception of risk. Alberola et al. (2008) established an econometric model to analyse the relationship between carbon price changes and energy prices and weather during 2005 to 2007 in the EU ETS. The results illustrated that the carbon price was influenced not only by energy prices, but also by unanticipated weather. Chevallier (2009) used a generalised auto-regressive conditional heteroscedasticity (GARCH) model to explain the relationship between EU ETS carbon futures and macroeconomic factors. Feng et al. (2011a, 2011b) examined carbon price volatility from a non-linear dynamics point of view and Ensemble Empirical Mode Decomposition.

Analysis has shown that the EU emissions allowances (EUAs), as a new type of commodity, are influenced by electricity demand. Oberndorfer (2009) researched the relationship between power companies' stock prices and carbon price. The results illustrated that carbon stock prices had a positive correlation with power companies' stock prices. Parsons et al. (2009) analysed SO_2 prices and CO_2 price fluctuations by comparing US and EU ETS SO_2 markets; the results illustrated that banking and borrowing impact CO_2 prices in the EU ETS. Alberola et al. (2009) demonstrated that industrial sector production impacts carbon prices in Germany, Spain, Poland, the UK, especially in German electricity production. Wei et al. (2008, 2010) studied the relationship between carbon prices and energy prices. Chevallier (2012) established a model of carbon price interactions with macroeconomic and energy dynamics and confirmed the existence of a link between the macroeconomy and the price of carbon. Creti et al. (2012) investigated the determinants of the carbon price during the two phases of the EU ETS, the results shown that the nature of this equilibrium relationship is different across the two subperiods, with an increasing role of fundamentals in phase II. Freitas and Silva (2013) used Vector Error Correction Model (VECM) to estimate both long-run equilibrium relations and short-run interactions between the electricity price and the fuel (natural gas and coal) and carbon prices. The outcomes suggest that the dynamic pass-through of carbon prices into electricity prices is strongly significant. Sousa et al.

(2014) use multivariate wavelet analysis to analyse the interrelation of CO_2 prices with energy prices (electricity, gas and coal), and with economic activity.

Currently, futures trading represent a significant proportion of the carbon market. There are many kinds of futures contracts, and this number is growing. Carbon prices are affected by many factors, some of which lead to carbon market risks. Wei et al. (2010) used an econometrics model to analyse market risk in EU ETS and describe the market's overall risk from the perspective of abnormal returns, the results shown the probability of abnormal returns is below 0.02% in 2008–2009; therefore, high expectations of returns are restricted. Zhu and Wei (2013) used three hybrid models to forecast carbon prices and proposed a novel hybrid methodology that exploits the unique strength of the ARIMA and least squares support vector machine (LSSVM) models in forecasting carbon prices. Zhu et al. (2015) examined the structural changes of European carbon futures price under the EU ETS during 2005–2012. Feng et al. (2012) used extreme value theory (EVT) to measure the Value at Risk (VaR) in carbon market; the results also show that the EVT VaR is more effective than the traditional method. Market risk is important in the carbon market. However, traders' behaviour such as expectations of returns cannot be negative, especially for carbon market. In the paper, we will investigate the nature of the relationship between traders' expectations of returns and carbon price fluctuations. Because investment expectations vary between traders, and longer contracts carry lower risk, investment time scales will impact carbon prices. Since a trader's judgement of the future is based upon appreciation of the past, it is crucially important to uncover the underlying cognition patterns that dominate a trader's decision-making process. The paper applies Zipf analysis technology (Zipf, 1949; Zipf, 1968) to establish a dynamic model. Zipf analysis technique has been applied widely as a powerful analytical tool in the fields of economics and finance to study price fluctuations (Powers, 1998; Ausloos, 2000; Axtell, 2001; Alvarez-Ramirez et al., 2003; Jiao et al., 2006; He et al., 2009). The paper analyses the impact of expectations of returns and time scales on carbon price.

In fact, because of the complexity of carbon price returns series, it is very significant to analyse effects of price volatility from the perspective of behavioural finance. For example, when carbon prices slump, carbon sellers incur losses. In this scenario, profits increase among purchasers; when the carbon price increases, the outcome is reversed. Therefore, in contrast to price volatility in financial markets, both the price declines and increases have to be considered in the carbon market. The price dynamic modelling based on Zipf analysis technique originally introduced in the context of natural language but nowadays widely applied as a powerful analytical tool to the fields of economics and finance. This study contributes to use psychological factors of expectations of returns and investment time scales of investment as important parameters in carbon market.

The remainder of the paper is organised as follows. Section 2 reviews the method and analyses the expectations of returns and time scales. Data sources are described in Section 3. Section 4 describes the empirical results discussions. Conclusions and policy suggestions are proposed in Section 5.

2 Method

2.1 Price dynamic modelling based on Zipf analysis

Let $P(t)=\{p(t_1),p(t_2),\cdots,p(t_n)\}$, $p(t_i)=p_i, i=1,2,\cdots,n$ be the original time series for carbon price. $r_i(\tau)$ is the returns for the given time scale τ. Let's define

$r_i(\tau) = \dfrac{p(t_i + \tau) - p(t_i)}{p(t_i)}$, $i = 1, 2, \cdots, n - \tau$, so the $r(\tau) = \{r_1(\tau), r_2(\tau), \cdots, r_{n-\tau}(\tau)\}$ shows the returns at different time scales, where τ is the time scale and the intervals are $\tau = 1, 5, 20, 60, 120, 250$. In business time units, these intervals stand for one transaction day, one transaction week, one transaction quarter, one transaction half year and one transaction year, respectively. ε is the psychological threshold of traders' expected returns. $f(\tau, \varepsilon)$ can be obtained from the analysis:

$$f_i(\tau, \varepsilon) = \begin{cases} -1, \text{if } r_i < -\varepsilon \\ 0, \text{if} - \varepsilon < r_i < \varepsilon \\ 1, \text{if } r_i > \varepsilon \end{cases}$$

$n_-(\tau, \varepsilon)$, $n_0(\tau, \varepsilon)$ and $n_+(\tau, \varepsilon)$ denote the frequencies of occurrences of carbon price declines (−1), constant prices (0) and increases (1) in the given sequence $f(\tau, \varepsilon)$. We define the absolute frequencies of price declines, constant prices and increasing carbon prices, respectively, as follows:

$$p_-(\tau, \varepsilon) = \frac{n_-(\tau, \varepsilon)}{n_-(\tau, \varepsilon) + n_0(\tau, \varepsilon) + n_+(\tau, \varepsilon)};$$

$$p_0(\tau, \varepsilon) = \frac{n_0(\tau, \varepsilon)}{n_-(\tau, \varepsilon) + n_0(\tau, \varepsilon) + n_+(\tau, \varepsilon)};$$

$$p_+(\tau, \varepsilon) = \frac{n_+(\tau, \varepsilon)}{n_-(\tau, \varepsilon) + n_0(\tau, \varepsilon) + n_+(\tau, \varepsilon)}$$

Similarly, the relative frequencies of declines and increases are:

$$\phi_-(\tau, \varepsilon) = \frac{n_-(\tau, \varepsilon)}{n_-(\tau, \varepsilon) + n_+(\tau, \varepsilon)};$$

$$\phi_+(\tau, \varepsilon) = \frac{n_+(\tau, \varepsilon)}{n_-(\tau, \varepsilon) + n_+(\tau, \varepsilon)},$$

The relative frequencies measure the total number of occurrences of carbon price increases and declines.

2.2 The analysis of expectations of returns and investment time scales in the model

In carbon market, there exist various kinds of traders, e.g. industry producers (allowances demander), industry producers (allowances holders), governments, speculators, etc. (Feng et al., 2011b). Among which traders' impacts on price behaviour are comparatively difficult to predict and analyse quantitatively, due to traders having diversified expectations of returns and choice in different times to invest. We use τ that denotes the average interval between two transactions by traders due to different predictions of returns. It is affected by the traders' cognitive patterns or interpretations of historical information. τ is high when traders prefer to do long-term transactions. ε denotes the expectation of return: the greater the ε, the greater the expectation of price return.

The expectation of carbon price return ε and investment time scale τ varies between traders. Short-term traders pay attention to every price peak and trough, since buying or selling carbon futures accordingly is how they make profits. The mid- and long-term traders' concerns are more focused on long-term trends in carbon prices.

Generally, traders make decisions according to their expectations, and only when carbon price returns can satisfy their expectations they are willing to trade. Here, we use the parameters ε and $-\varepsilon$ to analyse traders' behaviours according to He et al. (2009) because price fluctuations in the carbon and oil markets are similar. When the perceived return is greater than ε, from the trader's point of view, traders choose to trade. Similarly, when the actual return is lower than $-\varepsilon$, traders believe that the price is falling. When the actual return is between $\pm\varepsilon$, the carbon price remains unchanged to traders. In this way, ε describes traders' psychological endurance and market expectations.

3 Data

The EU ETS is a major international carbon trading market, with its trading value accounting for 84%, respectively, of the international carbon market.[1] The data for this study were selected from the European Climate Exchange (ECX), which is one of the largest markets in the EU ETS. The ECX includes carbon futures contracts for all years since 2005. The Dec12 that has been delivered in December 2012 is selected to analyse the impact of expectations of returns and time scales on carbon price, because this period represents carbon price fluctuations since April 2005 and therefore covers both the first (2005–2007) and second phases (2008–2012).

4 Empirical analysis and results

The expectations of returns and time scales of investment are found to have profound impacts on carbon price behaviours. However, price distortions are not limitless. Once traders' expectations of returns approach critical points, they will not distort prices.

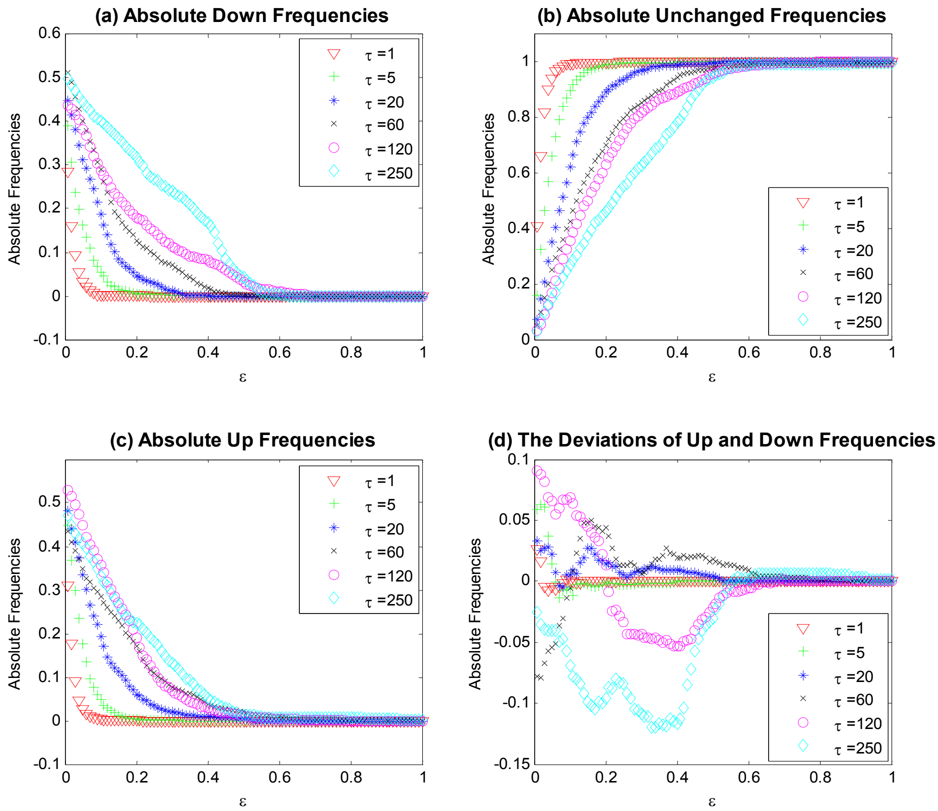
Table 1 Critical points for absolute and relative frequencies of carbon price fluctuations

τ	$p_-(\tau, \varepsilon)$	$p_0(\tau, \varepsilon)$	$p_+(\tau, \varepsilon)$	$\phi_+(\tau, \varepsilon)$	$\phi_-(\tau, \varepsilon)$
$\tau = 1$	0.23	0.23	0.21	0.23	0.23
$\tau = 5$	0.39	0.39	0.32	0.39	0.3
$\tau = 20$	0.41	0.52	0.52	0.52	0.52
$\tau = 60$	0.53	0.97	0.97	0.97	0.97
$\tau = 120$	0.68	0.79	0.79	0.78	0.78
$\tau = 250$	0.62	1.00	1.00	1.00	1.00

The absolute frequency of price fluctuations is close to 0 when the expectations of returns are greater than 0.6 (Figure 1(a) and (c)). The relative frequencies also have critical points similar to those for the absolute frequencies (Table 1, Figure 2(a) and (b)).

This indicates that, at a certain level, the traders' expectations of returns will not be able to distort carbon prices because the actual returns are unable to meet their high expectations. As shown in Figure 1, when the expectation of returns reaches 0.5, the price changes are close to critical points.

Figure 1 Changes in absolute frequencies as ε evolves ($0 < \varepsilon < 1$, computing step $h = 0.01$)



Note: $p(1, \varepsilon)$ shows the absolute frequency of prices increasing when the time scale is one day and the expectation of returns is ε (for all subsequent figures).

4.1 Impact of different expectations of return on carbon prices

An analysis of the impact of different expectations of returns on carbon prices shows:

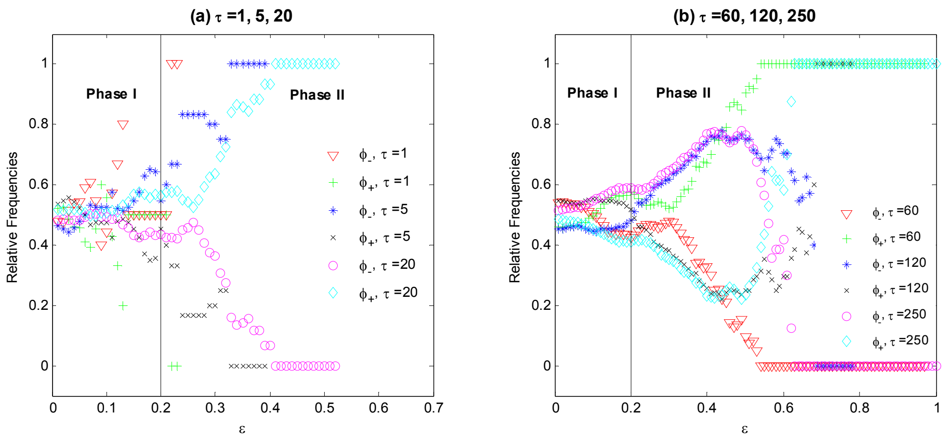
1 Traders whose expectations of returns are high perceive the price fluctuations in an extreme way. For $\tau = 1$, traders believe frequencies of fluctuations to be random when the expectations of returns are less than 0.1, while the frequencies of fluctuations are 0 if the expectations of returns are greater than 0.1 (Figure 1).

2 Different expectations of returns cause the deviations of fluctuation frequencies to vary over the same investment time scale. The deviations of these frequencies become larger until they reach a critical point with expectations of increasing returns (Figure 1(d)).

3 Carbon price fluctuations are asymmetrical. The deviations of price fluctuation frequencies are not equal to 0 before the frequencies reach a critical point. The frequencies for price declines are greater than those for price increases (Figure 1(d)).

4 The trends of fluctuation for price up and down frequencies exhibit some similarities. Traders perceive that the frequencies of carbon price changes increase with longer investment time scales. As shown in Figure 1(a)–(c), the fluctuation trends are similar and show that the probability margins become larger when the time scales are long.

Figure 2 Changes in relative frequencies as ε evolves ($0 < \varepsilon < 1$, computing step $h = 0.01$)



Note: $\phi(1, \varepsilon)$ shows the relative frequencies when the time scale is one day and the expectation of returns is ε (for all subsequent figures).

The analysis of relative frequencies of price fluctuations for different expectations of returns indicates that traders with low expectations of returns expect carbon price fluctuations are random, but the relationship becomes more complex for high expectations of returns. According to the relative frequencies shown in Figure 2, traders are divided into two types: the 'general traders' ($\varepsilon < 0.2$, shown in phase I in Figure 3) and 'speculators' ($\varepsilon > 0.2$, shown in phase II in Figure 2). For the general traders, the relative frequencies are near 0.5, the probability of increases compared to decreases is similar, and the price is random. For the speculators, the relative frequencies become scattered and quickly diverge. At short time scales, the relative frequencies of increases and decreases are different for the general traders and speculators (Figure 2(a)), while the difference becomes smaller when the time scale is long (Figure 2(b)).

4.2 Impact of different investment time scales on carbon prices

An analysis of the impact of different investment time scales on carbon prices shows:

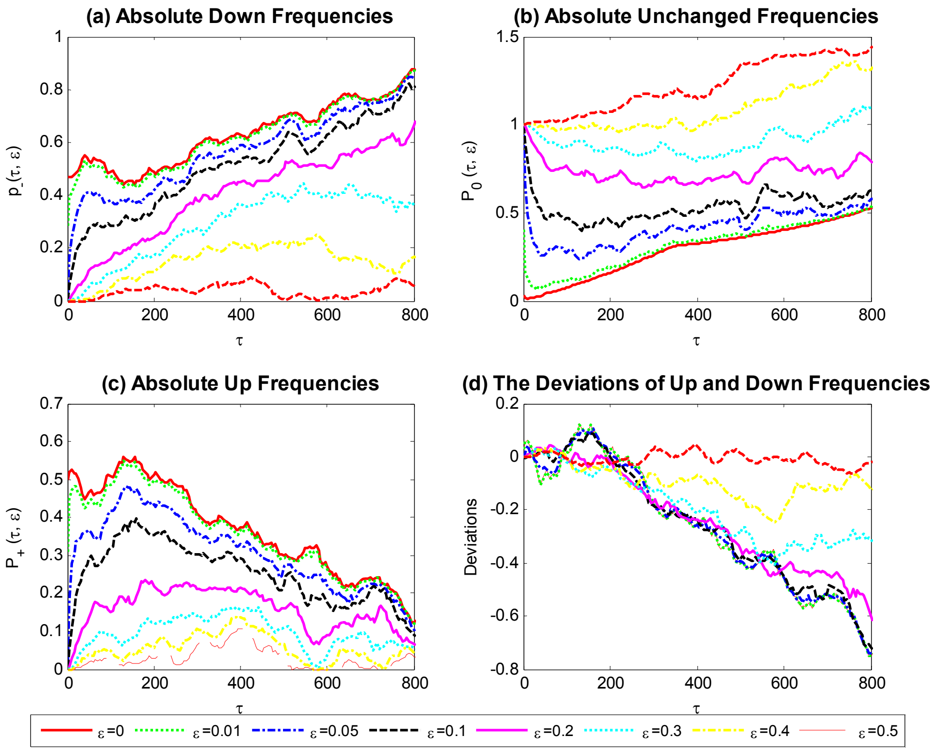
1 Traders who invest over short time scales perceive the price fluctuations in an extreme way. Fluctuation frequencies are near 0 when $\tau = 1$. Time scale impacts carbon price changes because the deviations of fluctuation frequencies vary with different time scales (Figure 1(d)).

2 For a given expectation of returns, the deviations of fluctuation frequencies become larger with increasing time scales (Figures 1(d) and 3(d)).

3 The probability of declining prices exceeds that of increasing prices at long time scales. Figure 4 shows that the frequencies of price declines dominate and the deviations of fluctuation frequencies are below 0 for time scales exceeding 150 days. This is due to the May accident of certification data leakage that has negatively affected carbon market, resulting in carbon price declines.

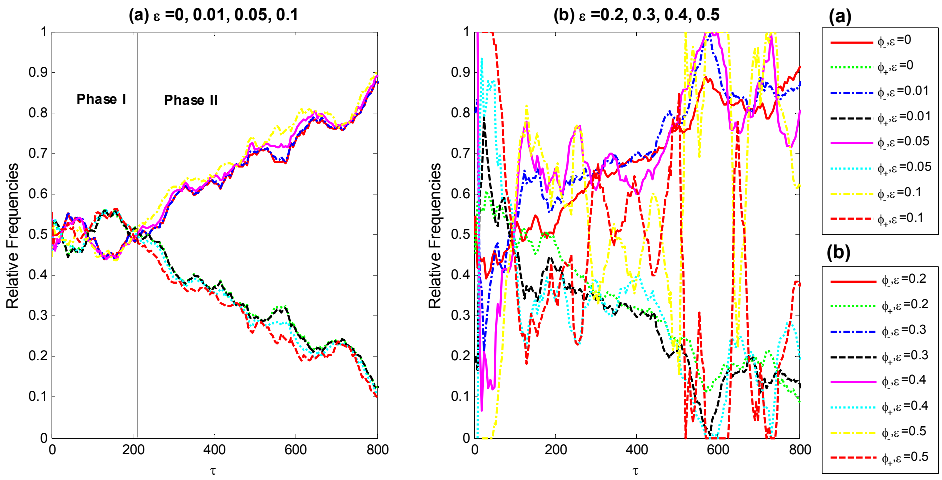
4 The results of the calculations of relative frequencies of price fluctuations for different time scales are shown in Figure 4.

Figure 3 Traders' perceptions of price fluctuations for different expectations of returns (absolute frequencies) ($1 < \tau < 800$)



With the omission of occurrences of unchanging prices, $\phi_{-}(\tau, \varepsilon)$ and $\phi_{+}(\tau, \varepsilon)$ should be symmetrical. If there is an obvious deviation of $\phi_{-}(\tau, \varepsilon)$ and $\phi_{+}(\tau, \varepsilon)$ from 0.5, the time series is indicative of persistent behaviours characterised with long-run memory and multi-fractal features. According to our results shown in Figure 4, most numerical results of $\phi_{+}(\tau, \varepsilon)$ are greater than 0.5 and deviate from 0.5 as time scale (τ) increases. At the same time, $\phi_{-}(\tau, \varepsilon)$ is below 0.5 and also deviates further as τ increases. These trends imply that carbon price behaviours are not unbiased. When τ is short, the bias is below 0.1. As τ increases, the bias becomes greater.

Figure 4 Traders' perceptions of price behaviours for different expectations of returns (relative frequencies) ($1 < \tau < 800$)



For traders with high expectations of returns, the bias is large and price fluctuations are irregular. In Figure 3, the relative frequencies of price increases $\phi_-(\tau, \varepsilon)$ and decreases $\phi_+(\tau, \varepsilon)$ are roughly 0.5 with low expectations of return ($\varepsilon = 0.1$). However, with increasing expectations ($\varepsilon = 0.5$), the relative frequencies ($\phi_-(\tau, \varepsilon)$ and $\phi_+(\tau, \varepsilon)$ vary widely (Figure 4(b)). At higher expectations of returns, traders tolerate higher uncertainty, and the risks of investment at both short (Figures 2(b) and 4(b)) and long time scales (Figures 2(b) and 4(b)) tend to be high.

For traders with low expectations of returns, carbon price fluctuations are influenced by market mechanisms, seasonal weather changes, and other heterogeneous events. Figure 5 illustrates some distinct critical points $\tau(\varepsilon)$ of $\phi_-(\tau, \varepsilon)$ and $\phi_+(\tau, \varepsilon)$:

1 Phase I (Figure 4(a)): market mechanism phase. The main feature of this phase is that the probabilities of price increases $\phi_+(\tau, \varepsilon)$ and decreases $\phi_-(\tau, \varepsilon)$ are highly stable, between 0.4 and 0.6. Carbon price changes are stochastic and affected by market trading. Speculating on either a rise or fall could to be profitable.

2 Phase II (Figure 4(a)): seasonal and special events phase. The phase is characterised by dynamic prices with time scales ranging beyond 365 business days. The market behaviour is unstable since fluctuations are persistent and greater than during the market mechanism phase. At the same time, carbon market is influenced by special events. The European economic crisis affects industrial production, and the requirement for carbon allowances declines. Carbon prices decline from 20 euro/tonne (Dec12) to 10 euro/tonne during 2008, and its prices decline during the end of 2012 for the second phase is 2008–2012. Although the impact of these events was great, the occurrence probability is low; therefore, phase I is considered more characteristic of the carbon market and is taken into account for short-term investments. High expectations of returns increase traders' risks and uncertainties, particularly in this phase.

In fact, the analysis results are very similar to Feng et al.'s (2011b) results, which use non-linear dynamics theory to analyse carbon price volatility in the carbon market, finding carbon price has short-term memory in the short time and a heterogeneous environment impacts the market price in the long time.

5 Conclusions

The paper uses a Zipf analysis technology to analyse the impact of expectations of returns and time scales on carbon price in EU ETS. Our main conclusions are as follows:

1. The expectations of returns and time scales of investment have deep impacts on the price behaviours. The larger the time scales are, the farther the deviations are from 0.5; the distortions of price returns in their cognition patterns are influenced by the expectations of returns great.
2. Carbon price fluctuations (increases and decreases) are asymmetrical. The probability of price declines becomes greater than the probability of price increases at long time scales. As an emerging market, the number of traders and the market capacity are limited; therefore, carbon price fluctuations are frequently due to the market's instability. The May accident that began in 2006 resulted in carbon price declines that lasted for several months.
3. Cognitive patterns vary between traders. For traders with low expectations, carbon price fluctuations seem to be impacted by market mechanisms, time of year, and external events. Carbon price changes are generally well understood. The perceptions are less straightforward for those with high expectations of returns; in general, risks and uncertainty are high. The carbon market is influenced by many factors such as carbon allocations, weather and external events, and carbon prices are frequently volatile. Therefore, we need to develop and regulate the carbon market, and enable it to continue playing its important role of reducing carbon emissions.

The results of this study provide an empirical foundation for the effect of EU ETS market carbon price. For future study, we suggest to study the optimal hedging ratio of spot and future market via behavioural finance.

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Note

1 These data are calculated by the authors using market transactions in 2009, according to the methods of Kossoy and Guigon (2012).

Nuclear power: irreplaceable before and after Fukushima

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Abstract: This paper analyses nuclear safety, monetary and energy economics of the nuclear power industry. We review and analyse economic, scientific, political, and regulatory environments in the broader energy sector. Competing economic and environmental interests are found as the world tries to deal with climate change and reduction of greenhouse gas (GHG) emissions. From cradle to grave, nuclear power is found to be safer and less carbon intensive than coal and gas. The longest-term outlook is still uncertain, but nuclear power is found to be more sustainable than fossil fuel energy. Increased technological R&D spending, government subsidies, and international cooperation to on safety compliance are suggested to spur growth in nuclear power as a replacement for coal.

Keywords: nuclear power; non-proliferation; climate change; renewable energy.

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1 Introduction

The 1968 United Nations Treaty on the Non-Proliferation of Nuclear Weapons (NPT) sets out clear goals of advancing technological and political cooperation in the development of nuclear power (American Society of International Law, 1968). 190 parties joined the treaty, forging a commitment to consider nuclear power and weapons as being legally separate. Despite this clear, unmistakable distinction between these two uses of nuclear materials, political activist groups continue to associate the two as if they were not mutually exclusive. Greenpeace (2014) opines that 'there is nothing "peaceful" about all things nuclear'. Regardless of such indictments, the United Nations has consistently endorsed the use of nuclear power as a replacement for fossil fuel electricity generation or a mitigation technology (IPCC, 2001; IPCC, 2014).

It is true that 'concerns over reactor safety, radioactive waste transport, waste disposal, and proliferation' (IPCC, 2001) constrain growth and development in nuclear power. Yet, if we approach the issue as legal positivists and embrace the rule of law, we find threats have long been taken care of. In addition to the NPT and other weapons bans, the International Atomic Energy Agency (IAEA) administers treaties on Nuclear Safety (1994), on the Safety of Spent Fuel and Radioactive Waste Management (1997b), on Nuclear Accidents and Damage (1963; 1986a; 1986b; 1997a), and on protection of Nuclear Material (1979). We find serious transnational crime and terrorism are addressed in several more treaties and UN resolutions. International treaty law binds parties to implement provisions at the national level. Such legal infrastructure leaves human error as the lone threatening variable.

On 11 March 2011, around 130 km offshore from Japan's north-eastern Miyagi prefecture, a magnitude 9.0 earthquake occurred. The earthquake created a 15-meter high tsunami. Both the earthquake and tsunami seriously damaged the Fukushima Daiichi nuclear reactors located on the coastline. The incident was labelled a category 7 event. No deaths or cases of radiation sickness were reported, but more than 100,000 people were evacuated from the area (World Nuclear Association, 2014d).

Fukushima uncovered dormant fears among the public about nuclear power, leading to increased media attention to safety, and national debates about whether or not nuclear power is an ethical source of energy. Numerous reports examine the Fukushima Daiichi catastrophe in detail (Rosner and Goldberg, 2011; Flaherty et al., 2012; Joskow and Parsons, 2012). Further discussion on that specific incident and its details is unneeded for this research, considering the enormous amount of information available on the topic.

We found Fukushima was an extraordinarily anomalous incident in the history of nuclear power, which has seen only three catastrophic incidents – Three Mile Island, Chernobyl, and Fukushima. Fukushima created a buzz about the continuing dangers of nuclear power despite advances in technology and regulations since the 1980s. We inferred human error in the planning stages of the Daiichi project, which was improperly located in an area prone to seismic activity and tsunamis. Instead of reviewing and analysing Fukushima, however, we approached this research with an objective of surveying opinions regarding nuclear power across multiple professional sectors.

This paper presents an evidence-based inquiry of nuclear power, its advantages and disadvantages, its safety record and ratings, its competitiveness as a power source, and its place in the future global energy mix. We review and analyse economic, scientific, political, and regulatory environments in the energy sector. Competing economic and environmental interests are found as the world tries to deal with climate change and reduction of greenhouse gas (GHG) emissions. Renewable energies are not found compatible with load demands that nuclear power serves. Carbon-capture systems for nuclear's main competitor – coal – are found economically unfeasible, and theoretical super-power sources like fusion are not found to be a realistic option for the middle to late 21st century, when fossil fuel reserves are expected to be in scarce supply. Nuclear power should emerge as the champion of our power grids, providing massive amounts of virtually GHG-free electricity. Although the latter part of the 22nd, and into the 23rd, century remains largely unimaginable, nuclear power is shown to offer ample, sustainable, and clean power for more than 100 years, into a time when energy is crucial and somewhat threatened. Increased technological R&D, safety systems management, and international cooperation are paramount to a successful rebirth of nuclear as the remaining rational choice in power.

2 A staple base power source

Load over any grid varies at different times of day. In order to supply the changing demand, generation is broken down into base load, intermediate, and peak segments. Base load power is generated by plants that have low operating costs and consistent fuel. Capacity factor, or the percent of time the plants operate at full output, also influences what part of the load cycle plants will serve. Nuclear plants usually have a capacity factor of around 90%, compared to 44% for hydro, 20–40% for wind, and 5–19% for solar (Frank, 2014), making nuclear a perfect base load source, like coal. Geothermal has a good capacity factor for base load power, but high costs keep it out of the mix. Combined cycle gas plants can ramp up and turn down production quickly, making them staple intermediate and peak sources. Although gas production is growing as we try to cut emissions, higher operating costs have kept gas from seriously competing with coal as a base load source (Kaplan, 2008). Wind and solar are subject to intermittent shutdowns caused by weather, that plus the high capital costs make them a good supplemental source during daylight hours, but nothing consistent.

2.1 Trends in production and consumption

World electricity generation increased by about 86% between 1990 and 2011, by which time it was 21 petawatt hours (EIA, 2014). Production is set to increase to 39 petawatt hours by 2040 (EIA, 2013b). IAEA (2011) forecasted 44–99% growth in nuclear power generating capacity between 2010 and 2035, making it the second fastest-growing source behind renewable energies (EIA, 2013b). As of 2014, only about 11% of the world's electricity came from nuclear power. Five countries – the USA, France, Russia, South Korea, and China – generate more than two-thirds of the roughly two and a half gigawatt hours produced among all reactors worldwide (Schneider and Froggatt, 2014). 13 countries relied upon nuclear to generate at least one-quarter of their total electricity, but nuclear power has not yet been deployed widely. Only 30 countries are home to the 440 operational reactors worldwide (IAEA, 2016).

Nuclear power generation declined significantly following Fukushima, both in net terawatt hours and share of electricity production (Schneider and Froggatt, 2014).

Germany closed all reactors that began in 1980 or earlier and vowed to close all other reactors by 2022 (European Commission, 2014b). In Switzerland, about 40% of power comes from nuclear, and despite a public vote in favour of keeping it, the government decided to phase out reactors by 2034 (World Nuclear Association, 2014a). The EU as a whole set a goal to supply 27% of its energy with renewables by 2030 (European Commission, 2014a), but renewables cannot replace nuclear power per se. If nuclear power generation or growth is decreased or stalled, it is nearly certain that a fossil fuel source will replace it, which makes it more difficult to achieve aggressive targets for reduction of GHG emissions.

Renewable technologies are relatively new compared to other sources, giving them a natural advantage in growth markets. Opportunity cost may also influence investment in renewables in the early 21st century. Given the unpredictable future of rare earth mineral prices, and their integral role in wind turbines, recent investments into renewables may have been made with future prices in mind. Nevertheless, a diverse energy mix is desirable, and in the longer-term nuclear power is not likely threatened by expansive use of renewables because renewables are not suitable for base load power generation. High capital costs and capacity factors constrain solar, wind, and geothermal to supplemental producers.

2.2 A comparison of plant costs

Nuclear plants are among the most expensive facilities to build, but they are also able to generate more power than other sources. EIA (2013c) found costs for nuclear plants were less than municipal solid waste, dual flash geothermal, offshore wind, biomass, fuel cell natural gas, and single unit coal gasification with carbon capture. A dual unit nuclear reactor project costs about the same as single unit pulverised coal with carbon capture, and pumped storage hydroelectric generators. Fixed costs for nuclear are higher than all coal, gas, wind, solar, and hydroelectric sources, but less than combined cycle biomass, municipal solid waste, and geothermal. Nuclear power weighs-in as the cheapest in terms of variable costs among gas, coal, biomass, and municipal solid waste. In other words, nuclear fuel is cheaper than all other fuels. As a result, total operating costs for nuclear have been lower than those for fossil steam, gas turbine, and small scale utilities (EIA, 2013d).

Low fuel costs currently make nuclear a competitive source of electricity, despite high capital investment costs. Capital cost concerns tend to favour combustion turbine or combined cycle natural gas plants, which run about one-eighth to one-fifth the price of nuclear plants (EIA, 2013c). Hence, opportunities for utility service providers in the immediate future lie primarily in the gas sector considering that government emissions regulations favour gas over coal. The future, however, may not be as simple. Government incentives, air emissions controls, and fuel costs could threaten fossil fuel production considerably, leaving nuclear power as the only remaining source for base load power that is economically feasible.

In 2006, in the USA, publicly owned utilities generated only 22% of all power, while investor-owned utilities and independent power producers supplied near equal shares for the remaining demand (Kaplan, 2008). Privatisation and liberalisation of electricity utilities as seen in the USA and Europe (Heddenhausen, 2007) will only increase the focus on profitability, which will change alongside construction and fuel costs in the middle of the 21st century. When discussing financial aspects of nuclear power on a global scale, we would be remiss to omit that capital costs for advanced nuclear technologies in China and Korea are lower than supercritical coal and onshore wind in the USA and Western Europe (Rong and Victor, 2012). Plant costs change from country to country depending on costs of labour. Since the majority of new demand for electricity through the 21st century will come from the developing world, where labour costs are lower, nuclear power remains a financially feasible option in global markets.

2.3 Subsidised clean energy

In 2010, the US government gave more than $37 billion in energy subsidies, 40% of which went to renewables (EIA, 2011). By cutting costs for nuclear power providers with tax breaks and incentives, governments can promote the clean energy transition. While Canada's low population density and high per capita natural resource base make it a less than suitable global model, other countries can find some sense of direction by looking into Canada's energy plans. The Canadian Clean Energy Fund helps keep 80% of the country's power coming from sources that are not significant GHG emitters (NRCAN, 2013). Meanwhile, in Belgium, phase-out legislation included tax hikes that removed up to 70% of electricity provider profit (Schneider and Froggatt, 2014).

Loan guarantees and tax credits significantly influence the composition of power grids (Kaplan, 2008). While developed economies are trending towards privatisation and submission of utilities to market forces (Heddenhausen, 2007), governments still influence development and deployment of certain types of power. Without subsidies and tax incentives intended to promote clean energy growth, there would be little chance of reducing the market share of coal. Whereas renewable energy subsidies can relieve some of the burden from carbon-intensive suppliers, and gas subsidies help transition the intermediate load towards cleaner production, without significant subsidies for building nuclear plants, coal is the runaway leader for base load power due to financial concerns of utilities. Carbon taxes or cap-and-trade mechanisms can help motivate coal power producers to changeover, but the future of carbon regulation is still unwritten. In the shorter term, subsidies and incentives provide support for cleaner energy.

3 The low-carbon future case

Owing to negative political attitudes towards nuclear power and still low-scale investment in renewables, fossil fuels are expected to supply up to 80% of energy demands by 2030. Theoretically, nuclear power could replace coal power, but it faces serious challenges with public opinion that focuses on perceived dangers of production and waste storage (JOE, 2010). Still, climate change has already prompted individuals, companies, and societies to make behavioural changes intended to reduce carbon emissions. The future is yet unknown, but it is plausible that through the latter half of the 21st century we could come to live in a world where a combination of carbon taxes, resource scarcity, and public resistance to emissions change the way we think about and use energy. Renewable energy can help reduce the amount of carbon sent into the atmosphere, but renewables are not suitable for base load production. Fuel prices for gas could create profitability issues beyond 2050. Clean coal is not currently an option due to high costs and 15–20% energy penalty (US Department of Energy, 2013; World Nuclear Association, 2014b). Clean coal's Canadian debut came by way of the Boundary Dam Project, a 110 megawatt plant costing a billion dollars, which is an investment nightmare (Saskpower, 2014; Kemp, 2014). Nuclear power stands out as having multiple benefits as we enter a time of unprecedented energy consciousness.

Nuclear energy should appeal to people concerned about both climate change and global corporate ethics. Although nuclear waste disposal presents certain environmental challenges, the power generation process is essentially carbon-free. And while uranium is a non-renewable natural resource required for nuclear power, uranium mining and processing organisations are subject to far more extensive regulations than the average extraction industry player. As a result of international controls over uranium supplies, there is less room for human rights abuses and corruption when compared to oil, gas, and coal. Access to electricity is a human right (Tully, 2006), and nuclear power increases our potential to satisfy this basic need. In our era of 'Occupy' movements and protests over oligopolies, nuclear power offers some clean competition in a notoriously dirty industry.

Notwithstanding the merits of nuclear power as a clean alternative, public opinion swayed against its use and expansion even in nuclear-friendly countries. Bird et al. (2014) reported on changing public opinion in Australia, where the majority of survey respondents supported nuclear power just before Fukushima, and then did an about-face shortly after the accident. This type of fearful reaction is not unique to Australia, but it is perhaps more significant for Australians, who battle some of the highest CO_2 emissions per capita in the world. Essentially, what Australians and others are facing is a dilemma over whether they want higher perceived safety (from nuclear incidents) or cleaner energy. Still, reliance on gas and coal over nuclear does not necessarily guarantee safety. Rather, for most countries, fossil fuels present other serious security and safety threats.

3.1 Political volatility and European energy security

By 2030, the EU is expected to depend on imports for 70% of its energy needs (F4E, 2014). France and Italy were expected to have completely run out of fossil fuels by 2015, with the UK following by 2020 (Vincent, 2014). About 30% of Europe's gas in 2014 came from Russia (Pirani et al., 2014), which is perceived as a potential threat considering political tensions over Ukraine (Nelsen, 2014). In a dual effort to cut carbon and increase energy security, the EU planned to generate 40–44% of its power from renewables by 2035, using gas for 28–33% of electricity, and nuclear for 17–21% (Eurogas, 2013). Shale-gas basins are found across Europe, but extraction is banned in four countries and extremely limited in others (The Economist, 2014).

We cannot accurately quantify the degree to which European energy security is threatened, but military sources suggest increased competition for shares of a limited supply of resources could spark conflict (JOE, 2010). Considering the new integrated global economic model, we expect any serious volatility or depreciation in one mega-market (i.e. the USA, EU, China) to negatively impact global economic conditions as was the case in early 21st-century financial crises. Those infectious financial conditions may give rise to military conflict, both between states and between non-state actors and states. Such scenarios threaten healthy business activity, driving up costs for consumers, thereby restricting access among lower classes, which contributes to further strife.

3.2 Rare earth mineral shortages constrain green growth

Wind farms might seem like a brilliant idea, but high-performance turbines require about two tons of rare earth minerals (Jones, 2013). China holds a near-monopoly on rare earths production, with more than 95% of global output coming from the mainland (Ives, 2013). In 2010, China cut export quotas on rare earths, which led to soaring prices on global markets and a complaint by the USA at the World Trade Organisation.[1] Beijing cited environmental concerns as reason for export restrictions, but the WTO panel decided China had violated international trade law to 'achieve industrial policy goals' rather than to protect the environment (Jolly, 2014).

Nonetheless, environmental concerns are legitimate when it comes to producing rare earths. China may manufacture 95% of the world's supply, but the country only holds about 36% of global reserves. The USA actually holds about 13% of global reserves (UNEP, 2011), but produces nothing, like Australia, which holds 5% of world reserves. The primary reason that rare earth elements (REEs) have not been mined in the USA for the past couple decades is that pollution is a nearly unavoidable aspect of extraction and production (EPA, 2012). REEs are recyclable, but recent estimates show recycled products account for only about 1% of supply. More extensive recycling could reduce environmental impacts of extraction, but REEs are generally used in very small amounts, resulting in a very costly and resource-intensive process when it comes to leeching grams at a time from mobile phone handsets and laptop computers (Ali, 2014).

3.3 Human rights and environmental concerns over hydroelectric

Dams are irreplaceable parts of existing power grids, with total contribution from hydropower at around one-fifth of global electricity production (Perlman, 2014). Conventional hydroelectric plants are among the cheapest generation facilities to construct, and fuel costs are nil thereafter (EIA, 2013c). Hydroelectric turbines produce about the same amount of GHGs as wind turbines, roughly 1% that of coal-fired plants (Hydro Quebec, 2014). Furthermore, water is a renewable resource, leaving nearly endless potential to produce power from rivers and streams. However, utility-scale hydroelectric production transforms the landscape upstream from the plant into a reservoir, displacing people and damaging ecosystems (Ledec and Quintero, 2003). Recent research has shown that the formerly terrestrial organic material, such as trees and bushes lying beneath manmade reservoirs, emits significant amounts of GHGs – about 4% of global emissions from inland waters (Barros et al., 2011). While GHG emissions are not a deal-breaker for hydroelectric development, human rights concerns are gaining increasing attention as the rights of indigenous people are often threatened by dams.

The World Wildlife Fund (Oxfam, WaterAid.org, & WWF, 2006) reported that between 40 and 80 million people had been displaced by one or more of the 48,000 dams in operation in the year 2003. Hoshour and Kalafut (2010) found that between 1980 and 2000, more than 10 million people annually were displaced by dam and urban transport development. Indigenous people, women, the elderly, poor, and handicapped people are disproportionately affected by involuntary resettlement compared to more well-off groups (World Bank, 2004; Hoshour and Kalafut, 2010). Although dams offer cheap, clean power, we found human rights concerns preclude recommendation of expanded dam systems. Instead, we suggest renewable expansion should be built upon solar, wind, tidal, and geothermal energy projects with government support.

3.4 No fusion

Nuclear fusion, the same energy created by the sun, is the dark horse of the energy race. A few hopeful engineers believe a fusion-powered electric plant could be built for lower cost than a coal plant, but nobody knows if fusion is possible outside of computer-generated models (Boyle, 2014). After 50 years of research and development, no fusion reactor has produced more energy than it consumes (Cowley, 2010). Even if fusion energy does prove possible in the real world, the first commercial reactors are not expected until mid-21st century at best (Thomson, 2002; Chameides, 2012), and not scalable for decades thereafter, leaving exawatts of new demand to be met by existing sources.

3.5 Price elasticity

Electricity is a necessity of modern life, and as such short-term demand is relatively inelastic (Bernstein and Griffin, 2006). That is, when spot prices increase, demand stays the same or decreases insignificantly. However, consumers are likely to modify behaviour in response to long-term price increases. Residential consumers faced with consistent annual increases in electricity costs will take measures such as turning down air conditioning units, turning off lights and appliances when not in use, replacing incandescent bulbs with high-efficiency fluorescent ones, etc. Commercial and industrial consumers will seek to cut overhead by investing in higher-efficiency equipment, and designing new facilities to maximise usage of natural light and cooling. A more aggressive approach entails fitting homes, businesses, and industrial estates with renewable energy generators like solar or wind. A result of energy-conscious behaviour changes is long-term reduction in per capita electricity consumption, or delayed elastic responses (Siddiqui, 2003; Borenstein, 2009).

The EPA (2005) forecasts demand elasticity to rise over time. Owing to methodological issues in predicting consumer responses to price increases (Siddiqui, 2003), the precise change in future demand is incalculable. Commonsense analysis tells us that there is a static non-zero demand floor which will be approached as price increases infinitely over time, but it would not likely be a simple mathematical function to graph. As consumers face increasing energy costs across sectors – petroleum, gas, and electricity – demand for one will likely be influenced by prices of others. Enhanced and interrelated demand elasticities through mid-21st century will undoubtedly affect preferences in electricity production methods. The World Coal Association (2014) estimated oil and gas supplies will be exhausted by the year 2070, with coal following around the year 2125. As we enter an era of unprecedented global resource scarcity, the low fuel costs associated with nuclear power presumably increase consumer demand.

4 The longer-term future

ExxonMobil (2014) predicted that by the year 2040:

1 the earth will be home to more than 9 billion people;

2 global economies will grow to 130% their present size;

3 demand for electricity will rise by 90%;

4 about 60% of energy will come from oil and gas; and

5 gas will surpass coal as the second-largest fuel source.

Developing nations are expected to drive growth in demand for energy through mid-century (ExxonMobil, 2014; BP, 2014; Shell, 2014). As Asian economies enter into their most energy-intensive phases of development, new competition factors will emerge in a world which struggles to maintain adequate supplies of finite resources.

4.1 Non-renewable resources

OPEC (2013) expects passenger car ownership to more than double between 2010 and 2035, pushing oil demand upward of 108mb/d. Prices rise to $160/bbl in OPEC's year 2035 reference case. High estimates of future prices remain over $200/bbl for the year 2030 (Natural Resources Canada, 2010). EIA (2013a) predicts gas prices will rise 90% between 2013 and 2040, at which time gas will be the largest source of American electricity and second largest energy source behind petroleum. These outlooks are not contradicted by forecasts from the UK Department of Energy & Climate Change (2013), which has coal prices set to increase by about 30% by 2030. Such price changes reflect not only inflationary economics, but also potential shortages of disappearing natural resources.

Uranium is another finite resource, though more abundant than gas and oil, and possibly more than coal in comparison to how it is used. Low estimates for longevity of current supplies are over 100 years (IAEA, 2012), and higher estimates extend more than 200 years (World Nuclear Association, 2014f). Theoretical technologies such as breeder reactors and seawater-uranium extraction could extend the life of the resource indefinitely (Fetter, 2009). One of the advantages uranium has when compared to other fuels is the location of its supplies. With 41% of known recoverable global resources in Australia, Canada, and the USA (World Nuclear Association, 2014f), major nuclear power producers in North America and Western Europe would have more stable access to supplies than if the resources were in lesser-developed countries. Prices will undoubtedly rise and face volatility as oil and gas run low, which will likely drive innovation and growth in renewables, but towards the end of the 21st century, uranium should be a preferred resource as climate change concerns continue to plague the coal industry.

4.2 The no-substitute utility sources case

Since the late-1800s, humans have witnessed technological and scientific change unparalleled in prior history. Since Second World War, people have made exponential advancements in all areas of natural sciences, including addition of entirely new fields of study. Aside from basic physical and biological processes, we live completely different lives than people only a handful of generations before us. Despite the optimistic forecasts from investment bankers and researchers, such radical change is unlikely to continue at the breakneck speeds observed over the past century. While we are likely to see incremental improvements in technological efficiencies and decreases in size in the coming decades, humans may not experience another scientific revolution for millennia.

A fusion reaction may never be sustained. Asteroid mining may never be an economically or technologically feasible option for harvesting minerals. Should the continent thaw, we may find Antarctica does not have enough fossil fuels to sustain so much as another 50 years of consumption. Solar cells may never be efficient or affordable enough to compete in a utility market. Biofuels may never produce an energy output–input ratio high enough to make them commercially scalable. Considering the trend of increasing global population and energy demand, if one were to live into the 22nd century, absent near-miraculous scientific breakthroughs, it seems that one would have little choice but to learn to love nuclear fission power because it would be the only affordable, scalable, high-quality source of electricity available. To abandon its use or curtail its development at any stage would be extremely short-sighted.

5 Our future energy portfolio

Safety has been an overriding focus in nuclear power since inception. Despite public fears surrounding meltdown and disaster provoked by the Fukushima incident, nuclear energy is actually very safe. Union of Concerned Scientists (2014) found 'serious nuclear accidents have been few and far between', citing seven since 1957 – Fukushima, Chernobyl, Three Mile Island, Fermi 1, SL-1, Sodium Reactor Experiment, and Windscale. Of those seven serious accidents, three were of particular concern – Fukushima, Chernobyl, and Three Mile Island.

Between 2003 and 2014, there were an average 163 annual fatal injuries in US mining and extraction industries (BLS, 2016). By comparison, nuclear plants experience about 2–4 radiation deaths per year worldwide (World Nuclear Association, 2014c). NASA estimated that nuclear power prevented 1.8 million deaths between 1971 and 2009, hundreds or even thousands of times more than deaths it caused (Kharecha and Hansen, 2013). Owing to its lower mortality and emissions factors, fuel switching to nuclear power was recommended at NASA's Goddard Institute for Space Studies. In spite of scientific support, nuclear power faces public opposition due to perceived safety threats.

Through 31 December 2012, all operating and shutdown reactors in the world had a combined operating experience of just over 15,247 years (IAEA, 2013). Given that humans experienced three serious nuclear accidents, nuclear power has an incident rate of 1 per 5082 reactor years. By comparison, thousands of people die in coal mines every year (World Nuclear Association, 2014c). Gas power plants are some 8.75 times safer than coal plants, with gas causing 2.8 deaths and 30 serious illnesses per terawatt hour as compared to 24.5 deaths and 225 serious illnesses attributable to coal electricity generation. That looks great for gas until we see nuclear power, which causes 0.052 deaths and 0.22 serious injuries per terawatt hour – nearly 54 times safer than gas according to Markandya and Wilkinson (2007). By the numbers alone, nuclear power should be the preferred power source if safety is a number one concern.

Quantitative risk assessments most frequently find the broadly acceptable risk of death for individuals lies between 1 in 1000 and 1 in 1,000,000 per annum (La Guen, 2008; Law, n.d.). Hunter and Fewtrell (2001) found the maximum tolerable death risk to the public from any new nuclear station is 1 in 100,000. Accordingly, the US Nuclear Regulatory Commission set goals for core damage frequency at 1 in 10,000 reactor years, and large early release frequency at 1 in 100,000 reactor years (Cochran and McKinzie, 2011). Newer plants operate with around a 1 in 1 million year core damage frequency, and those planned to be built have roughly a 1 in 10 million year rating (World Nuclear Association, 2014c).

Hunter and Fewtrell (2001) identified specific 'fright factors' which influenced people to reduce their tolerance for risk. These factors included:

1 whether the threat is man-made rather than natural;

2 if the threat may cause hidden and irreversible damage that may result in disease many years later;

3 if the threat is a particular threat to future generations, pregnant women, or children; and

4 whether it causes damage to identifiable, rather than anonymous individuals.

Psychosocial factors seem to make the low risk associated with nuclear power less tolerable than more prevalent dangers related to fossil fuels. Ironically, people like those in Germany pushed for lower carbon and higher safety but rejected nuclear power, which is a leader on both fronts. As decades pass into the future, it seems rather obvious that we cannot achieve our carbon or safety objectives without nuclear power, but gaining public support is difficult, if not impossible, in an era of internet media scares.

5.1 Energy security overshadows public fears

Energy policy should be drafted and implemented based upon facts and evidence rather than the whims and emotions of the general public. Electricity production is not threatened today, but lacking near-miraculous breakthroughs in technology, people born in the 21st century are likely to experience fuel shortages, which could lead to utility rate volatility, brownouts, and serious industrial crises. This is not a 'gloom and doom' prophecy, but rather a natural economic law in any case where a non-renewable resource is continually consumed over long periods of time. Unlike climate change, which is likely yet also generally unknown as for precise details, the future of low and diminishing fossil fuel production is generally known and endorsed by numerous scientific and governmental agencies, some of which were cited in this research. Uranium is not likely to be available over an infinite timeline, but it gives us more time to develop new technologies and adjust consumption patterns.

Germany's decision to scrap its entire nuclear fleet appears to be without clear rationale, considering that its risk of seismic activity is about as low as the UK or France, far away from fault lines where the Eurasian plate meets the African or Arabian plate (USGS, 2014). Sensing a relatively similar degree of freedom from seismic activity, the head of the British Office for Nuclear Regulation (UKONR, 2011) said, 'The extreme natural events that preceded the accident at Fukushima – the magnitude 9 earthquake and subsequent huge tsunami – are not credible in the UK'. Locations of fault lines worldwide further suggest that there is no credible threat of a Fukushima-like event throughout the majority of world's countries.

5.2 Location, location, location

Without Fukushima, our most recent nuclear disaster would have been Chernobyl – an incident we can infer resulted from inefficiencies and corruption of the Soviet empire in its final stages. Technological and regulatory improvements virtually guarantee disaster-free power production throughout the life of newer reactors. Such facts are why Japan did not abandon nuclear power after the horrific accident on the Northeast side of Honshu Island. It is implicit to say that if Fukushima had not happened, there would not have been such a sharp increase in anti-nuclear ideology in the mainstream media and political conversation. Still, little attention has been paid to the underlying cause of the disaster – poor planning.

Japan's decision to authorise Fukushima plant construction on the East side of the island, where severe earthquakes and tsunamis had been documented throughout history, was an incomprehensible oversight that ultimately endangered the lives of millions of people for generations to come. Japan's entire Eastern border sits nearly on top of a massive fault system where the Pacific, Eurasian, North American, and Philippine plates meet. This system poses an especially high threat for tsunamis because they are all convergent plates (Annenberg Learner, 2014; Damen, n.d.).

If earthquake hazards are our main concern, considering how well-made and managed nuclear reactors are today, nuclear power plants may be safely built anywhere aside from the Western edge of the Americas, the Mediterranean and Red Sea region, the Asian Pacific coast, parts of Oceania and Central Asia, or wherever faults lie. Natural disaster risk alone should not motivate such strong opposition to nuclear power within the leadership of developed nations like Germany, where natural disasters pose no serious threat. At most, a shutdown of a few specific existing plants based on risk of natural disaster may be rational, but we found no evidence suggesting a total cancellation of an existing and future nuclear energy program is anything but irrational.

Active nuclear power generation facilities have very low incident rates when compared to other base load power supplies. The evolution of technologies and standards since the 1990s make nuclear accidents extremely rare. Outside of regions prone to earthquake, there is virtually no chance of a disaster occurring. Even in areas of mild seismic activity, reactors and plants are safe, having been designed to handle earthquakes. Managing nuclear waste then becomes the main health and safety concern.

5.3 Managing spent fuel

Radioactive waste is a challenge to work with. It stays very hot for years after separation. If a storage facility were to experience loss of coolant in the first few years, it could result in an overheating accident, which has never happened but presents certain risks (Feiveson et al., 2011). Spent fuel takes about 1000 years before its radioactivity level is roughly equal to the original ore (World Nuclear Association, 2014e); it needs to be stored with extreme caution, deep under the surface of the earth in order to retain its safety rating. Transport and storage technologies are incredibly trustworthy in the modern age, leaving terrorism and malevolent acts the main concerns (Feiveson et al., 2011). Military and other government support is implicit in nuclear matters, leaving a very low risk of accident so long as security protocols are properly designed and continuously enforced.

Towards 2030, non-OECD countries, especially in Asia, are expected to grow energy demand, and as a result build the lion's share of new nuclear reactors (IAEA, 2014). State-of-the-art technologies further the cause of public safety when it comes to new plants in developing countries like China, where 28 new units are under construction and scheduled to be online before 2020 (Schneider and Froggatt, 2014). It is especially important in these lesser-developed countries that government agencies responsible for overseeing nuclear power have and enforce globally accepted regulations.

6 Conclusions

Nuclear weapons are not comparable to nuclear power. To confuse the two is to ignore scientific and legal theory. A world without nuclear technology may seem 'natural' to activist groups who claim nuclear fission threatens our general safety, but the reality is that nuclear power protects us from strife and conflict over fossil fuels along with the carbon they create. Uranium mining is far more regulated than hydrocarbon extraction, resulting in less corrupt and crony capitalist manipulation of markets and peoples. True it is that renewables like wind and solar are less damaging to the ecosystem, but those sources are unsuitable for base load production. Nuclear's only real competitor is coal, which generates 26% of global GHGs – double that of the transportation sector (Magill, 2014).

There are no simple solutions for the bundle of problems that come with simultaneous shortages in non-renewable resources and increasing carbon emissions, which are believed to cause climate change (IPCC, 2001; IPCC, 2014). Nuclear power is a vital source of electricity in the 21st century. Germany's discontinuation of nuclear power is neither scientifically nor economically rational (Johnson, 2011). Scientific sources show that nuclear is actually safer than other sources, that nuclear has lower operating costs, and that its fuel has the greatest longevity. NASA scientists endorsed nuclear energy wholeheartedly when they said:

> *"We conclude that nuclear energy – despite posing several challenges, as do all energy sources – needs to be retained and significantly expanded in order to avoid or minimize the devastating impacts of unabated climate change and air pollution caused by fossil fuel burning."* (Kharecha and Hansen, 2013)

Our research found little credible opposing argument; rather, we found overwhelming support among scientists and governmental personnel for nuclear power development and deployment. Continuance and advancement of atomic energy naturally entails evolving technological and safety systems. Such is the nature of physical sciences in our age – continuously improving. Likewise essential to safe power is international nuclear cooperation, from cradle to grave. Standards, procedures, methods, protocols and systems should be shared between nuclear nations and those with ambitions to achieve nuclear energy security. Via cooperation on civil use of nuclear materials for electricity, nations may also step closer to their stated goals of non-proliferation. As the future is revealed, nuclear energy is bound to be a mainstay utility because of its pragmatic value. Thus, the dissenting minority view should take a back seat to progress – safe, reliable, clean, long-term progress.

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Notes

1 WTO Dispute DS431 (13 March 2012).

India revamps green energy sector: what lies for domestic biogas technology?

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Abstract: Present study, in the wake of India revamping its green energy sector, revisits long established rural-based energy technology domestic biogas plants (DBPs). To this end, we present its status-policy design, nature of diffusion and factors that determine their adoption. While more than 60% of the biogas plant potential are still left untapped, their installation declined steadily across all the states in the last decade. While only three of 1000 rural households use DBPs, half of them find it inadequate. Increment in the financial assistance to the state, presence of educated woman in the household, and ideal physical conditions enhance the households' chances to adopt DBP. On the contrary, improvement in the status of alternative energy sources (firewood), belonging to backward social community and being a poor household reduces the odds to adopt biogas plants. Characterised by fractured support system, biogas plants still has long way to go before emerging as reliable and sustainable source of energy in rural India.

Keywords: domestic biogas plants; green energy technologies; rural energy; energy poverty; India; national biogas and manure management program; sustainable development; diffusion.

Reference to this paper should be made as follows: Choragudi, S. (2016) 'India revamps green energy sector: what lies for domestic biogas technology?' *Int. J. Global Energy Issues*, Vol. 39, No. 6, pp.413–431.

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1 Introduction

In the pursuit of sustainable development (11th and 12th five-year plans), India is multiplying efforts to strengthen its Green Energy (GE) sector. In this regard, while it urges for technological assistance from developed countries, one cannot surpass the fact that it came a long way developing and promoting GE technologies. However, the way in which India perceived GEs changed in the recent past. Firstly, while GEs were once paid lukewarm attention, now they are developed and generated to complement conventional energy sources. Secondly, for a very long time State's attention towards GE primarily comprised of small scale off-grid applications focusing on energy poor households in rural India. However, recently, India's GE sector witnessed a shift towards industrial scale energy production to feed the grid. While the former development is undoubtedly a boost to GEs, the latter ought to be tread cautiously owing to the fact that rural India is still characterised by significant proportion of energy poor households.

While dealing with rural energy, the thrust should be on energy sources and devices that are renewable, biomass-based, universally accessible, affordable, reliable, of high quality and safe. A special attention must be devoted to sources that are small scale, decentralised and renewable systems, and amenable to local control (Moulik and Srivastava, 1975; Moulik, 1978; Reddy, 1999; Reddy, 2002; Kaundinya et al., 2009). GE applications for cooking fuel in rural India like Domestic Biogas Plants (DBPs) are a point in case. Significant proportion of rural households in India depends on traditional and unsustainable sources of energy like firewood. According to National Sample Survey Organisation (NSSO), *Energy Sources of Indian Households for Cooking and Lighting, 2009–10*,[1] 76% of the rural households reported to use firewood as their primary source of energy for cooking. In fact, this trend remained almost same in the past decade and half.[2] Smith and Sagar (2014) term this scenario as '*Chulha* trap'. Collection of firewood and transporting it to long distances involves drudgery and economic loss in terms of opportunity cost (Shailaja, 2000; Laxmi et al., 2003; Parikh, 2011). Further, combustion of firewood results in serious health hazards. 50% of pneumonia deaths among children under five are due to particulate matter inhaled from indoor air pollution and adults exposed to heavy indoor smoke are 2–3 times more likely to develop chronic respiratory diseases (WHO, 2011).

At the same time, modern sources of energy like Liquefied Petroleum Gas (LPG) have a different set of problems like rising costs, restricted supply, anomalies in the subsidies associated with them and weak distribution system in rural India. While only 11% of the households use LPG as cooking fuel, 38% of them reported to use firewood to complement their energy requirements since LPG is inadequate and the degree of inadequacy is as high as 72%.[3] The use of alternative, sustainable and clean energies specifically those that are generated using local produce like DBPs is by far negligible. According to the recent estimates, an average rural household possesses two to three cattle heads which will facilitate the household to at least partly depend on biogas for their cooking fuel.[4] However, by 2009 only three of 1000 households use DBPs (NSSO, 2012). To sum up, cooking fuel scenario in rural India is characterised by heavy dependence on unclean source of energy, limited use of modern source of energy like LPG which is often found inadequate and lacking in the use of clean source of energy generated using local produce. While India reshapes its GE sector, where does DBPs stand? We urge to seize this opportunity to refresh the outlook towards one of the India's long established GEs that holds prospect to tackle rural energy poverty. This calls for a fair understanding of the status of DBPs in India, i.e. policy design, nature of diffusion and factors that determine their adoption. This summarises the objective of the present paper. Studies that captured comprehensive picture of India's biogas program specifically through the lens of policy design in the recent times are limited saving for few studies that made reference to the policies (e.g. see Bond and Templeton, 2011; Bansal et al., 2013). Present paper is an attempt to fill this gap. Rest of the paper is organised as follows. Section 2 presents a critical evaluation of the policy initiatives towards DBPs. Section 3 provides trends and patterns of the diffusion of DBPs at province and household level. Diffusion of DBPs is an outcome of cumulative adoption choices made at household level. Therefore, in Section 4 we conduct an econometric exercise to examine the factors that determine the adoption choices of the household. Summary of the paper is presented in Section 5.

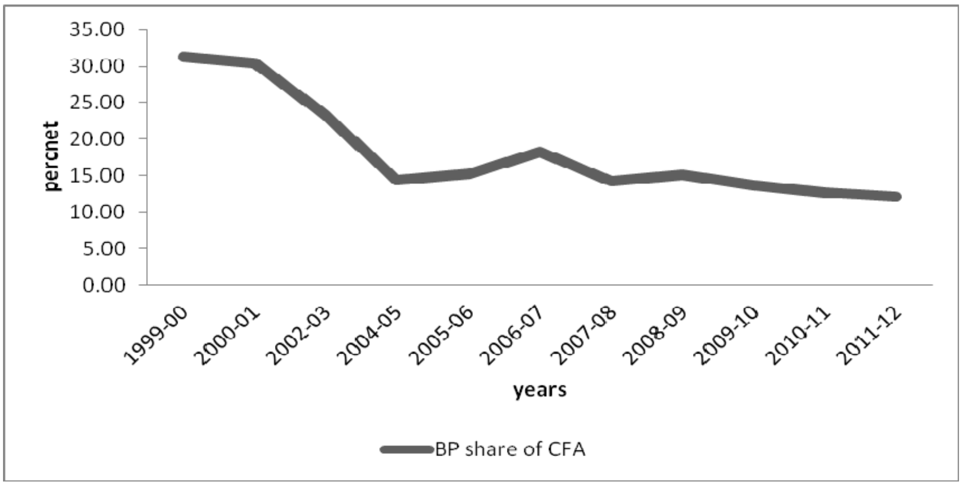
2 Domestic biogas plants: a policy assessment

The demonstration and limited extension phase of DBPs was first initiated in India by Khadi Village Industry Corporation (KVIC) in 1960.[5] However, DBPs received impetus, after the Ministry of New and Renewable Energy (MNRE, 2009) Sources, Government of India, launched a centrally sponsored scheme, known as National Project on Biogas Development, in 1981–1982. This is renamed as National Biogas and Manure Management Program (NBMMP) in 2002–2003. The primary objectives of this program are (i) to provide fuel for cooking purposes and organic manure to rural households, (ii) to mitigate drudgery of rural women, reduce pressure on forests and accentuate social benefits, and (iii) to improve sanitation in villages by linking sanitary toilets with biogas plants. As a result of India's participation in the international climate discourse, a new objective was attributed to the program, i.e. 'to mitigate climate change by preventing black carbon and methane emissions' (GOI, 2009). In periodical assessment of energy status and other related review reports, DBPs often received a mention albeit a serious consideration about reviewing its status, road map to strengthen the program was missing. After two decades of the initiation, the State evaluated the program : Programme Evaluation Organisation (PEO, 2002). The evaluation report pointed out that the program lags in accomplishing the objectives and made few prominent suggestions to redress the same. The report highlighted significant failure rate of DBPs and, among many other, the major reasons cited were: user being unprepared for preventive maintenance, inadequate supervision during construction and lack of periodical verification. Further limited financial resources constrained the employment and training of technical personnel and thus their shortage. In light of above noted drawbacks the following were suggested: to prioritise engaging sufficient number of well-trained technical personnel with lucrative financial incentives, train users to ensure efficient usage of the plant; in light of changing occupation structure, sociocultural transformations and transition in generation/ distribution mechanism of other alternative clean cooking fuel, potential of DBPs and the strategy to approach the entire issue ought to be revised; to explore the possibilities of generating biogas for domestic use through different method/scale, with alternative investment/usage mode, organisational/maintenance structure. However, none of these suggestions were considered in the subsequent planning period. In fact in tenth five-year plan (2002–2007) biogas program was put on the back burner to focus on 'high-tech areas' of renewable energies (GOI, 2002). Unlike what is anticipated in the project evaluation report, 2002, not only did the Working Group Report on R&D in Energy Sector of Eleventh Five-Year Plan (2007–2012) dampened the prospects of technological advancements in DBPs but also connoted the program ineffective (GOI, 2006).

Accounting for the economic status of the target cliental, that is largely poor rural households, the cost of the technology, lack of extensive production line of the technology, limited technical manpower to reach far flung dwellings in rural India, states' success in installation and promotion of DBPs is largely determined by the funds they receive. Centre's financial assistance is provided to the states in order to provide subsidies to the DBP users; employ turnkey job workers, train masons/turnkey workers/users; publicity and extension; administrative charges, Biogas Development Training Centres (BDTCs) for training the technical personnel. In the last decade or so, CFA share to DBPs to the total CFA[6] witnessed a steady decline (see Figure 1). This trend indicates a shift in State's attention away from domestic DBPs. However, recent amendments (GOI, 2009; GOI, 2014) made with respect to financial assistance are worth mentioning. Unlike earlier, funds are earmarked to explore and establish innovative models for financing and implementation, repairing non-functional DBPs and enhancing the transparency of the program. Further, subsidy to the beneficiary increased from 20% to 25% in the earlier years to 50% in the recent past, which on accounting for inflation would reduce the cost burden of the users by 14%. Nevertheless few aspects call for attention. Revision of fund allocation especially for turnkey workers' fees, funds for user training may come as a relief at the first glance but on accounting for the hike in the inflation it is doubtful this revision would make any significant impact. Fees of the turnkey worker, who is expected to identify the user, supervise the construction of the plant, conduct periodical verification and guarantee its able functioning for next five years, in real terms increased by a very meagre amount. Moreover, this amount is to be paid to the technician in small instalments for over five years after the installation of the plant. Funds allocated for training are also limited.[7] Resources designated for the publicity/awareness of the program were noted to be inadequate by PEO (2002) (Rs. 0.5 million per annum) but remained unaltered from the year 1993–1994 till date. In short, though funds were boosted to ease the cost burden of the user, little is done to strengthen the support system. This might affect the longevity of the plant and efficiency of the program as a whole. Present affairs ought to be reflected in the context of well-established evidence that successful diffusion of energy technologies among rural households call for a balance between production investment (hardware) and investment in people to create a efficient network system (software) (Ruttan, 1984; Lichtman, 1987; Reddy, 2002; Cust et al., 2007).

After three decades of entirely being run by the State, the program opened up for private agents, biogas-fertiliser companies/entrepreneurs, and initiated a pilot program of competitive bidding. While this might lead DBPs to emerge as a market driven commodity and thus eventually result in its commercial sustainability, one should exercise caution to the idea of opening the program for competitive bidding. This may lead the players to aim at only the number of plants and jeopardise on their quality by overlooking supervision/verification. Moreover, in order to widen the profit-margin there is a possibility to compromise on the material used for construction. While lacking of technical manpower has already impaired the program, competitive bidding may worsen the situation.

Figure 1 Share of funds allotted to domestic biogas plants



Source: MNRE

3 An appraisal of domestic biogas plant technology in India: state- and household-level analysis

According to the latest estimates, till now 4.6 million DBPs have been installed in India. Starting from early 1980s, DBPs registered an impressive and a steady growth rate of 24.13% till late 1990s. However, from the early 2000s installation of DBPs witnessed a decline and in the last 14 years DBPs installation is growing at a meagre rate of only 3.34% (see Figure 2). Potential for the DBPs had been estimated by the MNRE based on the presence of bovine population, lack of clean source of cooking fuel, geo-climatic conditions, etc., and the targets for the states are allotted accordingly. Table 1 provides states' share of estimated potential and their installation ratio. India took 28 years to achieve 36% installation ratio and the installation ratio varies widely across states: Maharashtra stands first followed by Kerala, Gujarat and Karnataka. Interestingly, states with similar potential display significant difference regarding their installation ratio. For example, Karnataka and Tamil Nadu though possess similar potential of about 5% each; their installation ratios are 64% and 35%, respectively. The origin of the dissimilarities in the states' response to the centrally planned program lies in varying state-level policies, infrastructure, status of alternative sources of energy, and differences in the adoptive nature of the households.

Following analysis relies on data published by NSSO (2012). 76% of the rural households use firewood for cooking, 12% of the households use LPG and only 0.3% of the households use biogas plants for cooking. Table 2 presents DBP preference as the primary source of energy and the households' perception about its adequacy and the degree of inadequacy in terms of firewood. While 81% households that adopted biogas plants reported to use biogas as their primary source of energy, only 46% of them reported finding it adequate.[8] Further, 86% of the households that found biogas inadequate complement their cooking-fuel requirements with firewood[9] as an alternative source of energy. The degree of inadequacy amounts to as high as 70%.[10] In fact, those states that had reported high installation rates are also characterised by a high percentage and degree of inadequacy. For example, Maharashtra attained an installation ratio of 89% (see Table 1); however, nearly 80% of the households find biogas as an inadequate source of energy and 96% of them use firewood to complement their energy requirements. Further, the degree of inadequacy is as high as 40% (see Table 2).

State set the goals in terms of gross numbers. Thus, it might target these goals by simply distributing the devices or setting up the equipment by heavily subsidising them with little regard for their longevity. Therefore, inefficiency of the plant and loss of confidence in the technology might eventually force the households to abandon the plant and revert back to unsustainable sources of energy. In other words, there is a significant difference in installation and final usage of the technology. By 2011, 4 million biogas plants were installed. Assessing by the household data provided by the Census India (2011), this should ideally provide clean energy to 16 of 1000 rural households. However, according to the 2011 Census only four of 1000 households reported to use biogas as their cooking fuel. This ought to be observed against feeble efforts by the State to create a robust supporting network system as discussed in Section 2. However, this gloomy scenario, notwithstanding, the status of biogas use in few states, is worth mentioning: Uttarakhand, Jharkhand, Tamil Nadu, Karnataka and Gujarat where all the households that reported to adopt biogas plants find it adequate and their dependence on firewood is nil.

Owing to its one-time bulk investment, it is more likely that households with higher income levels have better chances to adopt and use biogas plants. From our analysis, we observed that 68% of biogas plants are adopted by high income, 24% by medium income and only 8% by the low income households.[11] At the same time, ideal physical conditions, i.e. possessing three or more cattle heads, are also crucial for adoption of biogas plants. We examined the users and the potential users among the households across different economic classes. The potential users are defined as those households that possess physical conditions sufficient to install biogas plants and at the same time there exists a need to shift away from unsustainable sources of fuel for cooking like firewood. From Table 3 it is evident that only 1% of the potential users are currently using biogas. Households that own two or more cattle and dependent on unsustainable sources of energy like firewood account for about 74% at the all India level. 86% of the low-income and 87% of the medium-income households that possess ideal physical conditions do not own biogas plants. This speaks about the missed opportunity to tap the abundant potential, available for achieving the twin goals of sustainable and inclusive development. Interestingly, even among the high-income households that have potential for biogas plants, nearly 50% of the households use firewood for cooking indicating that adoption and success of biogas does not solely depend on the economic factors. This observation further reinforces the importance of a system that ensures reliability in the technology and instils confidence among the potential users.

Table 1 States' share of the biogas plants estimated potential and installation ratio

States	*States' share of estimated potential (percent)*	*Installation ratio (percent)*
Andhra Pradesh	8.74	44.53
Assam	2.52	28.77
Bihar	6.01	15.86
Chhattisgarh	3.28	8.90
Gujarat	4.54	75.46
Haryana	2.46	18.49
Himachal Pradesh	1.03	36.93
Jammu and Kashmir	1.05	2.03
Jharkhand	0.82	5.846
Karnataka	5.58	63.71
Kerala	1.23	86.94
Madhya Pradesh	12.23	18.41
Maharashtra	7.36	89.41
Odisha	4.96	40.64
Punjab	3.37	31.38
Rajasthan	7.50	7.39
Tamil Nadu	5.04	35.45
Uttar Pradesh	16.58	21.74
Uttaranchal	0.68	15.17
West Bengal	5.70	48.27
India	100	35.81

Note: Installation ratio = (State's cumulative achievement in the latest period/State's estimated potential)*100.

Source: Compiled using data provided by Annual Report of Ministry of New and Renewable Energy Resources (2012)

Table 2 Biogas plants: preference and adequacy

States	*BP per 1000 households*	*Preference of biogas and its adequacy (percent)*		*BP found inadequate (percent)*	
		BP as primary source	*BP adequate*	*Firewood as alternative*	*Degree of inadequacy*[a]
Jammu and Kashmir	0.00	–	–	–	–
Himachal Pradesh	0.60	100.00	0.00	100	51.16
Punjab	14.10	95.45	38.10	69.23	38.95
Uttarakhand	0.95	100.00	100.00	–	–
Haryana	2.78	100.00	50.00	50	86.27
Rajasthan	0.00	–	–	–	–
Uttar Pradesh	0.51	66.67	50.00	–	–
Bihar	1.21	25.00	100.00	–	–

Table 2 Biogas plants: preference and adequacy (continued)

States	*BP per 1000 households*	*Preference of biogas and its adequacy (percent)*		*BP found inadequate (percent)*	
		BP as primary source	*BP adequate*	*Firewood as alternative*	*Degree of inadequacy*[a]
Assam	0.00	–	–	–	–
West Bengal	0.28	100.00	100.00	–	–
Jharkhand	0.57	100.00	100.00	–	–
Odisha	2.69	50.00	25.00	100	29.29
Chhattisgarh	4.01	83.33	40.00	100	43.60
Madhya Pradesh	7.32	85.00	35.29	90.91	31.41
Gujarat	5.82	100.00	100.00	–	–
Maharashtra	10.21	85.37	22.86	96.30	40.11
Andhra Pradesh	1.78	85.71	83.33	–	–
Karnataka	4.91	100.00	100.00	–	–
Kerala	8.06	47.62	0.00	90	55.43
Tamil Nadu	1.20	100.00	100.00	–	–
India	3.17	81.10	45.86	86.11	70.00

Note: [a]Degree of inadequacy is calculated as the ratio of the average quantity of the firewood used by the households that reported firewood as their primary source of energy for cooking as primary source of energy. Here, we normalised the quantity of firewood with size of the household.

Source: Calculated using data published by NSSO, 66th round

Table 3 Use and potential for biogas across income classes, 2009–2010 (percent)

States	*Low income*		*Middle income*		*High income*		*Total*	
	Users	*Potential*	*Users*	*Potential*	*Users*	*Potential*	*Users*	*Potential*
Jammu and Kashmir	–	–	0.00	100.00	0.00	58.64	0.00	88.29
Himachal Pradesh	–	–	0.00	98.27	0.00	67.75	0.00	79.31
Punjab	0	0	0.00	87.89	3.66	18.27	3.12	24.36
Uttaranchal	–	–	7.85	42.15	0.00	40.29	2.94	40.98
Haryana	0	100.00	0.00	97.28	1.24	65.30	0.99	71.82
Rajasthan	0	100.00	0.00	98.04	0.00	89.51	0.00	94.92
Uttar Pradesh	0	71.84	0.00	75.03	0.00	45.93	0.00	65.47
Bihar	0	75.19	0.00	79.95	0.00	55.93	0.00	73.44
Assam	0	100.00	0.00	87.79	0.00	84.21	0.00	87.29
West Bengal	0	99.22	0.00	82.30	0.00	13.22	0.00	79.83
Jharkhand	0	29.86	0.00	95.44	0.00	50.45	0.00	52.48
Orissa	0	76.93	0.00	96.88	0.00	46.50	0.00	70.65
Chhattisgarh	0	98.17	0.00	97.41	1.61	85.79	0.50	94.06
Madhya Pradesh	0.4	86.87	1.03	87.22	1.61	50.09	1.02	74.21

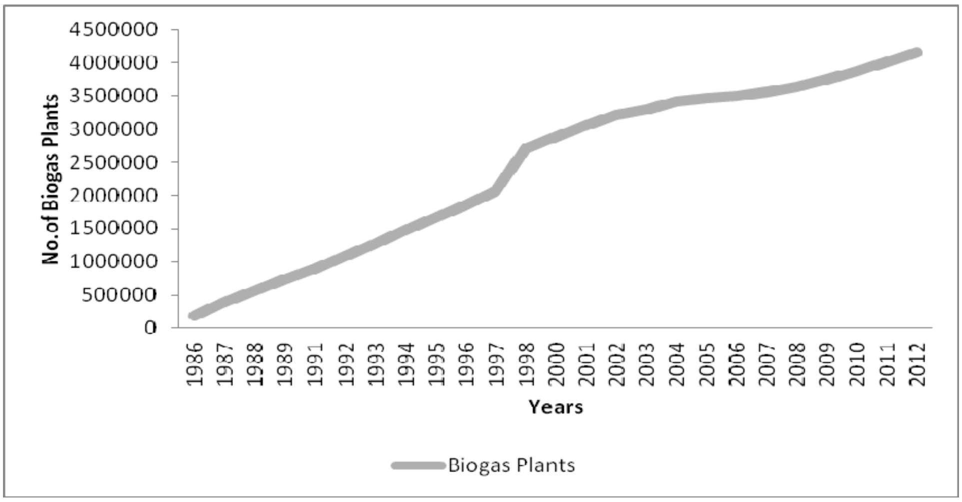
Table 3 Use and potential for biogas across income classes, 2009–2010 (percent) (continued)

States	*Low income*		*Middle income*		*High income*		*Total*	
	Users	*Potential*	*Users*	*Potential*	*Users*	*Potential*	*Users*	*Potential*
Gujarat	0	100.00	7.70	80.72	3.49	55.41	4.78	65.66
Maharashtra	0	98.49	1.23	85.93	0.32	48.07	0.67	71.42
Andhra Pradesh	0	99.83	0.00	92.88	0.00	39.65	0.00	74.44
Karnataka	0	96.27	0.00	79.86	8.22	38.69	3.02	67.32
Kerala	–	–	0.00	26.95	0.00	63.16	0.00	53.83
Tamil Nadu	0	99.44	0.00	86.59	0.14	62.10	0.08	75.12
India	0.40	86.23	0.82	87.03	1.35	56.05	0.90	73.96*
Percentage of households adopting biogas plants	8		24		68			

Note: *Rest of the households that possess physical conditions to adopt biogas use other energy sources like LPG.

Source: Same as Table 3

Figure 2 Cumulative installation of biogas plants in India: 1986–2012



Source: Compiled from various Annual Reports of MNRE

4 Factors determining the adoption of biogas plants: a household-level analysis

The above observed trend is a result of adoption choices made at the disaggregated level, i.e. at the household level. Therefore, it is worthwhile to examine the factors that determine the technology choices at the household level. The hypothesis for the present analysis is based on the theoretical insights provided by Brown (1981) about differential rate of technology adoption. For the present study adoption, market and infrastructure perspectives of diffusion by Brown (1981) are particularly relevant. Similar heuristic framework is employed in Choragudi (2013) in case of adoption of solar lighting systems in rural India. This section presents variable construction (Section 4.1), brief discussion on the econometric model employed, i.e. multinomial logit model (Section 4.2) and results and discussion (Section 4.3). This exercise is conducted for 20 major states that were subdivided into 71 state regions with 51,717 households. NSSO (2012) data are used for this exercise.

4.1 Hypotheses and variable construction

4.1.1 Market and infrastructure perspective

Market and infrastructure perspective propagates that the opportunity to adopt a particular technology is essentially dependent on various supply side factors which primarily involve the nature and operation of the diffusion agents. Further, the perspective identifies price, promotional communications, market selection and segmentation and organisational capabilities, as primary strategies of the diffusion agents. In the case of DBPs, the State acts as the major diffusion agent. In order to conduct the above stated activities, it identifies/sets up agencies and actors and provides them with financial assistance. This, in turn, is expected to result in the provision of infrastructure like service, delivery, information, transport, knowledge sharing, etc. In this regard we consider two factors: central funds to the states and presence of BDTCs.

Central funds to the states: In Section 3, we discussed that Central Financial Assistance (CFA) to the states is a crucial component that defines both the adoption and successful usage of green energies. We hypothesise that with every one unit increase in the CFA, the probability of the household belonging to that state to adopt biogas plants increases. There involves time lag in the financial assistance manifesting into desired infrastructure system. For the analysis based on data published in 2010, we considered average of CFA for the period 2002–2010.

Biogas development training centres (BDTCs): Supported by the State, these centres act as the focal knowledge centres of domestic biogas technology by both conducting technological innovations and conducting training programs for the users and the technicians. As they are located in few selected states, we attempt to capture the bearing of presence of BDTCs on the adoption choice of the households.

4.1.2 Adoption perspective

One of the few characteristics that clearly distinguish successful from unsuccessful innovations is whether the technology meets the needs of the particular users (Freeman, 1982). A range of economic, social, locational and demographic factors influence the rate at which the households adopt the technology under question. This perspective propagates that the successful spread of the technology is an outcome of learning or communication. However, the diffusion of inclusive and sustainable innovations like DBPs is not as obvious as stated above. The potential consumers operate and make decisions in a given sociocultural and economic domain. As far as economic factors are concerned, the cost of technology, availability and cost of alternatives may influence the decision of the potential user. These alternatives may be modern sources of energy like LPG or cheaper but inefficient and unsustainable sources like firewood. The other factors include the social status of households and their preparedness to adopt the technology.

Economic status of the household: The installation of biogas plant involves a one-time investment. This is the deciding factor in its adoption. A few selected models had been specified by the MNRE that meet different load requirements and thus varying costs. Since the subsidies are based on the model promoted, all the households ought to face the same cost. Nevertheless, the economic status of the households has a significant role in the households' preparedness to install biogas plant. In order to incorporate this factor, we classified the households based on their economic status: low, medium and high. We generated a variable that was an interaction of the economic group classification mentioned above and the financial strength of the households. The annual income of households was taken as the proxy for the financial strength of households.

Alternative sources of energy: Availability, adequacy and cost of alternative sources of energy have their impact on the households' choice of adopting green energies. In this regard, we considered two most important alternative energy sources: traditional and modern, i.e. firewood and LPG.

The extent of availability of LPG, apart from other factors, largely depends on the distribution mechanism involving producers, dealers at the nearby town/city and their extent of reach out to the peripheral rural areas. To take this into consideration, we considered the presence of households dependent on LPG as their primary source for cooking, i.e. the share of households using LPG as their primary sources of energy for cooking per every 1000 households in the state.

The distribution network efficiency that determines the households' perception regarding the adequacy of energy service depends on timely delivery, repairing, etc., that ensures (or not) an uninterrupted supply of cooking fuel. The percentage of households that reported energy services as adequate is a proxy for the adequacy of energy sources to the number of LPG users in a given state. By combining the above two indicators, a status index was calculated. Higher the index value, better is the status of energy sources, and we hypothesised that the probability of adopting biogas plants would fall with improvement in the status of these energy sources and that the probability of adopting biogas plants would increase if the status of the alternative energy sources worsened. This exercise is conducted for LPG and firewood. In case of firewood we added another component, i.e. free availability of firewood (free collection/home grown stock).[12]

The average cost of alternatives energy sources was calculated and adjusted for the household size, i.e. the fuel expenditure households have to incur, if they are solely dependent on a given energy source. The analysis was conducted at the most disaggregated geographical level as possible by taking into consideration state 'region' instead of state.

Ideal physical conditions: Households may or may not possess physical conditions necessary for installing and operating biogas plants. The ideal physical condition is to possess three or more cattle heads. Further, climate, ecosystem and economic reasons determine the abundance/lack of bovine stock in a given state and the possibilities of households possessing them. The number of cattle heads per ten rural households indicates the presence of bovine stock in a given region. For the analysis, we considered an interactive variable comprising the presence of cattle in the given households and the presence of bovine stock in a given region. We hypothesised that an increase in this value was likely to increase the probability of households adopting DBPs.

Scope of biogas plants: The number of members in the house determines length of the cooking time which in turn determines the energy source or the combination they opt. To test this hypothesis we take size of the household as a proxy for scope for green energies.

User preparedness: The need for participation of the end-users in the successful diffusion of technologies is well established in the earlier studies (e.g. see Bernardo and Kilayko, 1990; Blenkinsopp et al., 2013). The two major reasons are: first, the participation becomes far more important in the public sector activity where complex objectives are pursued. Secondly, for an efficient and continuous usage of the technology, it is important that the users have an adequate know-how about the operation of the device and certain level of trouble shooting, to follow the instructions during training period and to give feedback to the implementing agencies. This calls for minimum cognizant skills. Studies argue that unpreparedness of the user to handle the technology can eventually lead to abandoning them. Since cooking activities in rural households in India are primarily concern of the women folk, setting up of biogas plants and their successful operation depends on them. Therefore, we took the educational status of the women folk at the household level as proxy for their preparedness to use biogas plant.

Social group: National Biogas Development and Manure Management Program is designed to give a special attention to the less developed social groups: Scheduled Cast (SC) and Scheduled Tribe (ST) communities. This is done by either earmarking a certain number of systems to these communities or granting extra subsidies. This ought to increase their chances of opting for green energies. We intended to examine the same by taking a dummy variable that takes the value 1 if the household reports to belong to SC/ST community and zero if not.

4.2 An econometric analysis: multinomial logit model

Multinomial logit regression is the linear regression analysis to conduct when the dependent variable is nominal with more than two choices. Multinomial probit model is the closest alternative. However, of these techniques, multinomial logit model is more robust than multinomial probit model (Dow and Endersby, 2004; Kropko, 2008). However, it suffers from the disadvantage of assuming independence of irrelevant alternatives which might affect the results. Therefore, we conducted a post estimation test, likelihood-ratio test, to assess the impact of this assumption on our model and its robustness. Multinomial logit model can be motivated by a random utility formulation. Let U^* be the maximum attainable utility of the household by adopting different choices of energy, and U_{ij}^* as the realised utility that a household *i* gets by choosing particular choice *j*. Suppose, stochastic utility of *i*th household faced with *J* (= 1, 2 and 3) choices is

$$U_{ij}^* = \beta_i'.X_i + \varepsilon_{ij} \tag{1}$$

where choices 1, 2 and 3 are to choose:

1 Only green energy;

2 Only non-green energy; and

3 A combination of both.

X_i is the vector of non-stochastic components and ε_{ij} is the stochastic component. X_i in our model denotes the vector of household, state- and state-region-level characteristics. If a household makes choice j in particular, then we assume that U_{ij}^* is the maximum among the J pay-offs. Hence, the statistical model is driven by the probability that choice j is made, such that P_{ij} = Prob $\left(U_{ij}^* > U_{ik}^*\right)$ for all other $k \neq j$. Our interest is to predict the probability P_{ij}. We assume that the logit L is a linear explanation of explanatory variables:

$$L_i = \beta_j'.X_i \tag{2}$$

Expanding equation (2), models constructed for our purpose are

$$\begin{aligned} L_{ijk} &= \alpha + \beta_1 \text{ CFA}_k + \beta_2 \text{ lw\_cls}_{ijk} + \beta_3 \text{ md\_cls}_{jk} + \beta_4 \text{ lpg\_status}_{jk} \\ &+ \beta_5 \text{ lpg\_cost}_{ijk} + \beta_6 \text{ fw\_status}_{jk} + \beta_7 \text{ fw\_cost}_{ijk} + \beta_8 \text{ edu}_{ijk} \\ &+ \beta_9 \text{ BDTC}_k + \beta_{10} \text{ idl\_cond}_k + \beta_{11} \text{ scope}_{ijk} + \beta_{12} \text{ soc\_grp}_{ijk} + u_{ijk} \end{aligned} \tag{3}$$

for all $i = 1, 2,\ldots, n_1, j = 1, 2,\ldots, n_2$ and $k = 1, 2,\ldots, n_3$, where $n_1 > n_2 > n_3$.

CFA: Central Financial Assistance share of the states.

lw_cls: interaction variable of the economic class (dummy variable which takes the value 1, if the household belongs to low-income class and zero, if not) and the financial strength of the household.

md_cls: interaction variable of the economic class (dummy variable which takes the value 1 if the household belongs to middle-income class and zero if not) and the financial strength of the household. The comparison group is high-income class group.

edu: education status. In equation (3) educational status of adults in a given household is shown. Dummy variable takes value 1, if at least one adult female member of the household is formally educated and zero if not.

scope: size of the household, i.e. number of members residing in the household.

soc_grp: social group. Dummy variable takes value 1, if the household belongs to SC/ST community and zero, if not.

lpg_status: status of LPG.

lpg_cost: cost of LPG.

fw_status: status of firewood.

fw_cost: cost of firewood.

idl_cond: ideal physical condition for adoption biogas plant.

BDTC: interaction of the presence of BDTC and funds allocated to them.

e_i: error term.

In the estimated model, the comparison group is not using biogas at all.

4.3 Results and discussion

Table 4 presents the maximum likelihood estimates of the multinomial logit model. As expected, the creation of market and infrastructure facilities for setting up and supporting interaction between users, technicians and the State enhances the households' probability of adopting green energies. The estimates indicate that the financial assistance to the states has a statistically significant positive impact on households' choice of opting biogas plant. With one unit increase in CFA share to the state, households' choice to use biogas only and use it as a complementary source of energy increases by 30% and 12%, respectively. BDTC has no significant positive impact on the household's choice to adopt biogas. Economic strength of the households has a significant impact on the households' choice for DBPs. The chances of households belonging to low-income class using biogas as the only source of cooking and using it as a complementary source of energy in comparison with high-income class, reduces by 79% and 97%, respectively. In the case of medium-income households, the odds have dwindled by 94% and 82%, respectively. Clearly the cost of DBPs has a determining impact on households' choice for opting it. With every one unit improvement in the status of LPG, the households' chances of using biogas as a complementary source of energy reduce by 3%. Similarly improvement in the firewood status reduces the households' probability of using DBPs as a primary or complementary source of energy by 1%.

An improvement in the *ideal conditions* improves households' chances to opt biogas by 6%. Households with at least one educated woman have four times higher odds of opting for biogas plants. However, owing to the fact that nearly 40% of the rural households do not have any educated women, the state/non-state agents ought to make an extra effort to reach out to them. Increase in the size of the household enhances the households' probability to opt biogas as one of the energy sources for cooking by 12%. Households belonging to SC/ST groups do not have any better odds of opting DBPs in that SC/ST households have approximately 60% less chances of opting for biogas plants. It is noteworthy that 50% of these households' possess physical conditions ideal for the installation of DBPs. However, three-fourths of these households use firewood as cooking fuel. Paradoxically, from 2009, special fund allocation to SC/ST households was brought to a halt.

Likelihood ratio test, post-estimation test, had been conducted on the model and all the variables discussed above significantly explain the model at statistically significant level of 5%.

Table 4 Adoption of biogas plants: maximum likelihood estimates of the multinomial logit model

	Domestic biogas plants	
Regressors	*Only biogas*	*Biogas and others*
CFA_share	1.13** (3.99)	1.12** (3.73)
BDTCs	0.99 (–0.59)	0.99 (–0.54)
lw_cls	0.21** (–1.83)	0.03** (–3.50)

Table 4 Adoption of biogas plants: maximum likelihood estimates of the multinomial logit model (continued)

	Domestic biogas plants	
Regressors	*Only biogas*	*Biogas and others*
md_cls	0.06** (–2.80)	0.09** (–3.01)
lpg_status	1.00 (1.12)	0.97** (–5.88)
lpg_cost	0.99 (–0.66)	0.99 (–1.04)
fw_status	0.99 (–1.45)	0.99** (–5.34)
fw_cost	1.00 (1.39)	1.01 (1.42)
Idl_cond	1.06** (4.55)	1.06** (6.05)
Edu	4.26** (3.18)	3.99** (3.47)
Scope	1.03 (0.87)	1.12** (4.23)
soc_grp	0.43** (–2.01)	0.41** (–2.36)
Log Likelihood	–1025.517	
LR $\chi^2_{(20)}$	380.13	
Number of observations	51717	

Notes: Figures in parenthesis are *Z*-values.
**Statistically significant at 1%.

5 Summary

In light of India revamping its GE sector, we argue for a fresh look into the DBPs and in this footing, this paper reviews its present status: policy design, nature of diffusion and factors that determine adoption of DBPs. Albeit DBP program had been revised after a very long time, efforts fall short of creating a robust system to ensure its success and sustainability. Moreover, financial assistance to DBPs was gradually deprioritised in the last decade. After about three decades of the inception of program, more than 60% of the DBP potential are left untapped. At the same time, installation rate of DBPs declined across all the states in the last decade. States with similar physical potential exhibited significant variations in their installation ratios indicating differences in their response towards biogas plants.

At the household level, biogas plants falls far behind firewood and LPG with only three of 1000 households adopting them. Moreover, little more than 50% of these households find biogas to be an inadequate source of energy. In fact, we have identified states with high installation rate of biogas plants and at same time significant percentage of households finding biogas plants inadequate. These differences in installation and usage pattern indicate at the limited success of biogas technology. This in turn might discourage other potential users thus rendering the biogas unreliable and defeating the objective of the program. This ought to be observed against the fact that three-fourth of the households that possess ideal physical conditions to adopt biogas plants still depend on unsustainable energy sources especially firewood.

In order to examine factors that determine households' choice to opt for biogas plants, we employed a multinomial logit exercise. We considered household to face three choices: use green energy only or complement with other source of energy or not to use green energy at all. The results show that increase in the CFA to the states and improvement in household's economic strength heightens the household's choice of adopting DBPs. Further, an improvement of alternative energy source discourages the household from opting for biogas plants. Presence of educated women tends to positively influence the households' choice of opting DBPs. Households that belong to socially backward communities, though possess ideal physical conditions to operate biogas plants, have far lesser chances of owning DBPs.

Biogas program in India was one of the earliest rural-based green energy initiatives. However, over all these years it lacked in evolving into a comprehensive and compact delivery and support system. While India revamps its green energy sector, small-scale tail end green energy applications like biogas plants that directly affect the energy poor warrant a fresh look. This is an opportunity to identify and repair the weak links in the system, set short, medium- and long-term goals to build and strengthen support system that facilitates revolutionising biogas into a suitable and successful energy service in the rural energy spectrum. This calls for both technological and institutional innovations but above all, bringing three-fourth of rural households out of energy poverty calls for resolute commitment by the State. Though present paper made a modest attempt to take stock of the status of biogas program, success in the above suggested proportions demand a detailed field-level analysis encompassing the State, research and development centres, diffusion agencies, and users, formal and informal institutions that guide the interaction among them.

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Notes

1 Analysis in the present paper is largely based on these data and hereafter it will be referred to as NSSO (2012).

2 Percentage of rural households using firewood as cooking fuel: 1993–1994: 78%, 1999–2000: 76%, 2004–2005: 75% and 2009–2010: 76%.

3 Degree of inadequacy is calculated as the ratio of the average quantity of kerosene used by households that reported LPG as their 'primary source' of energy to the average quantity of kerosene used by those households that reported kerosene as their 'primary source' of energy for cooking. For example, in a given state, household '*F*' reported firewood as its primary source of energy, i.e. 10 kg firewood per head for cooking. Another household '*L*' though reported LPG as a primary source of energy, also used 4 kg of firewood per head. This implies that household '*L*', to complement its cooking requirements, not met by LPG, has to use as much as 40% of firewood that household '*F*' uses. Thus, 40% are the degree of inadequacy of LPG.

4 The average growth of bovine in the past 20 years as provided by Livestock Census (2007) is used to calculate the potential total bovine population for 2011.

5 KVIC is a statutory body formed by the Government of India, under the Act of Parliament, Khadi and Village Industries Commission Act of 1956.

6 CFA is disbursed by the Central government to the States for variety of GE technologies.

7 Discounting for inflation, the turnkey worker fees and funds allocated for single training program increased only by a meagre amount of Rs. 1–2 from 2004–2005 to 2009–2010.

8 A household is considered to find biogas adequate if it does not report spending/collecting alternative source of cooking fuel (LPG/firewood).

9 Others being LPG, kerosene, coke, etc.

10 The definition of degree of inadequacy is same as discussed earlier. In this case, biogas is examined against firewood.

11 NSSO does not provide data on income. However, it provides data on estimated monthly per capita expenditure of the households. We classified the households into low, medium and high class based on MPCE in the range of Rs. 0–750, Rs. 750–1200 and more than Rs. 1200, respectively.

12 Index was calculated as Status of LPG = 1[(number of households who use energy services/total number of households)*1000] + 2[(number of households who find energies adequate/total number of households that use the energy source under question)*1000].

In the case of firewood: 1[(number of households who use firewood/total number of households)*1000] + 2[(number of households who find firewood adequate/total number of households that use firewood)*1000] + 3[(number of households whose sole source of firewood is collection or free of cost/total number of households that use firewood)*1000].

Decomposition of carbon dioxide emission from highway transportation in Tunisia

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Abstract: We have adopted the Divisia index approach to study the effects of five factors on the total emissions of carbon dioxide (CO_2) arising from highway vehicles in Tunisia during the period ranging from 1980 to 2011. CO_2 emissions have been decomposed into five factors, namely emission coefficient, vehicle fuel intensity, vehicle ownership, population intensity and economic growth. We show that fast-paced economic growth and vehicle ownership have been the most important factors which have participated in the augmentation of CO_2 emissions, while population intensity has contributed significantly to the decrease of emissions.

Keywords: Divisia index; road transport; CO_2 emissions.

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1 Introduction

The notion of durable development relies on several economic, social and environmental principles. Concerning environmental principles, these latter are articulated on the questions of the preservation of non-renewable energy, the implementation of their replacement and the fight against pollution. However, current evolution trends are against the objectives of sustainable development. The consumption of fossil fuels and more particularly petrol is growing constantly all over the world. This consumption continues in an exponential way, and translates into important emissions of gas producing a greenhouse effect, responsible to a huge extent for global warming. The impact of means of transport on these emissions is particularly important.

The transport sector with its four modes of people's and goods displacement makes up the spinal cord of the Tunisian economy. At the same time, it plays inductive and structural roles in the economic growth of the country and it is considered as being the engine of the social and durable economic development. Seen from another angle and according to the National Agency for Energy Conservation (NAEC), the transport sector holds the second position behind the industry in energy consumption with a rate of 31%. This consumption is monopolised in majority by the two terrestrial modes with 78% of the global consumption of energy in the transport sector. This energy consumption of the transport sector in Tunisia produces external negative effects such as carbon dioxide (CO_2) emissions, ranking as the second main cause of greenhouse gas emissions with 5648.5 thousand tons equivalent of CO_2, behind the energy industry sector. If no action is taken, this situation reveals that the development of a well-established transport system would accelerate the exhaustion of resources and, consequently, a serious environmental pollution, even though it may simulate regional economic growth and the rise of living standards.

A number of modelling techniques have, as a result, been developed and employed to address complex energy and environmental (E&E) issues. For example, Jebaraj and Iniyan (2006) reviewed different types of models for energy planning and management. Ang and Zhang (2000) listed a total of 124 studies that applied Index Decomposition Analysis (IDA) techniques to energy demand and gas emissions analysis. The applications of decision analysis in E&E studies have been reviewed by Huang et al. (1995) and updated by Zhou et al. (2006).

Among the wide range of modelling techniques in the field of E&E, we find the decomposition analysis which is a popular approach largely used to identify the direct and complex factors which affect the evolution of emissions of road transport or of the consumption of energy. The application of the decomposition analysis has been conducted by a variety of studies. For example, Howarth et al. (1991) utilised both the Laspeyres index and the Divisia index to characterise energy consumption in the manufacturing sector in eight OECD countries for the 1973–1987 period and compared the advantages and disadvantages of these two methods. The influences of transport activity, the mix of travel modes, energy intensity, CO_2 intensity and fuel mix on the increase of CO_2 emission in nine OECD countries were explored by Lynn et al. (1996), who discovered that travel-related activity was the major cause of emission increase. Lin and Chang (1996) used the Divisia index approach to examine emissions of CO_2, NOx and SO_2 from major economic sectors in Taiwan during the period 1980–1992. They found that economic growth had the greatest impact on the variation of emission intensities during this period, while the influence of fuel mix was limited. Shrestha and Timilsina (1996) utilised the Divisia decomposition approach to examine the effects of fuel mix, fuel quality and generation efficiency from thermal power plants on CO_2 intensity in 12 selected Asian countries during 1980–1990. Greening et al. (1999) adopted the adaptive weighted Divisia index (with a rolling base year) to analyse energy consumption and carbon intensity of the freight sector of ten OECD countries. Key factors affecting the variation of CO_2 emission from the transport sector in Italy in the period 1980–1995 were identified by Mazzarino (2000). He decomposed CO_2 emissions into five components, including fuel mix, energy intensity, modal structure, transportation intensity and economic growth, and found that the growth of GDP was the main cause of the increase in CO_2. Zhang (2000) analysed the relationships of fuel mix, energy saving, economic productivity and population expansion to the increase of China's CO_2 emissions during 1980–1997. Lee and Lin (2001) combined structure decomposition, input–output modelling and integrative index decomposition to decompose CO_2 emissions from Taiwan petrochemical industries into eight factors. Gonzalez and Suarez (2003) decomposed changes in aggregate electric energy intensity in Spain and found that a considerable reduction in intensity was primarily due to structural and energy intensity effects. Paul and Bhattacharya (2004) selected pollution coefficient, energy intensity, structural changes and economic activity as primary inputs to identify the major factors affecting the energy-related CO_2 emissions from the major economic sectors in India from 1980 to 1996. Their results showed that economic growth was the most important component of CO_2 emissions. The Laspeyres index method was adopted by Steenhof (2006) to decompose electricity demand in the industrial sector into industrial activity, structure share and energy intensity. He found that industrial activity and fuel shift were the key factors for the increase of electricity demand in China. Lin et al. (2006) adopted the simple average Divisia index approach with a rolling base year to identify key factors and strategies for industrial CO_2 reduction in Taiwan.

The application of the decomposition analysis in the Tunisian economy and more precisely in the transport sector is limited. Mraihi et al. (2013) used decomposition analysis to discuss the effects of economic, demographic and urban factors on the evolution of transport energy consumption. The main result is that vehicle fuel intensity, vehicle intensity, GDP per capita, urbanised kilometres and national road network are found to be the main drivers of energy consumption change in the road transport sector during 1990–2006 period. Compared to our study which presents an original essay that explains the driving forces behind the increase of highway transportation CO_2 emissions, Mraihi et al.'s (2013) study explains the main drivers of energy consumption change in the road transport sector.

In addition, the studies of methodological issues were explored in recent years. Ang and Lee (1994) analysed five methods and found that the adaptive weighting and the simple average Divisia index methods tended to yield smaller residuals in decomposition. In order to get perfect decomposition, handle the zero values in the dataset and study the decomposition of a differential change, a refined Divisia index method, Logarithmic

Mean Divisia Index (LMDI) approach, was introduced by Ang et al. (1998). Ang and Liu (2001) presented a new decomposition method, log-mean Divisia method I (LMDI I), which had the desirable characteristics of perfect decomposition and consistency in aggregation. Divisia index approach was applied by Choi and Ang (2002) to decompose the conventional thermal efficiency index in the Korean power sector. They concluded that thermal efficiency was improved by 1.1% per year during 1970–1998, which was higher than the 0.9% improvement per year based on the conventional method. Ang (2004) compared the decomposition methodologies and concluded that the multiplicative and additive LMDI approach is the best method for theoretical foundation, adaptability, ease of operation and result interpretation. Ang (2005) proposed a practical guide for the general formulation of the LMDI method and used industrial energy consumption and CO_2 emissions as examples for realising the application and advantages of the LMDI approach. Ang (2006) examined and illustrated how the technique of IDA provides a bottom-up framework for economy-wide composite energy efficiency index and national energy efficiency trend monitoring. Ang and Liu (2007) explored whether the residual term arising from the interactions among factors is really insignificant and can be ignored and to compare the differences between the Laspeyres index approach and other methods.

Several decomposition methodologies, as mentioned above, have been used to analyse energy use, energy intensity and pollution emission. In general, all these methods try to decompose an object of interest into a multiplication of several components for identifying the key factors affecting its change. In our study, the simple average Divisia index method is adopted for reasons of simplicity's use and its small residuals (Lin and Chang, 1996), since Tunisia's energy and the related CO_2 emission data varied greatly during 1980–2011. Furthermore, the simple average Divisia index method has been used for other several previous studies, and it is important that consistency be maintained for comparison purposes.

Our study tries, therefore, to identify the major factors affecting the total emissions of CO_2 resulting from highway vehicles in Tunisia during the period of 1980 until 2011 by using the Divisia index method which serves to quantify the relative contributions of each factor.[1]

2 Methodology

Decomposition methodologies, such as Laspeyres index and Divisia index, have been used to analyse energy use, energy intensity and pollution emission. Although the Divisia index is considered to have a more robust theoretical foundation, the main advantage of the Laspeyres index is the use of the familiar concept of percentage changes facilitating comprehension and exploitation of results in comparative assessments (Ang, 2004). The major problem in the Laspeyres method is the large residual term found in most applications and leaving a significant part of the examined changes unexplained. As Ang and Lee (1994) illustrated by analysis of two Laspeyres-based methods, two simple average Divisia methods and the adaptive weighting method, the adaptive weighting and the simple average Divisia index methods tend to yield smaller residuals in decomposition.

In our work, we use the simple average Divisia index approach with a rolling base year to analyse factors that affect CO_2 emission from road vehicles because it gives a smaller residual in decomposition, ease of use and understanding, as well as a clear result for interpretation (Ang and Lee, 1994; Lin and Chang, 1996; Ang, 2004):

$$Q_t = \frac{Q_t}{E_t} \times \frac{E_t}{V_t} \times \frac{V_t}{P_t} \times \frac{P_t}{G_t} \times G_t \tag{1}$$

where Q_t is the highway transportation CO_2 emission from energy use for year t (million metric tons); E_t represents the highway transportation energy consumption for year t (kilotons of oil equivalent); V_t refers to the number of motor vehicles for year t (10,000 unit vehicles); P_t is the human population for year t; G_t stands for the GDP for year t (MDT).

Equation (1) can be rewritten as:

$$Q_t = C_t \times E_t \times V_t \times P_t \times G_t \tag{2}$$

where $C_t = Q_t/E_t$ is the emission coefficient for year t; $E_T = E_t/V_t$ refers to the vehicle fuel intensity for year t; $V_t = V_t/P_t$ represents the vehicle ownership for year t; $P_t = P_t/G_t$ stands to the population growth per unit GDP for year t. So, by differentiating equation (2) with respect to time t, we can decompose emission growth rate into the sum of the growth rates for each component:

$$\begin{aligned} \frac{dQ_t}{dt} = & \frac{dC_t}{C_t} \times \frac{Q_t}{dt} + \frac{d\,E_t}{E_t} \times \frac{Q_t}{dt} + \frac{d\,V_t}{V_t} \\ & \times \frac{Q_t}{dt} + \frac{dP_t}{P_t} \times \frac{Q_t}{dt} + \frac{d\,G_t}{G_t} \times \frac{Q_t}{dt} \end{aligned} \tag{3}$$

Integrating both sides of equation (3) from year 0 to year t yields, we have:

$$\begin{aligned} \Delta Q_t = & \int_0^t d\ln(C_t) \times Q_t + \int_0^t d\ln(E_t) \times Q_t \\ & + \int_0^t d\ln(V_t) \times Q_t + \int_0^t d\ln(P_t) \times Q_t \\ & + \int_0^t d\ln(G_t) \times Q_t \end{aligned} \tag{4}$$

From the simple average parametric Divisia method, the integral of equation (4) can be estimated by the mean of the beginning points and end points over a short period of time because the data in our study are discrete. So, we obtain:

$$\begin{aligned} \Delta Q_t = & \ln\left(\frac{C_t}{C_0}\right) \times \left(\frac{Q_t + Q_t}{2}\right) + \ln\left(\frac{E_t}{E_0}\right) \times \left(\frac{Q_t + Q_0}{2}\right) + \ln\left(\frac{V_t}{V_0}\right) \times \left(\frac{Q_t + Q_0}{2}\right) \\ & + \ln\left(\frac{P_t}{P_0}\right) \times \left(\frac{Q_t + Q_0}{2}\right) + \ln\left(\frac{G_t}{G_0}\right) \times \left(\frac{Q_t + Q_0}{2}\right) + RD \\ = & \text{DC} + \text{DE} + \text{DV} + \text{DP} + \text{DG} + \text{RD} \end{aligned} \tag{5}$$

Equation (5) represents the Divisia indices for effects due to changes in emission coefficient (DC), vehicle fuel intensity (DE), vehicle ownership (DV), population intensity (DP) and economic growth (DG). We note by RD the residual term.

3 Data

The data on the energy consumption and on the CO_2 emissions of the transport sector in Tunisia are adopted from the statistics database of the National Agency of Energy Conservation (NAEC), whereas the data on the recorded population in Tunisia and on the GPD are provided by the National Institute of Statistics (NIS). The Land Transport Technical Agency (LTT) provided us with the data on the number of engine vehicles from 1980 to 2011.

4 Results

4.1 Energy consumption in Tunisia

According to ANME statistics, the energy consumption of the road transport system in Tunisia has reached 1830 kilotons of oil equivalent (Ktoe) in 2011, which is higher to that of 1980 by 221% and it has kept increasing at a rate of 3.8% per annum (Figure 1).

The evolution of energy consumption per unit GDP (energy intensity) from 1980 up to 2011 is represented by Figure 2. Indeed, energy intensity represents the quantity of energy required to form a GDP unit. The evolution of this intensity shows the capacity of the economy to manage the wealth by using more or less energy. The global energy intensity in Tunisia has decreased by 12.5% between 1990 and 2003, that is to say, a decrease by more than 1% on average and per annum during the same period. This result is obtained mainly due to the orientation of economic activities towards less energy intensive activities as well as the development of a plan for the rational utilisation of energy. This decrease reflects the evolution towards a mode of less consumer – bound economic growth, in particular at the level of transport where energy intensity has witnessed an important decrease of 2.9% on average each year (Figure 2). The country's objective was to keep this 1% decrease of global energy intensity per year until 2010.

Figure 1 The evolution of energy consumption of the road transport system in Tunisia (see online for colour versions)

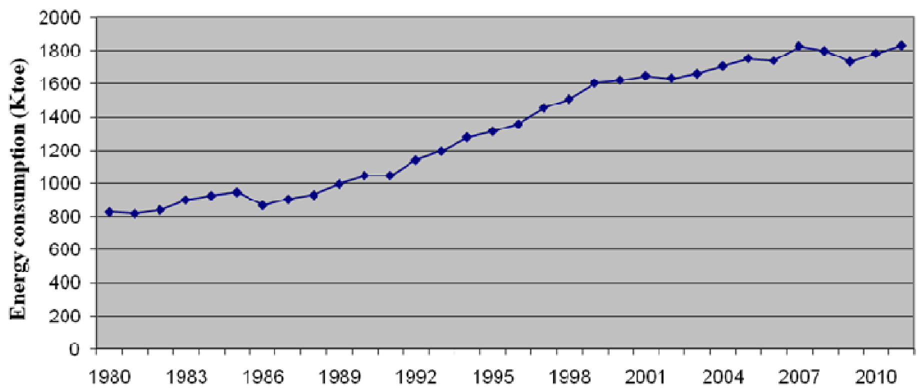
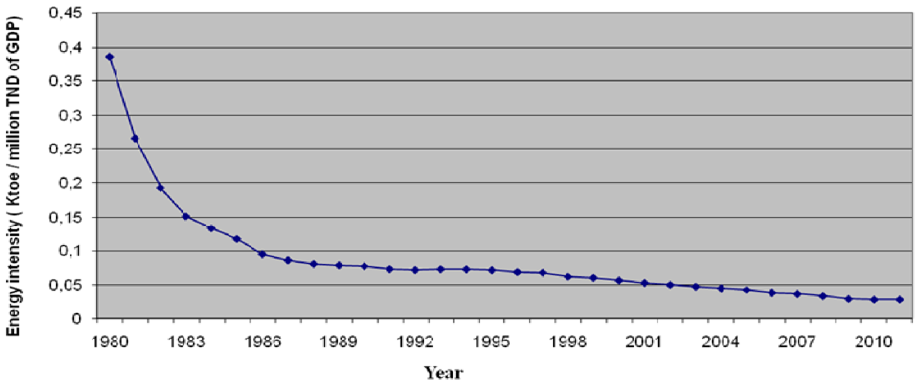


Figure 2 The evolution of energy intensity in Tunisia (see online for colour versions)



4.2 CO_2 emissions in Tunisia

The growth of CO_2 emissions (Figure 3) of road transport had the same tendencies as its energy consumption. The ratio of the transport sector in the emissions caused by combustion has remained relatively stable, moving from 25.9% in 1980 to 26.1% in 2008. Indeed, outside international hold, the emissions of this sector moved from 2.5 $MTECO_2$ in 1980, to 7.5 $MTECO_2$ in 2011, that is to say a mean growth rate of 6.2% per year due to the strong dependence on petrol consumption for automobile vehicles. The augmentation of emissions of this sector is attributed to the development of road transport which represents 75% (of which 50% comes from private cars) of energy consumption of the sector. CO_2 remains the dominant gas in the emissions of the sector, with around 99.4% of the emissions in 2008. Reported by GDP unit, CO_2 emissions have moved from 1.183 $KTECO_2$/1000 TD in 1980 to 0.121 $KTECO_2$/1000 TD in 2011, with a mean decrease of 2.80% per year over the period 1980–2011 (Figure 4). This continual decrease of the energy intensity results from the decoupling between economic growth and greenhouse gas emissions

This performance is mainly explained by the policy of energy control assumed by Tunisia from the mid-1980s and the ambitious objectives of the government regarding the rate of penetration of renewable energies and natural gas.

Figure 3 The evolution of CO_2 emissions for the transport sector in Tunisia (see online for colour versions)

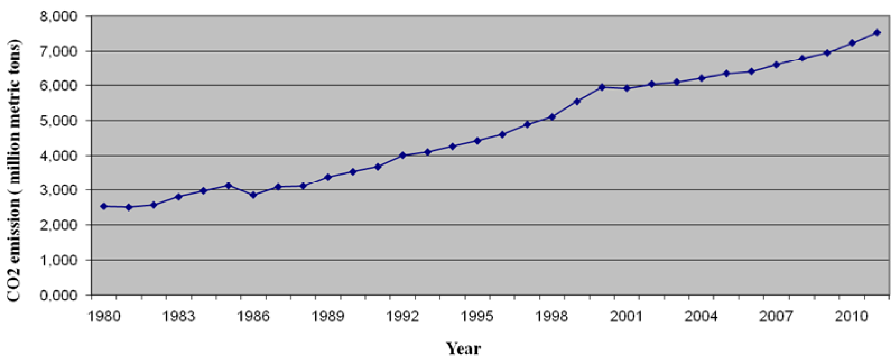
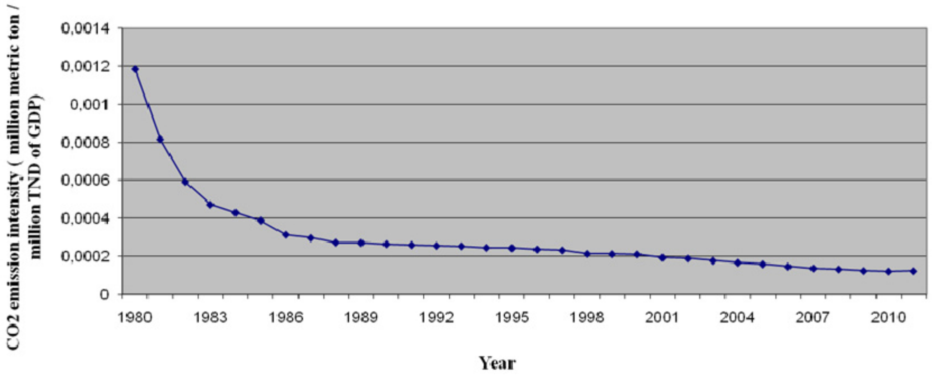


Figure 4 The evolution of CO2 emissions intensity in the transport sector in Tunisia (see online for colour versions)



4.3 The decomposition of CO_2 emissions in Tunisia

The global variation of emissions of the road transport sector in Tunisia is estimated of 5 million metric tons for the period 1980–2011 (Table 1). The economic drive is an indispensable factor which touches the variation of CO_2 emissions. Consequently, the net increase in emissions due to the economic growth is evaluated to about 15.09 million metric tons. Several available studies confirmed this result, such as those of Kamakate and Schipper (2009), Eom et al. (2012) and Sorrell et al. (2012). The strong impacts of the economic growth occur through the higher consumption share of petroleum needed by the development of the economic activity in Tunisia (i.e. 69% in 2006) (NAEC, 2009). Moreover, with the contribution of some sectors, namely transport and industry, the economic growth is accompanied by negative environmental impacts. Then, because of the prevailing role of industry in the Tunisian economic structure, the realised economic growth may be one of the main sources of CO_2 emissions increase.

The number of motor vehicles registered in Tunisia has risen from 130,217 in 1980 to 1,545,305 vehicles in 2011. This fact is explained by many factors, such as particular credits for ownership cars, particularly ‘popular cars’ and leasing credits for road freight vehicles. Going alongside with the motor vehicles, the index of per capita vehicle ownership contributes to a rise of emissions of 9.6 million metric tons. This is mainly due to the fact that the car park structure is characterised by old gasoline vehicles that contribute more to CO_2 emissions. The gasoline car represents more than 76% of total car park in 2010 with an average annual growth rate of 5.5% (NAEC, 2009). This result confirms the study of Pongthanaisawan and Sorapipatana (2010). The interesting conclusion of their study is that the improvement of public transport system will lead to a reduction of the traffic mobility of private vehicles, promotion of the vehicle efficiency and hence the reduction of fuel consumption and gas emissions.

Population intensity is the main reason of the diminution of emissions and it has led to a reduction of 13 million metric tons because the population has increased more slowly than the GDP. This result is similar to that found by Lu et al. (2007).

Another important reason for the diminution of emissions was the improvement of energy conservation. On the whole, fuel consumption per unit of 10,000 vehicles in Tunisia contributes to a global diminution of CO_2 emissions by 7.7 million metric tons. Other studies (Timilsina and Shrestha, 2009a; Timilsina and Shrestha, 2009b) have corroborated these results. Thus, the energy efficiency is a key parameter for policies reduce carbon emissions. Energy intensity has a significant reduction effect on energy-related carbon emissions; it is the main inhibitory factor. Improving energy efficiency and reducing energy intensity has a significant constraining effect on the increase of carbon emissions.

Besides, the emission coefficient contributes to the augmentation of CO_2 emissions by 1.5 million metric tons. Consequently, the important effect of average emissions of petroleum on CO_2 emissions changes is largely accounted for by the increase in fuel share consumption. However, the fuel types (petrol and gasoil) used for road vehicles in Tunisia have a higher carbon content compared to other clean fuel available in Tunisia, namely liquid petroleum gas (LPG), which is currently used by private cars.

Table 1 The decomposition of CO2 emission changes in Tunisia (emission unit: 10^6 metric tons)

Year	*(Qit+Qi0)/2*	*DC*	*DE*	*DV*	*DP*	*DG*	*EC*	*RD*	*%*
1981–1984	3	0.13	–0.85	1.02	–2.07	2.23	0.47	0	–0.24
1984–1987	3	0.19	–1.21	1.00	–1.11	1.24	0.11	0	–0.01
1987–1990	3	–0.03	–0.33	0.62	–0.65	0.84	0.46	0	–0.16
1990–1993	4	0.06	–0.31	0.65	–0.56	0.72	0.56	0	–0.18
1993–1996	4	–0.06	–0.42	0.72	–0.55	0.80	0.50	0	–0.11
1996–1999	5	0.09	–0.29	0.94	–1.30	1.50	0.94	0	–0.29
1999–2002	6	0.40	–0.77	0.70	–1.01	1.18	0.50	0	–0.06
2002–2005	6	–0.14	–0.59	0.85	–1.21	1.39	0.30	0	–0.02
2005–2008	7	0.28	–0.84	0.81	–1.47	1.67	0.45	0	–0.04
2008–2011	7	0.61	–0.92	0.82	–1.03	1.26	0.74	0	–0.09
1981–2011	5	1.48	–7.66	9.56	–12.95	15.09	5.02	0	–9.86

Note: DC: emission factor; DE: energy intensity; DV: vehicle ownership; DP: population intensity; DG: economic growth; EC: emission changes; RD: residuals.

5 Conclusion

The analysis of the decomposition has been applied in order to explore the relative contributions of the emission coefficient, vehicle fuel intensity, vehicle ownership, population expansion and economic productivity to the increase of highway transportation CO_2 emissions in Tunisia during the period 1980–2011. This analysis has revealed that the economic growth in Tunisia, the vehicle ownership, the emission factor and the motor vehicles growth are the important factors which lead to the constant increase of CO_2 emissions. On the other hand, the growth of population per unit GDP has been the key factor of the reduction of emissions. The vehicle fuel intensity factor has also contributed to the reduction of CO_2 emissions.

This study's results have a number of policy implications for Tunisia. In order to reduce CO_2 emissions, the Tunisian transport authorities are invited to approve several instruments (economic, fiscal and regulatory) to reduce both energy and transport intensities. The economic growth effect is found to be the main driving factor of emissions growth. Decoupling road activity from economic growth by shifting to rail mode would be an efficient solution to reduce transport intensity. Incentives to use clean fuel and clean vehicles are also considered to be helpful tools to enhance energy efficiency.

Policy-makers should integrate socio-economic and environmental dimensions in their strategy to improve the energy efficiency in transport sector. First, the development of road networks is not appropriate to improve energy performance and leads to the vicious circle of dependence on cars. More attention must be given to spatial distribution of households and activities, urban density and the urbanised kilometres. Secondly, Tunisian authorities should think to modal shifting by improvement of the supply and the quality of public transport which is a key factor in mobility behaviour determinants in Tunisia (Daldoul et al., 2015). Finally, the price policy of fuel in Tunisia, characterised by the presence of subsidy and absence of taxation, presents a driving factor affecting the energy performance. Therefore, reforming the energy subsidies, as planned by the government, will have a significant impact on household welfare and energy-intensive sectors, such as the transport sector and its CO_2 emissions.

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Notes

1 Mraihi et al. (2013) used the LMDI method with a shorter period (1990–2006) in order to highlight the main drivers of energy consumption change in the road transport sector.

A modelling framework for the forecasting of energy consumption and CO_2 emissions at local/regional level

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Abstract: Building appropriate scenarios for the elaboration of Sustainable Energy Action Plans, within the framework of the Covenant of Mayors, is a complex task. One major question to be addressed is whether the selected combination of examined measures and actions is considered enough for the local authorities to achieve their long-term target of CO_2 emissions reduction. The proposed decision support model aims to address this issue, by enabling the elaboration of long-term scenarios of energy consumption and CO_2 emissions at local/regional level. The Delphi method is appropriately applied for embracing experts' judgements. Moreover, an overall algorithm for the future scenarios ('BAU Scenario', 'Economic Prosperity Scenario' and 'Economic Recession Scenario') is introduced, along with a corresponding computerised software. The system's pilot application to a Greek community is presented and discussed. The proposed approach could support the decision-making process for the elaboration of Sustainable Energy Action Plan within the Covenant of Mayors.

Keywords: decision support; scenario analysis; sustainable energy action plan; sustainable development; covenant of mayors.

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1 Introduction

The European Union (EU) had always put high in its agenda activities related to the attainment of economic growth and prosperity. In the context of Europe 2020 strategy, a comprehensive strategic approach has been put forward for the next decade to foster smart, inclusive and sustainable growth in Europe and to provide a framework for the EU to emerge strengthened from the current financial and economic crisis (European Commission [EC], 2010a). The EU 2020 sustainable development vision also provides an opportunity to support the global fight against climate change. The EU Climate and Energy Package has set very ambitious targets for sustainable development, known as the '20-20-20' targets for 2020 (EC, 2008). Moreover, EU countries have agreed on a new 2030 Framework for climate and energy, including EU-wide targets and policy objectives for the period between 2020 and 2030 (EC, 2014b):

- A 40% cut in greenhouse gas emissions compared to 1990 levels.
- At least a 27% share of renewable energy consumption.
- At least 27% energy savings compared with the business-as-usual scenario.

The local and regional authorities are expected to play a key role in the implementation of Europe 2020 and its flagship initiatives, as well as to address climate and energy challenges using technologically innovative approaches. At the 6th European Summit of Regions and Cities in Athens (7–8 March 2014) the Bureau of the Committee of the Regions (CoR) adopted a declaration on the mid-term review of Europe 2020, titled 'A Territorial Vision for Growth and Jobs' (CoR, 2014a). The political declaration argues that the future success of the EU's growth strategy hinges on better engagement of local and regional authorities. In addition, a handbook has been developed as a part of the follow-up to the adopted CoR's opinion on the role of local and regional authorities in achieving the objectives of the Europe 2020 strategy (CoR, 2014b).

The Covenant of Mayors (CoM) takes this European vision one step further through a voluntary agreement of the municipalities to go beyond the EU objectives in terms of CO_2 emission reduction and achieve at least 20% reduction of CO_2 emissions by 2020 (EC, 2010b). To reach this objective, the Covenant signatories commit to submitting a Sustainable Energy Action Plan (SEAP), approved by their municipal council within the year following their official adhesion. SEAP is a key document that presents the Baseline Emission Inventory and shows how the Covenant signatory will reach its commitment by 2020, including concrete actions to the building sector, transport and energy production (Marinakis et al., 2012a; Marinakis et al., 2013; Doukas et al., 2012).

The CoM initiative counts more than 6400 signatories, covering 206 million inhabitants from 42 counties. In addition, 5167 SEAPs have been submitted and 3867 of them have been accepted. Moreover, 19 MWh per capita of final energy consumption consumed and 5.4 tn of CO_2 equivalent per capita emitted by signatory cities in their baseline years. The share of overall final energy use satisfied by energy carriers, such as electricity and heat, locally produced is 9% (CoM, 2016).

With many cities and communities aiming to reduce their CO_2 emissions, the urban metabolism metrics could have a particularly useful application (Kennedy et al., 2010). The concept of the urban metabolism, conceived by Wolman (1965), is fundamental to developing sustainable cities and communities. Urban metabolism may be defined as 'the sum total of the technical and socio-economic processes that occur in cities, resulting in growth, production of energy, and elimination of waste' (Kennedy et al., 2007). The recent studies indicates that there are two related, non-conflicting, schools of urban metabolism: one following Odum describes metabolism in terms of energy equivalents, while the second more broadly expresses a city's flows of water, materials and nutrients in terms of mass fluxes (Kennedy et al., 2010). The study of urban sustainability can be carried out through different perspectives (Conke and Ferreira, 2015). The perspective of carbon metabolism in urban communities can help in unveiling emission characteristics and complex interactions between urban environment and communities (Lu and Chen, 2015).

Building appropriate scenarios for the elaboration of SEAPs, within the framework of the CoM, is a complex task. One major question to be addressed is whether the selected combination of examined measures and actions is considered enough for the local authorities to achieve their long-term target of CO_2 emissions reduction (Marinakis et al., 2015a; Marinakis et al., 2012b). In this context, a model supporting the elaboration of SEAP within the CoM initiative, in terms of scenarios' building and assessment, would be of important added value for local authorities (Marinakis et al., 2015a; EC, 2014a).

In the international literature, there is a number of studies covering a wide range of aspects related to scenario analysis for the long-term energy status and renewable energy development (Kikuchi et al., 2014; Sanstad et al., 2014; Kambezidis et al., 2011; Stocker et al., 2011; Cinar and Kayakutlu, 2010; Doukas et al., 2008; Doukas et al., 2007; Busuttil et al., 2008; Hillman and Sandén, 2008; Simões et al., 2008; Christodoulakis et al., 2000; Madlener et al., 2007; Hainoun et al., 2006; Medved, 2006; Wei et al., 2006; Renn, 2003; Oniszk-Poplawska et al., 2003; Yamamoto et al., 2000). However, the majority of existing studies are focused on the assessment of future energy status at national or European rather than local or regional level.

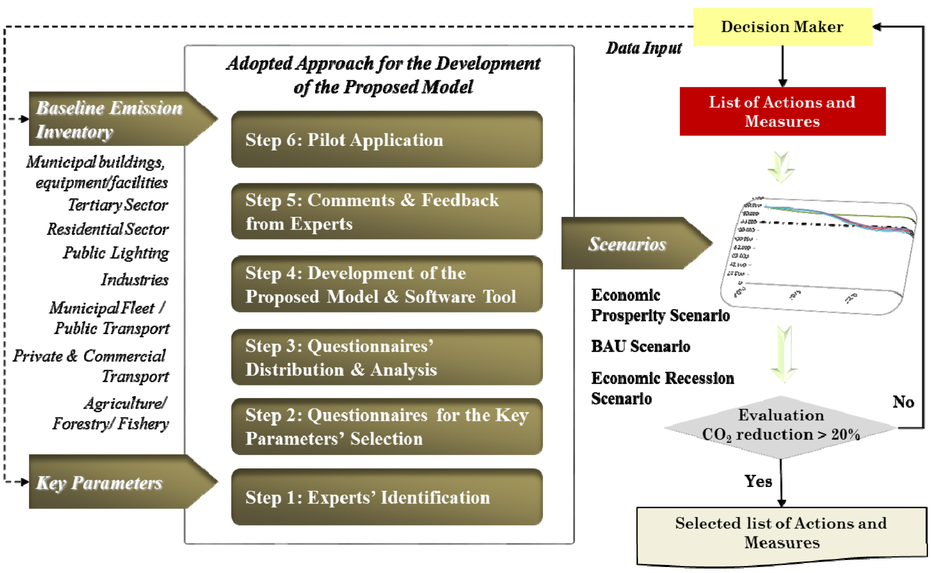
The main objective of this paper is to present a decision support model for the elaboration of scenarios of energy consumption and CO_2 emissions at local/regional level. The Delphi method is appropriately applied for embracing experts' judgements. Moreover, an overall algorithm for the future scenarios ('BAU Scenario', 'Economic Prosperity Scenario' and 'Economic Recession Scenario') is introduced, along with a corresponding computerised software. The system's pilot application to a Greek community is also presented and discussed.

Apart from the introduction, the paper is structured along four sections. The overall procedure of the adopted approach is presented in the second section. The third section is devoted to the presentation of the proposed model. The computerised software and its pilot appraisal are presented in the fourth section. Finally, the last section is summarising the key issues that have arisen in this paper.

2 Adopted approach

The proposed model integrates data from the final energy consumption of each sector for the baseline year, a number of external key parameters, as well as the expected energy and CO_2 emissions reduction from the application of examined RES and RUE actions. The adopted approach for the development of the proposed model was based on experts' engagement though the Delphi method (Figure 1). The Delphi method includes a structured process for collecting and distilling knowledge from a group of experts by means of a series of questionnaires interspersed with controlled opinion feedback (Adler and Ziglio, 1996). Delphi represents a useful communication device among a group of experts and thus facilitates the formation of a group judgement (Helmer, 1977). According to Fowles (1978), study anonymity, controlled feedback, and statistical response characterise Delphi. Delphi method has been applied to a number of problems, such as primary-energy sources and socio-economic development (de Oliveira Matias and Devezas, 2007) and small-sized biogas systems (Cheng et al., 2014).

Figure 1 Technical framework



More specifically, the adopted approach includes the following steps:

- *Step 1 – Experts' identification:* Identification of a number of key experts, mainly from Austria, Bulgaria, Germany, Greece and Portugal, including the following categories:
  - Energy agencies, utilities and energy companies.
  - Planners, developers.
  - National, regional, municipal institutions.

- *Step 2 – Questionnaires for the key parameters' selection:* The identified experts were asked to evaluate key parameters of each sector (municipal, tertiary, residential, transport, agriculture/forestry/fishery and industry sector). A number of questions were developed. Each question could be answered with only one of the following ways: objective multiple choice marking the desired option with an 'x', alternatives' rating based on Likert scale from 1 to 5 (the value of 1 is assigned to the lowest importance/impact and value of 5 is assigned to the highest importance/impact).
- *Step 3 – Questionnaires' distribution & analysis:* Distribution of the questionnaires to the experts with various methods, such as through email, direct interviews with selected experts, etc. Data gathered from the questionnaires were processed (e.g. use of SPSS Statistics, a software package used for statistical analysis) through the calculation of the descriptive statistics (e.g. averages, standard deviations, etc.).
- *Step 4 – Development of the proposed model:* The overall algorithm for the future scenarios ('BAU Scenario', 'Economic Prosperity Scenario' and 'Economic Recession Scenario') was developed.
- *Step 5: Comments and feedback from experts on the proposed model:* The key experts were asked to comment and provide feedback on the proposed model, generating new ideas and solutions. The responses are compiled and analysed.
- *Step 6: Computerised software & pilot appraisal:* A computerised software was developed for the scenario analysis, in order to provide support and interaction with the decision-makers. A pilot appraisal of the proposed model and the relevant software in a Greek municipality is presented and discussed.

3 Decision support model

3.1 Elicitation of the model's key parameters

In depth analysis of the key stakeholders in each country was carried out and for each country a number of different experts were identified. A total of 210 experts (national, regional, municipal institutions; energy agencies, utilities and energy companies; planners, developers) were identified. The experts were asked to provide their preferences and options for a number of parameters, such as:

- Rate of population growth at national level by 2020;
- Rate of electricity and fuels prices by 2020;
- Rate of energy consumption growth by 2020 of the tertiary, residential, industry, transport and agriculture sector;
- Rate of per capita gross domestic product by 2020;
- Annual heating and cooling degree days.

The contribution of the key parameters to each sector (tertiary, residential, transport, agriculture/forestry/fishery and industry sector) is described below (Table 1):

- *Municipal buildings, equipment/facilities:* The future energy consumption of the municipal buildings, equipment and facilities is related to the aggregation of the energy consumption of each category (schools, municipal buildings and equipment/ facilities), taking also into consideration the following parameters:
    - Schools: Rate of population growth (age 0–19) at municipal level;
    - Municipal buildings: Stable energy consumption;
    - Equipment/facilities: Rate of population growth at municipal level.
- *Tertiary or residential sector:* The future energy consumption of the tertiary or residential sector is related to the relevant energy consumption in the baseline year, in combination with a number of local parameters and the rate of energy consumption growth at national level adjusted to the municipal level, as follows:
    - Rate of population growth at municipal level;
    - Rate of per capita gross domestic product growth at municipal level, taking also into consideration a correction factor;
    - Annual heating and cooling degree days at municipal level multiplied by the rate of per capita gross domestic product growth at municipal level and divided by the heating and cooling degree days at national level, respectively;
    - Rate of electricity and fuels prices, taking also into consideration a correction factor;
    - Rate of energy consumption growth by 2020 of the tertiary sector at national level adjusted to the municipal level, according to the following parameters.
        - Per capita gross domestic product at municipal level divided by per capita gross domestic product at national level;
        - Annual heating degree days at municipal level divided by annual heating degree days at national level, taking also into consideration the rate of per capita gross domestic product growth at municipal level;
        - Annual heating degree days at municipal level divided by annual heating degree days at national level, taking also into consideration the rate of per capita gross domestic product growth at municipal level.

  It should be noted that the impact of the population growth is considered higher in the residential sector compared to the tertiary sector. On the other hand, the per capita gross domestic product growth will contribute significantly in the future energy consumption of the tertiary sector. Moreover, the annual heating degree days have increased impact on the future energy consumption for heating (heating oil, natural gas, etc.), while the annual cooling degree days contribute significantly to the future electricity consumption.
- *Public lighting:* The rate of population growth at municipal level is the key parameter.

- *Industries:* The future energy consumption of the industry sector is related to the energy consumption in the baseline year, in combination with the rate of electricity and fuels prices and the rate of energy consumption growth by 2020 of the industry sector at national level.
- *Municipal fleet or public transport:* The future energy consumption of the municipal fleet is considered stable.
- *Private and commercial transport:* Similar to the tertiary or residential sector, the future energy consumption of the transport sector is related to a number of local parameters and the rate of energy consumption growth at national level, as follows:
  - Rate of population growth at municipal level;
  - Rate of per capita gross domestic product growth at municipal level, taking also into consideration a correction factor;
  - Rate of fuels prices, taking also into consideration a correction factor;
  - Rate of energy consumption growth by 2020 of the transport sector at national level, adjusted to the municipal level according to the per capita gross domestic product at municipal level divided by per capita gross domestic product at national level and a correction factor;
  - Development of the road network.
- *Agriculture/forestry/fishery:* The rates of population growth at municipal level, electricity and fuels prices, as well as energy consumption growth by 2020 of the agricultural sector are the key parameters, taking also into consideration the relevant correction factors.

Table 1 Contribution of each parameter to the future energy consumption

	Tertiary	*Residential*	*Industry*	*Transport*	*Agriculture/forestry/fishery*
Rate of population growth at municipal level	20%	35%	–	35%	30%
Rate of per capita gross domestic product at municipal level	35%	25%	–	15%	–
Annual heating and cooling degree days at municipal level	10%	10%	–	–	–
Rate of electricity and fuel prices	10%	10%	40%	20%	20%
Rate of energy consumption growth of the relevant sector at national level	25%	20%	60%	25%	50%
Development of the road network	–	–	–	5%	–

3.2 Development of the proposed model

Following the identification of key parameters, the overall algorithm for the future scenarios ('BAU Scenario', 'Economic Prosperity Scenario' and 'Economic Recession Scenario') was developed. These scenarios present the growth of the community's energy demand and CO_2 emissions, in order to evaluate whether the selected combination of RES and RUE actions is considered enough to achieve the target of at least 20% CO_2 reduction by 2020.

Municipal buildings, equipment/facilities

$$EC_{Mf\text{-}e} = EC_{Ms\text{-}e} \times (1 + PG_{0\text{-}19}) + EC_{Mb\text{-}e} + EC_{Mef\text{-}e} \times (1 + PG) \tag{1}$$

$$EC_{Mf\text{-}h} = EC_{Ms\text{-}h} \times (1 + PG_{0\text{-}19}) + EC_{Mb\text{-}h} \tag{2}$$

$$EC_{Mf\text{-}ng} = EC_{Ms\text{-}ng} \times (1 + PG_{0\text{-}19}) + EC_{Mb\text{-}ng} + EC_{Mef\text{-}ng} \times (1 + PG) \tag{3}$$

$$EC_{Mf\text{-}b} = EC_{Ms\text{-}b} \times (1 + PG_{0\text{-}19}) + EC_{Mb\text{-}b} \tag{4}$$

$$EC_{Mf\text{-}d} = EC_{Mef\text{-}d} \times (1 + PG) \tag{5}$$

Tertiary sector

$$\begin{aligned} EC_{Tf\text{-}e} = {} & 0.2 \times EC_{T\text{-}e} \times (1 + PG) + 0.35 \times EC_{T\text{-}e} \times (1 + GDP_{pcM} \times a) + 0.1 \\ & \times EC_{T\text{-}e} \times [1 + (0.15 \times GDP_{pcM} \times HDD_M/HDD_N + 0.85 \times GDP_{pcM} \\ & \times CDD_M/CDD_N)] + 0.1 \times EC_{T\text{-}e} \times (1 - P_e \times b) + 0.25 \times EC_{T\text{-}e} \\ & \times [1 + ECG_T \times (1 + 0.5 \times GDP_{pcM/N} + 0.1 \times GDP_{pcM} \times HDD_{M/N} + 0.4 \\ & \times GDP_{pcM} \times CDD_{M/N}) \times c] \end{aligned} \tag{6}$$

$$\begin{aligned} EC_{Tf\text{-}h} = {} & 0.2 \times EC_{T\text{-}h} \times (1 + PG) + 0.35 \times EC_{T\text{-}h} \times (1 + GDP_{pcM} \times a) + 0.10 \\ & \times EC_{T\text{-}h} \times [1 + (0{,}9 \times GDP_{pcM} \times HDD_M + 0{,}1 \times GDP_{pcM} \\ & \times CDD_M)/HDD_N] + 0.1 \times EC_{T\text{-}h} \times (1 - P_f \times b) + 0.25 \times EC_{T\text{-}h} \\ & \times [1 + ECG_T \times (0.5 \times GDP_{pcM/N} + 0.45 \times HDD_{M/N} + 0.05 \\ & \times CDD_{M/N}) \times c] \end{aligned} \tag{7}$$

$$\begin{aligned} EC_{Tf\text{-}b} = {} & 0.2 \times EC_{T\text{-}b} \times (1 + PG) + 0.35 \times EC_{T\text{-}b} \times (1 + GDP_{pcM} \times a) + 0.10 \\ & \times EC_{T\text{-}b} \times [1 + (0{,}9 \times GDP_{pcM} \times HDD_M + 0{,}1 \times GDP_{pcM} \\ & \times CDD_M)/HDD_N] + 0.1 \times EC_{T\text{-}b} \times (1 - P_b \times b) + 0.25 \times EC_{T\text{-}b} \\ & \times [1 + ECG_T \times (0.5 \times GDP_{pcM/N} + 0.45 \times HDD_{M/N} + 0.05 \\ & \times CDD_{M/N}) \times c] \end{aligned} \tag{8}$$

$$\begin{aligned} EC_{Tf\text{-}ng} = {} & 0.2 \times EC_{T\text{-}ng} \times (1 + PG) + 0.35 \times EC_{T\text{-}ng} \times (1 + GDP_{pcM} \times a) + 0.10 \\ & \times EC_{T\text{-}ng} \times [1 + (0{,}9 \times GDP_{pcM} \times HDD_M + 0{,}1 \times GDP_{pcM} \\ & \times CDD_M)/HDD_N] + 0.1 \times EC_{T\text{-}ng} \times (1 - P_{ng} \times b) + 0.25 \times EC_{T\text{-}ng} \\ & \times [1 + ECG_T \times (0.5 \times GDP_{pcM/N} + 0.45 \times HDD_{M/N} + 0.05 \\ & \times CDD_{M/N}) \times c] \end{aligned} \tag{9}$$

Residential sector

$$\begin{aligned} EC_{Rf\text{-}e} &= 0.35 \times EC_{R\text{-}e} \times (1 + PG) + 0.25 \times EC_{R\text{-}e} \times (1 + GDP_{pcM} \times a) + 0.1 \\ &\times EC_{R\text{-}e} \times [1 + (0.15 \times GDP_{pcM} \times HDD_M/HDD_N + 0.85 \times GDP_{pcM} \\ &\times CDD_M/CDD_N)] + 0.1 \times EC_{R\text{-}e} \times (1 - P_e \times b) + 0.2 \times EC_{R\text{-}e} \\ &\times [1 + ECG_R \times (1 + 0.5 \times GDP_{pcM/N} + 0.1 \times GDP_{pcM} \times HDD_{M/N} + 0.4 \\ &\times GDP_{pcM} \times CDD_{M/N}) \times c] \end{aligned} \tag{10}$$

$$\begin{aligned} EC_{Rf\text{-}h} &= 0.35 \times EC_{R\text{-}h} \times (1 + PG) + 0.25 \times EC_{R\text{-}h} \times (1 + GDP_{pcM} \times a) + 0.1 \\ &\times EC_{R\text{-}h} \times [1 + (0,9 \times GDP_{pcM} \times HDD_M + 0,1 \times GDP_{pcM} \\ &\times CDD_M)/HDD_N] + 0.1 \times EC_{R\text{-}h} \times (1 - P_f \times b) + 0.2 \times EC_{R\text{-}h} \\ &\times [1 + ECG_R \times (0.5 \times GDP_{pcM/N} + 0.45 \times HDD_{M/N} + 0.05 \\ &\times CDD_{M/N}) \times c] \end{aligned} \tag{11}$$

$$\begin{aligned} EC_{Rf\text{-}b} &= 0.35 \times EC_{R\text{-}b} \times (1 + PG) + 0.25 \times EC_{R\text{-}b} \times (1 + GDP_{pcM} \times a) + 0.1 \\ &\times EC_{R\text{-}b} \times [1 + (0,9 \times GDP_{pcM} \times HDD_M + 0,1 \times GDP_{pcM} \\ &\times CDD_M)/HDD_N] + 0.1 \times EC_{R\text{-}b} \times (1 - P_b \times b) + 0.2 \times EC_{R\text{-}b} \\ &\times [1 + ECG_R \times (0.5 \times GDP_{pcM/N} + 0.45 \times HDD_{M/N} + 0.05 \\ &\times CDD_{M/N}) \times c] \end{aligned} \tag{12}$$

$$\begin{aligned} EC_{Rf\text{-}ng} &= 0.35 \times EC_{R\text{-}ng} \times (1 + PG) + 0.25 \times EC_{R\text{-}ng} \times (1 + GDP_{pcM} \times a) + 0.1 \\ &\times EC_{R\text{-}ng} \times [1 + (0,9 \times GDP_{pcM} \times HDD_M + 0,1 \times GDP_{pcM} \\ &\times CDD_M)/HDD_N] + 0.1 \times EC_{R\text{-}ng} \times (1 - P_{ng} \times b) + 0.2 \times EC_{R\text{-}ng} \\ &\times [1 + ECG_T \times (0.5 \times GDP_{pcM/N} + 0.45 \times HDD_{M/N} + 0.05 \\ &\times CDD_{M/N}) \times c] \end{aligned} \tag{13}$$

Public lighting

$$EC_{PLf\text{-}e} = EC_{PL\text{-}e} \times (1 + PG) \tag{14}$$

Industries

$$EC_{If\text{-}e/h/d/ng/g} = 0.6 \times EC_{I\text{-}e/h/d/ng/g} \times (1 + ECG_I \times a) + 0.4 \times ECI \times (1 + P_{e/h/d/ng} \times b) \tag{15}$$

Municipal fleet or public transport

$$EC_{MLPTf\text{-}d/g/ng/lg} = EC_{MLPT\text{-}d/g/ng/lg} \times (1 + PG) \tag{16}$$

Private and commercial transport

$$\begin{aligned} EC_{PCTf\text{-}d/g/ng/lg} &= 0.35 \times EC_{PCT\text{-}d/g/ng/lg} \times (1 + PG) + 0.15 \times EC_{PCT\text{-}d/g/ng/lg} \\ &\times (1 + GDP_{pcM} \times a) + 0.2 \times EC_{PCT\text{-}d/g/ng/lg} \times (1 - P_{d/ng} \times b) \\ &+ 0.25 \times EC_{PCT\text{-}d/g/ng/lg} \times [1 + ECG_{PCT} \times (1 + GDP_{pcM/N}) \times c] \\ &+ 0.05 \times EC_{PCT\text{-}d/g/ng/lg} \times (1 + 0.01 \times DV_{rn}) \end{aligned} \tag{17}$$

Agricultural sector

$$EC_{Af\text{-}e/d/g/ng} = 0.3 \times EC_{A\text{-}e/d/g/ng} \times (1 + PG) + 0.2 \times EC_{A\text{-}e/d/g/ng} \times (1 - P_E \times a) + 0.5 \times EC_{A\text{-}e/d/g/ng} \times (1 + ECG_A \times b) \quad (18)$$

where:

- $EC_{Mf\text{-}e/h/ng/b/d}$: Future electricity/heating oil/natural gas/biomass/diesel consumption in the municipal buildings, equipment/facilities
- $EC_{Tf\text{-}e/h/b/ng}$: Future electricity/heating oil/biomass/natural gas/consumption in the tertiary sector
- $EC_{Rf\text{-}e/h/b/ng}$: Future electricity/heating oil/biomass/natural gas/consumption in the residential sector
- $EC_{PLf\text{-}e}$: Future electricity consumption in the public lighting
- $EC_{If\text{-}e/h/d/ng/g}$: Future electricity/heating oil/natural gas/gasoline consumption in the industrial sector
- $EC_{MLPTf\text{-}d/g/ng/lg}$: Future diesel/gasoline/natural gas/liquid gas consumption in the municipal fleet or public transport
- $EC_{PCTf\text{-}d/g/ng/lg}$: Future diesel/gasoline/natural gas/liquid gas consumption in the private and commercial transport
- $EC_{Af\text{-}e/d/g/ng}$: Future electricity/diesel/gasoline/natural gas consumption in the agricultural sector
- $EC_{Ms\text{-}e/h/ng/b}$: Current electricity/heating oil/natural gas/biomass consumption in schools
- $EC_{Mb\text{-}e/h/ng/b}$: Current electricity/heating oil/natural gas/biomass consumption in municipal buildings
- $EC_{Mef\text{-}e/d/ng}$: Current electricity/diesel/natural gas consumption in equipment/facilities
- $EC_{T\text{-}e/h/b/ng}$: Current electricity/heating oil/natural gas/consumption of the tertiary sector
- $EC_{R\text{-}e/h/b/ng}$: Current electricity/heating oil/natural gas/consumption of the residential sector
- $EC_{PL\text{-}e}$: Current electricity consumption in the public lighting
- $EC_{I\text{-}e/h/d/ng/g}$: Current electricity/heating oil/natural gas/gasoline consumption in the industrial sector
- $EC_{MLPT\text{-}d/g/ng/lg}$: Current diesel/gasoline/natural gas/liquid gas consumption in the municipal fleet or public transport
- EC_{PCT}: Current diesel/gasoline/natural gas/liquid gas consumption in the private and commercial transport

- $EC_{A\text{-}e/d/g/ng}$: Current electricity/diesel/gasoline/natural gas consumption in the agricultural sector
- PG: Rate of population growth at municipal level
- $PG_{0\text{-}19}$: Rate of population growth (0–19 years old) at municipal level
- $P_{e/h/d/ng}$: Rate of electricity/diesel/natural gas price
- HDD_M: Annual heating degree days at municipal level
- CDD_M: Annual cooling degree days at municipal level
- HDD_N: Average value of annual heating degree days at national level
- CDD_N: Average value of annual cooling degree days at national level
- $HDD_{M/N}$: Annual heating degree days at municipal level/average value of annual heating degree days at national level
- $CDD_{M/N}$: Annual cooling degree days at municipal level/average value of annual cooling degree days at national level
- GDP_{pcM}: Rate of per capita gross domestic product at municipal level
- $GDP_{pcM/N}$: Per capita gross domestic product at municipal level/per capita gross domestic product at national level
- ECG_{pct}: Rate of energy consumption growth of the transport sector at national level
- $ECG_{T/R/I/PCT/A}$: Rate of energy consumption growth of the tertiary/residential/industry/private and commercial transport/agricultural sector at national level
- DV_{rn}: Development index of road network
- a, b, c: Correction factors (different in each sector)

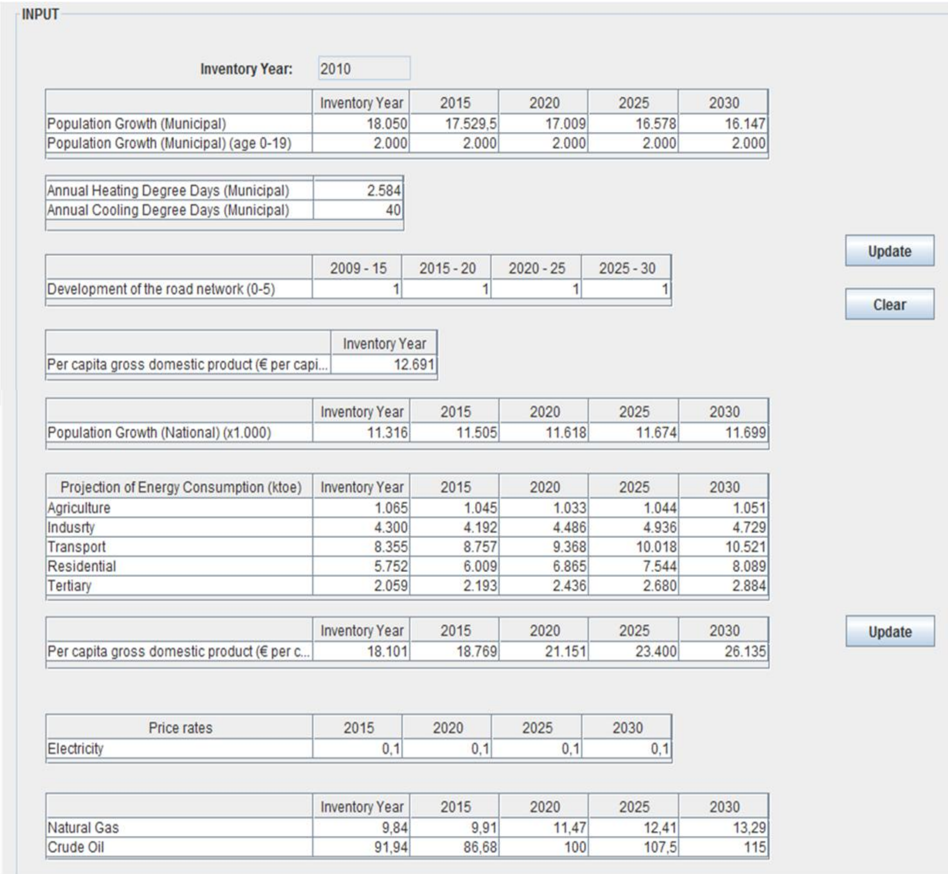
4 Pilot appraisal

4.1 Computerised software

The proposed model's computerised software was developed for its pilot appraisal, through the use of 'Java' programming language and the software development platform 'NetBeans IDE'. Basic aim was to simplify the required procedure for the evaluation of the proposed RES and RUE actions and to provide the necessary support to the decision-makers. In this respect, special forms were developed for data input and process.

The end-user provides data on the baseline energy and emission inventory, the expected energy and CO_2 emissions reductions by 2020, as well as the values of the key parameters for the local community, such as population growth, electricity and fuels prices, etc. (Figure 2). Following the data inputs, the relevant calculations take place and the future scenarios are displayed to the end-user.

Figure 2 Data input



INPUT

Inventory Year: 2010

	Inventory Year	2015	2020	2025	2030
Population Growth (Municipal)	18.050	17.529,5	17.009	16.578	16.147
Population Growth (Municipal) (age 0-19)	2.000	2.000	2.000	2.000	2.000

Annual Heating Degree Days (Municipal)	2.584
Annual Cooling Degree Days (Municipal)	40

	2009 - 15	2015 - 20	2020 - 25	2025 - 30
Development of the road network (0-5)	1	1	1	1

Update

Clear

	Inventory Year
Per capita gross domestic product (€ per capi...	12.691

	Inventory Year	2015	2020	2025	2030
Population Growth (National) (x1.000)	11.316	11.505	11.618	11.674	11.699

Projection of Energy Consumption (ktoe)	Inventory Year	2015	2020	2025	2030
Agriculture	1.065	1.045	1.033	1.044	1.051
Indusrty	4.300	4.192	4.486	4.936	4.729
Transport	8.355	8.757	9.368	10.018	10.521
Residential	5.752	6.009	6.865	7.544	8.089
Tertiary	2.059	2.193	2.436	2.680	2.884

	Inventory Year	2015	2020	2025	2030
Per capita gross domestic product (€ per c...	18.101	18.769	21.151	23.400	26.135

Update

Price rates	2015	2020	2025	2030
Electricity	0,1	0,1	0,1	0,1

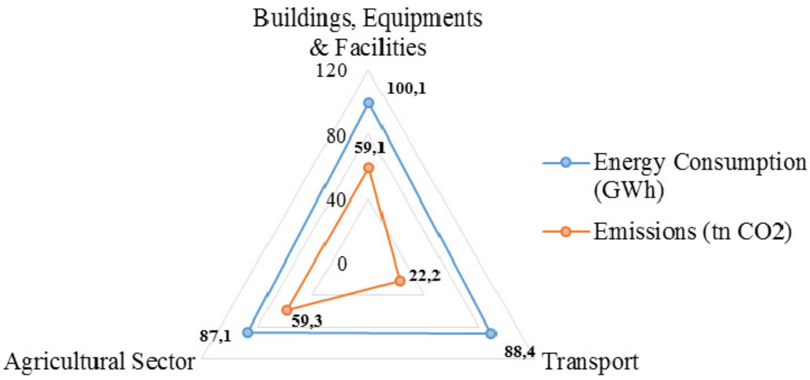
	Inventory Year	2015	2020	2025	2030
Natural Gas	9,84	9,91	11,47	12,41	13,29
Crude Oil	91,94	86,68	100	107,5	115

4.2 Results – discussion

The application of the proposed model was made to the Municipality of Evrota, Greece, during the development of its SEAP for the CoM's initiative. It is located in the southern part of the Prefecture of Laconia in the Peloponnese. It is bordered to the Northwest by the Municipality of Sparti, Southwest with the Municipality of Eastern Mani and Southeast with the Municipality of Monemvasia, as it is situated on the South-side of the Laconian Gulf. The population of the municipality is about 17,755 inhabitants.

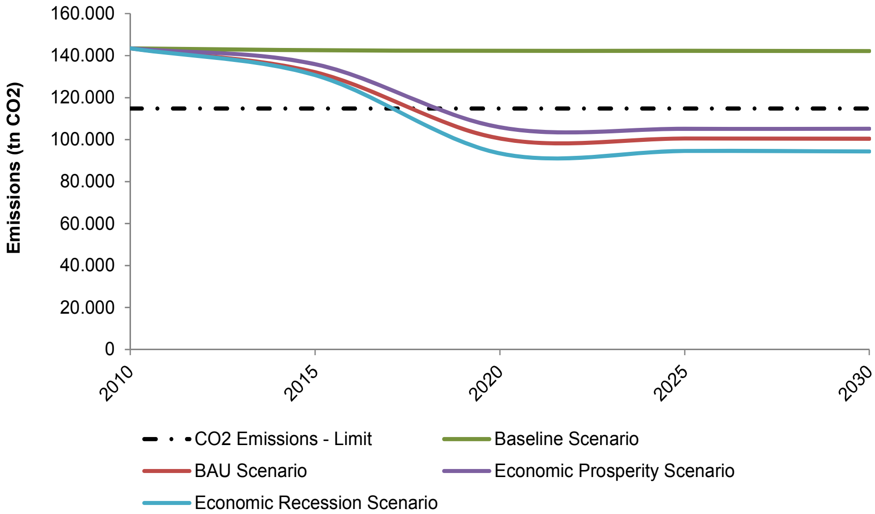
The selected inventory year for the Municipality of Evrota is 2010. The total final energy consumption in 2010 was 275,627 MWh. The Baseline Emission Inventory was based on the 'standard' emission factors in line with the IPCC (2006) principles. For CO_2 emissions' calculation the standard CO_2 emission factors for heating oil, gasoline, biomass and solar thermal energy were used, derived from the CoM's guidelines. Figure 3 presents the contribution of each sector in the energy consumption and CO_2 emissions of the Municipality of Evrota.

Figure 3 Contribution to the energy and CO_2 emissions



The overall CO_2 emission reduction target by 2020 of the Municipality of Evrota is 23%. The municipality has committed to implement a series of appropriate RES and RUE actions in its territory. From the results of the future scenarios (Figure 4), it can be said that the selected combination of RES and RUE actions is concerned enough to achieve the target of at least 20% CO_2 reduction by 2020. It should be noted that the results have been included in the submitted SEAP of the Municipality of Evrota (Eurota, 2014).

Figure 4 Results from the computerised software (emissions reduction – tn CO_2)



The proposed tool supports the decision-making procedure for the selection of appropriate combination of RES and RUE actions, taking into consideration a number of external parameters for the growth of the community's energy demand. The results are considered more reliable and accurate for the application of the proposed model to rural communities rather than large cities, due to the complexity of data input in cities. Except from the evaluation of future scenarios, the incorporation of financial feasibility assessment could also support the decision-making process. The relevant algorithm for the calculation of a series of financial indicators, such as Net Present Value (NPV), Internal rate of Return (IRR) and Discounted Pay Back Period (DBP), could be included in the proposed model.

5 Conclusions

The majority of the studies in the international literature are focused on the assessment of future energy status at national or European level. This paper presented a transparent and flexible decision support model for scenarios' building and assessment within the CoM. In particular, the introduced system elaborates appropriate scenarios of energy consumption and CO_2 emissions at local or regional level. The Delphi method was appropriately applied for embracing experts' judgements.

The relevant calculations are based on data from the Baseline Emission Inventory, as well as a number of external key parameters and the expected energy and CO_2 emissions reduction from the application of examined RES and RUE actions. More specifically, the identified key parameters for the community's energy growth are the following:

- Rate of population growth at municipal level.
- Rate of per capita gross domestic product at municipal level.
- Annual heating and cooling degree days at municipal level.
- Rate of electricity and fuel prices.
- Rate of energy consumption growth of the relevant sector at national level.
- Development of the road network.

The future scenarios ('BAU Scenario', 'Economic Prosperity Scenario' and 'Economic Recession Scenario') can support local authorities to evaluate if the selected combination of RES and RUE actions is considered enough to achieve the long-term target of CO_2 reduction. The computerised software was applied to a Greek community and its results were included to the submitted SEAP to the CoM.

Future research efforts could be also laid on the incorporation of respective uncertainties (e.g. fuel prices) for supporting financial feasibility assessments.

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