Sustainable educational supply chain performance measurement through DEA and Differential Evolution: a case on Indian HEI

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Abstract: Data envelopment analysis or DEA methodology is employed for assessing the relative efficiency of different homogeneous units. Through DEA one can analyze the areas which need more attention and can suggest measures for improving the performance of different sectors. Through this article, the authors have tried to analyze the relative efficiency of IITR (The Indian Institute of Technology Roorkee), a higher educational institute (HEI) in India. The efficiency of nineteen academic departments of IIT Roorkee is measured with respect to teaching and research. The novlty of the paper is twofold (1) the authiors have considered the environmental aspects (sustainability criteria) while measuring efficiency (2) Differential Evolution (DE) algorithm is employed in accordance with DEA on the fractional model generated for calculating efficiency.

Keywords: Educational supply chain management, Differential evolution, Performance measurement, Data envelop analysis, higher educational institute

1. Introduction

The tactical growth of a nation is directly proportional the type of education that is being made available to its citizens at basic level to the highest degree. John F. Kennedy once rightly said in his famous quote, “Our progress as a nation can be no swifter than our progress in education. The human mind is our fundamental resource.” (US Congress speech, 1961) [1]. This statement is perhaps more relevant today than it was in 1961 particular in India scenario where we have several academic institutions involved in teaching and research. However, to appraise the progress of education it is necessary to investigate the working of educational institutes with respect to teaching or research or both from time to time. By appraising the performance of an education system, one can identify its weaknesses or shortcomings and can suggest suitable measures for betterment. In this study, the authors have focused on measuring the teaching and research efficiency of nineteen (19) academic departments of IITR, Roorkee a HEI of India. The time period considered is 12 academic years (2001 – 02 to 2012 – 2013) using suitable inputs and outputs.

The idea here is to consider the entire system in accordance with educational supply chain management (ESCM) framework. According to global supply chain forum (GSCF), the concepts of SCM can be applied to education sector by following the basic rules of SCM. Research papers in context with ESCM can be found in [2–6]. Literature is also available for the performance assessment of HEI in various countries all over the globe (USA [7-11], UK [12-18], Australia [19-20], China [21-24], India [25-26], Germany [27], Canada [28], Taiwan [29], Europe (30-31], Spain [32], Russia [33], Turkey [34], Vietnam [35], Czech [36], Italy [37-38], Sweden [39], Mexico [40], Chile [41] and Greek [42]). The novelty of the present work lies in the inclusion of sustainability factors (Greenhouse gas emissions (GHG) in our case) while measuring the teaching and research efficiency. The present work lies in the category of sustainable educational supply chain management (SESCM).

In the literature, one can find several approaches for efficiency measurement. Some commonly used methods include: performance indicators, stochastic frontier method, ordinary least square method, Free Disposal Hull (FDH) and DEA etc. Out of these, DEA is perhaps the most suitable approach for dealing with cases where there are several inputs and outputs. In literature, one can find the applications of DEA to various service industries like airlines [43], airport companies [44], banking [45], financial service [46], hotel [47], railway [48], and Telecom [49].

This article is an extension of the work previously done by the authors [50] with sufficient changes. Firstly, in current study, the authors have assessed IITR's performance on the basis of 12 consecutive academic years in contrast to [50], where performance is evaluated on the basis of a single year only. Secondly in this paper the authors have embedded DE with DEA to solve and evaluate the fractional model of the problem, this again is in contrast with the usual DEA method where the fractional model is reduced to a linear model.

This article has a division of seven sections. Introduction given in section 1 is followed by a brief description of educational supply chain management in Sections 2. DEA and DE are briefed in Sections 3 and 4 respectively. Experimental setup is given in section 5. Result and Discussions are briefed in Section 6. Lastly, conclusions and future research directions detailed in section 7.

2. Educational supply chain management (ESCM)

ESCM is nothing but the incorporation of the philosophy of SCM into the education sector. ESCM is relatively a newer concept where industry and business models are adopted to enhance and improve the working of an educational management. A significant point however is that SCM is usually focused on profit making industries while education institutes are generally nonprofit organizations. In the HEIs supply chain "one of the primary suppliers of process inputs is customers themselves. They provide their bodies and souls, minds, belongings, or information as inputs to the service processes [3]".

In case of HEI, where the focus is on teaching as well as research, ESCM may be defined as a process of transforming inputs which are in the form of students (undergraduates/ post graduates/ research scholars), and research projects (internal or external) through the educational process to obtain the best possible outputs (graduates, research outcomes).

The processing (HEIs) involves teachers or the academic staff, the administrative staff, infrastructure and research centers as well as social amenities like sports and recreational facilities etc. The supplied outputs are the students (graduates, post graduates and doctorates) and quality research outcomes that have gained value through the process after being monitored through examinations, development and continuous assessment.

The figures below (1 and 2) provide a generic framework for teaching and research supply chain frameworks respectively [5].

Figure 1

Figure 2

2.1 The Teaching Supply Chain

It may be said that the teaching supply chain is responsible for the overall development of the students. It provides a framework for the supply chain network for students. The raw material here is the students who have to undergo through various processes like admission, course work, lectures, tutorials, and practical, projects research papers, technical reports and thesis/ dissertation writing, industrial training, internship and extracurricular activities like social events, sports, cultural fests etc. The end products of the teaching supply chain are the graduates, post graduates and doctoral students.

2.2 The Research Supply Chain

Besides teaching, HEI also focus on research through research projects, consultancies etc. Research also means generation of research ideas, development of new instruments and prototypes, collection and analysis of data, etc. Researchers, academic and non-academic staff as well as funding agencies and industries are the operators of the research activities. It forms the second core process in the HEIs. In the 'Research' supply chain the raw material is the research idea or activity while the development or achievement is the finished product.

2.3 Sustainability in ESCM

An HEI usually have a well developed infrastructure with well equipped labs and offices. But how these facilities and arrangements effects the environment should also be taken into consideration. Besides it should also be noted how the academic and non academic staff is contributing towards the sustainability of environment. In the present study the authors have incorporated the concept of sustainability in ESCM which is all about managing the supplied input and output units and the association between teaching and research supply chain.

3. Data envelopment analysis (DEA)

In the simplest manner, DEA can be defined as performance measurement tool most beneficial in scenarios when comparison is to be done among several units (called decision making units or DMUs in DEA terminology) and several inputs and outputs are to be taken into account. Mathematically, it tries to maximize the relative efficiency, (= weighted sum of outputs/ weighted sum of inputs), of different units by determining the optimum set of weights. The initial model obtained is in a form of fractional programming problem. It is generally reduced to a linear model and is solved by linear programming technique. For more information on DEA, the interested reader may consult [51-58].

Working of DEA can be explained as follows: if there are N numbers of DMUs, then the efficiency of each DMU is maximized relatively. The model obtained is reduced to a constrained linear programming problem with the aim to determine the set of optimized weights which will maximize the efficiency. Problem formulation takes the form:

$$\text{Max } E_m = \frac{\sum_{k=1}^{O} w_k Output_{k,m}}{\sum_{l=1}^{i} z_l Input_{l,m}} \quad (1)$$

$$0 \le \frac{\sum_{k=1}^{O} w_k Output_{k,n}}{\sum_{l=1}^{i} z_l Input_{l,n}} \le 1; n = 1, 2..., m..N \quad (2)$$

$$w_k, z_l \ge 0; \quad \forall\, k, l \quad (3)$$

Where:

E_m – m^{th} DMU's efficiency, k=1 to O, l =1 to I and n =1 to N.

$Output_{k,m}$ – k^{th} output of the m^{th} DMU

w_k – weight of output $Output_{k,m}$

$Input_{l,m}$ – l^{th} input of m^{th} DMU

z_l – weight of $Input_{l,m}$

$output_{k,n}$ and $input_{l,n}$ are the k^{th} output and l^{th} input respectively of the n^{th} DMU, Where n=1, 2 …m...N

The fractional programming problem shown in (1), (2), (3) is reduced to a linear programming format as follows. This also represents the general CCR [51] model:

$$\text{Max } E_m \sum_{k=1}^{O} w_k Output_{k,m} \qquad (4)$$

$s.t.$

$$\sum_{l=1}^{I} z_l Input_{l,m} = 1 \qquad (5)$$

$$\sum_{k=1}^{O} w_k Output_{k,n} - \sum_{l=1}^{I} z_l Input_{l,n} \leq 0, \quad \forall\, n \qquad (6)$$

$$w_k, z_l \geq 0; \quad \forall\, k, l \qquad (7)$$

BCC [52] model in general form can be written as:

$$\text{Max } E_m \sum_{k=1}^{O} w_k Output_{k,m} + z_{0l} \qquad (8)$$

$s.t.$

$$\sum_{l=1}^{I} z_l Input_{l,m} = 1 \qquad (9)$$

$$\sum_{k=1}^{O} w_k Output_{k,n} - \sum_{l=1}^{I} z_l Input_{l,n} + z_{0l} \leq 0, \quad \forall\, n \qquad (10)$$

$$w_k, z_l \geq 0; \quad \forall\, k, l \qquad (11)$$

z_{0l} is unrestricted in sign.

Score of 1 implies the efficiency of DMU while any real number below 1 indicates that the DMU is comparatively less efficient.

4. Differential Evolution (DE)

DE [59] is basically a Metaheuristics techniques generally used for optimization of complex problems. Like most of the Metaheuristics, DE is population based and has a certain set of parameters for guiding the algorithm. In this article, DE is used for solving the efficiency model shown in Section 3. While applying DE, objective function is taken as equation (2) and the constraints are taken as equations (3) and (4). This fact is worth mentioning here that with DE the problem will be considered in the fractional form. This is in contrast to the usual DEA tool where the problem is first reduced to a linear model. The simple structure of DE can be understood with the help of pseudo code given below. For more details the interested reader may refer to [59]

Start
Generate initial population of uniformly distributed random numbers between the lower and the upper bound.
Do
{
Mutation
Crossover

Selection
}
While (stopping criteria is met)
End

5. Experimental Setup

Case study is done for IIT Roorkee, situated in Uttarakhand, India. It is one of the oldest technical institutes of India and at present ranks 6th among technical institutes of India. The necessary data taken for study is given below:

1. ***DMU-*** These are Decision Making Units, homogeneous in nature, for which the efficiency is to be determined. In this study**, nineteen** departments that deal with academics, given in Appendix A, are selected as DMUs. In the past also, academic departments have been selected as DMUs [14, 17, 60, and 61]. All these departments are involved in a parallel job of teaching and research and can therefore be treated as homogeneous.
2. ***Inputs and outputs-*** The authors have considered five inputs and five outputs, presented in Appendix B, for measuring the teaching supply chain efficiency *(T_0)* and research supply chain efficiency *(R_0)*. This data is carefully selected in consultation with different literature. Since departmental operating cost (DOC) is a common factor for both teaching and research supply chain, it is therefore calculated separately in proportion for measuring T_0 and R_0.
3. ***Data collection –*** The relevant data (Table 1) for 12 academic years (2001-02 to 2012–13) is majorly collected from three sources: (1) annual report book (2) office of Dean, Finance and Planning and (3) Establishment office of the Institute.
4. ***Sustainability Factor –*** Green House Gas (GHG) emission is the environmental factor considered here. It is measured as: GHG = activity/consumption data * emission factor [62].
5. **DEA settings**
   a) DEAP 2.1 [63] open source software.
   b) Model considered is output oriented as it will be more suitable for the present case study [50].
   c) For performance evaluation, both constant returns to scale (CRS) and variable returns to scale (VRS) approaches are considered.
6. **Parameter setting for DE**
   The DE program is executed in DEV C++. Pop size (NP) is taken as 100; Scale Factor (F) is taken as 0.5 while the crossover rate (Cr) is taken as 0.9; maximum iterations are kept as 3000. The DE variant utilized is DE/rand/1/bin [59] and for handling the constraints Pareto ranking method given in [64] is employed.

5.2 Mathematical Model

The basic mathematical model considered in this study is defined in section 3. The main difference is that for DE, fractional model is used while for DEA, the fractional model is reduced to a linear model. There are overall n=19 DMUs in the present case study. Department m which is the m^{th} DMU, (k= 1, 2, …, N) uses 5 $\text{Inputs}_{l,m}$ (l = 1, …, 5) to generate 5 outputs_{km} (k = 1, …, 5) from its teaching supply chain activities; and 5 $\text{Inputs}_{l,m}$ (l = 6, …, 10) to generate 5 outputs_{km} (k = 6, …, 10) from the research supply chain.

DOC, is a common input for both teaching supply chain and research supply chain and is therefore used in a proportionate manner. Since it is difficult for HEIs to apportion the exact amount of DOC, the distribution for each function is done with an objective of maximizing its overall relative sustainable supply chain efficiency (E_0).

It can be assumed that if p is the proportion of DOC allocated for teaching than (1 - p) is the proportion of DOC for research.

z_l and w_k are assumed to be the input and output variables where l = 1, …,I and k = 1, …, O.

The m^{th} DMU to be measured on a particular trial is designated as DMU_0 (0 = 1, 2, …,n).

T_0 and R_0 of DMU_0 can now be defined [65] as:

$$T_o = \frac{\sum_{k=1}^{5} w_k Output_{k,o}}{\sum_{l=1}^{4} z_l Input_{l,o} + p(z_5 Input_{5,o})} \quad (13)$$

$$R_o = \frac{\sum_{k=6}^{10} w_k Output_{k,o}}{(1-p)(z_5 Input_{5,o}) + \sum_{l=6}^{10} z_l Input_{l,o}} \quad (14)$$

The CCR (CRS score), DEA model used to evaluate and measure the overall E_0 is given as:

$$\text{Max } E_o = \frac{\sum_{k=1}^{10} w_k Output_{k,m}}{\sum_{k=1}^{10} z_l Input_{l,m}} \quad (15)$$

$s.t.$

$$\sum_{k=1}^{10} w_k Output_{k,n} - \sum_{k=1}^{10} w_k Input_{k,n} \leq 0, \quad \forall\, n \quad (16)$$

$$\sum_{k=1}^{5} w_k Output_{k,n} - \sum_{l=1}^{4} z_l Input_{l,n} + p(z_5 Input_{5,n}) \leq 0, \quad \forall\, n \quad (17)$$

$$\sum_{k=6}^{10} w_k Output_{k,n} - (1-p)(z_5 Input_{5,n}) - \sum_{l=6}^{10} z_l Input_{l,n} \leq 0, \quad \forall\, n \quad (18)$$

$$w_k, z_l \geq \in \quad (19)$$

Through equation (15) the set of optimum weights (w_k and z_l) is determined. This will give the maximum relative overall sustainable supply chain efficiency for m^{th} DMU under evaluation. The objective function is subjected to the constraints (16) to (18) for limiting the relative E_0. Constraint (19) is for non-negativity restrictions. ε is a small quantity taken as 0.01.

The number of times the model is executed is 19 which is equal to the number of DMUs for determining the relative performance for all the departments. A department is considered to be efficient if the score obtained is 1 otherwise the department can be assumed to be less efficient in comparison to other departments.

After obtaining the set of optimum weights for m^{th} DMU, teaching and research supply chain efficiencies evaluated separately with the help equations (13) and (14) separately.

Similarly, for BCC (VRS score), DEA can be modeled to evaluate and measure the E_0.

6. Result and discussion

6.1 DEA results

Tables 2 and 3 provides the results of T_0 and R_0 scores of academic years from 2001-02 to 2006-07 and 2007-08 to 2012-13 respectively and Table 4 shows average supply chain efficiency scores of 12 years based on DEA. The performance metrics for DEA used are TE (Technical Efficiency), PTE (Pure Technical Efficiency) and SE (Scale Efficiency).

6.1.1 Teaching supply chain efficiency:

a) ***TE :*** The mean TE is calculated as 0.9947. From the results it can be observed that out of nineteen, seven departments viz. ARP, CH, ECE, HSS, HY, MS and AHEC are technically efficient as the score obtained is 1, while the remaining twelve departments are not technically efficient as the score obtained is less than 1.

b) ***PTE:*** The average of PTE score for teaching supply chain is calculated as 0.9971. 8. Departments BT, CY, CE, MIE, MME, PT, PH and WRDM do not satisfy PTE criteria but the remaining 11 departments satisfy this metric.

c) ***SE:*** The average SE scores for T_o is 0.9975**.** The analysis shows that out of 19, 7 departments viz. ARP, CH, ECE, HSS, HY, MS and AHEC are efficient as T_o is calculated as one for them. All the remaining 12 departments are relatively inefficient. Figure 3 shows the corresponding histogram.

Figure 3

6.1.2 Research supply chain efficiency:

a) ***TE:*** Mean TE score for research supply chain is obtained as 0.9728, it can be seen that, out of 19, 3 departments: CY, EQE and AHEC are technically efficient while the remaining 16 departments with score less than 1 are not technically efficient.

b) ***PTE:*** Mean PTE score for research supply chain is calculated as 0.9854. It is observed that CH, CY, CE, EQE, HSS, MIE and AHEC attained a score of 1 and can therefore be considered as pure technically efficient. All other twelve departments are technically lesser efficient.

c) SE: Average SE score is calculated as 0.9872, here the results indicate that out of 19, 16 departments viz. ARP, BT, CH, CE, ES, EE, ECE, HSS, HY, MS, MA, MIE, MME, PT, PH and WRDM are inefficient as the calculated SE is less than one. The remaining 3 departments: CY, EQE and AHEC can be called relatively efficient as the total R_o score is calculated as one for these departments. Figure 4 shows the corresponding histogram.

Figure 4

6.1.3 Total supply chain efficiency:

The overall result for supply chain performance for 12 years is given in Table 5. The corresponding histogram for T_o, R_o and E_o with respect to their SE scores is depicted in Figure 5.

(a) Out of 19 departments, only AHEC is efficient. All the other departments are comparatively less efficient as they have the total E_o score less than one.

(b) The mean efficiency score of 12 academics years for T_o is 0.9975 and for R_o is 0.9872 and the Total SESCM efficiency (E_o) is 0.9924.

(c) The lowest efficiency score (0.9795) is measured for the HSS department. Its T_0 is 1 and R_0 is 0.9591. This indicates that improvement measures need to be formulated for research efficiency.

(d) The R_o of Departments CY and EQE is (100%) but their T_0 are measured as 0.993 and 0.9968 respectively indicating that these departments should work on improving their teaching efficiency.

(e) In case of ARP, CH, ECE, HSS, HY and MS departments the T_0 100% but R_0 are 0.9993, 0.9974, 0.9853, 0.9591, 0.9721 and 0.9827 respectively suggesting that these departments have to improve their research outcomes.

Figure 5

Table 1. Descriptive statistics of inputs and outputs

Charact -eristics	Teaching supply chain										Research supply chain									
	Inputs					outputs					Inputs					outputs				
	I_1	I_2	I_3	I_4	I_5	O_1	O_2	O_3	O_4	O_5	I_6	I_7	I_8	I_9	I_{10}	O_6	O_7	O_8	O_9	O_{10}
Max.	**51**	**142**	**321**	**9.12**	**164.1215**	**259**	**9.11**	**366.6666**	**700**	**4267.6562**	**164.1215**	**51**	**165**	**112**	**1962.3234**	**20**	**910**	**75**	**93**	**16.9671**
Min.	**5**	**0**	**0**	**0**	**4.2814**	**0**	**0**	**0**	**0**	**0.0841**	**4.2814**	**5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0.1262**
Avg.	**19.2850**	**32.4473**	**62.2938**	**7.2043**	**15.8553**	**56.531**	**7.4995**	**86.7913**	**54.2972**	**182.0561**	**15.8146**	**19.285**	**47.6403**	**12.1013**	**137.9405**	**5.1227**	**164.2631**	**9.9723**	**21.2187**	**3.7175**
STDEV	**10.127**	**29.0951**	**58.2348**	**1.0552**	**13.8444**	**50.4847**	**1.036**	**33.5461**	**67.24**	**700.0723**	**13.8615**	**10.127**	**33.7896**	**11.698**	**269.9783**	**4.3822**	**128.0001**	**12.9468**	**16.9618**	**2.8174**

Table 2. T_0 and R_0 scores from academic years 2001-02 to 2006-07 based on DEA

Dept. no.	Departments	2001-02			2002-03			2003-04			2004-05			2005-06			2006-07		
		Teaching	Research	Total Efficiency	Teaching	Research	Total Efficiency	Teaching	Research	Total Efficiency	Teaching	Research	Total Efficiency	Teaching	Research	Total Efficiency	Teaching	Research	Total Efficiency
1	ARP	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	BT	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.9686	0.9843
3	CH	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4	CY	1	1	1	1	1	1	1	1	1	0.917	1	0.9585	1	1	1	1	1	1
5	CE	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	EQE	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	ES	1	1	1	1	0.9978	1	1	0.9607	0.9803	0.978	1	0.989	1	1	1	1	1	1
8	EE	1	1	1	1	1	1	1	0.96	0.98	0.946	1	0.973	1	1	1	1	1	1
9	ECE	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.9909	0.9954
10	HSS	1	0.51	0.755	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	HY	1	0.934	0.967	1	1	1	1	0.825	0.9125	1	1	1	1	1	1	1	1	1
12	MS	1	0.5033	0.8569	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
13	MA	1	1	1	1	1	1	1	1	1	0.996	1	0.998	1	1	1	1	1	1
14	MIE	1	1	1	0.936	0.953	0.9445	0.9947	0.964	0.9793	1	1	1	1	1	1	0.999	1	0.9995
15	MME	1	1	1	1	1	1	1	0.9945	0.9972	1	1	1	1	1	1	0.982	1	0.991
16	PT	1	1	1	1	1	1	1	0.9	0.95	1	1	1	1	1	1	0.9989	1	0.9994
17	PH	1	1	1	0.99	0.9989	0.9944	1	0.8356	0.9178	0.9979	1	0.9989	1	1	1	1	1	1
18	WRDTC	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.9948	0.9320	0.9634
19	AHEC	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	MEAN	1	0.9594	0.9797	0.9961	0.9973	0.9967	0.9997	0.9717	0.9857	0.9913	1	0.9956	1	1	1	00.9986	0.9945	0.9966

Table 3. T_0 and R_0 scores from academic years 2007-08 to 2012-13 based on DEA

Dept. no.	Departments	2007-08			2008-09			2009-10			2010-11			2011-12			2012-13		
		Teaching	Research	Total Efficiency	Teaching	Research	Total Efficiency	Teaching	Research	Total Efficiency	Teaching	Research	Total Efficiency	Teaching	Research	Total Efficiency	Teaching	Research	Total Efficiency
1	**ARP**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**0.9903**	**0.995**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
2	**BT**	**1**	**0.9693**	**0.9846**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**0.9911**	**0.9529**	**0.9720**	**1**	**1**	**1**
3	**CH**	**1**	**0.969**	**0.9845**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
4	**CY**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
5	**CE**	**0.9077**	**1**	**0.9538**	**1**	**1**	**1**	**1**	**0.991**	**0.9955**	**1**	**1**	**1**	**1**	**0.934**	**0.967**	**1**	**1**	**1**
6	**EQE**	**1**	**1**	**1**	**1**	**1**	**1**	**0.965**	**1**	**0.9825**	**1**	**1**	**1**	**0.997**	**1**	**0.9985**	**1**	**1**	**1**
7	**ES**	**1**	**1**	**1**	**1**	**0.9723**	**0.9861**	**1**	**0.9621**	**0.9810**	**1**	**1**	**1**	**1**	**0.9967**	**0.9983**	**1**	**1**	**1**
8	**EE**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**0.7112**	**0.8556**	**1**	**1**	**1**	**1**	**0.98**	**0.99**	**1**	**1**	**1**
9	**ECE**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**0.833**	**0.9165**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
10	**HSS**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
11	**HY**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**0.8336**	**0.9168**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
12	**MS**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
13	**MA**	**1**	**1**	**1**	**1**	**0.8683**	**0.9341**	**1**	**0.826**	**0.913**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
14	**MIE**	**1**	**0.991**	**0.9955**	**1**	**1**	**1**	**1**	**0.973**	**0.9865**	**1**	**1**	**1**	**0.994**	**1**	**0.997**	**1**	**1**	**1**
15	**MME**	**1**	**0.9617**	**0.9808**	**1**	**0.9869**	**0.9934**	**1**	**1**	**1**	**1**	**1**	**1**	**0.9838**	**0.9988**	**0.9913**	**1**	**1**	**1**
16	**PT**	**1**	**1**	**1**	**1**	**0.9494**	**0.9747**	**0.9299**	**0.8171**	**0.8735**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
17	**PH**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**0.983**	**0.9915**	**1**	**1**	**1**	**1**	**1**	**1**	**0.9685**	**1**	**0.9842**
18	**WRDTC**	**1**	**0.9763**	**0.9881**	**1**	**0.9432**	**0.9716**	**0.9836**	**0.9388**	**0.9612**	**0.9911**	**1**	**0.9955**	**1**	**1**	**1**	**1**	**1**	**1**
19	**AHEC**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
	MEAN	**0.9953**	**0.9931**	**0.9942**	**1**	**0.9863**	**0.9926**	**0.9938**	**0.9477**	**0.9707**	**0.9995**	**1**	**0.9997**	**0.9982**	**0.9931**	**0.9957**	**0.9983**	**1**	**0.9991**

Table 4. Average supply chain efficiency scores of 12 years based on DEA

Dept. no.	Departments	Teaching supply chain			Research supply chain			
		TE (CRS score)	PTE (VRS score)	*To*	TE (CRS score)	PTE (VRS score)	*Ro*	*Eo*
1	**ARP**	**1**	**1**	**1**	**0.9854**	**0.986**	**0.9993**	**0.9996**
2	**BT**	**0.9915**	**0.9921**	**0.9993**	**0.9556**	**0.9633**	**0.992**	**0.9956**
3	**CH**	**1**	**1**	**1**	**0.9974**	**1**	**0.9974**	**0.9987**
4	**CY**	**0.991**	**0.998**	**0.993**	**1**	**1**	**1**	**0.9965**
5	**CE**	**0.9896**	**0.997**	**0.9925**	**0.9937**	**1**	**0.9937**	**0.9931**
6	**EQE**	**0.9968**	**1**	**0.9968**	**1**	**1**	**1**	**0.9984**
7	**ES**	**0.9981**	**1**	**0.9981**	**0.972**	**0.9808**	**0.9909**	**0.9945**
8	**EE**	**0.9955**	**1**	**0.9955**	**0.948**	**0.9677**	**0.97959**	**0.9875**
9	**ECE**	**1**	**1**	**1**	**0.9845**	**0.9992**	**0.9853**	**0.9926**
10	**HSS**	**1**	**1**	**1**	**0.9591**	**1**	**0.9591**	**0.9795**
11	**HY**	**1**	**1**	**1**	**0.9291**	**0.9557**	**0.9721**	**0.986**
12	**MS**	**1**	**1**	**1**	**0.9586**	**0.9754**	**0.9827**	**0.9913**
13	**MA**	**0.9996**	**1**	**0.9996**	**0.972**	**0.997**	**0.9748**	**0.9872**
14	**MIE**	**0.9904**	**0.9967**	**0.9936**	**0.99**	**1**	**0.99**	**0.99185**
15	**MME**	**0.9965**	**0.9994**	**0.9971**	**0.9605**	**0.9651**	**0.9951**	**0.9961**
16	**PT**	**0.9834**	**0.989**	**0.9942**	**0.9434**	**0.9681**	**0.9744**	**0.9843**
17	**PH**	**0.9886**	**0.9922**	**0.9963**	**0.9773**	**0.9915**	**0.9857**	**0.991**
18	**WRDTC**	**0.9791**	**0.9815**	**0.9976**	**0.957**	**0.973**	**0.9835**	**0.9905**
19	**AHEC**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
	MEAN	**0.9947**	**0.9971**	**0.9975**	**0.9728**	**0.9854**	**0.9872**	**0.9924**

Table 5. Total Supply chain efficiency scores for 12 academic years based on DEA

Dept. no.	Departments	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	12 years' efficiency score
1	ARP	1	1	1	1	1	1	1	1	0.995	1	1	1	0.9996
2	BT	1	1	1	1	1	0.9843	0.9846	1	1	1	0.9720	1	0.9956
3	CH	1	1	1	1	1	1	0.9845	1	1	1	1	1	0.9987
4	CY	1	1	1	0.9585	1	1	1	1	1	1	1	1	0.9965
5	CE	1	1	1	1	1	1	0.9538	1	0.9955	1	0.967	1	0.9931
6	EQE	1	1	1	1	1	1	1	1	0.9825	1	0.9985	1	0.9984
7	ES	1	1	0.9803	0.989	1	1	1	0.9861	0.9810	1	0.9983	1	0.9945
8	EE	1	1	0.98	0.973	1	1	1	1	0.8556	1	0.99	1	0.9875
9	ECE	1	1	1	1	1	0.9954	1	1	0.9165	1	1	1	0.9926
10	HSS	0.755	1	1	1	1	1	1	1	1	1	1	1	0.9795
11	HY	0.967	1	0.9125	1	1	1	1	1	0.9168	1	1	1	0.986
12	MS	0.8569	1	1	1	1	1	1	1	1	1	1	1	0.9913
13	MA	1	1	1	0.998	1	1	1	0.9341	0.913	1	1	1	0.9872
14	MIE	1	0.9445	0.9793	1	1	0.9995	0.9955	1	0.9865	1	0.997	1	0.99185
15	MME	1	1	0.9972	1	1	0.991	0.9808	0.9934	1	1	0.9913	1	0.9961
16	PT	1	1	0.95	1	1	0.9994	1	0.9747	0.8735	1	1	1	0.9843
17	PH	1	0.9944	0.9178	0.9989	1	1	1	1	0.9915	1	1	0.9842	0.991
18	WRDTC	1	1	1	1	1	0.9634	0.9881	0.9716	0.9612	0.9955	1	1	0.9905
19	AHEC	1	1	1	1	1	1	1	1	1	1	1	1	1
	MEAN	0.9797	0.9967	0.9857	0.9956	1	0.9966	0.9942	0.9926	0.9707	0.9997	0.9957	0.9991	0.9924

6.2 Results obtained by DE

In this section the results obtained by DE are discussed. Tables 6, 7 and 8 provides the results for T_0 and R_0 scores of academic years from 2001 to 2007 and from 2008 to 2013 and average supply chain efficiency scores *(*E_0*)* of 12 years respectively.

6.2.1 Teaching supply chain efficiency:

Average T_o is calculated as 0.9732. Table 8 indicates that out of 19, ECE and HY, have obtained an efficiency score of 1 and can therefore assumed to be 100% efficient however for the remaining 17 departments are not as efficient as the score obtained is less than 1. The results is shown graphically in Figure 6 through a histogram.

Figure 6

6.2.2 Research supply chain efficiency:

Average R_o calculated by DE is 0.9685. Here, AHEC, EQE, MS and HSS obtained a score of 1 and can therefore considered to be 100% efficient while all the other academic departments are comparatively lesser efficient. This result can also be viewed from Figure 7.

Figure 7

6.2.3 Total supply chain efficiency:

The results for E_0 for 12 years are presented in Table 9 and the corresponding histogram of all three efficiency scores is given in Figure 8. The following outcomes are observed:

(a) Mean T_o is 0.9732; Ro is 0.9685 and E_o is 0.9709.

(b) All the departments are relatively inefficient as they have the total E_o scores are evaluated as less than one.

(d) T_0 for ECE and HY are 100% but R_0 are 0.9580 and 0.9732 respectively. This indicates that the focus of these departments is more on teaching in comparison to research activities.

(e) Some departments like EQE, HSS, MS and AHEC have 100% research efficiency but have teaching efficiency less than 1indicating that these departments needs to improve teaching efficiency.

Figure 8

Table 6. T_0 and R_0 scores of academic years 2001-02 to 2006-07 based on DE

Dept. no.	Departments	2001-02			2002-03			2003-04			2004-05			2005-06			2006-07		
		Teaching	Research	Total Efficiency	Teaching	Research	Total Efficiency	Teaching	Research	Total Efficiency	Teaching	Research	Total Efficiency	Teaching	Research	Total Efficiency	Teaching	Research	Total Efficiency
1	ARP	0.9953	1	0.9976835	1	1	1	1	1	1	1	0.9967	0.9983	1	1	1	1	1	1
2	BT	1	1	1	1	1	1	1	1	1	1	1	1	1	0.8696	0.9348	1	0.8096	0.9048
3	CH	0.9880	0.9753	0.9817	1	1	1	1	1	1	1	1	1	1	1	1	0.9950	1	0.9975
4	CY	1.0001	0.9176	0.9589	1	1	1	1	1	1	0.8923	1	0.9461	1	1	1	1	1	1
5	CE	0.9831	1	0.9915	1	1	1	1	1	1	0.9805	1	0.9902	1	1	1	1	1	1
6	EQE	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	ES	0.9575	0.9666	0.9621	0.9968	0.9285	0.9626	0.9998	0.9133	0.9566	1	1	1	0.9492	0.9888	0.9690	1	1	1
8	EE	1	1	1	0.9999	1	0.9999	0.9769	0.9353	0.9561	0.9241	0.7730	0.8485	1	0.9619	0.9809	1	0.9998	0.9999
9	ECE	1	0.9732	0.9866	1	1	1	1	1	1	1	1	1	1	0.8670	0.9335	1	0.9523	0.9761
10	HSS	0.6410	1	0.8205	0.4372	1	0.7186	0.8560	1	0.9280	0.9303	1	0.9651	0.8930	1	0.9465	0.8318	1	0.9159
11	HY	1	0.8815	0.9407	1	1	1	1	0.8003	0.9001	1	0.9970	0.9985	1	1	1	1	1	1
12	MS	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
13	MA	1	0.9383	0.9383	0.9827	1	0.9913	1	0.9846	0.9923	0.9877	1	0.9938	1	1	1	1	1	1
14	MIE	1	0.9652	0.9826	0.8968	0.9294	0.9131	0.9133	0.9496	0.9314	1	1	1	0.9916	0.9356	0.9636	0.9953	0.9894	0.9923
15	MME	1	0.9790	0.9895	1	1	1	0.9999	0.6975	0.8487	1	0.9974	0.9987	0.9996	0.9811	0.9903	0.9967	1	0.9983
16	PT	1	1	1	1	1	1	1	0.6507	0.8253	0.9998	0.9839	0.9918	0.9389	0.7728	0.8559	0.9394	1	0.9697
17	PH	0.9977	0.6810	0.8394	0.9662	0.9243	0.9452	0.9897	0.7564	0.8730	0.9436	0.6606	0.8021	0.9957	1	0.9978	1	1	1
18	WRDTC	1	0.8194	0.9097	0.9146	1	0.9573	1	0.9876	0.9938	1	0.9746	0.9873	0.9994	1	0.9997	1	0.8898	0.9449
19	AHEC	1	1	1	1	1	1	1	1	1	1	1	1	0.9014	1	0.9507	1	1	1
	MEAN	0.9770	0.9268	0.9502	0.9576	0.9885	0.9730	0.9861	0.9303	0.9582	0.9820	0.9675	0.9747	0.9825	0.9672	0.9749	0.9872	0.9811	0.9841

Table 7. T_0 and R_0 scores of academic years 2007-08 to 2012-13 based on DE

Dept. no.	Departments	2007-08			2008-09			2009-10			2010-11			2011-12			2012-13		
		Teaching	Research	Total Efficiency	Teaching	Research	Total Efficiency	Teaching	Research	Total Efficiency	Teaching	Research	Total Efficiency	Teaching	Research	Total Efficiency	Teaching	Research	Total Efficiency
1	ARP	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	BT	1	0.8381	0.9190	1	1	1	1	1	1	1	1	1	0.8159	0.7289	0.7724	1	1	1
3	CH	1	0.9959	0.9979	1	1	1	1	1	1	1	1	1	0.9980	1	0.9990	1	1	1
4	CY	1	1	1	1	1	1	0.9735	1	0.9867	1	0.9903	0.9951	0.9949	0.9708	0.9828	1	1	1
5	CE	1	1	1	1	1	1	1	1	1	1	1	1	0.9886	0.8592	0.9239	1	1	1
6	EQE	1	1	1	1	1	1	0.9134	1	0.9567	1	1	1	0.9677	1	0.9838	1	1	1
7	ES	0.9982	0.9853	0.9917	1	0.9434	0.9717	1	1	1	1	0.8470	0.9235	0.9953	0.8720	0.9337	1	1	1
8	EE	1	1	1	1	1	1	1	0.7826	0.8913	1	0.7417	0.8708	1	0.9556	0.9778	1	0.9187	0.9593
9	ECE	1	1	1	1	1	1	1	0.7043	0.8521	1	1	1	1	1	1	1	1	1
10	HSS	1	1	1	0.9867	1	0.9933	1	1	1	0.9747	1	0.9873	0.9316	1	0.9658	0.6963	1	0.8481
11	HY	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12	MS	1	1	1	0	1	0.5	1	1	1	1	1	1	1	1	1	1	1	1
13	MA	1	0.9275	0.9637	0	0.9163	0.4581	1	1	1	1	1	1	1	1	1	1	1	1
14	MIE	1	0.9412	0.9706	0.9997	0.9456	0.9726	1	1	1	1	1	1	0.9488	1	0.9744	1	0.9650	0.9825
15	MME	1	0.9995	0.9997	1	0.9561	0.9780	1	1	1	1	0.6574	0.8287	0.9469	0.8346	0.8907	1	1	1
16	PT	0.9444	1	0.9722	0.9680	0.8055	0.8868	0.8541	0.8852	0.8696	0.9136	1	0.9568	0.8956	0.9802	0.9379	1	1	1
17	PH	1	1	1	1	0.9883	0.9941	1	1	1	1	1	1	0.9624	1	0.9812	0.9343	1	0.9671
18	WRDTC	1	0.9451	0.9725	1	1	1	0.8706	1	0.9353	0.8648	1	0.9324	0.9984	0.9985	0.9984	1	1	1
19	AHEC	1	1	1	0.9833	1	0.9916	1	1	1	1	1	1	1	1	1	1	1	1
	MEAN	0.9969	0.9806	0.9888	0.8914	0.9766	0.9340	0.9795	0.9669	0.9732	0.9870	0.9598	0.9734	0.9707	0.9579	0.9643	0.9805	0.9938	0.9872

Table 8. Average supply chain efficiency scores based on DE

Dept. no.	Departments	***To***	***Ro***	12 years' efficiency score
1	**ARP**	**0.9996**	**0.9997**	**0.9996**
2	**BT**	**0.9846**	**0.9372**	**0.9609**
3	**CH**	**0.9984**	**0.9976**	**0.9980**
4	**CY**	**0.9884**	**0.9899**	**0.9891**
5	**CE**	**0.9960**	**0.9882**	**0.9921**
6	**EQE**	**0.9901**	**1**	**0.9950**
7	**ES**	**0.9914**	**0.9537**	**0.9726**
8	**EE**	**0.9917**	**0.9224**	**0.9570**
9	**ECE**	**1**	**0.9580**	**0.9790**
10	**HSS**	**0.8482**	**1**	**0.9241**
11	**HY**	**1**	**0.9732**	**0.98661**
12	**MS**	**0.9166**	**1**	**0.9583**
13	**MA**	**0.9142**	**0.9805**	**0.9473**
14	**MIE**	**0.9788**	**0.9684**	**0.9736**
15	**MME**	**0.9952**	**0.9252**	**0.9602**
16	**PT**	**0.9545**	**0.9232**	**0.9388**
17	**PH**	**0.9824**	**0.9175**	**0.9500**
18	**WRDTC**	**0.9706**	**0.9679**	**0.9692**
19	**AHEC**	**0.9903**	**1**	**0.9951**
	MEAN	**0.9732**	**0.9685**	**0.9709**

Table 9. Total supply chain efficiency scores for 12 academic years based on DE

Dept. no.	Departments	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	12 years' efficiency score
1	ARP	0.9976	1	1	0.9983	1	1	1	1	1	1	1	1	0.9996
2	BT	1	1	1	1	0.9348	0.9048	0.9190	1	1	1	0.7724	1	0.9609
3	CH	0.9817	1	1	1	1	0.9975	0.9979	1	1	1	0.9990	1	0.9980
4	CY	0.9589	1	1	0.9461	1	1	1	1	0.9867	0.9951	0.9828	1	0.9891
5	CE	0.9915	1	1	0.9902	1	1	1	1	1	1	0.9239	1	0.9921
6	EQE	1	1	1	1	1	1	1	1	0.9567	1	0.9838	1	0.9950
7	ES	0.9621	0.9626	0.9566	1	0.9690	1	0.9917	0.9717	1	0.9235	0.9337	1	0.9726
8	EE	1	0.9999	0.9561	0.8485	0.9809	0.9999	1	1	0.8913	0.8708	0.9778	0.9593	0.9570
9	ECE	0.9866	1	1	1	0.9335	0.9761	1	1	0.8521	1	1	1	0.9790
10	HSS	0.8205	0.7186	0.9280	0.9651	0.9465	0.9159	1	0.9933	1	0.9873	0.9658	0.8481	0.9241
11	HY	0.9407	1	0.9001	0.9985	1	1	1	1	1	1	1	1	0.9866
12	MS	1	1	1	1	1	1	1	0.5	1	1	1	1	0.9583
13	MA	0.9383	0.9913	0.9923	0.9938	1	1	0.9637	0.4581	1	1	1	1	0.9473
14	MIE	0.9826	0.9131	0.9314	1	0.9636	0.9923	0.9706	0.9726	1	1	0.9744	0.9825	0.9736
15	MME	0.9895	1	0.8487	0.9987	0.9903	0.9983	0.9997	0.9780	1	0.8287	0.8907	1	0.9602
16	PT	1	1	0.8253	0.9918	0.8559	0.9697	0.9722	0.8868	0.8696	0.9568	0.9379	1	0.9388
17	PH	0.8394	0.9452	0.8730	0.8021	0.9978	1	1	0.9941	1	1	0.9812	0.9671	0.9500
18	WRDTC	0.9097	0.9573	0.9938	0.9873	0.9997	0.9449	0.9725	1	0.9353	0.9324	0.9984	1	0.9692
19	AHEC	1	1	1	1	0.9507	1	1	0.9916	1	1	1	1	0.9951
	MEAN	0.9368	0.9730	0.9582	0.9747	0.9749	0.9841	0.9888	0.9340	0.9732	0.9734	0.9643	0.9872	0.9709

6.3 Sustainable educational supply chain efficiency scores comparison with two techniques

Tables 10 and 11 shows a comparison of sustainable educational supply chain efficiency scores for DEA and DE. Table 11 indicates that AHEC department is 100% efficient, when performance is assessed through DEA. However, when the assessment is done through DE, ARP department scores the rank 1st while AHEC secures the 3rd rank. None of the departments score 100% efficiency when DE is applied. The results are depicted pictorially through Figures 9, 10 and 11.

Figure 9

Figure 10

Figure 11

Table 10. Comparison of supply chain efficiency scores with DEA and DE

Dept. no.	Departments	2001-02		2002-03		2003-04		2004-05		2005-06		2006-07		2007-08		2008-09		2009-10		2010-11		2011-12		2012-13		Total 12 years' efficiency score	
		DEA	DE	DEA	DE	DEA	DE	DEA	DE	DEA	DE	DEA	DE	DEA	DE	DEA	DE	DEA	DE	DEA	DE	DEA	DE	DEA	DE	DEA	DE
1	ARP	1	0.9976	1	1	1	1	1	0.9983	1	1	1	1	1	1	1	1	0.995	1	1	1	1	1	1	1	0.9996	0.9996
2	BT	1	1	1	1	1	1	1	1	1	0.9348	0.9843	0.9048	0.9846	0.9190	1	1	1	1	1	1	0.9720	0.7724	1	1	0.9956	0.9609
3	CH	1	0.9817	1	1	1	1	1	1	1	1	1	0.9975	0.9845	0.9979	1	1	1	1	1	1	1	0.9990	1	1	0.9987	0.9980
4	CY	1	0.9589	1	1	1	1	0.9585	0.9461	1	1	1	1	1	1	1	1	1	0.9867	1	0.9951	1	0.9828	1	1	0.9965	0.9891
5	CE	1	0.9915	1	1	1	1	1	0.9902	1	1	1	1	0.9538	1	1	1	0.9955	1	1	1	0.967	0.9239	1	1	0.9931	0.9921
6	EQE	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.9825	0.9567	1	1	0.9985	0.9838	1	1	0.9984	0.9950
7	ES	1	0.9621	1	0.9626	0.9803	0.9566	0.989	1	1	0.9690	1	1	1	0.9917	0.9861	0.9717	0.9810	1	1	0.9235	0.9983	0.9337	1	1	0.9945	0.9726
8	EE	1	1	1	0.9999	0.98	0.9561	0.973	0.8485	1	0.9809	1	0.9999	1	1	1	1	0.8556	0.8913	1	0.8708	0.99	0.9778	1	0.9593	0.9875	0.9570
9	ECE	1	0.9866	1	1	1	1	1	1	1	0.9335	0.9954	0.9761	1	1	1	1	0.9165	0.8521	1	1	1	1	1	1	0.9926	0.9790
10	HSS	0.755	0.8205	1	0.7186	1	0.9280	1	0.9651	1	0.9465	1	0.9159	1	1	1	0.9933	1	1	1	0.9873	1	0.9658	1	0.8481	0.9795	0.9241
11	HY	0.967	0.9407	1	1	0.9125	0.9001	1	0.9985	1	1	1	1	1	1	1	1	0.9168	1	1	1	1	1	1	1	0.986	0.9866
12	MS	0.8569	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.5	1	1	1	1	1	1	1	1	0.9913	0.9583
13	MA	1	0.9383	1	0.9913	1	0.9923	0.998	0.9938	1	1	1	1	1	0.9637	0.9341	0.4581	0.913	1	1	1	1	1	1	1	0.9872	0.9473
14	MIE	1	0.9826	0.9445	0.9131	0.9793	0.9314	1	1	1	0.9636	0.9995	0.9923	0.9955	0.9706	1	0.9726	0.9865	1	1	1	0.997	0.9744	1	0.9825	0.9918	0.9736
15	MME	1	0.9895	1	1	0.9972	0.8487	1	0.9987	1	0.9903	0.991	0.9983	0.9808	0.9997	0.9934	0.9780	1	1	1	0.8287	0.9913	0.8907	1	1	0.9961	0.9602
16	PT	1	1	1	1	0.95	0.8253	1	0.9918	1	0.8559	0.9994	0.9697	1	0.9722	0.9747	0.8868	0.8735	0.8696	1	0.9568	1	0.9379	1	1	0.9843	0.9388
17	PH	1	0.8394	0.9944	0.9452	0.9178	0.8730	0.9989	0.8021	1	0.9978	1	1	1	1	1	0.9941	0.9915	1	1	1	1	0.9812	0.9842	0.9671	0.991	0.9500
18	WRDTC	1	0.9097	1	0.9573	1	0.9938	1	0.9873	1	0.9997	0.9634	0.9449	0.9881	0.9725	0.9716	1	0.9612	0.9353	0.9955	0.9324	1	0.9984	1	1	0.9905	0.9692
19	AHEC	1	1	1	1	1	1	1	1	1	0.9507	1	1	1	1	1	0.9916	1	1	1	1	1	1	1	1	1	0.9951
	MEAN	0.9797	0.9368	0.9967	0.9730	0.9857	0.9582	0.9956	0.9747	1	0.9749	0.9966	0.9841	0.9942	0.9888	0.9926	0.9340	0.9707	0.9732	0.9997	0.9734	0.9957	0.9643	0.9991	0.9872	0.9924	0.9709

Table 11. Ranking of departments based on T_0 and R_0 scores for 12 years with DEA and DE

Dept. no.	Departments	DEA Technique				DE Technique			
		T_0	R_0	E_0	Ranking	T_0	R_0	E_0	Ranking
1	ARP	1	0.9993	0.9996	2	0.9996	0.9997	0.9996	1
2	BT	0.9993	0.992	0.9956	7	0.9846	0.9372	0.9609	12
3	CH	1	0.9974	0.9987	3	0.9984	0.9976	0.9980	2
4	CY	0.993	1	0.9965	5	0.9884	0.9899	0.9891	6
5	CE	0.9925	0.9937	0.9931	9	0.9960	0.9882	0.9921	5
6	EQE	0.9968	1	0.9984	4	0.9901	1	0.9950	4
7	ES	0.9981	0.9909	0.9945	8	0.9914	0.9537	0.9726	10
8	EE	0.9955	0.97959	0.9875	16	0.9917	0.9224	0.9570	15
9	ECE	1	0.9853	0.9926	10	1	0.9580	0.9790	8
10	HSS	1	0.9591	0.9795	19	0.8482	1	0.9241	19
11	HY	1	0.9721	0.986	18	1	0.9732	0.9866	7
12	MS	1	0.9827	0.9913	14	0.9166	1	0.9583	14
13	MA	0.9996	0.9748	0.9872	15	0.9142	0.9805	0.9473	17
14	MIE	0.9936	0.99	0.9918	11	0.9788	0.9684	0.9736	9
15	MME	0.9971	0.9951	0.9961	6	0.9952	0.9252	0.9602	13
16	PT	0.9942	0.9744	0.9843	17	0.9545	0.9232	0.9388	18
17	PH	0.9963	0.9857	0.991	12	0.9824	0.9175	0.9500	16
18	WRDTC	0.9976	0.9835	0.9905	13	0.9706	0.9679	0.9692	11
19	AHEC	1	1	1	1	0.9903	1	0.9951	3
	MEAN	0.9975	0.9872	9924		0.9732	0.9685	0.9709	

7. Summary and directions of future research

Focal point of the present article is to appraise the competence of nineteen academic departments of IITR, an HEI of India in terms of teaching and research while considering the environmental factors (greenhouse gas emission). The objective here is not to judge a particular department but it is to provide a candid review of different departments engaged in teaching and research.

For appraising the performance, the tool used is DEA, a linear programming based technique for measuring efficiency. The authors have also applied DE on the mathematical model and compared the results. In case of DEA, the linear model is considered while in case of DE, fractional model is considered. All the results are taken while considering the sustainability criterion.

If we talk of results in terms of overall ranking than we can see that the average T_0 obtained by DEA and DE both is better than average R_0. This is an expected outcome because the primary aim of this HEI is teaching.

If we analyze department wise, the results are more or less similar with both the methods (DE and DEA). In fact, there are 3 departments (EE, HSS and MS) which have received the same rank through DEA and through DE. In most of the other departments there is not much difference in the rank. However, there are three cases of BT, HY and MME departments where there is a significant change of rank by the two methods. BT department scored rank 7th with DEA but its rank reduced to 12th when DE is applied. In case of HY department, the rank 18th obtained by DEA improved to rank 7th, when results were taken by DE. Similarly, MME department scored rank 6th with DEA but its rank reduced to 13th when DE is applied. This could be due to discrepancy in data and can be subject to future investigations. However, we may add that the results obtained by DE are likely to be more efficient because we have considered the model in its original form.

It may added that besides DE, other Metaheuristics like genetic algorithms (GA) [66, 67], particle swarm optimization (PSO) [68] and artificial bee colony (ABC) [69] may be combined with DEA or the effect of other soft computing techniques [70, 71] like artificial neural networks etc. may be tested on DEA. Possibilities may also be explored to apply the concept of DEA to other sectors of the society.

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APPENDIX A: List of selected departments of IIT Roorkee

Dept. Code	Departments
ARP	Architecture and Planning
BT	Biotechnology
CH	Chemical Engineering
CY	Chemistry
CE	Civil Engineering
EQE	Earthquake Engineering
ES	Earth Sciences
EE	Electrical Engineering
ECE	Electronics and Computer Engineering
HSS	Humanities and Social Sciences
HY	Hydrology
MS	Management Studies
MA	Mathematics
MIE	Mechanical and Industrial Engineering
MME	Metallurgical and Materials Engineering
PT	Paper Technology
PH	Physics
WRDTC	Water Resources Development and Management
AHEC	Alternate hydro energy centre

APPENDIX B: Inputs and Outputs for teaching supply chain and research supply chain efficiencies

1. Details of input and output Teaching supply chain mix

Input criteria for Teaching supply chain	Output criteria for Teaching supply chain
I_1*: *Number* of academic staffs:** This is the main work force in form of human resource used by all academic departments of IIT Roorkee for teaching purpose. ***I_2*: *Number* of non-academic staffs:** This is the secondary work force in form of human resource used by all academic departments of IIT Roorkee, those works for academic staff and under graduate (UG) and post graduate (PG) students. ***I_3*: *Number* of taught course students:** Total number of enrolled under UG and PG students in an academic department. ***I_4*: *Average* students' qualifications (CGPA)*: Total number of enrolled UG and PG student's qualification ***I_5*: *Departmental* operating cost (DOC)** ***(Thousand Euro)*: "**Each department disposes of certain amount of funds intended to the development of its teaching and research purposes" called DOC of individual department [25].	***O_1* : Number of graduates from taught courses:** Total number of UG and PG pass out students, which is the outputs for teaching purpose. ***O_2*. Average graduates' results*:*** Total number of enrolled UG and PG pass out student's average result, in cumulative grade points average (CGPA), graduates' results of any HEI department are allied with the academic quality of passed students. ***O_3*: Graduation rate*:*** Total number of enrolled UG and PG students pass out rate in %, graduation rate of any HEI departments students are related with the academic quality of graduate students. ***O_4*: Graduates' employment rate (%)*:*** The rate of which student got recruited is showing the recruiters' perception on the quality of graduate student from a HEIs department. ***O_5*. GHG emission*:** Net greenhouse gas (GHG) emissions **(**t CO_2e**)** by the teaching activity of a department, GHG emission have been measured for teaching supply chain of the academic departments through a consumption-based carbon footprint approach [62].

2. Details of input and output Research supply chain mix

Input criteria for Research supply chain	Output criteria for Research supply chain
$I_{6:}$ **Departmental operating cost:** Same as ***I_5***.	***$O_{6:}$*** **Number of PhD awards:** Total number of PhD awarded in a department.
$I_{7:}$ **Number of research staffs:** This is also the main work force in form of human resource used by all academic departments of IIT Roorkee for research purpose.	***$O_{7:}$*** **Number of publications:** Research publication is one of the main research activity performed by a department. Thus authors are considered as output for the Research supply chain. Which includes A-book/chapter in books/monograph, B-papers in journals, C-papers in conference/symposia
$I_{8:}$ **Average research staffs' qualifications:** The average research staffs' qualification of IIT Rookree is calculated based on scoring system presented in [65], (professors and above = 4, associate professors = 3, assistant professors = 2, lecturer and others = 1).	***$O_{8:}$*** **Number of awards:** Total number of honors and awards to the staff
$I_{9:}$ **Number of research students:** Total number of enrolled students for PhD courses	***$O_{9:}$*** **Number of intellectual activities:** Organization and Participation of staff in conferences, seminar, symposia, workshop, short term courses attended
$I_{10:}$ ***Research grants (Thousand Euro):*** Research grants for institute are treated as a resource for research purpose, thus it is considered as an input for research supply chain on a HEIs.	***$O_{10:}$*** **GHG emission:** Net greenhouse gas (GHG) emissions **(**t CO_2e**)** by the research activities of a department.