IADIS International Journal on Computer Science and Information Systems
Vol. 12, No. 2, pp. 133-147
ISSN: 1646-3692

ECO-INNOVATION ANALYSIS WITH DEA: AN APPLICATION TO OECD COUNTRIES

Reza Kiani Mavi[1] and Craig Standing.
Center for Innovative Practice, School of Business and Law, Edith Cowan University, Australia

ABSTRACT

Government regulations require businesses to improve their processes and products/services in a green and sustainable manner. For being environmentally friendly, businesses should invest more on eco-innovation practices. Firms eco-innovate to promote eco-efficiency and sustainability. This paper evaluates the eco-innovation performance of Organisation for Economic Co-operation and Development (OECD) countries with data envelopment analysis (DEA). Output oriented CCR (Charnes, Cooper and Rhodes) is applied because of more desirability of outputs for decision makers. Data were gathered from the World bank database and global innovation index report. Findings show that for most OECD countries, energy use and ecological sustainability are more important than other inputs and outputs for enhancing eco-innovation.

KEYWORDS

Eco-innovation, Eco-efficiency, Data Envelopment Analysis, Sustainability

1. INTRODUCTION

Discussions about climate change and the dangerous environmental effects of humankind require a broader research focus on sustainable, eco-friendly and/or green behaviour. (Haws et al., 2014; Teichmann, 2016). Organizations must provide green education and training for the growth and application of cleaner and more efficient technologies regarding natural resources utilization (Martin and Rigola, 2001). Such educational programs improve employees' environmental knowledge and equip the labour force with the expertise, skills and incentives to create and implement new processes to gain environmental advantages (Hilson and Nayee, 2002).

[1] *Corresponding author, E-mail: R.kianimavi@ecu.edu.au

Eco-innovations are solutions purposefully planned to minimize the environmental effect of manufacturing, consumption and discarding activities, even if their primary incentive is to capture opportunities and take advantage from environmental issues (Neto et al., 2014). Eco-innovation is of vital role for national, industrial, and corporate sustainable development (Mirata & Emtairah, 2005; Peng and Liu, 2016). According to Reid and Miedzinski (2008), eco-innovation is the generation of new and competitive activities of products, processes, systems, services and procedures that can satisfy human needs and improve the quality of life for everyone, with a least amount of usage of the life cycle of natural resources and a minimum emission of toxic pollutants.

Yang and yang (2015) pointed out that three distinctive features of eco innovation are: (1) *Universality*: Eco-innovation goes beyond the traditional innovation and encompasses any type of innovation which considers sustainable development including eco-product, eco-process and eco-organization innovation. (2) *Effectiveness*: In measuring eco-innovation effects, it is not important that those innovation activities be ecology intended, but their positive impact on environment is of interest. Therefore, eco-innovation gains can resulted from other operations such as extending the market and diminishing production costs which probably they are not environment focused (Horbach et al., 2012). (3) *Relativity*: The new technology, process and organizational procedures that implemented as eco-innovative should improve the environmental performance of users.

Eco-innovation can be seen as an essential real economic facilitator (Montalvo et al., 2011). Interrelationships among many actors such as consumers, communities, and suppliers, in addition to firms are another significant characteristic of eco-innovation practices (Mele and Russo-Spena, 2015). It is expected that eco-innovation practices can deliver “lower consumption of natural resources, new sustainable energy generation methods and new eco operating practices and products” (DECC, 2010).

Carrillo-Hermosilla et al. (2010) claim that user behaviour has a crucial effect on the implementation of eco-innovations and their following influences on society. Many activities are essential in making eco-innovations successful, such as training staff on environmental concerns, including environmental communications in product packaging; decreasing the volume of packaging used in the products vended; funding environmental activities in society; and utilizing reprocessed material in packaging products sold (Martin et al., 2013).

The survey by Eurobarometer (2011) revealed that 76 percent of organizations within the European Union (EU) have devoted in eco-innovation solutions since 2006. 41 percent of that companies spent more than 10 percent of their innovation budget on eco-innovation, whilst 16 percent invested over 30 percent of their innovation budgets on it. Some of eco-innovation activities such as less material usage, less energy usage, minimizing carbon dioxide (CO_2) footprint of companies, utilizing less pollutant material, decreasing soil, water and air pollution and recycling more waste can add value during the manufacturing stage. On the other hand, activities like decreased energy use, decreased soil, water and air pollution and enhanced recyclability of the product after use may add value to the post sale usage of the product (Doran and Ryan, 2014). It is evident that using resources efficiently could significantly diminish a firms’ operation costs. Therefore, firms can invest more on innovation activities especially eco-innovations. Such activities play a vital role in creating new job opportunities and delivering strategies for eco-efficient and sustainable growth. To this end, firms and countries must meet eco-innovation principles with material efficiency, minimizing greenhouse gas emissions, enhancing recycling and minimizing pollutions (water, air and soil).

The Background Statement for the OECD Global Forum on Environment on Eco-innovation in November 2009 declares: “Most OECD countries consider eco-innovation as an important part of the response to contemporary challenges, including climate change and energy security. In addition, many countries consider that eco-innovation could be a source of competitive advantages in the fast-growing environmental goods and services sector” (OECD, 2009a).

DEA is a nonparametric linear programming based technique for measuring efficiency and evaluating the productivity of homogenous decision making units (DMUs). DEA is extensively used in various fields such as eco-efficiency analysis (Egilmez et al., 2016; Masuda, 2016; Mahdiloo et al. 2015; Lorenzo-Toja et al., 2015; Avadi et al., 2014) and technology innovation (Sueyoshi and Wang, 2014). Therefore, this paper aims to determine eco-innovation of OECD countries via data envelopment analysis (DEA). For the first time, this paper measures eco-innovation using DEA.

The remainder of this paper is organized as follow: Section 2 briefly reviews the literature of eco-innovation. Section 3 presents research methodology used. In Section 4, an illustrative case study is analysed. Finally, Section 5 concludes the paper.

2. LITERATURE REVIEW

Eco-innovations are those activities which consider the sustainability of the environment (Rennings et al., 2008) and all companies and non-for-profit organizations can develop them by promoting their existing practices. Therefore, it also can be called environmental innovation, green innovation or sustainable innovation (Halila and Rundquist, 2011).

Oslo-Manual of the OECD (2005) described four traditional modes of innovation as follow:

- Process innovations are the result of producing the same amount of goods and services by consuming fewer amount of inputs.
- Product innovations need to improve present products and services or even initiate new goods and services.
- Organisational innovation requires establishing new management philosophies in the organization such as 5S and total quality management.
- Market innovation is important for the promotion and pricing of products and services, and other market-oriented strategies.

On the other hand, the main theme in eco-innovations is deliberate intention to minimize the environmental impact of products and processes (Leitner et al., 2010) to promote living conditions of present and future generations (Halila and Rundquist, 2011). Removing or minimizing CO2 emission is a very important factor in eco-innovation.

Some companies simply innovate by replacing dangerous material, consuming less energy, managing waste and minimizing pollutants, while other firms tend to design technologies to control pollution and waste management (Doran and Ryan, 2012). Incorporating sustainability as an obvious objective in the design process and turning environmental innovation strategy to a pertinent element is essential in adopting eco- innovation to warrant significant business performance and better internal efficiency (Tseng et al., 2013; Bossle et al., 2016). On the other hand, attitudes of senior management toward risk and technology advancement overtime are important factors in initiating eco-innovation. (Bossle et al., 2016). Figure 1 illustrates factors that can affect the initiation of eco-innovation by organizations.

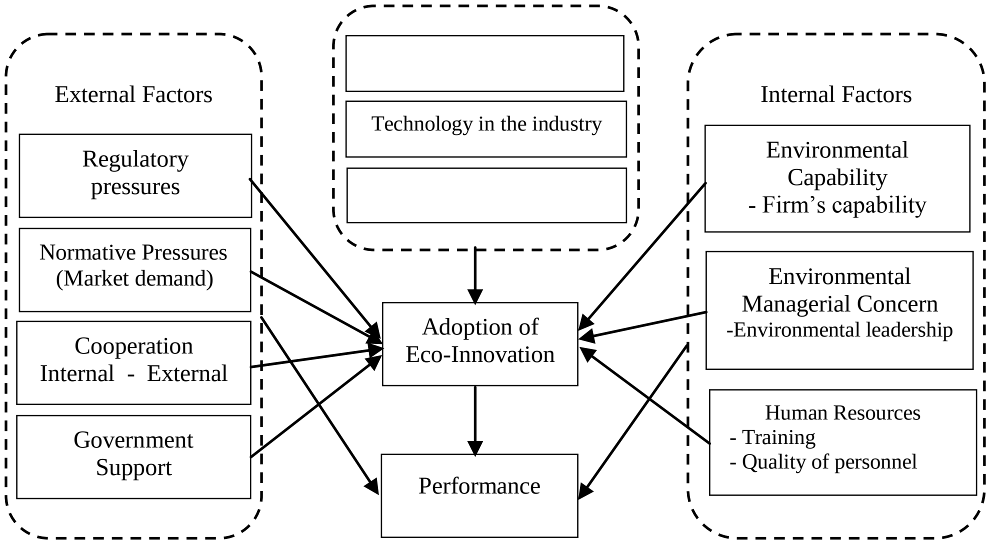

Figure 1. Factors affecting the initiation of eco-innovation by organizations (Bossle et al., 2016)

From the business point of view, eco-innovation efforts lead to better organizational performance (Santos et al. 2014). Investment in eco-innovation may have other benefits as improvement in the competitiveness of the firms, higher profit margins, decreased pollutions and waste (Porter and van der Linde, 1995), reduced costs, reduced risks, increased sales and profit margins, improved reputation and brand value, being more attractive as an employer, and building up innovation capabilities (Schaltegger, 2011). Although eco-innovation has potential benefits for the organizations, considering sustainability-related concerns is a challenge for most firms. As a result, many concepts, tools and technologies must be developed to address environmental and social issues.

It must be noted that well-designed government regulations and supportive organizational procedures can lead to eco-innovations (Halila and Rundquist, 2011) through risk and uncertainty management, increasing cooperation among innovative agents and limiting activities of free riders (Caiazza et al., 2014). Providing such conditions can lead to "win-win" situations in which both economic and environmental benefits gained for the firms and government (Horbach, 2008).

Doran and Ryan (2012) categorized eco-innovation drivers into four groups of (i) Regulation and government support, (ii) Perception, (iii) External linkages and (iv) Knowledge generation (Doran and Geraldine Ryan, 2012). Wah and Fernando (2015) claim that drivers of eco-innovation are five groups of regulation, technology, cross-functional coordination, supplier involvement and market focus drivers. Diaz Lopez and Montalvo (2015) classified top factors of eco-innovation in the chemical industry into technological, institutional, organizational, markets, economics and societal factors. Other factors such as supply chain and cost-savings are important drivers organizational and process eco-innovations (Vallet at al, 2016; Triguero et al., 2013).

Tamayo-Orbegozo et al. (2017) classified main factors of eco-innovation in the organisation into external factors including environmental concern of society, environmental regulation and policy and knowledge and technological development; and internal factors including organisation's philosophy and culture, surveillance system, differentiation/competitive advantage, cooperation/collaboration, and implementation of eco-innovation at a functional level.

Klewitz et al. (2012) found that the proactive perspective by a public intermediary is one important push factor to activate eco-innovations in SMEs with low absorptive capacity. Other reasons for eco-innovation can be meeting demand of consumers (Horbach, 2008), pressures of interest groups (Wagner, 2007), variations in regulation (Porter and van der Linde, 1995), economic concerns such as reducing costs (Barsoumian et al., 2011) and developing socially responsible strategy (Saxena and Khandelwal, 2012).

Yang and Holgaard (2012) point out particular aspects of eco-innovation as follow:

(i) Intents towards environmental benefits: While most authors emphasize the environmental benefits of eco-innovation, others clearly focus on economic value generated by eco-innovation. Also, both intentional and unintentional innovations which lead to environmental advantages are considered as eco-innovations

(ii) Double externality problem: Environmental benefits are positive spillovers for the society, but it might be a problem for innovative organizations, since it needs extra investment in environmentally friendly solutions. Here, the issue is that such investment must be paid only by the innovative organizations themselves while the whole of society gain environmental benefits.

(iii) Regulatory push/pull: Policies and regulations should support firms that produce eco-product/services more than firms that do not produce eco-products/services to help them to gain a market niche. But pioneer companies are often proactive enough to affect the formulation of sector standards and regulations.

Consequently, implementing and embracing innovation and sustainability in business management are essential to realize main goals of sustainability (social, economic and environmental) (Korhonen, 2001). Sanjuan et al. (2011) used data envelopment analysis (DEA) for Spanish Mahón-Menorca cheese production to measure the eco-efficiency of production Techniques. Jansson (2011) examined factors driving and hindering adoption of eco-innovation. Findings show that adopters and non-adopters differ on norms, attitudes, novelty seeking and on how innovation attributes are perceived. del Rio et al. (2010) grouped eco-innovation promotion instruments into environmental policy instruments such as command and control, technology policy instruments like research development and demonstration (RD&D) support and other instruments such as long-term visions and suggested that for promoting eco-innovation, policy makers should consider some strategies such as maintaining diversity and flexibility of possible alternative technological trajectories, promoting a cooperative, participative approach between actors, finding a balance between short-term environmental protection and promotion of radical eco-innovation, and avoiding lock-in to suboptimal technologies, etc.

Marin et al. (2015) investigated the barriers and obstacles to eco-innovation in European Union (EU) small and medium size enterprises which hinder SMEs from implementing and utilizing green strategies. The barriers include internal funds, external funds, uncertain return, subsidies, cost barriers, qualified pers & tech capabilities, external information, business partners, research partner, technological lock in, knowledge barriers, uncertain demand, material priority, energy priority, market dominated, regulations, market barriers, eco-innovation investment. Kiani Mavi and Standing (2016) evaluated the eco-innovation of OECD countries with data envelopment analysis and used Andersen-Petersen technique for complete ranking of them.

Tsai and Liao (2016) developed a logit moderating regression model to investigate the role of a proactive environmental strategy on eco-innovation. They found that market demand, innovation intensity and government subsidy influence the effects of sustainability strategy on eco-innovation. Wan et al. (2015) evaluated the eco-efficiency of industrial enterprises by developing a regression model. The inputs of (1) total industrial wastewater discharge, (2) total industrial exhaust emissions (billion cubic meters), (3) total emissions of industrial solid waste, and (4) energy consumption per unit of industrial added value are used for determining industrial added value as output. Ji (2012) investigated the impact of product innovation and energy level jumps on clean trajectories developed on the basis of practices in China. Ding (2014) found that joint innovation capability plays a significant intermediary role in the transformation of supply chain collaboration to eco-innovation performance. Also, organizations must keenly participate in internal R&D because it positively influence the efficacy of supply chain collaboration in a firm's proactive environmental practices.

3. RESEARCH METHODOLOGY (CCR-O MODEL)

This paper aims to evaluate the eco-innovation of OECD countries based on common inputs and outputs. Because the inputs / outputs are assumed to be independent and the number of countries is 34, DEA can be the best choice for their evaluation. The CCR (Charnes, Cooper and Rhodes) model introduced by Charnes et al. (1978) evaluates relative efficiency of DMUs. Conventional DEA models as CCR and BCC (Banker, Charnes and Cooper) based on linear programming for calculating efficiency score of DMUs. CCR models (both input and output oriented) assume that constant return to scale prevails. The output oriented CCR model estimates maximum radial output expansion of the evaluated DMU such that the projection of it is within the production possibility set. Linear programming corresponding output oriented multiplier form of CCR model is as Model (1). For any DMU_j (j=1…n) of this model, it uses m inputs x_{ij} (i=1…m) to produce s outputs y_{rj} (r=1…s) (Charnes et al., 1978).

$$CCR^{OM}:\ \varphi_p^* = Min \sum_{i=1}^{m} v_i\, x_{ip}$$

subject to (1)

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i\, x_{ij} \leq 0;\ j = 1,2,\dots,n$$

$$\sum_{r=1}^{s} u_r y_{rp} = 1$$

$$u_r, v_i \geq \varepsilon;\ r = 1,2,\dots,s; i = 1,2,\dots,m$$

In the optimal solution, values u_r^* and v_i^* are the weights attributed to each unit of outputs and inputs, respectively. It is defined that when $E_p^* = 1$, then DMU_p is efficient. The efficiency of p^{th} decision making unit in CCR-O is obtained by $E_p^* = \frac{1}{\varphi_p^*}$.

Sometimes, many DMUs are efficient in which complete ranking of DMUs is not possible. One of efficient techniques for complete ranking of DMUs proposed by Andersen and Petersen (1993) as Model (2).

$$CCR^{OM}:\ \varphi_p^* = Min \sum_{i=1}^{m} v_i\, x_{ip}$$

subject to (2)

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i\, x_{ij} \leq 0;\ j = 1,2,\dots,n, j \neq p$$

$$\sum_{r=1}^{s} u_r y_{rp} = 1$$

$$u_r, v_i \geq \varepsilon;\ r = 1,2,\dots,s; i = 1,2,\dots,m$$

4. CASE STUDY

Eco-innovation studies integrate economics, management and environmental sciences (Crespi et al., 2016). Most countries (if not all) focus on eco-innovations and included it in regulations and policies, particularly after the global downturn of 2008-2009 (EEA, 2014). Based on the OECD Council Meeting at Ministerial Level (MCM) in June 2009, OECD countries agreed to develop and extend the "Green Growth Strategy" to improve economic growth by considering sustainability (OECD, 2009a).

For this end, OECD countries are expected to significantly reduce energy use, pollutions and waste and improve their eco-efficiency. It should be noted that assessing eco-innovation in national or regional level is more difficult than measuring their overall innovation. Because identifying the scope of the audit and a technique of measuring the effects of the implementation of innovative environmental solutions in significantly difficult (Smol et al. 2017). Evaluating performance of OECD countries in light of eco-innovation can help them to focus on their weaknesses. Many indices can be considered in evaluating eco-innovation. For measuring eco-innovation, The Eco-Innovation Scoreboard (2013) has outlined some inputs, activities and outputs as Table 1.

Table 1. Eco-innovations indicators by the Eco-Innovation Scoreboard (2013)

Eco-Innovation Dimension	Indicators
Eco-innovation inputs	• Government's environmental and energy R&D appropriations and outlays (% of GDP) • Total R&D personnel and researchers (% of total employment), • Total value of early stage green investments (USD /capita)
Eco-innovation activities	• Firms having implemented innovation activities aimed at a reduction of material input per unit output (% of total firms) • Firms having implemented innovation activities aimed at a reduction of energy input per unit output (% of total firms) • ISO 14001 registered organisations (per mln population)
Eco-innovation outputs	• Eco-innovation related patents (per mln population) • Eco-innovation related academic publications (per mln population) • Eco-innovation related media coverage (per numbers of electronic media)
Resource efficiency outcomes	• Material productivity (GDP/Domestic Material Consumption) • Water productivity (GDP/Water Footprint) • Energy productivity (GDP/gross inland energy consumption) • GHG emissions intensity (CO2e/GDP)
Socio-economic outcomes	• Exports of products from eco-industries (% of total exports) • Employment in eco-industries and the circular economy (% of total employment across all companies) • Revenue in eco-industries and the circular economy (% of total revenue across all companies)

This study emphasizes the most common indicators such as population and energy use (inputs) and knowledge workers, ecological sustainability and global innovation index (outputs). Data for this study (see Table 2) were collected from the report of The Global Innovation Index 2016 (Dutta et al., 2016) and www.worldbank.org.

Table 2. Data of OECD countries for eco-innovation analysis

OECD country	Population (m)	Energy use* (kg of oil equivalent) per $1,000 GDP (constant 2011 PPP)	Knowledge workers (%)	Ecological sustainability (%)	Global Innovation Index (%)
Australia	24	116.83	65.2	51.7	53.1
Austria	8.5	78.86	59.5	53.3	52.6
Belgium	11.3	108.72	68.1	44.8	52
Canada	35.9	156.05	53.9	41.7	54.7
Chile	17.9	91.92	44.5	44.5	38.4
Czech Republic	10.5	126.80	52.9	61.6	49.4
Denmark	5.7	62.01	67.7	57.9	58.8
Estonia	1.3	159.40	51.5	59	51.7

Finland	5.5	149.71	70.5	51.7	59.9
France	64.4	90.56	62.8	51.6	54
Germany	80.7	79.33	63.2	50.8	57.9
Greece	11	77.48	38.5	53.7	39.8
Hungary	9.9	89.05	40	58	44.7
Iceland	0.3	392.74	59.8	40.6	56
Ireland	4.7	52.70	60.3	61.2	59
Israel	8.1	83.31	60.5	50.9	52.3
Italy	59.7	66.49	45	69	47.2
Japan	126.6	89.87	63	52.6	54.5
Korea, Rep.	50.3	144.16	65.5	39.6	57.1
Luxembourg	0.6	68.71	61.3	50.8	57.1
Mexico	127	85.37	35	42.4	34.6
Netherlands	16.9	86.57	60.2	49.8	58.3
New Zealand	4.5	119.82	53.1	45.3	54.2
Norway	5.2	84.08	63.1	51.4	52
Poland	38.6	96.03	45.5	46.3	40.2
Portugal	10.3	71.41	45.3	58	46.4
Slovak Republic	5.4	99.12	41.9	62	41.7
Slovenia	2.1	107.10	61.5	55.9	46
Spain	46.1	71.11	49.4	64.8	49.2
Sweden	9.8	100.82	77.6	59.3	63.6
Switzerland	8.3	51.27	71	65.6	66.3
Turkey	78.7	76.74	32.8	42.1	39
United Kingdom	64.7	66.58	61.5	64.2	61.9
United States	321.8	123.29	63.8	42.8	61.4

*Energy use refers to use of primary energy before transformation to other end-use fuels, which is equal to indigenous production plus imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transport. Since data of energy use for 2016 is not available and energy usage in 2014 is 4$ lesser than 2013, therefore we estimated energy use for 2016 by (energy use of 2014*0.96*0.96).

For example, linear programming models (1),(2) for Ireland (DMU_{15}) is shown in Appendix 1 and the results are reported as Table 3.

Table 3. Optimal solution of CCR-O for Ireland

Model (1)			Model (2)	
Variable	Value		Variable	Value
V1	0.853484E-01		V1	0.5756463E-01
V2	0.1136361E-01		V2	0.5756463E-01
U1	0.1000000E-03		U1	0.1000000E-03
U2	0.1614493E-01		U2	0.1614493E-01
U3	0.1000000E-03		U3	0.1000000E-03
Objective value (φ_{15}^{*})	1.0000		Objective value (φ_{15}^{*})	0.8822020
Efficiency score	1.0000		Efficiency score	1.13352724

Table 4 illustrates the efficiency score and ranking of OECD countries regarding eco-innovation.

Table 4. Efficiency score and ranking of OECD countries

OECD country	Objective value (φ_p^{*})	Efficiency score (E_p^{*})	Andersen-Petersen efficiency score (Rank)
Australia	2.481429	0.4029936	0.4029936 (28)
Austria	1.604755	0.62314808	0.62314808 (14)
Belgium	1.913229	0.52267658	0.52267658 (20)
Canada	3.689153	0.27106493	0.27106493 (34)
Chile	2.64296	0.37836365	0.37836365 (31)
Czech Republic	2.321607	0.43073612	0.43073612 (26)
Denmark	1.062281	0.9413705	0.9413705 (5)
Estonia	1.873105	0.5338729	0.5338729 (19)
Finland	2.085838	0.47942362	0.47942362 (25)
France	1.996971	0.5007584	0.5007584 (23)
Germany	1.738263	0.57528694	0.57528694 (16)
Greece	1.799382	0.55574636	0.55574636 (17)
Hungary	1.837874	0.54410694	0.54410694 (18)
Iceland	1	1	1.96147121 (2)
Ireland	1	1	1.1335274 (4)
Israel	1.620517	0.61708702	0.61708702 (15)
Italy	1.232957	0.81105829	0.81105829 (6)
Japan	1.975464	0.50621019	0.50621019 (22)
Korea, Rep.	3.047884	0.32809648	0.32809648 (33)
Luxembourg	1	1	2.6573214 (1)

Mexico	2.576202	0.38816832	0.38816832 (29)
Netherlands	1.920212	0.52077583	0.52077583 (21)
New Zealand	2.065673	0.48410373	0.48410373 (24)
Norway	1.416449	0.70599083	0.70599083 (9)
Poland	2.653789	0.37681971	0.37681971 (32)
Portugal	1.539997	0.64935191	0.64935191 (12)
Slovak Republic	1.565572	0.63874418	0.63874418 (13)
Slovenia	1.525799	0.65539432	0.65539432 (10)
Spain	1.404094	0.71220303	0.71220303 (8)
Sweden	1.528861	0.6540817	0.6540817 (11)
Switzerland	1	1	1.21028686 (3)
Turkey	2.332277	0.42876554	0.42876554 (27)
United Kingdom	1.326934	0.75361698	0.75361698 (7)
United States	2.596628	0.38511485	0.38511485 (30)

Findings show that 4 countries of Iceland, Ireland, Luxembourg and Switzerland have the highest efficiency score and are efficient. That is, they are extensively engaged in eco-innovation practices and can transform inputs into outputs better than other countries.

It is evident that in Ireland, population is more important than energy use for eco-innovation. On the other hand, ecological sustainability with the weight of 0.1633987 is central for eco-innovation whilst knowledge workers and global innovation index have the second and third places, respectively. The same analysis for Australia reveals that energy use and knowledge workers are most significant for its eco-innovation. The reference set for Australia is Switzerland. Since Australia is not efficient, it should emphasize ecological sustainability and global innovation. By benchmarking against Switzerland, the main weakness of Australia is low value of GDP/unit of energy use. It seems that policy makers and economists in Australia must set strategies for better utilization of energy resources. Also, for improving ecological sustainability, they should consider the environment more closely since a lower portion of GDP in Australia (in comparison with Switzerland) spent on environment protection.

5. CONCLUSION

There is much evidence that climate change and negative impact of environmental pollutions have endangered human communities globally. In order to avoid and combat these negative impacts, countries must consider ecology and innovate mechanisms, tools and industries to promote their eco-efficiency. Performance evaluation enables entities to compare themselves with high performance ones and to improve capabilities to overcome weaknesses. This paper investigated eco-innovation of OECD countries using data envelopment analysis. Many indicators can be used for evaluating eco-innovation but in this paper five factors were considered because of their high importance in eco-innovation and sustainability. Findings show that Switzerland, Ireland, Iceland and Luxembourg are eco-innovative therefore other OECD countries must benchmark these ones to improve their own eco-innovation. This paper focused on outputs. Future studies can be devoted to input-oriented DEA models to evaluate eco-innovation of countries.

REFERENCES

Andersen P. and Petersen N.C. 1993. A Procedure for Ranking Efficient Units in Data Envelopment Analysis. *Management Science*, Vol. 39, No. 10, pp. 1261-1264.

Avadi A. et al., 2014. Eco-efficiency assessment of the Peruvian anchoveta steel and wooden fleets using the LCA+DEA framework. *Journal of Cleaner Production*, Vol. 70, pp. 118-131.

Barsoumian S. et al., 2011. Eco-innovation and national cluster policies in Europe. A Qualitative Review, Report by Greenovate, pp. 1-95.

Bossle M.B. et al., 2016. Why food companies go green? The determinant factors to adopt eco-innovations. *British Food Journal,* Vol. 118, No. 6, pp. 1317–1333.

Caiazza R. et al., 2014. Innovation in agro-food system: policies, actors and activities. *Journal of Enterprising Communities: People and Places in the Global Economy,* Vol. 8, No. 3, pp. 180-187.

Carrillo-Hermosilla, J., 2010. Diversity of eco-innovations: Reflections from selected case studies. *Journal of Cleaner Production*, Vol. 18, pp. 1073-1083.

Charnes A. et al., 1978. Cooper WW, Rhodes E. Measuring the efficiency of decision making units. *European Journal of Operational Research,* Vol. 2, pp. 429–44.

Crespi F. et al., 2016. Green growth, eco-innovation and sustainable Transitions. *Environmental Economics and Policy Studies,* Vol. 18, pp. 137-141.

DECC (2010), Energy Bill: Green Deal, Department of Energy and Climate Change, HMSO, London.

del Rio, P. et al., 2010. Policy strategies to promote eco-innovation an integrated framework. *Journal of Industrial Ecology*, Vol. 14, No. 4, pp. 541-557.

Díaz Lopez F.J. and Montalvo C. 2015. A comprehensive review of the evolving and cumulative nature of eco-innovation in the chemical industry. *Journal of Cleaner Production,* Vol. 102, pp. 30-43.

Ding M. 2014. Supply Chain Collaboration toward Eco-innovation: an SEM Analysis of the Inner Mechanism. *IEEE International Conference on Service Operations and Logistics, and Informatics (SOLI).* Shandong, China, pp. 129-134.

Doran J. and Ryan G., 2012. Regulation and firm perception, eco-innovation and firm Performance. *European Journal of Innovation Management,* Vol. 15, No. 4, pp. 421 – 441.

Doran J. and Ryan G., 2014. Eco-Innovation – does additional engagement lead to additional rewards?. *International Journal of Social Economics,* Vol. 41, No. 11, pp. 1110 – 1130.

Dutta S. et al. (Eds). 2016. Cornell University, INSEAD, and WIPO (2016): *The Global Innovation Index 2016: Winning with Global Innovation,* Ithaca, Fontainebleau, and Geneva.

Eco-Innovation Scoreboard. 2013. www.eco-innovation.eu/images/stories/Eco-Innovation Scoreboard_2013_Technical_Note.pdf.

Egilmez G. et al. 2016. A fuzzy data envelopment analysis framework for dealing with uncertainty impacts of input–output life cycle assessment models on eco-efficiency assessment. *Journal of Cleaner Production,* Vol. 129, pp. 622-636.

Eurobarometer F. 2011. Attitudes of European entrepreneurs towards eco-innovation, available at: http://ec.europa.eu/public_opinion/flash/fl_315_en.pdf (accessed 2 October 2016).

Halila F. and Rundquist J. 2011. The development and market success of eco-innovations. *European Journal of Innovation Management,* Vol. 14, No. 3, pp. 278 – 302.

Haws K.L. et al., 2014. Seeing the world through GREEN-tinted glasses. Green consumption values and responses to environmentally friendly products. *Journal of Consumer Psychology,* Vol. 24, No. 3, pp. 336–354.

Hilson, G., and Nayee, V., 2002. Environmental management system implementation in the mining industry: a key to achieving cleaner production. *International Journal of Mineral Processing*, Vol. 64, pp. 19–41.

Horbach J. 2008. Determinants of environmental innovation – new evidence from German panel data sources. *Research Policy,* Vol. 37, No. 1, pp. 163-73.

Horbach, J. et al., 2012. Determinants of eco-innovations by type of environmental impact - The role of regulatory push/pull, technology push and market pull. *Ecological Economics*, Vol. 78, pp. 112-122.

Jansson J. 2011. Consumer Eco-Innovation Adoption: Assessing Attitudinal Factors and Perceived Product Characteristics. *Business Strategy and the Environment,* Vol. 20, pp. 192-210.

Ji G. 2012. Eco-Innovation and Energy Level Jump in Supply Chain Clusters. *IEEE 9th International Conference on Service Systems and Service Management (ICSSSM),* Shanghai, China, pp. 810 – 817.

Kiani Mavi, R., and standing, C. 2016. Evaluating eco-innovation of OECD countries with data envelopment analysis. *5th International Conference on Sustainability, Technology and Education*, 6 – 8 December 2016, Melbourne, Australia.

Klewitz J. et al., 2012. Intermediaries driving eco-innovation in SMEs: a qualitative investigation. *European Journal of Innovation Management,* Vol. 15, No. 4, pp. 442 – 467.

Korhonen, J., 2001. Four ecosystem principles for an industrial ecosystem, *Journal of Cleaner Production*, Vol. 9 No. 3, pp. 253-259.

Leitner A. et al., 2010. The impact of regulation and policy on radical eco-innovation. *Management Research Review,* Vol. 33, No. 11, pp. 1022 – 1041.

Lorenzo-Toja l. et al., 2015. Eco-efficiency analysis of Spanish WWTPs using the LCA + DEA method. *Water Research,* Vol. 68, pp. 651-666.

Mahdiloo M. et al., 2015. Technical, environmental and eco-efficiency measurement for supplier selection: An extension and application of data envelopment analysis. *International Journal of Production Economics,* Vol. 168, pp. 279-289.

Marin, G. et al. 2015. SMEs and barriers to Eco-innovation in the EU: exploring different firm profiles. *Journal of Evolutionary Economics,* Vol. 25, pp. 671-705.

Martin L. et al., 2013. Exploring business growth and eco innovation in rural small firms. *International Journal of Entrepreneurial Behavior & Research,* Vol. 19, No. 6, pp. 592 – 610.

Martin M.J. and Rigola M., 2001. Incorporating cleaner production and environmental management systems in environmental science education at the University of Girona. *International Journal of Sustainability in Higher Education,* Vol. 2, No. 4, pp. 329-38.

Masuda K. 2016. Measuring eco-efficiency of wheat production in Japan: a combined application of life cycle assessment and data envelopment analysis. *Journal of Cleaner Production,* Vol. 126, pp. 373-381.

Mele C. and Russo-Spena T., 2015. Eco-innovation practices. *Journal of Organizational Change Management,* Vol. 28, No. 1, pp. 4 – 25.

Mirata, M., and Emtairah, T., 2005. Industrial symbiosis networks and the contribution to environmental innovation - The case of the Landskrona industrial symbiosis programme. *Journal of Cleaner Production*, Vol. 13, No. 10-11, pp. 993-1002.

Montalvo C. et al., 2011. Potential for eco-innovation in nine sectors of the European economy. DOI: 10.13140/RG.2.1.3718.6084 (accessed 2 October 2016).

Neto A.S. et al., 2014. Green training supporting eco-innovation in three Brazilian companies: practices and levels of integration. *Industrial and Commercial Training,* Vol. 46, No. 7, pp. 387 – 392.

OECD. 2009a. Declaration on green growth, adopted at the council meeting at ministerial level, 25 June, Paris: OECD, https://www.oecd.org/env/44077822.pdf (accessed 2 October 2016).

OECD. 2009b. Indicators of innovation and transfer in environmentally sound technologies. ENV/EPOC/WPNEP/(2009)FINAL, Environment Directorate/Environment Policy Committee, June, OECD, Paris, available at: http://www.olis.oecd.org/olis/2009doc.nsf/LinkTo/NT0000300E/$FILE/JT03267148.PDF

Peng, X. and Liu, Y., 2016. Behind eco-innovation: Managerial environmental awareness and external resource acquisition. *Journal of Cleaner Production*, Vol. 139, pp.347-360.

Porter M. and van der Linde C. 1995. Toward a new conception of the environment competitiveness Relationship. *The Journal of Economic Perspectives,* Vol. 9, No. 4, pp. 97-118.

Reid, A., and Miedzinski, M., 2008. Eco-Innovation, Final Report for Sectoral Innovation Watch. L Brussels: Technopolis Group, 2008.

Rennings K. 2000. Redefining innovation – eco-innovation research and the contribution from ecological economics. *Ecological Economics,* Vol. 32, No. 2, pp. 169-336.

Sanjuan N. et al., 2011. Measuring and improving eco-efficiency using data envelopment analysis: a case study of Mahón-Menorca Cheese. *Journal of Industrial Ecology,* Vol. 15, No. 4, pp. 614-628.

Santos D.F. et al., 2014. Innovation efforts and performances of Brazilian firms. *Journal of Business Research,* Vol. 67, No. 4, pp. 527–535.

Saxena R.P. and Khandelwal P.K. 2012. Greening of industries for sustainable growth: an exploratory study on durable, non-durable and services industries. *International Journal of Social Economics,* Vol. 39, No. 8, pp. 551-586.

Schaltegger, S. and Wagner, M., 2011. Sustainable entrepreneurship and sustainability innovation: categories and interactions. *Business Strategy and the Environment,* Vol. 20, No. 4, pp. 222-237.

Smol, M. et al., 2017. Circular economy indicators in relation to eco-innovation in European regions. *Clean Technologies and Environmental Policy,* DOI 10.1007/s10098-016-1323-8.

Sueyoshi T. and Wang D. 2014. Radial and non-radial approaches for environmental assessment by Data Envelopment Analysis: Corporate sustainability and effective investment for technology innovation. *Energy Economics,* Vol. 45, pp. 537-551.

Tamayo-Orbegozo, U., 2017. Eco-innovation strategic model. A multiple-case study from a highly eco-innovative European region. *Journal of Cleaner Production*, Vol. 142, No. 4, pp. 1347–1367.

Triguero, A., 2013.Drivers of different types of eco-innovation in European SMEs. *Ecological Economics*, Vol. 92, pp. 25-33.

Tsai K.H. and Liao Y.C. 2016. Sustainability Strategy and Eco-Innovation: A Moderation Model. *Business Strategy and the Environment,* DOI: 10.1002/bse.1926

Tseng, M.L. et al., 2013. Improving performance of green innovation practices under uncertainty. *Journal of Cleaner Production,* Vol. 40, pp. 71-82.

Vallet, F. et al., 2016. Research directions in eco-innovation: a French perspective. *International Journal on Interactive Design and Manufacturing*, Vol. 10, pp. 309-318.

Wagner M. 2007. On the relationship between environmental management, environmental innovation and patenting: evidence from German manufacturing firms. *Research Policy,* Vol. 36, No. 10, pp. 1587-1602.

Wah W.X. and Fernando Y. 2015. Moving forward a parsimonious model of eco-innovation: results from a content analysis. *Handbook of Research on Climate Change Impact on Health and Environmental Sustainability,* IGI publisher, Hershey, pp. 622-634.

Wan L. et al., 2015. Effects of technological innovation on eco-efficiency of industrial enterprises in China. *Nankai Business Review International,* Vol. 6, No. 3, pp. 226-239.

Yang Y. and Holgaard J.E. 2012. The important role of civil society groups in eco-innovation: a triple helix perspective. *Journal of Knowledge-based Innovation in China,* Vol. 4, No. 2, pp. 132-148.

Yang, F., and Yang, M., 2015. Analysis on China's eco-innovations: Regulation context, intertemporal change and regional differences. *European Journal of Operational Research,* Vol. 247, No. 3, pp. 1003-1012.

Zanon J. and Teichmann K. 2016. The role of message strategies in promoting eco-friendly accommodations. International *Journal of Culture, Tourism and Hospitality Research,* Vol. 10, No. 4, http://dx.doi.org/10.1108/IJCTHR-07-2016-0067.

APPENDIX 1: CCR-O FOR DMU 15.

Min 4.7 v1+ 52.7 v2

Subject to

65.2u1+	51.7u2+	53.1u3-	24v1-	116.83v2<=0	
59.5u1+	53.3u2+	52.6u3-	8.5v1-	78.86v2<=0	
68.1u1+	44.8u2+	52u3-	11.3v1-	108.72v2<=0	
53.9u1+	41.7u2+	54.7u3-	35.9v1-	156.05v2<=0	
44.5u1+	44.5u2+	38.4u3-	17.9v1-	91.92v2<=0	
52.9u1+	61.6u2+	49.4u3-	10.5v1-	126.8v2<=0	
67.7u1+	57.9u2+	58.8u3-	5.7v1-	62.01v2<=0	
51.5u1+	59u2+	51.7u3-	1.3v1-	159.4v2<=0	
70.5u1+	51.7u2+	59.9u3-	5.5v1-	149.71v2<=0	
62.8u1+	51.6u2+	54u3-	64.4v1-	90.56v2<=0	
63.2u1+	50.8u2+	57.9u3-	80.7v1-	79.33v2<=0	
38.5u1+	53.7u2+	39.8u3-	11v1-	77.48v2<=0	
40u1+	58u2+	44.7u3-	9.9v1-	89.05v2<=0	
59.8u1+	40.6u2+	56u3-	0.3v1-	392.74v2<=0	
60.3u1+	61.2u2+	59u3-	4.7v1-	52.7v2<=0	(*)
60.5u1+	50.9u2+	52.3u3-	8.1v1-	83.31v2<=0	
45u1+	69u2+	47.2u3-	59.7v1-	66.49v2<=0	
63u1+	52.6u2+	54.5u3-	126.6v1-	89.87v2<=0	
65.5u1+	39.6u2+	57.1u3-	50.3v1-	144.16v2<=0	
61.3u1+	50.8u2+	57.1u3-	0.6v1-	68.71v2<=0	
35u1+	42.4u2+	34.6u3-	127v1-	85.37v2<=0	
60.2u1+	49.8u2+	58.3u3-	16.9v1-	86.57v2<=0	
53.1u1+	45.3u2+	54.2u3-	4.5v1-	119.82v2<=0	
63.1u1+	51.4u2+	52u3-	5.2v1-	84.08v2<=0	
45.5u1+	46.3u2+	40.2u3-	38.6v1-	96.03v2<=0	
45.3u1+	58u2+	46.4u3-	10.3v1-	71.41v2<=0	
41.9u1+	62u2+	41.7u3-	5.4v1-	99.12v2<=0	
61.5u1+	55.9u2+	46u3-	2.1v1-	107.1v2<=0	
49.4u1+	64.8u2+	49.2u3-	46.1v1-	71.11v2<=0	
77.6u1+	59.3u2+	63.6u3-	9.8v1-	100.82v2<=0	
71u1+	65.6u2+	66.3u3-	8.3v1-	51.27v2<=0	
32.8u1+	42.1u2+	39u3-	78.7v1-	76.74v2<=0	
61.5u1+	64.2u2+	61.9u3-	64.7v1-	66.58v2<=0	
63.8u1+	42.8u2+	61.4u3-	321.8v1-	123.29v2<=0	
60.3u1+	61.2u2+	59u3=1			

u1>=0.0001
u2>=0.0001
u3>=0.0001
v1>=0.0001
v2>=0.0001

Model (2) is as same as Model (1) except that (*) is deleted.