

EVALUATING ECO-INNOVATION OF OECD COUNTRIES WITH DATA ENVELOPMENT ANALYSIS

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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). 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, Data Envelopment Analysis, Sustainability, Eco-efficiency

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).

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 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). 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 the 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 (CO₂) 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 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; Mahdilo 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 aim sustainability of 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 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).

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.

It must be noted that well-designed governmental 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).

Doran and Ryan (2012) categorized eco-innovation drivers into for 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 society factors.

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 of authors emphasize on 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 utilize gained 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.

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. 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) investigates 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 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).

$$\begin{aligned}
 &CCR^{OM}: \varphi_p^* = \text{Min } \sum_{i=1}^m v_i x_{ip} \\
 &\text{subject to} \\
 &\sum_{r=1}^s u_{rp} - \sum_{i=1}^m v_i x_{ij} \leq 0; j = 1, 2, \dots, n. \\
 &\sum_{r=1}^s u_{rp} = 1. \\
 &u_r, v_i \geq 0; r = 1, 2, \dots, s; i = 1, 2, \dots, m
 \end{aligned} \tag{1}$$

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 pth 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).

$$\begin{aligned}
 &CCR^{OM}: \varphi_p^* = \text{Min } \sum_{i=1}^m v_i x_{ip} \\
 &\text{subject to} \\
 &\sum_{r=1}^s u_{rp} - \sum_{i=1}^m v_i x_{ij} \leq 0; j = 1, 2, \dots, n, j \neq p. \\
 &\sum_{r=1}^s u_{rp} = 1. \\
 &u_r, v_i \geq 0; r = 1, 2, \dots, s; i = 1, 2, \dots, m
 \end{aligned} \tag{2}$$

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. 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. 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 1) were collected from the report of The Global Innovation Index 2016 (Dutta et al., 2016) and www.worldbank.org.

Table 1. 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 |

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|-----------------|-------|--------|------|------|------|
| 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). Table 2 illustrates the efficiency score and ranking of OECD countries regarding eco-innovation.

Table 2. 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 | 1.1350895 (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. For example, results of Model (1) for Ireland (DMU_{15}) are as Table 3.

Table 3. Optimal solution of CCR-O for Ireland

| Variable | V1 | V2 | U1 | U2 | U3 | Objective value (φ_{15}^*) |
|----------|----------|----------|----------|----------|----------|--------------------------------------|
| Value | 0.085698 | 0.011332 | 0.000007 | 0.016339 | 0.000001 | 1.000000 |

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.

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