Evaluation of sustainability of Irish Road transport sector and its comparison with European Union Countries

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ABSTRACT: Transport sustainability has been the topic of discussion since the past two decades and its importance has been recognised by most countries. Therefore, strategies and policies incorporating sustainable growth and development have been initiated as a measure to steer transport growth in the right path. This notion has led researchers to develop many ways of measuring transport sustainability, especially the frequently used road transport sector. Measurement of sustainability of the transport sector has been carried out using different methodologies in the past. Considering the complexity and multi-dimensional aspects of sustainability, multi-criteria analysis decision making tools have been considered in this paper. This paper aims to measure the efficiency of Irish road transport towards sustainability and assess its rank compared to European Union countries using a Non-radial Data Envelopment Analysis (Non-radial DEA) model. Evaluation and comparison of countries with Non-radial DEA model will be presented using the data of the year 2012 and 2016. Within the Non-radial DEA model, countries represent the decision-making units (DMUs) while the economic, environmental and social (EES) set of indicators are categorised as desirable and undesirable inputs and outputs. The results of this paper provide a decision-making methodology that can help future decision makers to make the right decisions in terms of ensuring transport sustainability in existing and future projects.

KEY WORDS: Sustainable Transport; Non-Radial DEA; Sustainable Indicators; EU Countries.

1 INTRODUCTION

Sustainable development has been recognized as the direction of growth by many countries, which has put immense pressure on policy makers regarding generation of initiatives to ensure its attainment [1]. The United Nations (UN) had put forward the 17 sustainable development goals to be achieved by 2030. Transportation is associated with eight of them which means attaining these goals require transport to be sustainable [2]. In the EU, the transport emissions account for 70% of the greenhouse gases of which road transport sector was found to contribute to 21% of the total CO_2 emission, which in turn affects climate change [3]. Recognizing the unsustainable and negative effects of transport, initiatives such as low-emission mobility policy etc. has been put forward [4]. Sustainable development aims to bring economic, social and environmental prosperity to the society, its practicality in everyday life needs to be judged to evaluate whether the present state of systems is moving toward or away from a sustainable path. Once such an evaluation strategy has been formulated, it will form an integral part of decision making tools to make future decisions regarding any sector of the society [5]. For this reason, decision makers are constantly required to measure the performance of their transport systems to determine their sustainability to induce policy change or innovations [6].

Although, sustainability is the main topic of many research literature a clear cut definition of what sustainability means to the development of transport hasn't been obtained [7, 8]. However, several researchers in the past have attempted to comprehensively define the meaning of sustainable transport. A sustainable transport system works towards "satisfying current transport and mobility needs without compromising future generations to meet these needs" [9]. In other words, a transport system that uses renewable resources, increases safe access while being affordable and convenient, appraises recycling and promotes equity and equality within and among generations while enhancing cost effectiveness is the true definition of sustainable transport [10].

Many methods have been used to assess the sustainability of transport such as cost-benefit analysis (CBA), life cycle assessments (LCA), Environmental impact assessment (EIA), Multi-criteria analysis decision method (MCDA) etc [10]. In this study, the data envelope analysis (DEA) method is used to assess the road transport sustainability of selected EU countries and provide a ranking of them based on sustainability. Further contribution of the paper includes a suggested sustainable indicator set based on literature and assessment of sustainability using two non-radial DEA models.

2 LITERATURE REVIEW – STATE OF THE ART

2.1 *Methods used to assess sustainability of transport*

Many literatures have been based on using MCDA such as TOPSIS, VIKOR, AHP etc. as a decision-making tool to analyse and rank various sustainable transport systems and countries [9, 11, 12]. Such methods are apt for sustainability measurement due to its capability of analysing multi-faceted systems such as sustainable transport [12]. Despite the many advantages posed by MCDA methods, their utilization of subjective weights can affect the results of analysis [13].

Data Envelope Analysis (DEA) is a non-parametric method of analysing the relative efficiency of almost homogenous comparable entities named Decision making units (DMU) that utilize multiple inputs to produce multiple outputs [2, 14]. Although DEA is highly related to MCDA, it avoids the disadvantage of subjectivity that MCDA methods possess by generating own weights, thus increasing objectivity [13]. The analysis includes attempts to maximize the outputs for a given input and can categorize the DMUs as efficient or inefficient [15]. Hence, DEA method can reveal the best practice standards [16].

Studies on measuring sustainability of transport using DEA mainly focusses on the environmental and social efficiency separately rather than jointly. Since sustainable transport has an element of environmental and social aspect, the outputs of transport can have negative effects such as GHG emissions and accidents which needs to be reduced. This led to many authors recognizing the need for categorizing the outputs as undesirable and desirable outputs and conducted analysis decreasing the undesirable outputs and inputs especially in environmental based studies. A study done by Evelin Krmac et al. [17] used the non-radial model proposed by [14] to reduce undesirable inputs and outputs identified in the energy-environmental efficiency determination of transport in 28 EU countries. Mo and Wang [18] aimed to assess the environmental sustainability of road transport of OECD countries by using two output oriented radial models that incorporated outputs as undesirable and desirable. However, certain inputs in such studies although desirable would require minimization along with the undesirable inputs and outputs [15]. A study done by Djordjevi´c et al. [19], utilized a non-radial DEA model to reduce the undesirable inputs, outputs and desirable inputs to assess the safety at rail-road level crossings (RLCs) of 25 EU countries. The study emphasized the necessity to minimize desirable inputs, and undesirable inputs and outputs. However, these studies focussed mainly on the environmental and social pillars of sustainability of transport.

Despite many studies focus on environmental and social sustainability of transport, very few DEA studies have incorporated all three pillars of sustainability to measure the sustainable efficiency of transport sectors [18]. A study done by Tian et al. [8] aimed to measure the sustainability of road and rail transport in China by identifying an EES indicator set and applying a super-efficiency slack-based DEA model (SUP-SBM model). A study done by Stephaniec et al. [20] aimed to measure the sustainability of inland transport (road, rail and inland water) using a triple bottom approach incorporating economic, environmental and social aspects of each DMU.

2.2 *Sustainable transport Indicators in Literature*

Identifying indicators have been suggested as an approach of quantifying sustainability of transport systems. An indicator set could allow the summarization and tracking of the extent to which transport systems have achieved the goals of sustainability [21, 22]. A study by May et al. [23] suggested that it was more useful to develop guidelines for selection of indicators rather than setting out long lists of recommended indicators. This project emphasized on the right selection of indicators for its required purpose. The guidelines should help pick those indicators with good properties and are measurable, controllable, understandable and responsive to change. A study done by Busazi and Csete [24], suggest that indicator selection can be based on literature review done previously.

The problem of long lists of indicators have been cited in studies and the appropriate selection of a set of indicators to describe the complete picture of sustainable transport can be challenging [21, 24-26]. The most common criteria is selecting indicators based on the EES three pillars of sustainable development (i.e. Environment, Economic and Social) [27]. These indicators have to be valid, reliable and sensitive from a measurement point of view, transparent, interpretable and relevant from a monitoring point of view [24]. Haghshenas and Vaziri's study [1] involved identification of nine sustainable transport indicators (STI) classified under the three dimensions of sustainability. Shiau and Liu's study [28] involved identification of 21 indicators which were then grouped into Environmental, Economic, Social and Energy categories for purpose of measuring sustainability of transport system at the county level. Nicholas, Pochet and Poimboeuf [29] identified 20 indicators that was divided into Mobility, Environment, Economics and social aspects of sustainability to understand the mobility phenomena. Alonso et al. [30] conducted a study of the sustainability of transport over 23 European cities and identified 9 indicators. Based on literature, table 1 shows the frequency of usage of the most commonly cited road transport indicators in 12 sustainable transport studies.

Table 1. Frequency of use of common sustainable indicators

Economic		Environmental		Social	
GDP	2	Energy consumption	12	Road fatalities	19
GVA	3	Noise level	5	Cycle fatalities	6
Road Investment	9	Land area used	7	Commuting time	6
Employment	4	CO_2 emissions	10	Car mode share	4
Density of road network	3	Green energy	5	Bus mode share	5
				Cycle mode share	6

Moreover, the EU has put forward initiatives to develop measurable set of sustainable transport indicators. The EEA framework of indicators reflect the dimensions of sustainable transport, integration of transport and environmental aspects [31]. The indicator system referred to as "transport and environment reporting mechanism" (TERM) includes indicators that address environmental sustainability of transport, access to infrastructure, desirable modal split, shift to cleaner fuel and technology. The EUROSTAT database has identified various sustainable transport indicators that capture topics such as mode infrastructure, investment, fatalities etc. that are grouped into relevant themes. In addition, quantitative targets such as air pollutant emission and fossil fuel use reduction put forward by the EU SDS and OECD are important indicators for sustainable transport [4, 32].

2.3 *Conclusions from Literature review*

From the existing literature on sustainable transport indicator selection, a lack of accessibility and cycling indicators except for cycling mode share and fatalities has been observed. Inclusion of more cycling indicators to the analysis of transport is necessary since it denotes a contribution to sustainability. Moreover, the indicator 'density of transport network' has been commonly used as an economic indicator even though it can also be used as an accessibility indicator under the social pillar.

Few DEA studies have combined all pillars of sustainability to measure sustainable transports. Papers have focussed on certain pillars of sustainability that minimizes undesirable inputs and outputs alone. However, there are certain desirable inputs that would also require minimization as suggested in [19]. In other words, the non-radial DEA model extension that reduces desirable inputs, undesirable inputs and outputs, introduced by [19], hasn't been used in sustainable transport studies. This paper aims to include cycling indicators in the sustainable transport indicator set, utilize the non-radial DEA model in [19] for sustainable transport measurement and analyse its results compared to the non-radial DEA model that reduces only undesirable inputs and outputs.

3 METHODOLOGY

The following section describes the methodology used in assessing the sustainability of road transport systems of selected EU countries, using indicators and DEA method.

3.1 Sustainable transport Indicator selection

. The indicators selected to measure sustainability of road transport was done considering the satisfaction of the criteria in table 2, frequently used relevant indicators as shown in table 1, EEA TERM indicators and EUROSTAT. From table 1, the road transport indicators except for GDP, noise level and land area were adopted for this study. This is due to the unavailability of data of noise level and land area for the selected EU countries.

Table 2. Criteria selected for Indicator selection.

Criteria	Description
Relevance	Indicators should be of some form of measure to assess the progress or deviation from sustainable transport and belong to EES category
Data availability and quality	Reliable data for the respective indicators must be available and accessible through known data sources
Comparability and ease to comprehend	Data of the respective indicators must be comparable among countries and easily understandable to DM
Consensus of actors in the field	Indicators selected must be frequently used in literature and EU studies

Table 3 provides the description of the finalized sustainable transport indicators used in the study. These indicators were found to be important since they have been reflected in many EU policies [4, 32].

GVA was used over GDP because it is the aim of the study to capture the contribution of transport sector to GDP and view sustainable transport as an economic activity that supports the economy [9, 32]. In addition, 'bicycle sales' was included to account for a lack in cycling indicators in the economic dimension. The indicator 'density of road' was used to represent accessibility considering the infrastructure-based definition as in [33].

3.2 Data Envelope Analysis (DEA) method

Introduced by Charnes et al. (1978), the DEA model assesses the DMUs based on their distance from the efficient frontier that has all the most efficient DMUs in terms of a single unified efficiency value [19, 34]. The DEA model can handle multiple inputs and multiple outputs; and doesn't require the inputs and outputs to be of the same units or have prior known relationships between them [2, 14, 15, 19, 35, 36].

The classical CCR DEA model considers a typical production process where labour, capital and resource are treated as inputs and the products are treated as outputs and basic goal is to maximize the outputs with given input levels [15]. Consider a set N containing *n* DMUs where each uses *p* number of inputs to produce *r* number of outputs. The input vector is represented as $X_j = \{x_1, x_2, \ldots, x_p\}$ and output vector is represented as $Y_j = \{y_1, y_2, \ldots, y_r\}$. The efficiency analysis is carried out by solving the LPP as shown in Baran and Gorecka [2] :

$$\min \theta; S.T: X\lambda \leq x_j, Y\lambda \geq y_j, \lambda \geq 0$$

where DMU_j is identified as efficient if θ has the value of 1 and inefficient if the value of θ is less than 1 [2].

Most traditional DEA models are radial models that try to proportionally maximize the output for a given input or proportionally minimize the input for the same output, which is not suitable for environmental studies where emissions never change proportionally [16, 17, 37]. However, a non-radial model is apt for sustainable transport studies than radial due to its higher discriminatory power and realism [14, 17, 38]. Another advantage is that non-radial models have the potential to incorporate decision-maker weights based on the importance given to certain outputs [38]. In this study, two non-radial models are used to assess sustainability of road transport; one which decreases the undesirable inputs and outputs for a given desirable input and output (M1), the other which decrease the undesirable inputs, outputs and desirable inputs for a given desirable output (M2). A comparison between the models for its suitability is also described as part of the results. The following describes both models used.

M1 is an extension to a radial model done by Wu et al. [2015] [14], *consider* k DMUs that utilize *n* desirable inputs indicated by *x* and *l* undesirable inputs indicated by *e* to produce *m* desirable outputs indicated by *y* and *j* undesirable outputs indicated by *u*. The non-radial DEA model M1 is as shown:

$$Min\ \frac{1}{2}\left(\frac{1}{L}\sum_{l=1}^{L}\theta_l + \frac{1}{J}\sum_{j=1}^{J}\theta_j\right)$$

Table 3. Description of the final Indicator set for measurement of road transport

Indicators	Description	Data Source
	Economic Indicators	
GVA	GVA added by transport, storage and communication	UNSD
Bicycle Sales	Number of bikes sold in countries	COLIBI
Infrastructure spending	Infrastructure and maintenance spending of road sector in EUR	OECD
Employment in transport	Percentage of share of employment in transport	OECD
	Environmental Indicators	
Energy consumption	Energy consumed by road transport in toe	EUROSTAT
CO_2 emissions	Share of CO_2 emissions due to road transport in total CO_2 emissions	OECD
	Social Indicators	
Cycle fatalities	Number of fatalities	EC
Road Fatalities	Number of people injured and killed	OECD
Cycle mode share	Percentage of people using bicycling as mode of transport	ECF
Passenger car mode share	Usage of car as percentage of share of transport mode in total inland transport	EUROSTAT
Commuting time	One-way travel time between work and home measured in minutes	EUROSTAT
Density of Road network	Length of roadway expressed as km per 100 sq. km.	OECD

$$S.T: \quad \sum_{k=1}^{K} \lambda_k x_{nk} \leq x_{n0}, n = 1,2, \dots, N$$
$$\sum_{k=1}^{K} \lambda_k e_{lk} \leq \theta_l e_{l0}, l = 1,2, \dots, L$$
$$\sum_{k=1}^{K} \lambda_k y_{mk} \geq y_{m0}, m = 1,2, \dots, M$$
$$\sum_{k=1}^{K} \lambda_k u_{jk} = \theta_j u_{j0}, j = 1,2, \dots, J$$
$$\lambda_k \geq 0, k = 1,2, \dots, K$$

Where λ is the variable weights vector of DMUs.

The non-radial model suggested has the capability of reducing undesirable inputs and outputs for a given level of desirable outputs and inputs. However, it may be required to assess the DMUs which are efficient in terms of its ability to reduce certain desirable inputs, which may lead to unsustainability, while increasing the desirable outputs. This can be done by using the non-radial DEA model M2 extended by [19] and is given as:

$$Min \; W_n \frac{1}{N} \sum_{n=1}^{N} \theta_n + W_l \frac{1}{L} \sum_{l=1}^{L} \theta_l + W_j \frac{1}{J} \sum_{j=1}^{J} \theta_j$$

$$S.T: \quad \sum_{k=1}^{K} \lambda_k x_{nk} \leq \theta_n x_{n0}, n = 1,2, \dots, N$$
$$\sum_{k=1}^{K} \lambda_k e_{lk} \leq \theta_l e_{l0}, l = 1,2, \dots, L$$
$$\sum_{k=1}^{K} \lambda_k y_{mk} \geq y_{m0}, m = 1,2, \dots, M$$
$$\sum_{k=1}^{K} \lambda_k u_{jk} = \theta_j u_{j0}, j = 1,2, \dots, J$$
$$\lambda_k \geq 0, k = 1,2, \dots, K$$

Both models have strong suitability for assessment of sustainability due to its strong discriminatory power which makes it easier to rank the DMUs contrast to radial models [15].

3.3 Categorization of Inputs and Outputs and DMUs

In DEA, the selected indicators were categorized into desirable inputs, outputs and undesirable inputs and outputs as shown in table 4. Desirable outputs (DO): GVA, cycle mode share and road density were categorized as desirable outputs, since these are elements that increases the sustainability of transport. An increase in road density as an accessibility criterion, would mean an increased accessibility to public transport such as Buses which is a sustainable mode of transport. Undesirable Outputs (UDO): A sustainable transport system aims to reduce environmental and safety negatives of transport such as CO_2, fatalities and reduce travel time. Desirable Inputs (DI): Although, bicycle sales are a desirable input that may increase cycle mode share which increases sustainability; it may also increase cycle fatalities which is against the concept of sustainability, hence its minimization is necessary. Employment contribution of transport is also highly desirable as a part of sustainability. Undesirable Inputs (UDI): Curbing conventional energy consumption at optimum costs can help reduce the CO_2 emissions, hence is taken as an UDI. It is also an aim to reduce road infrastructure spending and car use to attain sustainability.

Table 4. Categorization of inputs and outputs as desirable and undesirable.

Category	Indicators
Desirable Outputs (DO)	GVA, Cycle mode share, Density of road
Undesirable Outputs (UDO)	Commuting time, CO_2 emissions, Cycle and road fatalities
Desirable Inputs (DI)	Bicycle sales, employment
Undesirable Inputs (UDI)	Energy used, Road spending and Car mode share

The EU countries chosen as the DMUs were based on the data availability of the selected indicators, as shown in table 5. The data of two years 2016 and 2012 were collected for 19 EU countries such that each country-year acts as a DMU. It satisfies the condition that the number of DMUs should be greater than three times the number of inputs and outputs.

Table 5. Countries chosen for evaluation

Countries as DMUs
Austria (AT), Belgium (BE), Croatia (HR), Czechia (CZ), Denmark (DK), Finland (FI), France (FR), Germany (DE),

Hungary (HU), Ireland (IE), Italy (IT), Latvia (LV), Lithuania (LT), Luxembourg (LU), Poland (PL), Romania (RO), Spain (ES), Slovenia (SL), United Kingdom (UK)

4 RESULTS

The efficiency of each country-year (DMU) was obtained using Excel Solver. The results for the non-radial DEA model M1, which includes the road transport sustainable efficiency scores of EU countries is shown in figure 1. The two countries with the most sustainably efficient road transport sector for both years 2016 and 2012 were Hungary and Belgium, while Denmark and Croatia attained sustainability in 2012 and Luxembourg in 2016. Although Romania improved its road transport sustainability in 2016, it remained the least sustainable out of the analyzed 19 EU countries. Hungary and Belgium performed similar in sustainability in 2016 and 2012, hence can be considered as the best practice. Other countries such as Denmark, Luxembourg, Lithuania and Slovenia also attained similar high efficiencies for both years and have sustainable road transport sector. The most significant improvement in sustainability was observed in Luxembourg in 2016, while the most significant deterioration was observed in Croatia in 2016. The sustainably inefficient countries were Romania, Italy, Germany, Spain, UK, Poland and France.

The results for the non-radial DEA model M2 is shown in figure 2. This model produced the same two countries with the highest sustainable road transport score in both years 2016 and 2012 namely, Hungary and Belgium, while only Denmark attained sustainable efficiency in 2012. The most unsustainable road transport sector in 2012 according to M2 was that of Romania, while in 2016 it was that of Italy. However, Italy had increased its sustainable efficiency of road sector from 2012 although the increase was insignificant when compared to Romania. Since Hungary and Belgium both resulted as the most efficient DMUs in 2016 and 2012, they can be considered as best practice for sustainable road transport. Other countries such as Ireland, Denmark, Luxembourg, Lithuania and Slovenia also attained similar high efficiency scores for both years and are considered to have sustainable road transport sector whereas Germany, Romania, Italy, Spain, UK, Poland, France is found to be inefficient.

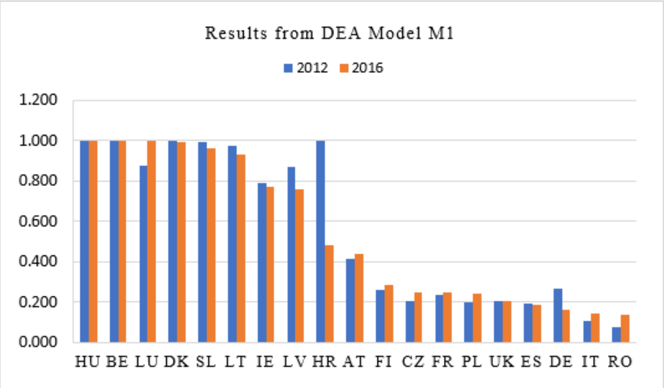

Figure 1. M1 model sustainable transport scores.

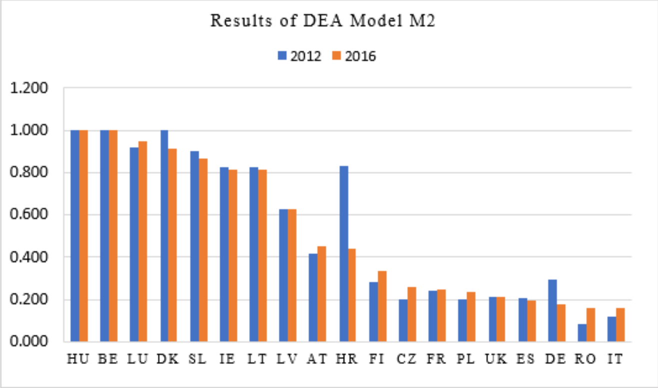

Figure 2. M2 model sustainable transport scores.

On comparison of the 2016 results of both models, Ireland is observed to have a relatively high sustainability efficiency. Both models revealed Ireland to have similar efficiency scores in both years, with 2016 being lower than 2012. Taking Hungary and Belgium to be the first rank, Irish road transport ranks 5th position in 2016.

5 DISCUSSION

The results of both models revealed Hungary and Belgium to be the most efficient DMUs in both years 2012 and 2016. This may be due to their higher values of desirable outputs such as GVA, cycle mode share and density of road and low values of undesirable outputs such as CO_2 emissions and fatalities as compared to the other DMUs. The most sustainably inefficient countries were Romania and Italy; both had higher values of undesirable inputs such as energy consumption and road fatalities. Both models captured the significant downfall of Croatia's road transport in terms of sustainability in 2016.

The ranking obtained for both models were similar except for the LT, IE, AT, HR, RO and IT. Both models can be used to identify measures that can be applied in improving transport sustainability and they are also suitable to be conducted on different levels such as city level. However, the DEA model M2 focusses on minimizing the DI, UDI and UDO while maintaining the level of DO, whereas M1 focusses on minimizing the UDI and UDO for the same level of DO and DI. In the context of sustainable road transport, although an increase in desirable inputs such as bicycle sales would in turn increase cycling mode implying higher sustainable road transport, it can also lead to higher cycling fatalities which is unsustainable. For this reason, it is essential to assess countries' road transport sustainability in terms of its ability to minimize such DI along with UDO and UDI and produce the same level of DO [19]. Moreover, the discriminatory power of M2 is higher than M1 as seen from the results. The model M1 produced seven efficient DMUs while the model M2 produced only 3 efficient DMUs. This higher discriminatory power of M2 can be utilized to distinguish those DMUs which M1 model produced as efficient. Hence, the DEA model M2 is suitable for complex systems such as sustainability assessment of road sector of EU countries.

6 CONCLUSION

The measurement of sustainability of transport has been recognized as an objective to achieve sustainable development. However, there has been no standard procedure of its measurement recognized in literature. The use of sustainable indicators as a means of measurement is highly popular which this paper utilizes. From literature, a lack of cycling and accessibility indicators has been cited. An indicator set considering this deficit and based on adopted criteria and literature has been used to measure road transport sustainability of EU countries. Two non-radial DEA models have been used to assess the road transport sustainability of 19 EU countries for the year 2012 and 2016. The analysis revealed Hungary and Belgium to have the most sustainable road transport in 2012 and 2016, with Ireland taking 5th place. The suitability of the non-radial DEA model M2 was suggested as more appropriate for sustainability measurements considering its higher discriminatory power and its capability to minimize desirable inputs which may cause unsustainability along with undesirable outputs and inputs. This paper suggested a decision-making methodology that can help future decision makers to make the right decisions in terms of ensuring transport sustainability in existing and future projects

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