Bridging the gap between SDG 2 indicators and agricultural efficiency: Insights from OECD countries

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DOI: 10.30682/nm2504a
JEL codes: Q01, Q56, R15

Abstract

This study examines the relationship between SDG 2 (Zero Hunger) outcomes and agricultural input efficiency in OECD countries using an input-oriented DEA model. Analyzing key agricultural inputs—such as area harvested, employment, pesticide, fertilizer, energy, and water use—reveals discrepancies between SDG 2 scores, which emphasize social indicators, and efficiency scores based on resource utilization. Results show that countries with high SDG 2 scores may still exhibit inefficiencies, while others achieve efficient practices with lower SDG 2 scores. The findings highlight the limitations of current SDG 2 indicators in reflecting sustainable resource management. Incorporating efficiency metrics into SDG 2 could enhance its alignment with sustainability objectives, promoting resource conservation and food security. This study also underscores SDG 2's connections with other goals, advocating for a holistic approach to measuring progress.

Keywords: *Sustainability, Food security, Resource use, Input-output analysis, Global hunger index*

1. Introduction

Global hunger remains one of the most pressing challenges of the 21st century, despite advancements in food production and distribution. Millions of people worldwide continue to experience undernourishment and food insecurity, underscoring the need for sustainable and equitable solutions (Wu *et al.*, 2014; Alaimo *et al.*, 2020; Cooper *et al.*, 2021). In response, the United Nations established the Sustainable Development Goals (SDGs) in 2015, with SDG 2 (Zero Hunger) aiming to end hunger, enhance food security, improve nutrition, and promote sustainable agriculture by 2030 (Table 1). However, achieving these goals requires not only addressing food access and malnutrition but also improving the efficiency of agricultural production systems.

SDG 2 primarily focuses on social outcomes such as the prevalence of undernourishment and malnutrition (Sabbahi *et al.*, 2018; Mensi and Udenigwe, 2021), yet the efficiency with which countries utilize agricultural inputs such as water, energy, and fertilizers plays a critical role in ensuring long-term food security and sustainability (Penuelas *et al.*, 2023). Agricultural systems that rely heavily on resource-intensive

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Table 1 - The Goals of the 2030 Agenda for Sustainable Development.

1. No poverty	4. Quality education	7. Affordable and clean energy	10. Reduced inequalities	13. Climate action	16. Peace, justice and strong institution
2. Zero Hunger	5. Gender equality	8. Decent work and economic growth	11. Sustainable cities and communities	14. Life below water	17. Partnership for the goals
3. Good health and well-being	6. Clean water and sanitation	9. Industry, innovation, and infrastructure	12. Responsible consumption and production	15. Life on land	

Source: UN, 2015.

practices may meet short-term food needs but risk degrading the ecosystems supporting future production. Moreover, inefficient resource use can increase production costs, reduce food availability, and worsen food affordability – ultimately exacerbating food insecurity and malnutrition (Ibrahim *et al.*, 2024; Karandish *et al.*, 2025). Thus, resource use efficiency must be a core consideration in evaluating progress towards SDG 2, ensuring that food security improvements do not come at the expense of long-term agricultural sustainability.

Figure 1 shows the current SDG 2 scores across OECD countries.

Although resource efficiency plays a crucial role in food security, current SDG 2 indicators fail to reflect the significance of optimizing agricultural inputs. As a result, discrepancies arise in the assessment of country performances. Various methodologies have been used to measure sustainable development (Böhringer and Jochem, 2007; Singh *et al.*, 2012), yet data inconsistencies persist. For instance, widely used indicators – such as the Food and Agriculture Organization's (FAO) undernourishment metric, household food consumption surveys, and anthropometric measurements – have exhibited inconsistencies across countries (De Haen *et al.*, 2011; Masset, 2011), raising concerns about the reliability of SDG assessments (Otekunrin *et al.*, 2019).

As a result, countries with strong social and nutritional outcomes may achieve high SDG 2 scores despite inefficient agricultural systems, while resource-efficient nations may receive lower SDG 2 rankings, despite their contributions to sustainability. These inconsistencies call for a re-

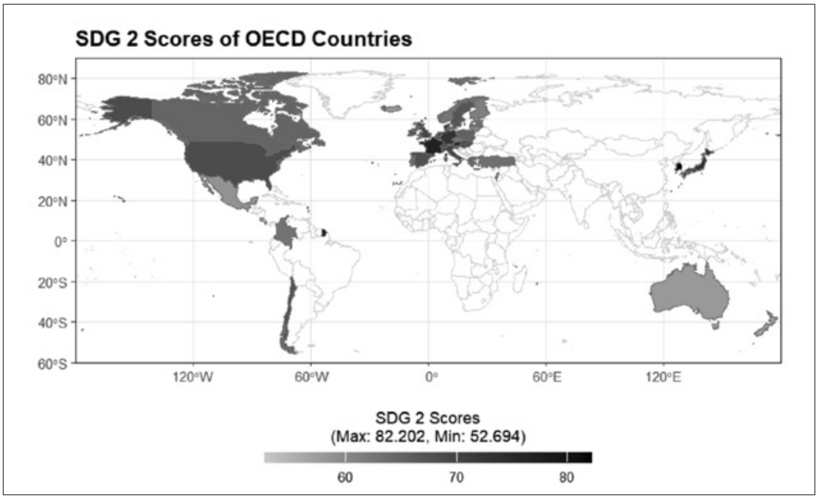


Figure 1 - SDG 2 scores of OECD Countries.
Source: SDR, 2024.

assessment of SDG 2 measurement, particularly regarding the role of resource management and agricultural efficiency (Burford *et al.*, 2016; Allen *et al.*, 2017; Guijarro and Poyatos, 2018). A refined evaluation framework should integrate both food security and sustainable resource use to provide a more accurate reflection of progress.

This study examines the relationship between SDG 2 outcomes and agricultural input efficiency in OECD countries using an input-oriented Data Envelopment Analysis (DEA). By analyzing key agricultural inputs – area harvested, agricultural employment, pesticide use, fertilizer use, energy use, and water use (Table 2) – this research investigates whether countries can achieve similar SDG 2 outcomes with fewer resources.

Despite SDG 2's pivotal role in addressing global hunger, it remains less studied than other SDGs (Salvia *et al.*, 2019). This study addresses two key questions: (1) Does agricultural input efficiency significantly impact SDG 2 outcomes? (2) Do existing SDG 2 indicators adequately capture both food security and agricultural sustainability? By challenging current measurement approaches and emphasizing the interconnections between SDG 2 and other sustainability goals, such as SDG 6 (Clean Water and Sanitation) and SDG 13 (Climate Action), this research contributes to a more comprehensive understanding of sustainability and informs future policy directions toward achieving Zero Hunger.

2. Methodology

2.1. *Data sources and selection of variable*

This study relies on internationally recognized databases, including FAO and OECD, which provide standardized and comprehensive agricultural and economic indicators for OECD countries. The variables used in the model were sourced from these databases, ensuring consistency and reliability. The data reflects the most recent available year (2021) to maintain accuracy and relevance. To enhance validity, a cross-verification process was conducted by comparing overlapping variables from both sources. In cases of discrepancies, data from sources with direct national reporting were prioritized, ensuring consistency across multiple reporting years. The use of these internationally accepted datasets strengthens the robustness of this study's findings and allows for meaningful comparisons across countries.

This study used an input-oriented DEA method to evaluate the SDG 2 scores of OECD countries. The SDG 2 score was set as the output variable in the model, while the input variables included area harvested, agricultural employment, pesticide use, fertilizer use, energy use, and water use (Table 2).

SDG 2 aims to end hunger, achieve food security, improve nutrition, and promote sustainable agriculture by 2030. It addresses multiple dimensions of food systems, including equitable access to nutritious food, eliminating all forms of malnutrition, and the sustainable production practices necessary to maintain long-term agricultural productivity. While SDG 2 indicators primarily focus on these social and health outcomes, achieving this goal also hinges on the efficient use of agricultural resources and minimizing environmental impact. Efficiency-focused agricultural studies, such as Ozden and Ozer (2019), highlight the need for sustainability-driven agricultural policies. Similarly, Ibrahim (2024) underscores the regional disparities in food security determinants, reinforcing the argument for a more holistic SDG 2 evaluation framework.

The selection of variables in this study is strategically designed to provide a clearer and more practical understanding of the SDG 2 target by focusing on key agricultural inputs that directly affect productivity and sustainability. By analyzing variables such as water use, energy consumption, and pesticide application, we aim to demonstrate that the same SDG 2 scores can potentially be achieved with reduced resource usage, thus minimizing environmental impact and promoting sustainable agricultural practices. This approach advocates for a balanced strategy to achieve SDG 2 with optimized resource expenditure, aligning with the broader goals of sustainability and conservation (Table 3). Other potential indicators, such as mechanization or biodiversity loss, were not included due to data limitations or lack of direct relevance to input

Table 2 - Descriptive Statistics of Variables Used in the Analysis.

Variables	*Unit*	*Mean*	*Std. Dev.*	*Min.*	*Max.*
Output					
SDG2	Index score	66.333	6.138	52.694	82.202
Inputs					
Area harvested	ha (x1000)	7357.418	17345.250	2.914	201584.800
Agricultural employment	persons (x1000)	759.519	1417.490	3.325	6751.959
Pesticide use	kg/ha	4.491	4.095	0.01	17.410
Fertilizer use[1]	kg/ha	146.471	64.430	75.44	388.610
Energy use[2]	Toe (x1000)	1904.066	3344.991	27.255	19233.110
Water use[3]	%	33.363	30.795	0	90.887

Source: FAOSTAT, 2024; OECD, 2024; SDR, 2024.

[1] *Fertilizer use amounts are calculated based on nutrients, with totals indicated for nitrogen (N), phosphate (P_2O_5), and potassium (K_2O).*

[2] *The amount of energy used considers the energy consumption directly used in agriculture. Toe refers to tonnes of oil equivalent, and this unit is used to compare and express the energy from different sources.*

[3] *The water use variable represents the percentage of freshwater use allocated to agriculture. This approach was taken due to the unavailability of precise freshwater usage data (in cubic meters) for agriculture across OECD countries.*

efficiency in the context of SDG 2.

By focusing on these critical agricultural inputs, this study aims to assess SDG 2 progress and explores the potential for achieving the same outcomes through more efficient resource usage. This leads to the following hypotheses, which are designed to evaluate whether resource optimization can maintain or enhance SDG 2 scores while minimizing environmental impact and supporting broader sustainability objectives.

H_0: Agricultural input efficiency does not significantly impact SDG 2 outcomes, and the current SDG 2 indicators sufficiently reflect both social outcomes and agricultural sustainability.

H_1: Agricultural input efficiency significantly improves SDG 2 outcomes, and the current SDG 2 indicators fail to adequately account for agricultural resource management and sustainability.

Moreover, through the incorporation of these variables, the model not only assesses efficiency in the context of SDG 2 but also demonstrates alignment with a broader array of sustainable development goals. This multidimensional approach highlights how optimized agricultural practices can contribute to a more resilient and sustainable global food system.

2.2. *Analytical Framework*

The input-oriented BCC (Banker, Charnes, and Cooper) model was chosen in this study. This model is a widely used Data Envelopment Analysis (DEA) method for measuring agricultural input efficiency, particularly favored for optimizing agricultural production processes with limited resources. It is suited to situations where returns to scale are variable, meaning that each agricultural entity or country may operate at different efficiency levels depending on its scale (Banker *et al.*, 1984). In evaluating the efficiency of agricultural inputs such as water, fertilizer, and energy, the input-oriented BCC model reveals the potential for maintaining output levels while minimizing input usage (Coelli *et al.*, 2005).

One primary reason for the model's frequent use in agricultural studies is that agricultural production is inherently input-dependent, and efficient resource use is essential for sustainability (Zhu and Lansink, 2010). For instance, the efficient use of inputs like water and fertilizer not only enhances agricultural productivity but also mitigates environmental impacts. Numerous studies have shown that input-oriented DEA

Table 3 - Analytical Framework and Variable Justification.

SDG2 indicators	*Variables used in the model*	*Relationship explanation*
Prevalence of undernourishment (%)	Agricultural Employment, Area Harvested	Reducing undernourishment is directly linked to increasing agricultural production. Efficient use of labor and sustainable management of harvested areas affect food production (Hemathilake and Gunathilake, 2022).
Prevalence of stunting in children under 5 years of age (%)	Agricultural Employment, Pesticide Use	Pesticide use can affect stunting in children (Purwestri *et al.*, 2017; Kartin *et al.*, 2019; Jaacks *et al.,* 2019). Limiting the use of harmful pesticides is important for producing healthy food.
Prevalence of wasting in children under 5 years of age (%)	Area Harvested, Fertilizer Use	Efficient use of harvested areas and fertilizers can increase agricultural productivity and crop diversity, thereby improving food security and supporting better nutrition, which in turn may reduce wasting in children (Kumar *et al.*, 2015; Sekiyama *et al.*, 2020).
Prevalence of obesity (% of adult population)	Energy Use, Pesticide Use	Energy and pesticide use can lead to higher agricultural production; however, energy-intensive agricultural processes may facilitate the production of processed foods (Balogh and Hall, 2016), whose increased consumption can contribute to unhealthy dietary habits and raise obesity risks (Popkin and Reardon, 2018), with pesticides potentially exerting indirect effects on human metabolism (Kim *et al.*, 2017).
Cereal yield (tonnes per hectare)	Fertilizer Use, Water Use	Cereal yield can be directly improved through the use of fertilizers and irrigation. However, sustainable practices are critical for mitigating environmental impacts (Ladha *et al.*, 2005; Zhou *et al.*, 2011).
Proportion of agricultural area under productive and sustainable agriculture (%)	Water Use, Energy Use, Pesticide Use	Sustainable agriculture requires efficient and environmentally conscious water, energy, and pesticide management. Overuse of these resources may harm the environment (Fabiani *et al.*, 2020; Bwambale *et al.*, 2022).

models effectively assess the efficiency of water usage (Cao *et al.*, 2020), fertilizer and labor use (Manogna and Mishra, 2022), and energy consumption (Mousavi-Avval *et al.*, 2011) in agriculture. Additionally, there are studies in which the efficiency of capital in agricultural enterprises is measured (Gunes and Guldal, 2019), further underscoring the model's versatility and applicability in evaluating resource use in diverse agricultural contexts.

DEA was chosen over alternative efficiency analysis methods, such as Stochastic Frontier Analysis (SFA), due to its flexibility in handling multiple inputs and outputs without imposing a predefined functional form on the production process. Unlike SFA, which requires parametric assumptions, DEA provides a data-driven frontier, making it particularly useful for benchmarking efficiency across diverse countries. Additionally, DEA allows for the identification of best-practice decision-making units (DMUs) within a sample, making it well-suited for evaluating resource use efficiency in the context of SDG 2.

The input-oriented BCC model further provides a fair assessment tool for cross-country comparisons by enabling each country or agricultural entity to reach optimal efficiency with its available resources (Aldanondo-Ochoa *et al.*, 2014). This approach supports sustainable agricultural production by promoting efficient use of limited natural resources, making it a valuable tool for addressing sustainability goals within the sector.

The input-oriented BCC model is calculated through the following linear programming problem:

Minimize *Θ*

Subject to:

$$\sum_{j=1}^{n} \lambda_j x_{ij} \leq \Theta x_{io}, \quad \forall_i = 1,2, \ldots, m$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} \leq y_{ro}, \quad \forall_r = 1,2, \ldots, s \tag{1}$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

$$\lambda \geq 0, \forall_j = 1,2, \ldots, n$$

Θ: The input-oriented efficiency score represents the technical efficiency of the evaluated Decision-Making Unit (DMU), in this case, the country. The score ranges between 0 and 1. If Θ = 1, the DMU is considered efficient; if Θ < 1, the DMU is inefficient and has the potential to reduce its input usage.

x_{ij}: Input i of DMU j

y_{rj}: Output r of DMU j

x_{io}: Input i of the evaluated DMU

y_{ro}: Output r of the evaluated DMU

λ_j: Weight variables representing the contribution of each DMU's performance to the evaluation

n: Number of decision-making units (DMUs)

m: Number of input variables

s: Number of output variables

The model's objective is to minimize the value of Θ, which allows us to determine how each country can use its resources more efficiently while maintaining its current SDG 2 score. Doing so reveals how countries can improve agricultural productivity and sustainability through more efficient resource use.

Although SDG 2 scores do not directly account for these inputs (as shown in Table 2), these inputs indirectly impact the efficiency and sustainability of agricultural production processes. Therefore, the input-oriented model used in this study aims to demonstrate how agricultural inputs can be minimized and used more efficiently to achieve the SDGs, particularly SDG 2.

3. Results and Discussion

3.1. *DEA Results and Benchmark Analysis*

The results of the DEA provide valuable insights into the agricultural efficiency of OECD countries concerning SDG 2 targets. The analysis highlights both efficient and inefficient use of resources across different nations by examining key input variables such as water use, energy consumption, pesticide and fertilizer application, agricultural employment, and harvested area. This section discusses the efficiency scores of the countries, identifies key patterns in the data, and explores the implications of these findings for sustainable agricultural practices. Additionally, the results are interpreted in the context of the broader SDG 2 objectives, emphasizing the potential to achieve similar food security outcomes with optimized resource use, thus minimizing environmental impact.

The DEA results, presented in Table 4, reveal how efficiently OECD countries utilize agricultural inputs to achieve their SDG 2 (Zero Hunger) scores. Countries such as Estonia, Iceland, Luxembourg, Mexico, and Australia demonstrate full efficiency (VRS score = 1.000), indicating that they are optimally utilizing their key inputs like water, energy, and pesticides (Table 4). These nations also efficiently manage agricultural labor and harvested area, maintaining high SDG 2 performance. Their ability to balance agricultural productivity with sustainable resource use underscores their effectiveness in achieving food security goals without excessive input consumption.

Conversely, countries such as Chile, Colombia, and Costa Rica show lower VRS efficiency scores, ranging from 0.393 to 0.585, indicating suboptimal resource utilization (Table 4). Chile and Colombia, in particular, exhibit inefficiencies in both resource use and operational management, suggesting that these countries could improve their SDG 2 performance by optimizing agricultural inputs, reducing excessive resource use, and enhancing their food security outcomes.

The benchmark analysis (Table 5) further

Table 4 - Efficiency Scores of OECD Countries (Input-Oriented BBC).

Countries	*Technical Efficiency Score (CRS)*	*Pure Technical Efficiency Score (VRS)*	*Scale Efficiency Score (SE)*
Australia	**1.000**	**1.000**	1.000
Austria	0.821	**1.000**	0.821
Belgium	0.530	**1.000**	0.530
Canada	0.743	0.777	0.955
Chile	0.358	0.585	0.612
Colombia	0.216	0.393	0.550
Costa Rica	0.499	0.548	0.912
Czechia	0.663	0.664	0.999
Denmark	0.805	**1.000**	0.805
Estonia	**1.000**	**1.000**	1.000
Finland	0.993	**1.000**	0.993
France	0.666	**1.000**	0.666
Germany	0.675	**1.000**	0.675
Greece	0.734	0.792	0.927
Hungary	0.638	0.731	0.872
Iceland	**1.000**	**1.000**	1.000
Ireland	0.218	**1.000**	0.218
Israel	0.521	0.643	0.810
Italy	0.817	0.939	0.870
Japan	0.514	0.614	0.837
Latvia	0.846	0.860	0.983
Lithuania	0.694	0.716	0.969
Luxembourg	**1.000**	**1.000**	1.000
Mexico	**1.000**	**1.000**	1.000
Netherlands	0.486	**1.000**	0.486
New Zealand	0.074	0.075	0.984
Norway	0.595	0.830	0.717
Poland	0.720	0.787	0.914
Portugal	0.529	0.536	0.987
South Korea	0.833	**1.000**	0.833
Slovakia	0.676	**1.000**	0.676
Slovenia	0.429	**1.000**	0.429
Spain	0.638	0.711	0.897
Sweden	0.971	**1.000**	0.971
Switzerland	0.805	**1.000**	0.805
Türkiye	0.629	0.647	0.972
United Kingdom	0.554	**1.000**	0.554
United States of America	0.777	0.914	0.851

Notes: CRS (Constant Returns to Scale), VRS (Variable Returns to Scale), and SE (Scale Efficiency) are efficiency measures used in Data Envelopment Analysis (DEA). CRS measures efficiency assuming constant returns to scale, meaning that input and output are proportionally scalable. VRS allows for variable returns to scale, meaning that the relationship between input and output may change as the scale of operations changes. SE (Scale Efficiency) is the ratio of CRS efficiency to VRS efficiency, indicating how close a decision-making unit (DMU) is to optimal scale.

Table 5 - Benchmark Analysis Results for Enhancing Agricultural Efficiency.

Country	*Efficiency Score (VRS)*	*Benchmark Countries*	*Benchmark Weight*	*Interpretation*
Chile	0.585	Denmark, Iceland, Ireland, Slovakia, Switzerland	0.2335, 0.3115, 0.0425, 0.2264, 0.1859	Chile can improve its efficiency by modeling 23.35% of Denmark's performance, 31.15% of Iceland's, etc.
Colombia	0.393	Denmark, Iceland, Ireland, Slovakia	0.2500, 0.6564, 0.0716, 0.0022	Colombia should focus on adopting Iceland's strategies (65.64%) and Denmark's (25%).
Canada	0.777	Austria, Estonia	0.1699, 0.8300	Canada can enhance efficiency by following 83% of Estonia's and 16.99% of Austria's practices.
Türkiye	0.647	Estonia, Slovakia, Sweden	0.9337, 0.0047, 0.0019	Türkiye should primarily model Estonia's high efficiency (93.37%) for improvement.

Notes: Benchmark Unit: This represents the efficient units that inefficient units should reference to become efficient. They provide insights into how inefficient units can improve their performance to achieve efficiency. Benchmark Weight: This represents the contribution of efficient units to the performance improvement of inefficient units. A higher benchmark weight indicates that the inefficient unit should rely more heavily on the referenced efficient unit to improve its performance and achieve efficiency.

highlights reference countries that can serve as models for improvement. For example:

Chile (efficiency score = 0.585) should consider the performance of Denmark (0.2335), Iceland (0.3115), Ireland (0.0425), Slovakia (0.2264), and Switzerland (0.1859) as benchmarks (Table 5). The assigned weights indicate that Chile could increase efficiency by modeling 23.35% of Denmark's strategies and 31.15% of Iceland's practices, along with the other reference countries.

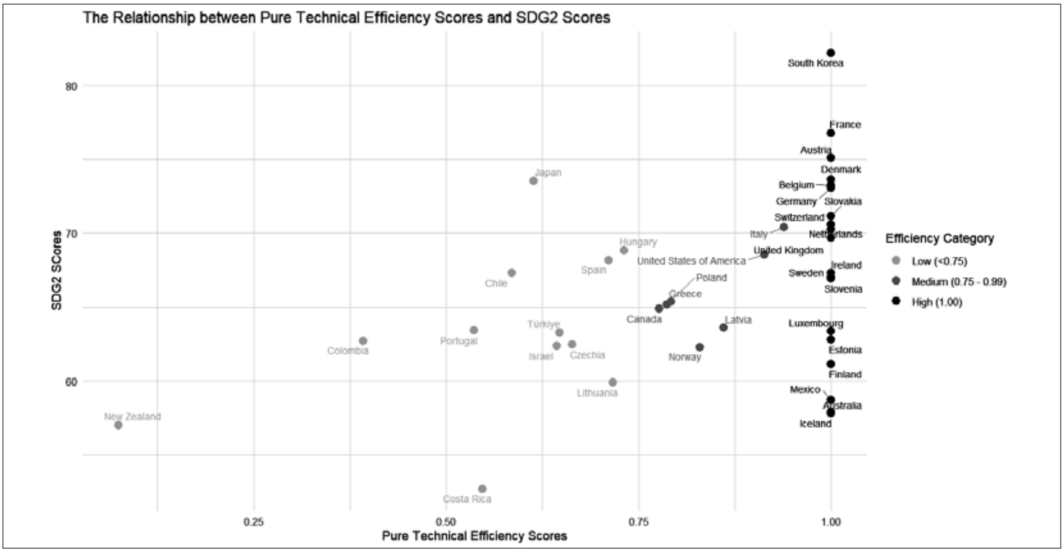
Colombia (efficiency score = 0.393) has benchmark countries Denmark (0.2500), Iceland (0.6564), Ireland (0.0716), and Slovakia (0.0022) (Table 5). Iceland's high weight (65.64%) suggests that Colombia could significantly enhance efficiency by adopting Iceland's agricultural resource management strategies.

For Canada, with an efficiency score of 0.777, the benchmark countries are Austria (0.1699) and Estonia (0.8300). Canada can improve its efficiency by adopting 83% of Estonia's and 16.99% of Austria's practices. This mix shows that Estonia's strategies are particularly relevant to Canada's agricultural efficiency (Table 5).

Türkiye (efficiency score = 0.647) is primarily benchmarked against Estonia (0.9337), Slovakia (0.0047), and Sweden (0.0019). The dominant benchmark weight (93.37%) from Estonia suggests that Türkiye should prioritize adopting Estonia's agricultural efficiency strategies to enhance its performance (Table 5).

Benchmarking high-performing reference countries is a widely accepted approach in DEA studies, particularly within agricultural and environmental contexts (Cook and Zhu, 2007). Previous research has demonstrated that adopting strategies from efficient benchmark countries can enhance resource efficiency and sustainability. Studies by Reinhard *et al.* (2000) and Kyrgiakos *et al.* (2021) indicate that adapting best practices from high-performing countries helps less efficient nations identify areas for improvement, such as optimizing input management and applying advanced agricultural techniques. Further research, including Sachs (2012), Hickmann *et al.* (2023), and Thow (2024), highlights that implementing policies from successful countries can effec-

Figure 2 - The Relationship Between Pure Technical Efficiency Scores and SDG2 Scores.



Source: Own source.

tively enhance efficiency and promote sustainable development. This underscores the value of cross-national learning for policy development and resource optimization.

3.2. *Comparing DEA Scores with SDG 2 Scores*

As shown in Figure 2, the comparison between SDG 2 and efficiency scores based on agricultural inputs reveals notable discrepancies. While SDG 2 indicators focus primarily on social and health outcomes, the efficiency scores – calculated through resource utilization metrics – highlight the potential to achieve similar food security objectives with optimized input use. This gap underscores the need to reassess how SDG 2 success is measured, particularly for countries that perform well in social indicators but fall behind in resource efficiency.

a) South Korea: A Model of Balance

South Korea serves as a leading example of balanced progress. Ranking at the top of SDG 2 scores and achieving a high-efficiency score, South Korea exemplifies how efficient agricultural practices can support social well-being and food security objectives (Figure 2). Notably, South Korea is ranked 11th out of 38 OECD countries in cereal yield indicator[1] (SDR 2024), which underscores its ability to maintain high productivity while optimizing resource inputs. This alignment between high productivity and social impact supports the vision of Target 2.3[2], which aims to double agricultural productivity and incomes for small-scale producers by 2030. South Korea's success demonstrates that efficient management of agricultural inputs – such as land, water, and energy – enables countries to meet food security goals sustainably. This synergy should ideally be reflected across all nations.

[1] Cereal yield is one of the few indicators within the SDG 2 framework that attempts to capture agricultural productivity.

[2] By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment.

b) Japan: A High Social Performer with Efficiency Gaps

In contrast, Japan presents a discrepancy within the SDG 2 framework. Despite ranking highly in SDG 2 due to strong social indicators such as food security and nutrition, Japan exhibits lower agricultural efficiency (Figure 2). This inefficiency is largely attributed to resource-intensive agricultural practices, which – while yielding positive social outcomes – suggest opportunities for improvement in input optimization. Japan ranks 12th in cereal yield, indicating high productivity; however, the current SDG 2 indicators fail to fully capture its potential for improving sustainability by enhancing efficiency in water and energy use. This example illustrates a key limitation of SDG 2 measurement, as the strong focus on social outcomes does not adequately reflect resource management efficiency, which is crucial for achieving long-term agricultural sustainability, particularly within Target 2.3.

c) Iceland and Australia: High Efficiency, Low SDG 2 Scores

On the other hand, Iceland and Australia represent a different type of discrepancy. These countries achieve high-efficiency scores, reflecting strong resource management practices, yet rank lower in SDG 2 (Figure 2). For instance, despite Iceland's relatively low cereal yield ranking, it has successfully implemented effective water and energy conservation strategies, resulting in high agricultural efficiency. Similarly, Australia, though ranking lower in cereal yield and SDG 2, excels in land and resource use efficiency but does not fully meet the social targets outlined in SDG 2. This further emphasizes the gap in SDG 2 criteria: while efficiency is essential for sustainable agriculture, the existing SDG 2 indicators fail to account for resource optimization.

d) Mexico: Efficient but Struggling with Social Performance

Mexico also illustrates this complexity. While scoring well in efficiency due to streamlined input use, its social outcomes are less pronounced, leading to lower SDG 2 rankings (Figure 2). This suggests that, despite effectively optimizing agricultural inputs, Mexico faces challenges in ensuring food security and equity. Similar to Iceland and Australia, Mexico's case indicates that efficiency alone does not guarantee strong social performance. Instead, a more comprehensive approach is needed—one that balances efficient input use with equitable access to resources.

e) Mediterranean Countries: Strong Social Outcomes, Uneven Resource Efficiency

The Mediterranean OECD countries – France, Italy, Spain, Greece, and Türkiye – exhibit diverse patterns in agricultural efficiency and SDG 2 performance, reflecting the complex interplay between food security outcomes and sustainable resource use.

Among these nations, France stands out as a strong performer, achieving both a high SDG 2 score and full efficiency, indicating a well-balanced agricultural system that effectively integrates resource management with food security goals. Similarly, Italy, with a relatively high SDG 2 score and efficiency level, demonstrates effective input use, yet still holds potential for further optimization in agricultural resource management.

Conversely, Spain and Greece exhibit moderate SDG 2 rankings while struggling with efficiency gaps, suggesting that despite favorable social outcomes, there is room for improving resource utilization. The case of Türkiye, which has the lowest SDG 2 score among Mediterranean OECD countries and a relatively low efficiency score, underscores challenges in both food security and agricultural sustainability. These disparities suggest that food security improvements in the region must be accompanied by stronger commitments to optimizing agricultural inputs, particularly given the Mediterranean's exposure to climate change, water scarcity, and land degradation (Gürsoy, 2020).

The clustering analysis by Coluccia *et al.* (2024) and Miglietta *et al.* (2023) further supports these findings, indicating that Mediterranean nations follow distinct patterns in agricultural sustainability and food security. The results align with previous research on SDG 2 food security assessments in the Mediterranean, which highlight regional disparities and policy gaps. These observations reinforce the argument that SDG 2 indicators should integrate efficiency metrics to better capture sustainability challenges across diverse agricultural systems.

3.3. *Interconnections with Other SDGs*

The country-specific findings illustrate the complex relationship between SDG 2 outcomes and agricultural efficiency. While the primary goal of SDG 2 is to ensure food security, the agricultural inputs analyzed in this study – water, energy, pesticides, fertilizers, employment, and harvested area – extend beyond food production, influencing multiple sustainability objectives. These interconnections emphasize the need for integrated policy approaches that optimize resource use while maintaining both environmental sustainability and social equity.

Water management plays a pivotal role in achieving both SDG 2 and SDG 6. Efficient water management in agriculture reduces water scarcity, minimizes waste, and helps preserve aquatic ecosystems, supporting long-term agricultural productivity and environmental health. Excessive or inefficient water use, by contrast, risks resource depletion and degraded water quality, ultimately threatening food security and ecological stability (Chartzoulakis and Bertaki, 2015; Li *et al.,* 2025).

Similarly, energy use in agriculture directly relates to SDG 7 (Affordable and Clean Energy) and SDG 13. Agricultural activities with high energy demands, especially from non-renewable sources, increase greenhouse gas emissions, impacting climate resilience (Khan *et al.,* 2014; Mohammadi *et al.*, 2014). Transitioning to renewable energy sources within agriculture could mitigate these effects, fostering climate stability while reducing operational costs for farmers (Chang *et al.*, 2015; Khan *et al.*, 2018).

The use of pesticides and fertilizers, while essential for agricultural productivity, also has significant environmental consequences, particularly affecting SDG 14 (Life Below Water) and SDG 15 (Life on Land). Excessive or improper application of these inputs leads to soil degradation, water pollution, and biodiversity loss (Campbell *et al.,* 2018). Implementing precision farming and controlled application techniques can help mitigate these risks, reducing agriculture's environmental footprint without compromising yields or food security.

Lastly, agricultural employment and harvested area directly influence SDG 1 (No Poverty) and SDG 8 (Decent Work and Economic Growth) by providing jobs and sustaining rural economies (Nasr-Allah *et al.,* 2020). However, ensuring fair wages, safe working conditions, and responsible land use practices is essential for achieving sustainable agricultural growth without compromising worker welfare or ecosystem integrity.

3.4. *Policy Implications for Agricultural Efficiency and SDG 2 Integration*

Current agricultural policy frameworks, such as the Common Agricultural Policy (CAP) in the EU and USDA agricultural programs in the U.S., are primarily designed to enhance food production, support farm incomes, and promote environmental conservation. However, despite their extensive role in shaping agricultural systems, these policies lack mechanisms to systematically evaluate how efficiently resources such as water, energy, and fertilizers are utilized in achieving food security (Cuéllar *et al.*, 2014; Grethe *et al.*, 2018). As a result, agricultural policies remain largely output-driven, focusing on production growth rather than sustainability and efficiency metrics. This limitation mirrors a broader concern regarding SDG 2 indicators, which primarily assess food security through social and nutritional outcomes while neglecting the sustainability of agricultural production processes. The absence of efficiency-based assessments within both policy frameworks and SDG 2 measurements raises critical questions about how agricultural sustainability is evaluated and incentivized in global food security strategies.

In parallel, technological advancements are rapidly transforming agricultural practices (Guldal and Ozcelik, 2024), offering opportunities to improve resource efficiency while maintaining high productivity. Precision agriculture, remote sensing, and AI-driven irrigation systems allow farmers to optimize input use, reducing water and chemical applications without compromising yields (Guldal, 2022). However, despite the demonstrated benefits of these innovations, their adoption remains uneven across OECD countries, often influenced by economic, infrastructural, and policy constraints (Wreford *et al.*, 2017; Dibbern *et al.*, 2024). Nations with lower efficiency scores may face greater challenges in integrating such technologies due to limited access to financial support, digital infrastructure, or technical expertise. This discrepancy highlights the critical role of national policies in facilitating the transition toward more sustainable and resource-efficient agricultural systems. Without structured incentives or regulatory frameworks that encourage efficiency improvements, many countries risk continuing resource-intensive production models that may undermine long-term food security and environmental sustainability.

4. Limitations and Future Research

While this study provides valuable insights into the efficiency of agricultural inputs in achieving SDG 2, it has certain limitations. First, the analysis is constrained by data availability, as some OECD countries lack comprehensive records on resource use. Second, the DEA model does not account for external factors such as climate change or geopolitical disruptions, which may influence efficiency scores. Future research could explore alternative methodologies, such as SFA, to validate the robustness of these findings. Additionally, longitudinal studies could assess how efficiency trends evolve over time, providing deeper insights into the long-term sustainability of agricultural practices in OECD countries.

5. Conclusion and Recommendations

5.1. *Conclusion*

This study reveals notable discrepancies between SDG 2 scores and agricultural efficiency among OECD countries, highlighting the need for a more refined approach to measuring progress toward the Zero Hunger goal. While SDG 2 indicators emphasize social and health outcomes such as undernourishment, malnutrition, and food access efficiency scores provide a different perspective by assessing how effectively agricultural inputs like water, energy, and fertilizers are managed. This divergence exposes a fundamental gap in how agricultural performance is evaluated within the SDG framework.

The findings emphasize the importance of considering agricultural input efficiency alongside social outcomes in SDG 2 assessments. Some countries optimize their resource use yet do not achieve high SDG 2 scores, while others rank well in social indicators despite inefficient resource utilization. This inconsistency suggests that SDG 2 evaluations may not fully capture agricultural sustainability, potentially overlooking the vital role of resource efficiency in achieving long-term food security.

Beyond SDG 2, optimizing agricultural input use has broader sustainability implications, as efficient water, energy, and input management supports environmental resilience and resource conservation. Aligning agricultural efficiency with SDG 2 would strengthen its synergy with other SDGs, such as SDG 6, SDG 13, and SDG 12 (Responsible Consumption and Production).

5.2. *Policy Recommendations*

To enhance SDG 2's effectiveness in measuring food security and sustainability, efficiency-based indicators should be integrated into both policy frameworks and SDG 2 assessments. While CAP and USDA policies address agricultural sustainability, they do not systematically evaluate resource efficiency, highlighting the need for performance indicators that align food security goals with sustainable input use.

Additionally, accelerating the adoption of precision agriculture, smart irrigation, and remote sensing technologies through targeted investments and digital infrastructure development will help countries optimize agricultural efficiency. Finally, enhancing global collaboration and standardizing efficiency indicators within SDG 2 evaluations would ensure a more comprehensive approach to food security, balancing both productivity and sustainability.

Acknowledgments

I would like to express our sincere gratitude to Dr. Burhan Özalp for his valuable contributions and insightful suggestions that greatly improved the quality of this study.

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