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The Infrastructure Sector Sustainability: Using of the Deterministic Frontier Analysis for Performance-Accounting Measurement

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Abstract. The capacity of the infrastructure sector to generate value for the territory in terms of social inclusion, economic growth, and employment may be determined as of today (2023) on the basis of empirical evidence. With the technological advancements and the development of other modes of transportation over time, the system of roads and highways in particular has come to play a crucial role in the growth of a territory. It is also necessary for the infrastructure system, particularly the transportation sector, to adapt to international norms for sustainable growth. Operationally, this means that projects must be planned and carried out that have the potential to influence the territory's strategic progress from three different angles: economic, social, and environmental.

The goal of the current study is to provide a quantitative methodology to aid in the analysis of infrastructure sector performance, particularly that of the transportation one. The framework suggested directs evaluation of the infrastructure sector in terms of sustainability and takes into consideration potential performance indicators in order to develop accounting procedures for the sustainability performance. The formalization of the analytical tool based on the proposed framework adheres to the logical rules of Deterministic Frontier Analysis (DFA). The transport infrastructure sector is evaluated by the DFA in relation to the achievement of the sustainability goals set at the European Union level. In the conclusions, it is discussed how the use of the proposed framework may affect the allocation of initiatives related to the sector being tested on the territory's sustainable development.

Keywords: infrastructure sector · sustainable development · multicriteria analysis · DFA

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1 Introduction

The 17 Sustainable Development Goals in the UN Agenda 2030 (2015), which are generally aimed at economic prosperity, social inclusion, and environmental sustainability, are the perspective that individual territorial contexts adopt when planning investments in various production sectors in order to address the new challenges of the 21st century [1]. Infrastructure investments are essential to attaining sustainable development and enhancing the capacity of communities in many nations. Infrastructure includes investments in transportation, irrigation, electricity, and information and communication technology. Infrastructure investment is necessary for productivity and income development as well as for improved health and educational results [2–6].

The Connecting Europe Facility (CEF) 2.0 (2021–2027) program in Europe aims to build, develop, modernize, and complete trans-European networks in the energy, digital, and transportation sectors with the goal of creating a unique global market while taking into account the goals of environmental, social, and economic cohesion [7]. Il CEF 2.0 emphasizes the value of collaboration across the transportation, energy, and digital sectors. A green, digital, and resilient Europe is another goal of the Next Generation EU (2020) for post-pandemic socio-economic recovery from COVID-19. The Recovery and Resilience initiative, which aims to encourage investment to promote post-pandemic recovery in Europe, is a crucial component of the Next Generation EU package. An average of 191.5 billion euros have been placed at Italy's disposal for projects and reforms associated with the National Recovery and Resilience Plan (NRRP) [8]. Separately, the Italian government commits an additional 30.6 billion euros to initiatives considered strategically important for the development and improvement of the country's infrastructure sector (e.g., the initiatives "Safe Roads - Implementation of a dynamic monitoring system for the remote control of bridges, viaducts and tunnels of the main road network" and "Interventions of the Complementary Plan in the territories affected by the 2009–2016 earthquake, Infrastructure and Mobility, Investments on the State Road Network"). The EU proposes the Green Deal plan (2019) as the foundation for CEF 2.0 (2021) and Next Generation (2020), aiming to focus sustainable investments to boost environmental-ecological trans-action in Europe. The Green Deal aims to reduce atmospheric pollutant emissions by 55% from 1990 levels by 2030 in order to have a "climate-neutral" economy by 2050 [9]. Based on a balanced participation of the public and private sectors in the processes of financing the initiatives, an investment plan (2020–2030) of about one trillion euros is put into place to support initiatives for the sustainable development of the sectors deemed to be the most energy-intensive (e.g., the infrastructure sector) [10, 11].

The basic objectives of the Green Deal (2019), which were also re-proposed in the more recent CEF 2.0 (2021), include: ecological transition; energy consumption; sustainable forms of transportation; circular economy; digital transactions.

The previously specified goals for the transportation infrastructure sector deviate as follows: *i*) resilience, with emphasis on energy efficiency and renewable energy generation; *ii*) sustainable mobility; *iii*) forms of circular economy; and *iv*) transport safety measures for the system's primary users.

i) Due to the ongoing conflict in Ukraine (2023), there is currently a great deal of uncertainty surrounding the energy supply, making energy efficiency and the generation of energy from renewable sources increasingly important. Infrastructure system operators are being forced to come up with customized ways to reduce energy consumption without compromising the safety of road users because to the high running expenses of electric power plants and the strict am-environmental requirements that must be satisfied. The installation of more energy-efficient lighting fixtures, whose usage is maximized by the use of IoT-based sensors, has shown potential solutions. It is necessary to implement a transition from a carbon emission-heavy energy system based on fossil fuels to one with lower carbon emissions in order to reduce energy consumption [4, 12, 13].

ii) Due to the restrictions imposed by the single member states of the Parigi Agreement, a gradual conversion of the circular park to other feeding mechanisms is taking place. It is predicted that there won't be any more internal combustion engines in the EU after 2035, only electric vehicles. Hence, as a result of this scenario, a single manager must act in order to prevent the use of electric vehicles [14–16].

iii) The existing road pavement production process is designed to use enormous amounts of virgin raw materials and natural resources in order to get ready for a circular economy. Discussions and disputes revolve on the effects of this element, which force a shift in perspective that the NRRP itself imposes. Thus, the usage of novel materials is being investigated in order to extend a pavement's lifespan and minimize maintenance. Because of their intimate ties to energy saving, these pavements may be used to advance both the circular economy and ecological transition [17–19].

iv) Also, the requirement to maintain infrastructure assets by actions that extend the infrastructure's useful life with an eye to road safety should be taken into account. There is a need to implement systems of monitoring and inspection vigilance on roads, capable of dealing in a predictive and timely manner with catastrophic events that can generate irreversible consequences on human life, due to the heterogeneity of materials and construction techniques that characterize the existing infrastructure sector. In the European environment, there is a propensity to support measures to assess the level of vulnerability of the current infrastructure network as well as monitoring activities of infrastructure located in seismic and hydrogeological risk zones. To that end, the Ministry of Infrastructure and Sustainable Mobility has allocated 450 million euros to the NRRP in Italy for the monitoring and remote management of bridges, viaducts, and tunnels on state and private roads [20–24].

So, setting up a system to track the performance of the infrastructure system in terms of sustainability plays a key role in achieving each of the objectives listed in *i*) through *iv*) in the best possible way. Through the use of appropriate performance indicators and evaluation tools, an auditing system may conceptualize valuation frameworks while accounting for the performance of infrastructure in relation to European sustainability targets. The challenge facing infrastructure managers, especially those in charge of constructing roads, is to plan and implement initiatives that take into account the effects that their actions would have on the local community and environment, particularly in light of territorial cohesion principles.

2 Aims

In light of the foregoing, the proposed work seeks to address the following research questions:

- What indicators may be used to assess a territory's infrastructure system's sustainability in terms of performance? Which letter-writing sustainability indicators are directly related to system infrastructure analysis, and which others are less so?
- Which evaluation methodology enables measuring the infrastructure system's performance in relation to the sustainable targets to achieve?

In order to respond to earlier concerns, the present contribution aims to provide a description of a methodological-operational apparatus based on processes for evaluating the sustainability of infrastructure systems, particularly transportation systems. The performance measurement framework proposed takes into account the use of efficiency potential indicators, as well as a system of analysis developed using Deterministic Frontier Analysis (DFA). This last one (DFA), as we shall see, allows for the execution of static comparative analyses between components of a homogeneous research field as well as the provision of preliminary predictions regarding the development of the same (components) in comparison to reference targets.

The work is structured as follows: Sect. 3 provides an overview of sustainability indicators and potential methods and tools for evaluating the sustainability performance of an infrastructure system; Sect. 4 is devoted to the discussion of the valuative framework proposed to support the sustainability analysis of the transportation infrastructure system. The conclusions are presented in Sect. 5, where you also analyse the methodology's limitations and outline the research directions that follow the presented work.

3 Materials and Method

To respond in a way that is in line with the new challenges of the twenty-first century, it is becoming more and more imperative for European states to align themselves with the sustainable development goals imposed at the community level. After the presentation and analysis of the various European-level objectives, it is intended to provide a methodology for evaluating the effectiveness of the road infrastructure system in terms of the degree to which sustainability objectives are pursued. The proposed methodological apparatus was developed with the intention of comparing the performance of the road network in relation to community sustainability goals. To do this, a preliminary overview of sustainability indicators used in scientific and grey literature to assess the sustainability of infrastructure systems is provided (3.1), along with a description of valuation models and tools used to assess sustainability performance (3.2). What is described in the two following subparagraphs is helpful in clarifying the framework of Sect. 4.

3.1 Accounting the Sustainability of Infrastructure Sector: Suite of Proper Performance Indicators

The measurement of sustainability, which is generally intended to be in terms of its three aspects of economic, social, and environmental, is done by using appropriate indicators for each one. With the first international instances of "sustainability" being defined, the term's meaning has gradually declined both linguistically and conceptually, especially when taking into account the various applicative and reference contexts [25]. In contrast to the scientific community's increased desire to define sustainability as a unique aggettivation of a country's social and economic system throughout the twentieth century, the interest in discussing sustainability in relation to a country's environmental and ecological aspects has increased significantly in the twenty-first one. In particular, especially due to phenomena related to climate change, renewable energy production, and the protection of terrestrial and marine ecosystems, sustainability has assumed an increasingly practical value. As such, it is used as a theoretical reference point to guide the planning and implementation of initiatives at various scales that may be able to respond to United States-level sustainability objectives. In this hypothetical, each individual initiative is initially assessed for its impact on environmental assets first, followed by its impact on increasing economic wealth and improving people's quality of life [26, 27].

A number of indicators have been proposed at the community level in completing the operations of impact assessment, and not. The assessment of the effects is feasible at several levels of analysis, including sub-urban, city, metropolitan, extra-metropolitan, national, and continental. There are suggested reference indicators for each that are more suited to measuring sustainability at that particular scale. It follows that we can make reference to a larger number of independently collected indicators that broaden the analysis's geographic scope. a basis for which it is possible to find a significant number of sustainability indicators at the national level, including economic, social, and environmental factors.

The indicators used in documentation to assess the current state of infrastructure in Europe with regard to the transportation system include the description of the system's physical structure, the level of usage, the management style, and even the most recent accessibility measures [11].

3.2 Approaches for Evaluating Efficiency in Assessment Procedures

The majority of writing on efficiency analysis focuses on comparing components of a standard studio set or different types of sets using key performance indicators, often of the financial variety, without taking into account relationships with exogenous factors of the environmental, social, and economic kinds. The studies that focus on evaluating products according to their life cycles while taking into account each stage of production are those that have received the most current in-depth attention [28–32].

It is feasible to determine that by studying existing literature the two main approaches to measuring effectiveness are *i*) traditional and *ii*) of frontier. Regardless of the method employed, the effectiveness measurements obtained at the end of an empirical analysis represent relative measurements: each decisional unit is evaluated in relation to the best performance obtained from the collection of the decisional units put to the test.

i) Using data on the amounts of input used and the levels of output obtained from a group of productive units, the construction of the production function is carried out while referring to the standard regression model. The level of effectiveness was determined by comparing the observed performance of the decision-making unit with the average observational field performance [33, 34].
ii) With information on the amount of input used and the output levels achieved by a group of production units, one proceeds to building a production possibility frontier that "circles" the points that correspond to the observed units. The measurement of effectiveness is based on a comparison of observed performance with literary references made to models (*best practice*) [35–37]. These last establish the analytical element's optimal efficiency boundary, which may be distinguished in:

   - Effective: The units are placed along the border;
   - Ineffective: The units are located just within the border.

As a result, the efficiency measurement is calculated in terms of distance from the border. The residuals from the regression are used to get the efficiency measurement.

I methods for measuring borderlines generally can be classified as *a*) parametric or *b*) not.

a) The frontier is expressed just by returning to a mathematical function notation that depends on a certain number of unknown parameters. Deterministic Frontier Analysis (DFA) and Stochastic Frontier Analysis are examples of parametric methods [38].
b) A collection of gathered information is used to reconstruct the production combination, with the border being constructed by taking into account certain characteristics and constituting the envelope. Among the non-parametric methods are the following: Data Envelopment Analysis and Free Disposal Hull.

The framework for performance analysis efficiency in the context of sustainable development is described in the section that follows with regard to the transportation infrastructure support system.

4 Proposal of a Framework DFA-Based for Transport System

As shown in Fig. 1, this aims to provide a framework for evaluating the sustainability of the transportation infrastructure system's performance. The proposed framework is organized into three sequential steps:

1. Identification of sustainable goals,
2. measurement of performance using appropriate indicators,
3. and selection of an efficient technique are the first three steps.

Everyone is described in the subsequent subparagraphs.

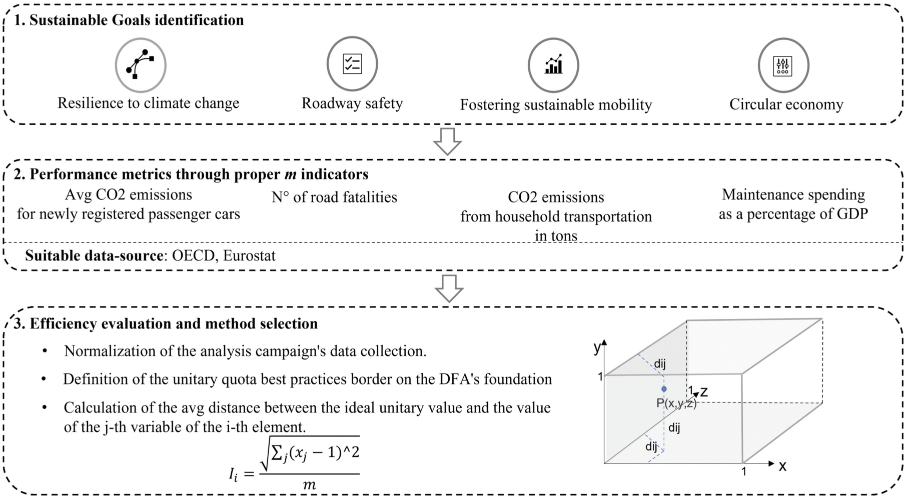

Fig. 1. Assessment framework DFA-based.

4.1 Sustainable Goals Identification and Performance Metrics

The European objectives that were sought to be examined were:

1. climate change resilience;
2. road safety;
3. promotion of sustainable mobility, and
4. circular economy and sustainable materials.

Each of the following objectives has been assigned a set of varying proxy variables that might depict the system's infrastructure's level of tracking relative to potential reference points. To be more explicit, the following conditions have been met:

1. for the goal of "road safety," the number of traffic accidents per 1,000 inhabitants is taken into consideration; this indicator is one of the SDG in the EU's collection of indicators. It is used to track progress on SDG 11 about making cities and human settlements inclusive, secure, resilient, and sustainable and SDG 3 about good health and wellbeing, which are included in the European Commission's top priorities for the European Green Deal. The indicator is comparable to SDG Global Indicator 3.6.1, "Rate of Mortality Due to Road Incidents." In 2010, the Commission adopted the communication "Toward a European Road Safety Space: Political Directions for Road Safety 2011–2020," with the goal of reducing the total number of traffic fatalities in the EU by 2020 in comparison to 2010. A reduction of 50% in fatalities and serious injuries by 2030 compared to 2019 is the goal set out in the EU's Strategic Road Safety Action Plan and its Road Safety Policy Framework for the 2021–2030 period. Ambitious goals have also been set for road safety to reach zero road fatalities by 2050;
2. in order to achieve the goal of "resilience to climate change," it was decided to use CO2 emissions from transportation for residents;

3. for the objective of “a circular economy and sustainable materials,” data on investments in road infrastructure as a percentage of GDP are used; this type of data is used to be able to represent maintenance investments to ensure a longer lifespan for the infrastructure;
4. the “median CO2 emission of new automobiles” can be used as a variable proxy for the objective of “promot[ing] sustainable mobility.“ The indicator is a part of the set of indicators for the EU’s sustainable development goals. It is used to track progress towards SDG 12 on ensuring sustainable consumption and production models and SDG 13 on adopting urgent measures to counteract climate change and its effects. These sustainable development goals are included in the European Commission’s list of priorities under the “Green Deal Europe.“

4.2 Efficiency Measurement

The effectiveness analysis was conducted by referring to the DFA’s underlying principles. This was initially developed in the economic sector for decision-makers who used several production factors to obtain more goods without explicitly stating the functional relationship. A frontier approach is used, where the distinctive feature is that the data are not surrounded or ignored rather than being interspaced by a function.

In this instance, a methodological approach to performance evaluation has been tested. It is based on the definition of the probability-optimal frontier for each analytical parameter and the measurement of the distance between the performance level at present and the ideal reference level. The series of values for each parameter has been appropriately normalized to an interval of $[0 \div 1]$ in order to combat the data set’s inhomogeneity, which is distinctive to the study field. This operation allows for the ability to deal with various sets of data of various types while also allowing for the consideration of an ideal boundary that is discretized in an original post-quota unitarian piano. Each piano’s front edge determines the calculation of the distance relating to the country’s performance level, which, in nautical terms, is defined as the vector to the number of evaluation factors, in our case four. Because of each veterinarian’s multidimensional characteristics, it was decided to calculate the relative distance using the Euclidean mathematical expression for distance.

5 Conclusions

It is crucial for the individual European States to respond to the new challenges of the twenty-first century [39–43]; as a result, it is necessary to analyze the modes of intervention in order for the individual European States to adhere to the new European directions in addition to understanding where to focus their investment.

In order to address the four community-level objectives of promoting sustainable mobility, addressing traffic safety, addressing climate change, and addressing circular economy, underling the Green New Deal, it has been decided to provide a quantitative methodology for assessing the efficiency of infrastructure system in sustainable perspective. Every single one of them was represented by a variable proxy. By doing an efficiency analysis based on the Deterministic Frontier Analysis, it is possible to obtain results in terms of relative average efficiency while also getting a global indication of how far a territory infrastructure system is from the boundaries of best practices.

It is clear the value of the evaluation method proposed for economic policy goals, particularly in the effort to implement an investment plan within a production-focused sector in sustainable development perspective. With an emphasis on that in Italy, the suggested evaluation approach will be used to analyse the sustainable performance of the European highway transportation system. Future findings from the effort will be based on a comparison of the European nations' respective transportation systems using the previously described methodology. It will be feasible to illustrate the limitations and potentials of the suggested assessment framework in connection to geographical elements of analysis by going over the data we will get.

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