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Quality Infrastructure and Sustainable Development: An Empirical Economic Analysis[1]

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Sustainable development is one of the most important goals set by many countries worldwide. The United Nations (UN) has prioritized it as a significant objective within the Sustainable Development Goals (SDGs) program. Sustainable development implies economic growth that benefits both present and future generations without compromising their well-being. Some analysts argue that sustainable infrastructure may be more advantageous when evaluated based on private cost-benefit criteria, although comparisons are needed for clarity. One challenge in testing this hypothesis is the lack of a clear measurable distinction between sustainable and non-sustainable infrastructure at the national or global level. In this study, we utilize two quality infrastructure indices to quantify the extent of sustainable infrastructure. These measures are then applied to a sample of countries to test hypotheses regarding the effect of per capita Gross Domestic Product (GDP) and population on a country's investment in quality infrastructure. The findings support the hypotheses that per capita GDP and population have a nonlinear effect on quality infrastructure, with both variables having a positive effect, albeit at a decreasing rate. At certain higher levels of per capita GDP or population, the effect turns negative. The policy implications for national governments and international organizations are also discussed, highlighting the need for tailored strategies to promote sustainable infrastructure development without undermining other much needed priorities such as eradicating extreme poverty.

Keywords: *development, sustainability, per capita GDP, population, quality infrastructure, marginal effects, elasticity, investment gaps*

Introduction

Since the times of written history, humanity has struggled to fight poverty. Unfortunately, the means were and are scarce, and people had to work hard to make ends meet. Otherwise, as Hesiod put it in the 8th century, "one day's work would have been sufficient to produce all you need for a year" (see Papanikos 2022a). Humanity has made great advances since Hesiodic times, primarily because of investing in infrastructure and continuously improving it, made possible by huge investments in human capital. This has produced new technologies, as beautifully allegorically illustrated by Hesiod's story of Prometheus, who "stole" the well-kept secret of fire. The discovery and learning of how to use fire was a significant step forward in achieving economic development.

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Using a theoretical model, I examined the macroeconomic implications of technical progress in Papanikos (1994).

Since then, humanity has made great achievements in creating the infrastructure which has permitted greater production of goods and services, and therefore satisfied the needs of more and more people. As explained in Papanikos (2024a), absolute (extreme) poverty has been drastically decreased. This was achieved by building huge infrastructures such as more and better roads, water reservoirs, ports, airports, energy grids, schools, hospitals, etc. To a great extent, this was the result of the industrial revolution, globalization, and more recently, hyperglobalization (Papanikos 2024a). The word “more” identifies quantity, and the word “better” identifies quality. A good example of "more and better" is the metro system of the historical city of Athens. There are three lines: one was constructed in the late 19th century, and the other two lines in the early 21st century. Both serve the same purpose, but a simple use of the three lines will demonstrate what "better" means. The new two lines are not only more numerous, but they are also better. They are safer, cleaner, and more comfortable, both the wagons and the stations. In other words, they are of better quality. There are many other such examples in Greece and elsewhere, relating to all types of infrastructures: old and new roads, airports, ports, schools, hospitals, etc. Some people might wrongly argue that this is simply a matter of maintenance, but it is not. What made them better is not just better maintenance, but also better technology which can be applied to old structures. As many contractors know, it is more expensive to renovate than to demolish and build from scratch.

The question that often arises is how much better we want our infrastructure to be. Economics might have an answer by using the well-known model of demand and supply. Demand implies a desire for both quantity and quality, but both come at a cost. This study discusses several issues related to infrastructure from an economic point of view. The first issue is how much infrastructure and quality infrastructure the world needs. Related to this issue is the estimation of future needs in infrastructure and quality infrastructure, and how the gap between the current trend and the future needs can be reduced.

The second issue relates to scarce resources that should be sacrificed to construct more and better infrastructure. This depends on the availability of resources. At the national and global levels, this is measured by per capita Gross Domestic Product (GDP). The higher the per capita GDP, the higher the demand for better infrastructure. The quality of infrastructure is measured by two indices: The Quality Infrastructure for Sustainable Development (QI4SD) Index developed by the United Nations Industrial Development Organization (UNIDO), and The Global Quality Infrastructure Index (GQII) developed by Germany.

There is both private and public infrastructure. Usually, public infrastructure is considered a public good. Governments pay for it through people’s taxes, but citizens use it for free or for a relatively low fee. The more people use the infrastructure, the higher the welfare benefits from building it. Thus, the higher the population of a country, the higher the demand for more and better infrastructure. For example, if 100 people benefit from a bridge and a plain bridge costs X amount of euros, then the per capita cost (price) to build the bridge is X/100. If instead, 1000 people benefit, then the per capita cost is X/1000. The lower cost implies that there might be opportunities to build a better bridge which might cost two times X, but still, the per person cost will be cheaper at X/500. Thus, we make the assumption that the size of the population is an important determinant of more and better infrastructure.

To test the effects of per capita GDP and population size, an empirical regression model is developed and tested using the most recent cross-sectional data of per capita GDP, population, and other variables found to be statistically significant. The empirical results enable the calculation of the marginal effects and the elasticities of per capita GDP and population in achieving optimal levels of quality infrastructure.

The remainder of the paper is structured as follows: The second section discusses and develops a simple ad hoc economic model of quality infrastructure, which leads to a statistical specification. The results of estimation are presented in the fifth section of the paper. The needs for infrastructure in general and quality infrastructure, in particular, are discussed in the third section of the paper. The fourth section presents the two indices of quality infrastructure used in the empirical estimation section of the paper. In the same section, summary statistics of these two indices are also presented. The final section is devoted to the discussion of the main results and policy implications of the findings.

A Simple Economic Model of Quality Infrastructure

Long-term economic prosperity has been one of the most important goals set by national governments and international organizations. Higher economic prosperity can only be achieved through higher economic growth, defined as the increase in the total final quantities of goods and services produced in an economy over the years. Economic growth is necessary for improving people's welfare and eradicating absolute (extreme) poverty. A sufficient condition for this is the presence of social policies that distribute benefits to all, but primarily to the less privileged in society. Social and welfare policies provide basic services to the entire community, such as security, healthcare, elderly care, and education.

How can long-term growth be achieved? While there are many controversies in economics, there is unanimous agreement on the role of infrastructure in promoting long-term economic growth, especially in countries with low levels of development, as measured by their per capita GDP[2]. The logic behind this thesis is straightforward: more machines cannot produce less output than fewer machines, more roads cannot produce less output than fewer roads, more bridges cannot produce less output than fewer bridges, and so on. If empirical studies find negative effects, then one should be suspicious of the quality of data used. This

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[2] Many international, regional, and national organizations, as well as governments, have realized the importance of infrastructure development for overall development. For example, UNCTAD (2011, p. 44) pointed out that "Infrastructure investment and social transfers, for example, are fundamental elements of a long-term development strategy." In Papanikos (1988), I examined the association between investment in construction and post-war Greek economic growth.

holds true for private investment in building infrastructure, but public investments might have different effects depending on the government's effectiveness and efficiency. This is also influenced by the established political system, such as authoritarian regimes versus democracies[3]. This is important because most mega infrastructure projects are built by public authorities, and historically, without exception, no country in the world has undertaken a public works project without it being associated with corruption, lack of transparency, money embezzlement, and lower-than-expected quality infrastructure. This is a widespread phenomenon, but it should not serve as a justification to refrain from building necessary infrastructure[4]. The word "necessary" should be emphasized. Building more than the necessary infrastructure may have the opposite effects on economic growth. This is to be expected when a country becomes so rich that most of its infrastructure might turn out to be akin to pharaonic works or what economists call conspicuous consumption.

Economics makes a fundamental distinction between intermediate and final goods. Only the final goods are included in the measurement of GDP. Intermediate goods are used to produce other intermediate goods and/or final commodities. However, there are some goods that, depending on how they are used, can be classified as either intermediate or final goods. Take, for example, a road. It is an intermediate good when used to transport raw materials to a factory that produces cars, and it is a final (consumption) good when used by a family of four to visit the nearby beach on a Sunday for leisure. A safe and pleasurable road defines quality infrastructure. "Pleasurable" is a multidimensional concept and includes sustainability[5]. This is actually the criterion for building new infrastructure. It should be safer, pleasurable (increasing people's welfare or utility), and of course, sustainable, as it should not undermine the welfare of future generations.

Economics helps policymakers choose among many alternatives in satisfying specific needs for sustainable infrastructure. Various projects are ranked according

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[3] What democracy entails is another issue altogether. Unfortunately, we are far from an ideal democracy. Even in ancient Athens, the cradle of democracy, the reality fell short of what great minds like Plato envisioned for a perfect society. This has serious repercussions in the political decision-making process. I have examined the issue of democracy in a series of papers; refer to Papanikos (2022c and 2022d) and the comments made by Meydani (2022) and Petratos (2022).

[4] This is a phenomenon that no country can eliminate. On the issue of corruption and taxes, refer to Papanikos (2015a, 2024b). Sometimes, in countries where there are many hurdles in decision-making, corruption may contribute to economic growth even if it is suboptimal.

[5] Road safety is an important aspect of what is meant by quality infrastructure. This is a matter of great concern for many countries. Numerous studies have examined various aspects of roads and transportation infrastructure; for example, see Ambunda and Johannes (2020), Athanasopoulos (2014), Babu et al. (2016), Degbe and Song (2019), ElSahly and Abdelfatah (2020), Ghuzlan et al. (2015), Heckmann et al. (2019), Kolpakov and Sipiora (2020), Kos et al. (2017), Onyango et al. (2015), Özen et al. (2021), Perić and Scholl (2017), Sisiopikou (2018), and Yankevich (2024). Energy has been also an important issue in the discussion of sustainability and international politics; see Baier and Meier (2020), Balku et al. (2016), Călătan and Dico (2022), Estrada and Lee (2023), Gavotsis and Moncaster (2015), Osorio et al. (2017), Papanikos (2015b and 2015c), Suru et al. (2017), Yasa (2022). Sustainability has influenced the teaching curriculum of engineering courses; for instance, see Issa (2017). It has also affected how cities are planned and developed; for example, see Chen et al. (2016), Hatem (2024), MacLeod et al. (2023), Mazzi and Gatto (2020), Miletić et al. (2023), Negas and Seco (2022) and Nikologianni et al. (2022).

to their total (private and social) rate of returns. From an economic perspective, infrastructure connects the present, during which time period a decision should be made, with the future, during which periods the benefits from infrastructure are realized. Infrastructures are built by sacrificing current consumption for presumably higher and better future consumption

Thus, one of the determinants of quality infrastructure is the economic wealth of a country. The richer the country, the more sustainable infrastructure can be produced. Infrastructure should also be used by people. The higher the number of people who are served, the higher the demand for such infrastructure, and therefore the lower the cost per person. The combination of these two variables determines not only the quantity of infrastructure (e.g., the number of bridges) but also their quality (sustainability). The richer the country and the more people the infrastructure serves, the higher the quality of infrastructure that can be built. Of course, other variables may play a role. One set of such variables might be captured by dummy geographical variables, such as the continent of the country. This might be a good proxy for different cultures across countries. Thus, a simple economic model of the quality of infrastructure can be depicted as follows:

$$QI = F\ (Y, N, D)$$

where QI represents the quality of infrastructure measured by an index as explained in the fourth section of the paper; Y represents the richness of the country measured by per capita GDP; N represents population, and D represents dummy variables.

This general function should take a reasonable functional form. It is assumed that the best explicit mathematical form that can explain the quality of infrastructure is quadratic because it allows testing the hypothesis of a negative effect of per capita GDP and population on quality infrastructure. The following is such a function:

$$QI = \beta_0 + \beta_1 Y + \beta_2 Y^2 + \beta_3 N + \beta_4 N^2 + \beta_5 D_1 + B_6 D_2 + \ldots + \beta_n D_n + U$$

The β's are parameters to be estimated, as demonstrated in the empirical section of the paper (see section five below). D's are dummy variables, and U is the error term.

This function is sufficiently flexible to permit the testing of the following hypotheses:

1. Per capita GDP (Y) may have a positive, negative, or zero effect on quality infrastructure. The sign of the effect may change depending on the level of per capita GDP.
2. Population (N) may have a positive, negative, or zero effect on quality infrastructure. The sign of the effect may change depending on the number of people living in the country.
3. A series of dummy variables that might have a statistically significant effect on quality infrastructure.

The above hypotheses depend on the sign and statistical significance of the parameters (the β's). The t-statistic is used to diagnose whether a coefficient estimate is statistically significant. The F-statistic is used to determine whether all regressors as a group are statistically significantly different from zero. The coefficient of determination is employed to account for the percentage of quality infrastructure variation that can be explained by the variations of the right-hand variables.

It was mentioned above that the quadratic functional form permits the test of a positive or negative effect of per capita GDP (Y). Taking the first derivative of the above equation with respect to Y, the following condition should hold for a positive marginal effect:

$$\beta_1 + 2\beta_2 Y > 0$$

If it is less than zero, then the effect is negative. If both β_1 and β_2 are positive, then the effect is always positive. However, if the β's are of opposite signs, then there might be a value of per capita GDP where this effect becomes negative.

Similar analysis applies to the variable population (N). The necessary condition for a positive effect is:

$$\beta_3 + 2\beta_4 N > 0$$

The estimation of the parameters also allows for the calculation of elasticities (e), defined as the percentage increase of quality infrastructure for a given percentage change in per capita GDP (Y) or population (N). These elasticities are given by the following two equations:

Income elasticity of quality infrastructure: $e_Y = (\beta_1 + 2\beta_2 Y)\frac{Y}{QI}$

and

Population elasticity of quality infrastructure: $e_N = (\beta_3 + 2\beta_4 N)\,\frac{N}{QI}$

The estimation of the coefficients, the calculation of the marginal effects, and the income and population elasticities are presented in the empirical section of the paper; see section five below.

The next section examines the forecasts of trend investments in infrastructure, the trend of investment needs, and the trend of investment that satisfies the Sustainable Development Goals (SDGs) set by the United Nations.

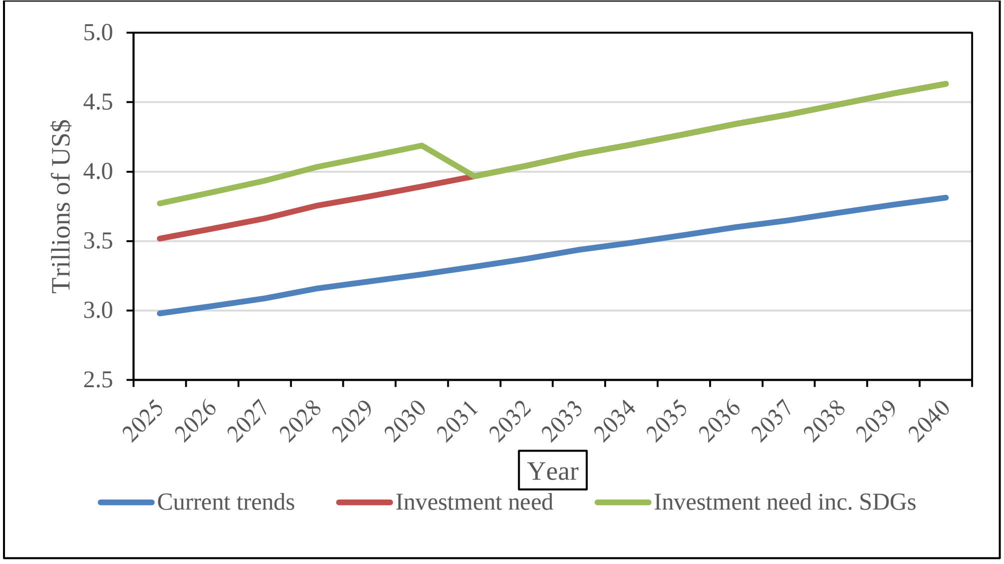
How much Infrastructure is needed?

Quality infrastructure requires investment in infrastructure. The question raised by many academics, policymakers, and various organizations is how much infrastructure is needed, or as economists would state it, what is the optimal size of public infrastructure. Private investment in infrastructure uses market criteria, with the most important criterion being profit maximization.

However, this is not the case for public infrastructure. National governments and international organizations make forecasts on how much infrastructure the world needs. Univariate methods of forecasting are used, which basically assume that past trajectories determine future trends. Figure 1 shows three such forecasts: (a) the trend if the current trajectory of investment continues, (b) the infrastructure that is needed, and (c) the sustainable infrastructure, which is defined as the one that meets the United Nations SDGs. The methodology of forecasting is available in the source shown at the foot of the figure.

The blue line in Figure 1 shows the infrastructure that will be created if the current trend continues. The forecasts are up to 2040. The red line shows how much infrastructure is needed up to 2040, and the green line displays how much quality infrastructure is needed, defined here as meeting the requirements of the SDGs. It is assumed here that the infrastructure and the quality infrastructure needs are the same after 2030. In 2025, the forecast of actual investment in infrastructure is estimated to be $2.98 trillion USD. By 2040, this will increase to $3.81 trillion USD. In 2025, the need for investment in infrastructure will be $3.52 trillion USD, and the need for quality infrastructure will be $3.77 trillion USD. By 2040, both needs will be the same and equal to $4.63 trillion USD.

Figure 1. *Forecasts of Infrastructure Trends and Needs*



Source: Global Infrastructure Hub (https://outlook.gihub.org/).

By 2040, there will be an investment gap of $0.8 trillion USD. However, one might question the linearity of the trendlines. A linear trend of investment implies that investment growth decreases over time. There is no economic justification to assume a declining growth rate. The growth rate of investment depends on the growth rate of GDP, among many other factors. While this goes beyond the scope of this paper, it should be noted that such long-term forecasts can only be used as desired goals rather than as certainties.

The next three figures (Figures 2-4) show the investment gaps in seven different types of infrastructure investment: roads, airports, ports, rail, energy, telecommunications, and water. One way to observe the differences is by examining the change in the investment gap year by year. This is represented by the coefficient of the linear function appearing in each graph. For example, the investment gap in roads is $9.61 billion USD. From 2016 to 2040, this gap accumulates from almost $200 billion USD at the beginning of the forecasting period (2016) to over $400 billion USD at the end of the forecast period in 2040.

Figure 2. *Infrastructure Gap (Needs minus Trends) in Roads*

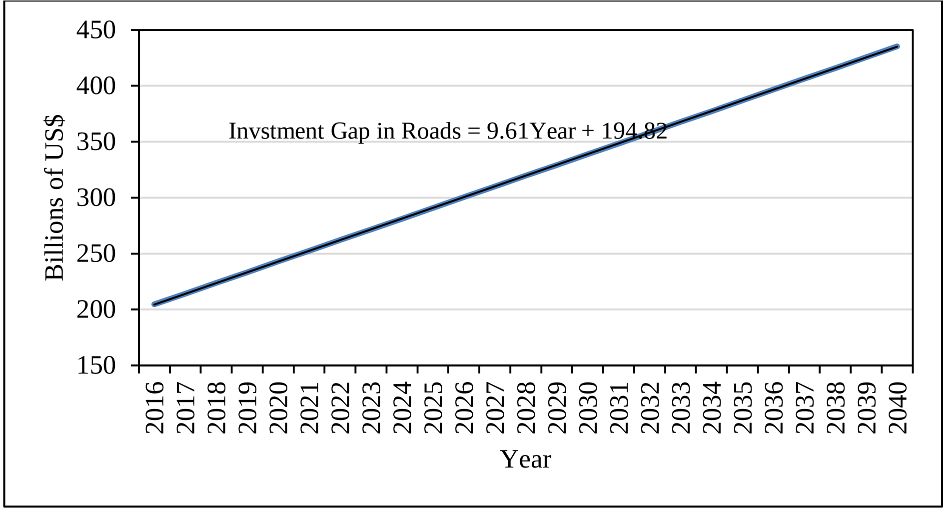


Figure 3. *Infrastructure Gap (Needs minus Trends) in Airports, Ports and Rail*

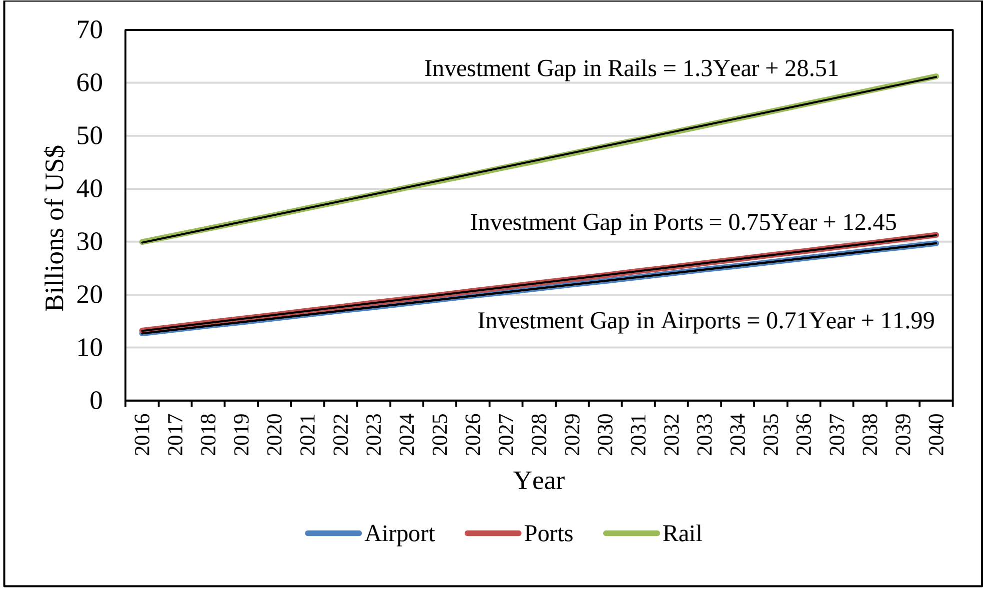
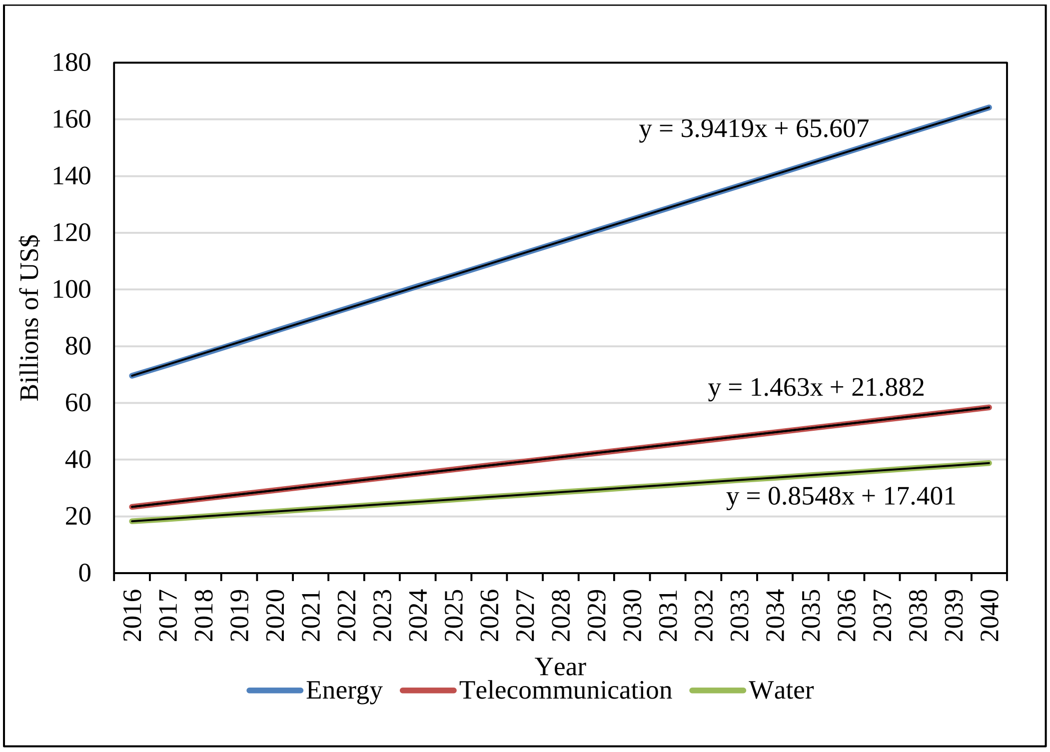


Figure 4. *Infrastructure Gap (Needs minus Trends) in Energy, Telecommunications and Water*



Similar analysis can be applied to the other six investment gaps shown in Figure 3 and Figure 4. In order of importance, the investment gap grows by $3.9 billion USD in energy, $1.5 billion USD in telecommunications, $1.3 billion USD in rail, $0.85 billion USD in water, $0.75 billion USD in ports, and $0.71 billion USD in airports.

These are significant investment gaps, and one may wonder who will finance all these investment projects and how they should be allocated around the globe. One view supports the idea of allocating more to countries that lag behind in economic development, as measured by per capita GDP. If this is true, then per capita GDP should have a positive impact on quality infrastructure when it is low and even negative when it is very high. This hypothesis is tested in the fifth section of the paper. The next section presents the two indices that measure quality infrastructure.

Definitions and Data Sources of Quality Infrastructure

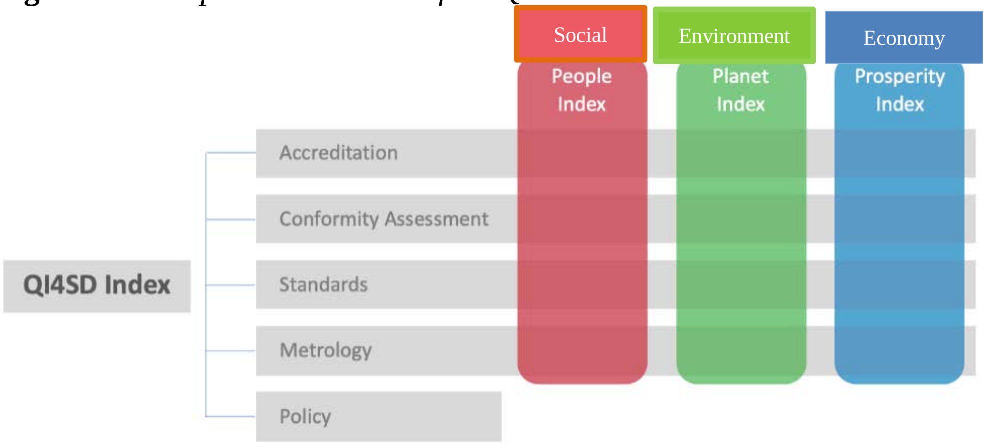
For the purposes of this study, Quality Infrastructure (QI) is considered identical to sustainable infrastructure, which takes into consideration not only private interests but also social concerns regarding the long-term effects that such investment projects might have on the environment, climate change, health, safety, etc. I have examined in detail the economic implications of distinguishing between sustainable and non-sustainable infrastructure in Papanikos (2022b). I argued that the entire discussion about the sustainability of investment projects stems from the higher opportunity cost this type of investment incurs relative to non-sustainable infrastructure. I also emphasized that sustainable investment is not directly observed. This is the reason various organizations have undertaken the herculean task of constructing measures of quality infrastructure. These indices typically range between zero and one or between zero and one hundred and synthesize many other indicators.

In this study, two such indices are used: *The Quality Infrastructure for Sustainable Development* (QI4SD) Index (https://hub.unido.org/qi4sd/) and the *Global Quality Infrastructure Index* (GQII) (https://www.gpqi.org/quality-infrastructure/articles/what-is-quality-infrastructure.html). In this section, these two indices are first defined and then their descriptive statistics are presented.

The Quality Infrastructure for Sustainable Development (QI4SD) Index

The QI4SD index is developed by the United Nations Industrial Development Organization (UNIDO) in collaboration with partner organizations of the International Network on Quality Infrastructure (INetQI). The index is used to compare the level of Quality Infrastructure (QI) to support the UN's Sustainable Development Goals (SDGs). Figure 5 shows the conceptual framework of the QI4SD, and in Appendix Table A1, all the indicators used to construct the overall index are provided, with Table 1 presenting summary statistics.

Figure 5. *Conceptual Framework of the QI4SD Index*



Source: https://hub.unido.org/qi4sd/about.

Each of the five dimensions consists of several indicators listed in Table A1 in the appendix. Data are available for 135 countries. These data are then used to ascertain the association between QI and the level of economic development of a country, as the latter is measured by the per capita GDP and population retrieved from the database of the International Monetary Fund (IMF).

Each dimension has an overall score from 0 to 100, and they are broken down into three different categories: social (people) index, environment (planet) index, and an economy (prosperity) index, with the exception of the policy dimension, in which case only an overall evaluation is available.

Table 1 provides summary statistics of all the dimensions and their breakdown into social, environment, and economy. This illustrates the high dispersion in the scores of the various indicators. However, in this study, only the overall index of quality infrastructure is used.

Table 1. *Summary Statistics of the Various Indicators*

		Average	**Maximum**	**Minimum**	**Standard Deviation**	**Total Countries**
1	QI4SD index	37	88	7	20	135
2	Standards	43	89	6	18	135
3	Conformity	13	77	1	17	135
4	Metrology	29	92	1	23	135
5	Accreditation	47	100	1	38	135
6	Policy	80	100	35	18	61
7	People index	27	98	1	24	135
8	Planet index	26	96	1	24	135
9	Prosperity index	26	92	1	24	135
10	People Standards	36	100	1	28	135
11	People Conformity	18	100	1	26	135
12	People Metrology	17	100	1	27	135
13	People Accreditation	37	100	1	34	135
14	Planet Standards	32	99	1	26	135
15	Planet Conformity	18	100	1	27	135
16	Planet Metrology	16	100	1	27	135
17	Planet Accreditation	36	100	1	33	135
18	Prosperity Standards	31	98	1	25	135
19	Prosperity Conformity	20	100	1	27	135
20	Prosperity Metrology	21	100	1	27	135
21	Prosperity Accreditation	33	100	1	31	135

The summary statistics of this overall index are presented in Table 3. Table 2 shows the geographical distribution of the countries included in this index. This is based on the World Bank classification of countries and is adopted here. However, in the next index, the strict geographical definition of the countries is applied. The empirical results are not sensitive to this difference in classification.

Table 3 provides the descriptive statistics of the three variables used in the empirical analysis. The minimum value of the index is 6.8, and the maximum is 87.57. It is not 100 because no country has 100 in all indicators. The average is 37.41, and the standard deviation is 20.31 percentage points. The median of 34.19 is not much different from the mean, and the measures of skewness and kurtosis show that the distribution of the index is close to a normal distribution. High skewness is evident in the distributions of per capita income and population. There are large variations in per capita GDP and population, with an average of $28,323 and 53.46 million people, respectively.

Table 2. *Geographical Distribution of the Countries Included in the QI4SD Index*

Region	**Number of Countries**	**Percentage of Total**
Sub-Saharan Africa	27	20%
East Asia & Pacific	15	11%
Europe & Central Asia	46	34%
Latin America & Caribbean	22	16%
Middle East & North Africa	16	12%
North America	2	1%
South Asia	7	5%
Total	**135**	**100%**

Table 3. *Summary Statistics of the QI4SD Index*

Statistic	**QI4SD Index**	**Per Capita GDP (US$)**	**Population (in millions)**
Mean	37.41	28323	53.46
Median	34.19	19295	10.85
Standard Deviation	20.31	25427	173.69
Kurtosis	-0.84	3	52.57
Skewness	0.42	2	7.04
Range	80.77	131663	1409.42
Minimum	6.80	809	0.10
Maximum	87.57	132472	1409.52
Countries	135	135	135

The Global Quality Infrastructure Index (GQII)

This index was initiated by the German Federal Ministry for Economic Affairs and Climate Action in collaboration with many national and international organizations, including the European Union. More information on the methodology of this index can be found at https://www.gpqi.org/about-the-project.html. As stated on their website, “The EU’s legal framework and approach to quality infrastructure form the basis for Germany’s position in the dialogues.” As we shall demonstrate in the empirical section of this paper (Section Five), this might be the reason why the regression results show that only the dummy variable “Europe” was statistically significant, indicating that these countries share a common policy approach to quality infrastructure. “Common” here should be interpreted as meaning obligations and, of course, a common fund for financing such projects at the European level. Even European countries that are not members of the European Union benefit from such funding opportunities.

The conceptual framework of the GQII measurement is depicted in Figure 6. It is very similar to the previous index. This index includes more countries, totaling 184, compared to the 135 countries included in the previous index. The geographical distribution of the countries included in this index is provided in Table 4.

Figure 6. *Conceptual Framework of the GQII Measurement*

Source: https://www.gpqi.org/quality-infrastructure/articles/what-is-quality-infrastructure.html.

Table 4 can be compared with Table 2, even though the classification is different; however, we retain the one suggested by the organization that developed this index. Countries from Africa account for 28% of the total, those from Asia for 24%, one-fourth of the countries were European, North America and South America represented 9% and 10%, respectively, and Oceania accounted for 4% of the total countries included in the sample.

Table 4. *Geographical Distribution of the Countries Included in the GQII Index*

Continent	Number of Countries	Percentage
Africa	51	28%
Asia	44	24%
Europe	46	25%
North America	17	9%
Oceania	8	4%
South America	18	10%
Total	184	100%

Table 5 provides summary statistics of the three variables. The average value of the index is 0.547, with a minimum value of 0.168 and a maximum of 0.994. It's worth noting that the values of the index range from zero to one. The mean value of per capita GDP is $17,196 thousand, and the population is about 4.3 million people.

Table 5. *Summary Statistics of the GQII 2023 Index*

Statistic	**GQII 2023**	**Per Capita GDP (US$)**	**Population**
Mean	0.547	17196	43239777
Median	0.508	6673	9918412
Standard Deviation	0.239	25824	153052634
Kurtosis	-1.206	12	71
Skewness	0.324	3	8
Range	0.826	183845	1428588079
Minimum	0.168	238	39584
Maximum	0.994	184083	1428627663
Countries	184	184	184

Source: Raw data were retrieved from https://gqii.org/gqii-2023/. Population is for 2023. The most recent (2022 or 2021) per capita GDP was used.

Empirical Evidence

The aim of this study is to demonstrate the association between quality infrastructure, per capita GDP, and population. We assume causality, with most economists agreeing that the causal relationship runs from output and population to quality infrastructure. The latter is considered a special type of investment with characteristics aligning with the Sustainable Development Goals (SDGs) set by the UN.

The accelerator model of investment in economic analysis establishes investment as a function of output, providing a theoretical foundation for the assumed causality. Additionally, we test the possibility that this relationship may not be linear. For the purposes of this empirical approach, we chose a quadratic functional form, nesting both hypotheses to be tested: the positive or negative effect of per capita GDP and population. This effect may vary and could depend on the level of per capita income and population. Furthermore, the marginal changes may not be consistent and could be influenced by income and population levels.

While many regressors were included in the empirical equation, only statistically significant coefficients are reported here. Table 6 presents the regression results with the dependent variable being the two quality infrastructure indices. The coefficient of determination is 53.17% for the first regression and 62.32% for the second. This indicates that the variations in the right-hand variables account for 53.17% and 62.32% of the variations in the quality infrastructure index. The F-statistic further indicates that all coefficients of the independent variables, as a group, are statistically significant.

In both indices, it was found that the same variables were statistically significant. Only the dummy variable "Europe" was statistically significant in the two regressions. The estimates for the other geographical dummy variables, which were not statistically significant, are not reported in the table. Why is Europe different? One obvious explanation might be that Europe has been pursuing policies at the European level, utilizing institutions such as the European Union and the Eurozone to promote quality infrastructure. There are no analogous institutions in other countries around the world, where each country follows its own policies. However, this intriguing analysis extends beyond the scope of this study.

Table 6. *Regression Results*

Quality Infrastructure Index **Variables**	**QI4SD** (mean=37.4979)	**GQII** (mean=0.5466)
Constant	12.56 (6.76)	0.33 (20.34)
Per Capita GDP (Y) in 000s	0.7993 (5.96)	0.0090 (8.65)
Per Capita GDP (Y) in 000s squared	-0.0051 (4.67	-5.9E-05 (9.28)
Population (N) in millions	0.1807 (5.55)	0.0025 (6.73)
Population (N) in millions squared	-0.0001 (4.59)	-1.46E-06 (5.75
Dummy: Europe	11.27 (2.98)	0.19 (6.59)
R^2 Adjusted	0.5317	0.6232
F-Statistic	31.43	61.54
Number of Observations (countries)	135	184

Note: Absolute values of t-statistics in parentheses.

In both regressions, the effects of per capita GDP and population exhibit consistent signs. It's worth noting that per capita GDP is measured in thousands of dollars and population in millions of people. Although the two indices have different scales, this doesn't affect the sign of the parameters and the elasticity. However, it does make it initially challenging to compare the magnitude of the marginal effects due to the scale differences of the quality infrastructure.

Per capita GDP shows a positive effect, as expected, indicating that quality infrastructure increases with per capita output. However, the squared term is negative, suggesting that this increase occurs at a decreasing rate. As income rises, countries can allocate more funds to quality infrastructure, but there's an upper limit beyond which the effect turns negative. Mathematically, it's possible for the squared term's effect to dominate the linear effect of per capita output, resulting in an overall negative effect. This occurs if and only if:

$$\beta_1 + 2\beta_2 Y < 0$$

By substituting the estimated values for the coefficients in the regression model of QI4SD, we can determine the threshold value of per capita income at which its effect becomes negative:

$$0.7993 - 0.01Y < 0 \Longrightarrow Y > 0.7993/0.01 \Longrightarrow Y > 78{,}363 \text{ US\$}$$

Similarly, we can calculate the income effect in the regression model that uses the GQII as the dependent variable:

$$0.0090 - 0.000118Y < 0 \Rightarrow Y > 0.000118/0.0090 \Rightarrow Y > 76{,}271 \text{ US\$}$$

The similarities between these two numbers are striking, despite being derived from different methodologies for measuring quality infrastructure and different country samples. Given that these values represent critical turning points from positive to negative effects on quality infrastructure, one could argue that optimal quality investment occurs around these thresholds.

A similar analysis can be applied to estimate the effect of population. Larger countries invest more in quality infrastructure but at a decreasing rate. This is intriguing as it may suggest economies of scale based on population size. More people mean more potential users, making quality investment more beneficial. What, then, is the optimal population size for the two indices?

For the QI4SD index: $0.1807 - 0.0001N = 0 \Rightarrow N = 0.1807/0.0001 \Rightarrow$
$N = 1807$ millions of people

For the GQII index: $0.0025 - 0.00000146N = 0 \Rightarrow N = 0.0025/0.00000146 \Rightarrow$
$N = 1712$ millions of people

Once again, the outstanding similarity between the results highlights that the two different methodologies of data collection for constructing a quality infrastructure index and the diverse country samples did not impact the outcomes. However, the figures of 1.8 and 1.7 billion people lie beyond the current population range of any single country. This suggests that, concerning population levels, there is a desire for more quality infrastructure.

Table 7 presents the marginal effects and elasticities evaluated at the average values of the two indices, per capita GDP, and population. As anticipated from the preceding analysis, all marginal effects are positive when evaluated at the mean values. However, what holds particular interest here is the elasticity of income per GDP and population on the demand for quality infrastructure.

The elasticities are unit-free numbers and comparable across samples. Given that the marginal effects are positive, all elasticities must also be positive. The elasticities of the GQII index are lower than those of the QI4SD. A 10% increase in per capita GDP increases the quality infrastructure by 3.86% in the first index and 2.19% in the second index. Similarly, a 10% increase in population raises the quality infrastructure index by 2.42% in the first case and 1.88% in the second case.

These empirical results align with economic theory expectations. The estimates obtained fall within the range of values predicted by economic theoretical analysis. However, it's important to note that these evaluations are conducted at the average values of all variables. They provide insights into the long-term trajectory of the effects of per capita GDP and population on quality infrastructure but do not address short-term effects at the country level. Some aspects of these important issues are discussed in the final section of this study.

Table 7. *Marginal Effects and Elasticities*

QI Index	Variable	Marginal Effect Evaluated at Mean Values	Elasticity Evaluated at Mean Values
QI4SD (mean=37.4979) (countries=135)	Per Capita GDP in 000s (mean=28.32)	0.51	0.386
	Population in Millions (mean=53.46)	0.17	0.242
GQII (mean=0.5466) (countries=184)	Per Capita GDP in 000s (mean=17.20)	0.007	0.219
	Population in Millions (mean=43.24)	0.002	0.188

As an example, we use the above findings to analyze one country, Greece, to determine whether it is an underperformer or overperformer compared to the other 183 countries used in the estimation of the second index. According to the GQII index, Greece obtained a score of 0.8253 in 2023, ranking 38th in the world. It's important to ascertain whether, given Greece's per capita GDP, population, and its status as a European country, it could achieve better performance, or if its score exceeds what the model would predict. The equation for Greece is as follows:

$$QI_{GR} = \beta_0 + \beta_1 Y_{GR} + \beta_2 Y_{GR}^2 + \beta_3 N_{GR} + \beta_4 N_{GR}^2 + \beta_5 EUROPE$$

Substituting the estimated parameters, we obtain:

$$QI_{GR} = 0.33 + 0.009Y_{GR} - 0.000059Y_{GR}^2 + 0.0025N_{GR} - 0.00000146N_{GR}^2 + 0.19*(1)$$

The per capita GDP of Greece was $20.73 thousand USD, and Greece's population was 10.52 million people. Substituting these numbers, we obtain:

$$QI_{GR}=0.33+0.009*20.73 - 0.000059*430 + 0.0025*10.52 - 0.00000146*111 + 0.19$$

The estimated score for Greece is:

$$QI_{GR} = 0.7074$$

The score reported by the GQII index is 0.8253, a difference of 0.1179 points or 16.67% higher. Thus, Greece is performing better than what would have been predicted by its per capita GDP and population alone. Additionally, Greece being European adds 0.19 points to the index.

Using the other index (QI4SD), which includes fewer countries (135), Greece is performing better than expected by 7.74%. The score reported by the index for Greece is 49.84. The expected score given Greece's per capita GDP and population is 46.26, a difference of 3.58 units.

Discussion and Conclusions

Are there any policy implications for national or international authorities? The evidence indicates that quality infrastructure increases with income, but there is an upper limit of less than $80,000 per capita GDP in US dollars. This suggests that priority should be given to raising per capita GDP, as presumably this would enable relatively less affluent countries to allocate more funds toward quality infrastructure. Population does not present a bottleneck. The evidence shows that there are still economies of scale to be realized, and the existing quality of infrastructure can accommodate more people than it currently does.

Overall, indices serve as valuable benchmarks, and national governments and other authorities can utilize them to not only enhance the quality of infrastructure but also to improve the evaluation process of what is beneficial for a country given its current per capita GDP, population, and other characteristics. This assumes, of course, that when policymakers face a dilemma between infrastructure and quality infrastructure, it's because the latter is typically more expensive than the former.

Many policymakers, governments, and lobby groups argue that there exists a difference between the social and private (profit-oriented) rates of returns for infrastructure and quality infrastructure. However, measuring social rates of returns is no easy task, and methods such as contingency evaluation methods are subjective and may not accurately reflect the true preferences of citizens. Additionally, considering that public investment projects are often burdened with corruption, there is a pecuniary incentive for those involved in illegal activities related to these projects to lobby in favor of overestimating the social rates of returns.

The evidence presented here could provide guidance to policymakers. Quality infrastructure, however it may be defined, has an upper limit determined by a country's per capita GDP and population size. The evidence for Greece, as demonstrated in this study, offers two interpretations. One is that Greece is an overperformer because it allocates more resources to quality infrastructure than expected given its per capita GDP, population, and status as a European country. The second interpretation could be that Greece is spending more (or possibly wasting) public funds to achieve higher quality infrastructure than necessary. These limited public resources might have been better utilized in smaller, more focused projects with higher social rates of return. Further research is necessary to illuminate this important issue not only for Greece but also for other countries.

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Appendix

Table A1. *List of Indicators in the QI4SD Index - General Indicators (G) and 3P Indicators (P) in the Framework*

Dimension	Name	Description	Unit	Organization	Type	Weight
Accreditation	Scopes of IAF accreditation bodies	Number of scopes for the IAF Multilateral Recognition Arrangement mapped into the 3Ps.	Number	IAF	P	1
	Signatory to the IAF MLA	Existence of an accreditation body that is a signatory to the IAF Multilateral Recognition Arrangement.	Yes/no	IAF	G	1
	Scopes of ILAC accreditation bodies	Number of scopes for the ILAC Mutual Recognition Arrangement mapped into the 3Ps.	Number	ILAC	P	1
	Signatory to the ILAC MRA	Existence of an accreditation body that is a signatory to the ILAC Mutual Recognition Arrangement.	Yes/no	ILAC	G	1
Conformity	Membership of IEC conformity assessment systems	Country membership in the four IEC conformity assessment systems (IECEE, IECEx, IECRE, IECQ), range 0 to 4.	Number	IEC	G	1
	Number of IECEE certificates recognised	Number of IECEE certificates present in country.	Number	IEC	G	1
	Number of recognised certificates (IQNet)	Number of recognised certificates from IQNet database mapped into 3Ps.	Number	IQNet	P	0.5
	Membership of IQNet	Level of involvement in IQNet, location of head, subsidiary offices and origin of Certification Bodies.	Composite score	IQNet	G	1
	Number of recognised certificates (ISO)	Number of recognised certificates from ISO database mapped into 3Ps.	Number	ISO	P	0.5
Metrology	Participation in CIPM Consultative Committees	Sum of overall participation in ten Consultative Committees, range 0 to 20.	Number	BIPM	G	1
	Participation in key and supplementary comparisons	Sum of the scores for the key and supplementary comparisons.	Number	BIPM	G	1
	Number of CMCs	Total number of Calibration and Measurement Capacities (CMCs) in any area mapped into 3Ps.	Number	BIPM	P	0.5
	Breadth of CMCs	Total breadth of Calibration and Measurement Capacity (CMC) types with at least one capacity mapped into 3Ps	Number of types	BIPM	P	0.5
	Membership of BIPM	Membership of BIPM, range 0 to 2.	Categorical	BIPM	G	1
	Membership of OIML	Membership of OIML, range 0 to 2.	Categorical	OIML	G	1
	OIML-CS - number of services offered	Number of OIML Certification System (CS) services offered.	Number	OIML	G	0.5
	OIML-CS - number of services recognised	Number of OIML Certification System (CS) services recognised.	Number	OIML	G	0.5
	Involvement in OIML project groups	Number of project groups for which each country is a convener (C), participating member (P) and observer (O).	Composite score	OIML	G	1
Policy	Participation in capacity building programmes	Participated in capacity building programmes related to QI from BIPM, OIML, ISO, WTO in the last two years, range 0 to 4.	Number of types	UNIDO/ISO	G	1
	Quality Policy in place	National or regional Quality Policy in place, a policy for developing and sustaining effective QI.	Yes/no	UNIDO/ISO	G	1
	Dimensions of QI addressed by Quality Policy	QI dimensions (Metrology, Standards, Accreditation, Conformity Assessment) addressed by the Quality Policy or regulatory framework, range 0 to 4.	Number	UNIDO/ISO	G	1
	Support and funding for Quality Policy	Governmental support, including funding, stipulated in the Quality Policy or in the regulations and directions supporting QI.	Yes/no	UNIDO/ISO	G	1
	Government/political endorsement for Quality Policy	Development and implementation of the Quality Policy being endorsed by the political level or led by the highest level of government.	Yes/no	UNIDO/ISO	G	1
	Government approval of Quality Policy	Quality Policy approved by government or regional country grouping.	Yes/no	UNIDO/ISO	G	1

	Stakeholder involvement of Quality Policy	Involvement of stakeholders from the private and public sectors, consumers, producers in the Quality Policy process.	Yes/no	UNIDO/ISO	G	1
	Consideration of diversity in Quality Policy	Gender balance and other diversity aspects considered in the Quality Policy process.	Yes/no	UNIDO/ISO	G	1
	Implementation plan for Quality Policy	Presence of implementation plan for the national Quality Policy, i.e. a plan that sets out the steps for achieving the policy objectives.	Yes/no	UNIDO/ISO	G	1
	Monitoring and evaluation for Quality Policy	Mechanism(s) for monitoring and/or evaluating the implementation/outcomes of the Quality Policy.	Yes/no	UNIDO/ISO	G	1
	Reviewing and updating for Quality Policy	Mechanism(s) for periodically reviewing and updating the Quality Policy.	Yes/no	UNIDO/ISO	G	1
Standards	Adopted ISO standards	ISO standards that had been adopted into national legislation and mapped into the 3Ps.	Number	ISO	P	1
	Adopted IEC standards	IEC standards that have been adopted and mapped into the 3Ps.	Number	IEC	P	1
	Membership of IEC	Membership of the IEC, range 0 to 3.	Categorical	IEC	G	1
	Participation in IEC technical committees	IEC technical committees (TCs) participation mapped into the 3Ps.	Number	IEC	P	1
	Membership of ISO	Membership of the ISO, range 0 to 3.	Categorical	ISO	G	1
	Participation in ISO technical committees	ISO technical committees (TCs) participation.	Number	ISO	G	1
	Membership of ITU	Composite score of membership of ITU.	Composite score	ITU	G	1