

Perez Martinez, Jorge; Hernandez-Gil, Felix; Peña, Daniel

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Assessing the relationship between the ICT development and the achievement of the Sustainable Development Goals in Europe using regression models: policy implications

Jorge Perez Martinez, Felix Hernandez-Gil, Daniel Peña
GTIC Group, Universidad Politecnica de Madrid (UPM), Spain

Abstract

The relationship between the implantation of Information and Communication Technologies (ICT) and the achievement of the Sustainable Development Goals (SDG), agreed at the United Nations is studied using regression models based on indicators on the SDG achievement and on the ICT adoption. The 17 SDG and their specific indicators are analyzed paying special attention to the European countries. Results show a high positive association between the general SDG achievement and the ICT adoption. The aspects that benefit most clearly from digitization are those related to social and economic progress, including those such as poverty reduction, health care, quality of education and industry improvement. However, the study also shows that digitalization is associated to a poor achievement in areas related to the natural environmental preservation and climate change fight, including among them those related to electronic waste and greenhouse gas emissions. This is probably mostly due to the indirect effects.

Keywords Sustainable Development Goals; Information and Communication Technologies; Inclusive Internet Index, European Union

1. Introduction

The Sustainable Development Goals (SDG) [1] were adopted at the United Nations in 2015 in order to facilitate the evolution towards a more sustainable economic growth model that preserves the planet's ecosystem and guarantees reasonable living conditions for all. There are 17 SDGs, with associated targets, that must be fulfilled by 2030. These goals have become a necessary reference to guide the activities of all stakeholders. Governments and companies worldwide are aligning their strategies as well as measure and manage their contribution to the achievement realization of the SDGs.

Information and Communication Technologies (ICT) are one of the most relevant transformation factors in today's society, and they should play a crucial role in advancing towards the fulfillment of the SDGs. Some studies have been published previously aimed at finding the contribution of ICT to the achievement of the SDG. Wu et al. [2] carried out a general review of the state of the art of studies linking the ICT and the SDG progress. Antonio García et al. studied how the investment in ICT infrastructures in some selected Latin American and

Caribbean countries can help to advance in some of the SDGs [3]; Huawei has analyzed the contribution of ICT to six selected SDGs [4]; the GSMA association is publishing yearly a report [5] explaining the contribution of the mobile connectivity services provided by their members to the achievement of the SDG.

There are also other studies aimed to link the advances in ICT with the environmental sustainability using panel statistical techniques that are related to the indicators used to measure the progress in the SDG linked to the environment. Añon et al. [6] concluded that ICT can contribute positively to reduce CO₂ emission once threshold level of development is reached. Khan et al. also investigated the same issue confirming the existence of the Kuznets curve [7]. Cioacă et al. [8] studied the impact of ICT on economic growth and reduction of inequality finding positive and negative impacts. Danish et al. [9] investigated the nexus between ICTs, economic growth, financial development, and environmental quality in emerging economies.

In this paper, the relationship between the progress in the implementation of ICTs and compliance with the 17 SDGs is studied, including specific indicators related to social progress and ecosystem preservation, with special emphasis on the European Union countries.

2. Data sources

The implementation of ICT technologies has been measured using the Internet Inclusive Index (3i) prepared by The Economist Intelligence Unit [10] which provides a very extensive information on various aspects of ICT including indicators related to the infrastructure availability, the Internet access, the value of being connected in terms of useful services, and the capacity among Internet users to take advantage of being online. This index includes data for more than 100 countries in the world including 21 countries in the European Union.

The 3i index includes an aggregated global indicator that is obtained by the weighted sum of lower-level indicators, 4 second level indicators: availability (quality and breadth of available infrastructure required for Internet access), affordability (the cost of accessing the Internet), relevance (value of being connected in terms of useful services) and readiness (the capacity among Internet users to take advantage of being online). Each category receives a score, calculated from a weighted average of the underlying indicators. There are several tens of third level

indicators to calculate the four categories. A detailed description of the methodology and data used can be found in [11].

The SDG achievement data have been obtained from the Sustainable Development Report published by the Bertelsmann Stiftung and the Sustainable Development Solution Network (SDSN). These data include a global aggregated SDG indicator, 17 indicators for each of the SDG objectives and several tens of third level indicators for specific parameters like CO₂ emission or electronic waste. Detailed information can be found in [12].

The Global Competitive Index (GCI), prepared by the World Economic Forum [13], which integrates the macroeconomic and the micro/business aspects of competitiveness into a single index has been also used to quantify the competitiveness. Other data like countries population or GDP were obtained from the World Bank data base [14].

All the data to calculate the indicators were normalized (0-100) and the aggregated indicators were obtained by the weighted sum, using the methodology previously referenced for each indicator.

3. Statistical methods

We considered the use of several multivariate regression models to characterize the relationship between the digitalization and the SDG achievement indicators. The use of a panel analysis based on the temporal evolution of the achievement indicators [15] could be a sound approach to understand the contribution of different factors to the achievement of the SDG. However, since these goals were defined in the year 2015, the length of temporal series of indicators on achievement is still too limited. So, we carried out the regression analysis on the available cross-sectional data.

The relationship among indicators was modelled using initially using linear regressions. The parameters of the functions were calculated using the linear least square method. For the case of bivariate regression, we saw that it is possible to improve the regression accuracy and best fit the scattered data, in some cases, by using nonlinear functions to reduce considerably the determination factors (R²). Table I shows the different kind of regression functions used.

Table I. Functions for bivariate regressions

Regression function	parameters
$y = ax + b$	a, b
$y = ax^2 + bx + c$	a, b, c
$y = a e^{bx}$	a, b
$y = a e^{bx} + c e^{dx}$	a, b, c, d
$y = \frac{a}{1 + (\frac{x}{b})^c}$	a, b, c
$y = a \log(x) + b$	a, b

4. Results

4.1 Relationship among digitalization, SDG, and competitiveness

The relationship between the global aggregated SDG, GCI, 3i and Gross Domestic Product (GDP) for 100 countries with available data was studied. Fig. 1 shows the global SDG achievement as function of the 3i index score. There is a strong positive correlation between the two indexes (R²=0.82) showing that an improvement in ICT is associated to a better SDG global achievement. For the case of the European Union countries (blue points in fig.1) is lower (R²= 0.45).

This positive correlation with ICT indicators occurs also for the competitiveness (GCI) and economic growth (GDP) indicating that the ICT indicator acts as a proxy for development. The autocorrelation matrix, shown in Table II, indicates a high collinearity among these indicators with correlation coefficients (R²) between 0.73 and 0.85.

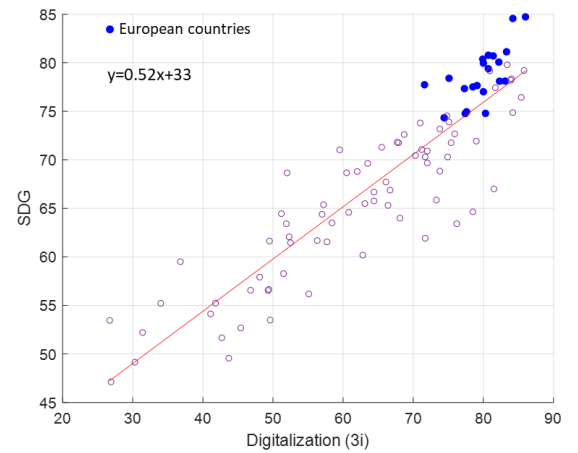


Fig. 1. SDG global score vs. 3i aggregated index

Table II. Correlation (R²) among SDG, 3i and log(GDP)

	3i	SDG	GCI	log(GDP)
3i	1			
SDG	0,82	1		
GCI	0,81	0,73	1	
log(GDP)	0,85	0,73	0,8	1

The possibility of using a multivariate regression was considered and some calculations were carried out to understand the contribution of the three factors (3i, GCI and GDP) to the SDG achievement. However, the high degree a collinearity among the variables impeded quantifying properly the relative contribution of each factor.

Fig. 2 shows a parallel plot where the scores in 3i, SDG, GCI and GDP can be seen for the 21 countries from the European Union included in the 3i statistics. The

countries are sorted in each column according to their score in the index for each column. There is, in general, a reasonable correlation between the ranking in the four indicators. However, some countries show significant differences in their position in the four rankings. The countries have been grouped in the clusters (yellow, violet, and green) according to their score in the four indicators using a dendrogram.

4.2 Contribution of ICT to the achievements of the 17 SDG

Table III shows the significant Pearson correlation coefficient ($p < 0.05$) among the 17 SDG achievement indicators and the 4 components of the 3i index. As it can be seen the correlation is not always as positive and strong as it was for the aggregated indicators. Availability of ICT services is the 3i indicator with a highest correlation with the SDG achievements in most cases. The three additional 3i indicators related to affordability, relevance and readiness show similar but lower correlation levels. The SDGs with higher positive correlation are those relate to no poverty, good health and well-being, quality education, affordable and clean energy and industry innovation and infrastructure. The indicators related to responsible consumption and production, and climate action have a high negative correlation, indicating that countries with better indicators in ICT have a lower score in the achievement of these SDGs.

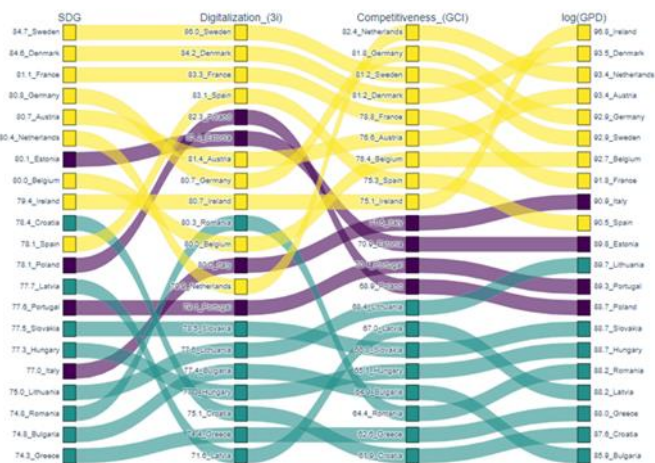


Fig. 2. Score of European countries for the aggregated 3i indicator, SDG, competitiveness (GCI) and GDP.

There are four SDG indicators which shows no or very low correlation with ICT: those related to inequalities reduction, life below water and on land, and the partnership to achieve the goals.

The analysis of the Pearson correlation coefficient between the 17 SDG achievement indicators and the 4 components of the 3i index for European countries showed limited statistically significant information because only 15% of the correlation coefficients were significant ($p < 0.05$). Figure 3 shows a parallel plot where the scores in the four components of the ICT aggregated indicators (availability, affordability, relevance and readiness) can be

seen together with SDG aggregated index for the European countries, showing the heterogeneity of the situation in each country.

Table III. Pearson correlation coefficient (R) between the 17 SDG achievement indicators and the 3i sub indicators.

	Availability	Affordability	Relevance	Readiness
1. No poverty	0,89	0,74	0,75	0,54
2. No hunger	0,69	0,57	0,61	0,56
3. Good health and Well-being	0,88	0,68	0,78	0,60
4. Quality education	0,83	0,66	0,71	0,59
5. Gender equality	0,39	0,32	0,32	0,33
6. Clean water and sanitation	0,73	0,68	0,65	0,52
7. Affordable and clean energy	0,87	0,75	0,74	0,54
8. Decent jobs and economic growth	0,61	0,52	0,61	0,59
9. Industry innovation and infrastructure	0,86	0,80	0,79	0,75
10. Reduced inequalities	0,39	0,30	0,32	-
11. Sustainable cities and communities	0,58	0,48	0,44	0,38
12. Responsible consumption and production	-0,71	-0,62	-0,60	-0,55
13. Climate action	-0,68	-0,54	-0,54	-0,55
14. Life below water	-0,29	-	-	-
15. Life on land	-	-	-	-
16. Peace and justice	0,74	0,63	0,60	0,60
17. Partnerships to achieve the goals	-	-	-	-

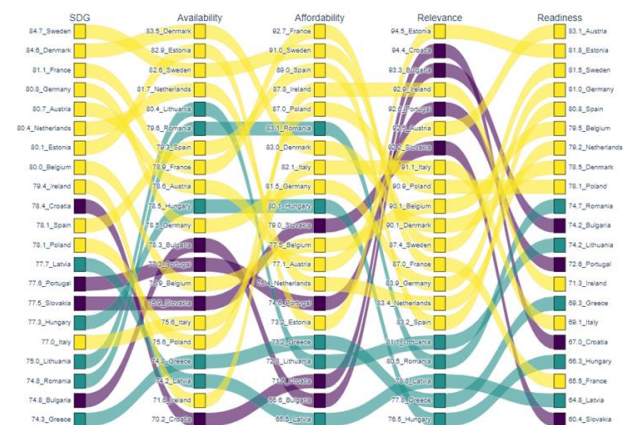


Fig. 3. SDG global score vs. four sub indicators of digitalization (3i) for European countries.

4.3 Contribution of ICT to specific SDG aspects

The SDG indicator achievement for each of the 17 objectives is calculated by an average weight of 85 third level indicators which include specific parameters intended to measure the score achievement of each SDG. Fig.4 shows a heatmap of the Pearson correlation coefficients for all the countries included in this study. As it can be seen in this case there are important differences in the behavior of the indicators depending on the 3i sub indicator considered. 281 of the 340 correlation coefficients were statistically significant with p value under 0.05 (83%). 78% of the significant coefficient have a positive correlation value indicating the clear positive association between the different aspects of the ICT

adoption and the improvement of the SDG indicator achievement.

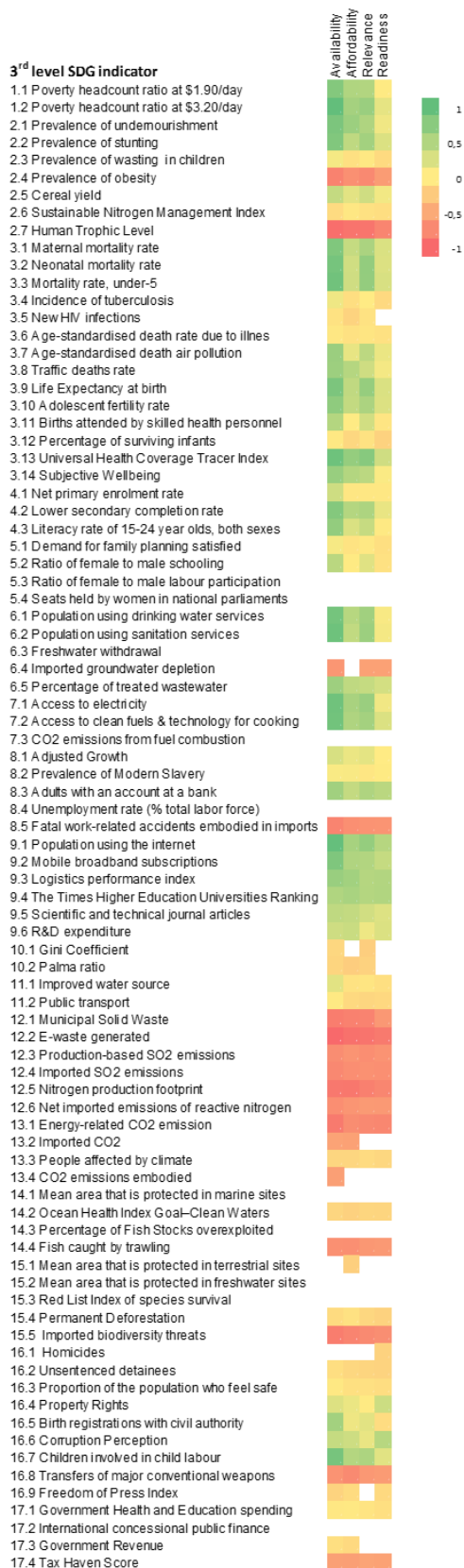


Fig. 4 Heatmap of the Pearson correlation coefficient (R) between the 85 third level SDG achievement indicators and the 3i sub indicators

Among others, we can see a high positive correlation between ICT indicators and those related to poverty headcount, prevalence of undernourishment, mortality of different kinds, lower secondary completion rate, population with access to sanitation services and children involved in child labour. 22 percent of the coefficients in the heatmap have negative coefficients values, indicating that improvement in ICT is often associated to a worse achievement in specific aspects of the SDGs. Some of SDG indicators with higher negative correlation are those related to the human trophic level, the electronic waste, the CO₂ emissions, the SO₂ emissions, the nitrogen emissions, or the protection of areas important for biodiversity.

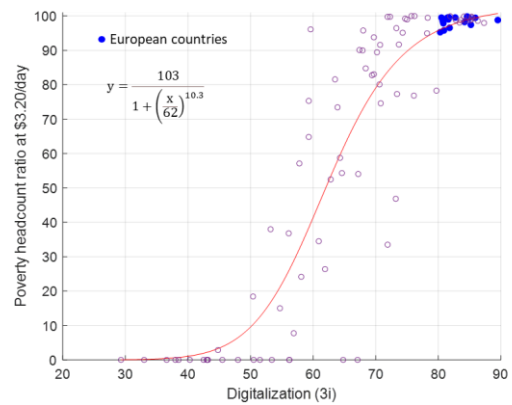


Fig. 5 Poverty head count at \$3.90/day as function of the 3i global score.

Fig.5 shows the poverty head count at \$3.90/day as function of the digitalization global score (3i). The three parameters logistic function fits well the behavior in this case. The determination coefficient is high (R²=0.82). The increase in digitalization is associated to a drastic and clear improvement in the achievement.

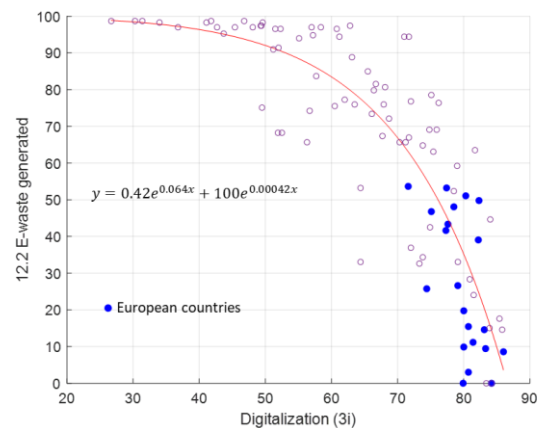


Fig. 6 Electronic waste as function of the digitalization global score (3i).

Fig.6 shows the electronic waste generated as a function of the digitalization global score (3i). A double exponential function fits well the data (R²=0.76). The countries with high digitalization level show a poor score in this indicator.

4.4 Relationship between ICT usage and SDG achievement in Europe

Among the indicators included in the 3i digitalization index, the ICT usage represents well the degree of adoption of the ICT technologies and shows a considerable level of correlation with the SDG indicators. Table IV shows the Pearson correlation coefficient between the ICT usage and the SDG indicators, and the sensitivity of the SDG indicators to the variations in the ICT usage (the slope of the linear regression function). Only significant values with $p < 0.05$ are shown.

There is a clear positive association between the ICT usage and improvement of most SDG indicators. 13 of the 18 indicators (17 SDG + 1 global SDG achievement) show significant correlation and most of them (11) show positive correlation.

The industry innovation and infrastructure SDG indicator shows the higher sensitivity and a high correlation coefficient. This is in part because the SDG achievement indicator includes the ICT technologies. European countries are in the group of countries with better achievement.

The gender and economic inequalities reduction indicators (SDG 5 and SDG10) show positive correlation with ICT usage. This is different from what happens if all the world countries are considered, where much lower levels of correlation exists.

Table IV. Pearson correlation coefficients and sensitivity for SDG achievement vs. ICT usage

SDG indicator	R	Sensitivity
SDG Global Index Score	0,79	0,48
1. No poverty	0,48	0,09
2. No hunger	-	-
3. Good health and Well-being	0,67	0,74
4. Quality education	0,49	0,78
5. Gender equality	0,75	1,42
6. Clean water and sanitation	-	-
7. Affordable and clean energy	0,44	0,34
8. Decent jobs and economic growth	-	-
9. Industry innovation and infrastructure	0,77	2,39
10. Reduced inequalities	0,69	2,24
11. Sustainable cities and communities	0,71	0,92
12. Responsible consumption and production	-0,72	-1,53
13. Climate action	-0,72	-1,45
14. Life below water	-	-
15. Life on land	-	-
16. Peace and justice	0,57	0,80
17. Partnerships to achieve the goals	0,48	1,47

The SDG indicators related to climate action (SDG 12) and responsible consumption and production (SDG13) show a negative correlation coefficient with high sensitivity. Compared with the rest of the world, Europe is in the group of countries with poor behavior in these indicators.

The SDG related to poverty reduction is almost achieved in the European Union, that is why the sensitivity, even though positive, is almost zero. That is not the case for the rest of the world, where the best fitted regression has a logistic shape with inflection point in an ICT usage level of 46.

Europe is also at the forefront of the world in good health and well being (SDG 3) with most countries with a high level of achievement and good correlation level with ICT usage. The situation in the rest of the world also shows a similar positive correlation and sensitivity level.

Fig.8 shows a parallel plot of the ranking of the European countries for ICT usage, global SDG, and SDGs 9, 10, 12 and 13. It can be seen clearly how the countries leaders in the global SDG performing indicator are situated in a lower position in the environmental issue's rankings.

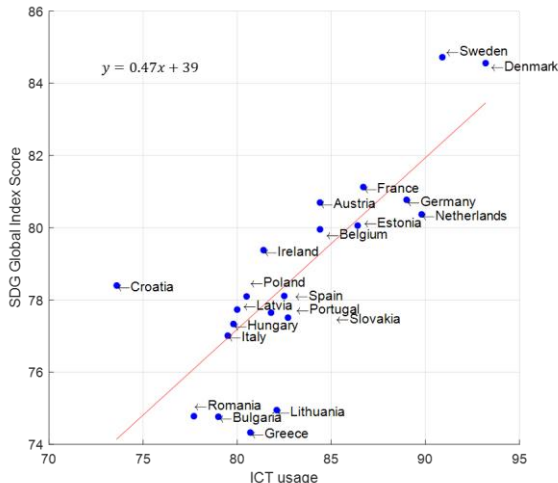
5. Conclusions and policy implications

Digitization is an essential transformation factor which is being rapidly and widely embraced by most countries. The results of the research presented in this paper show that its adoption is strongly associated with economic progress, competitiveness, and the advancement towards meeting the Sustainable Development Goals established for the year 2030 by United Nations.

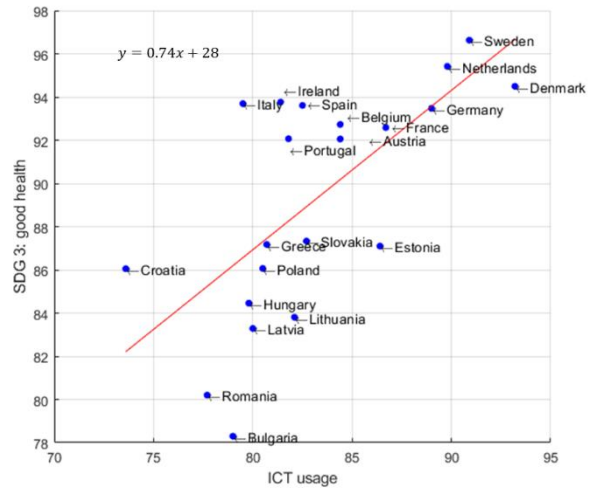
The analysis of the relationship by means of regressions among various indicators of digitization and those related to progress in the accomplishment rate of the Sustainable Development Goals shows that, in general, digitization is associated to a very positive impact in the progress to the achievement of the SDG. The aspects that benefit most clearly from digitization are those related to social and economic progress, including those such as poverty reduction, health care, quality of education and industry improvement.

However, the study also shows that digitalization is associated to a poor achievement in areas related to the natural environmental preservation and climate change fight, including among them those related to electronic waste and greenhouse gas emissions. This show that an increase in the digitalization levels is presently associated to poor results toward the SDG 12 and 13 achievements.

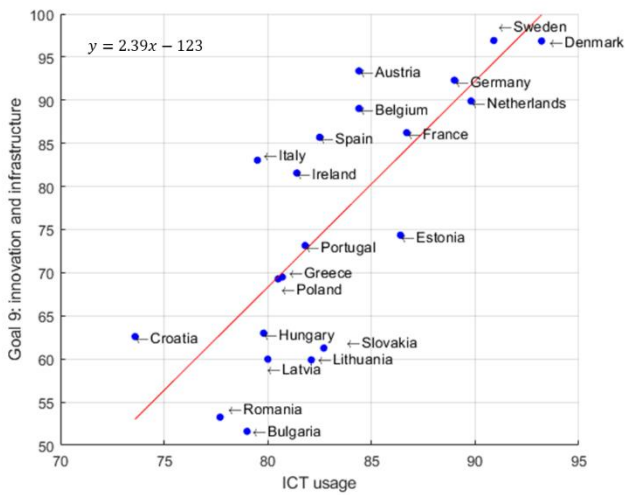
The European Union is at the forefront in the general advance toward achieving the SDG established for the year 2030 with very high level of achievement for most socio-economic SDG. The adoption of ICT is clearly associated to the level of achievement for most SDG (12 of the 17 SDG) showing a positive high correlation for all the SDG indicators related to social and economic progress including those related to gender and economic inequalities reduction.



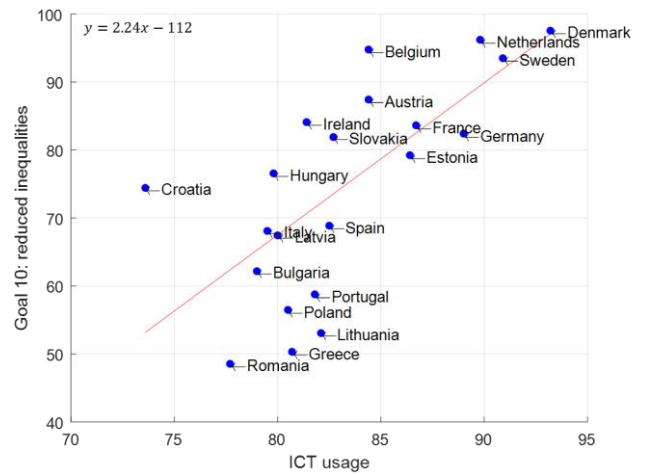
(a)



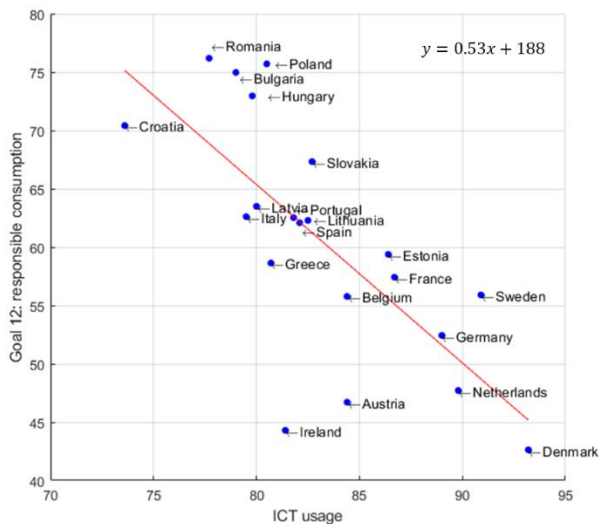
(b)



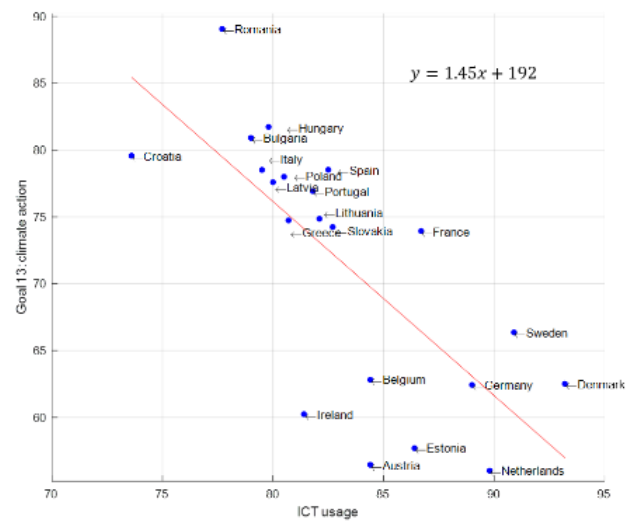
(c)



(d)



(e)



(f)

Fig. 7. SGD vs. ICT usage. (a) Global SDG score, (b) SDG 3, (c) SDG 9, (d) SDG 10, (e) SDG 12, (f) SDG 13

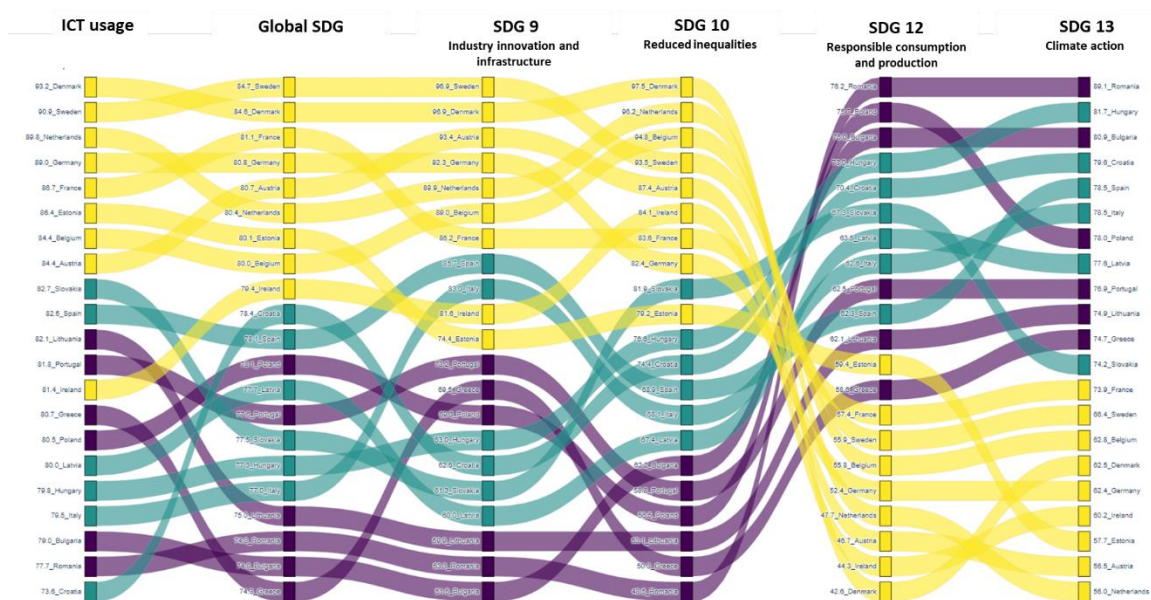


Fig. 8. European countries ranking: ICT usage, global SDG, SDG9, SDG10, SDG12 and SDG 13

Nevertheless, the level of achievement for the SDG12 and 13 related to the environment preservation is low. In this area the EU achievement is low compared to other world areas. These indicators show a negative correlation with the ICT usage.

This study shows the association between the ICT adoption and the SDG achievement but what are the specific contributions, positive or negative, cannot be derived from the results. ICT adoption can produce direct and indirect effects on the SDG. Direct effects are due to the physical existence of ICT and produce negative contributions to the SDG related to the environment (environmental impacts of the production, use, recycling, and disposal of ICT hardware). Indirect effects are those that change processes associated to activities (such as production, transport, education, or health assistance), human behavior (e.g., consumption patterns) or the economic structures due to the availability of ICT services resulting in a modification (decrease or increase) of their impacts on the SDG.

European policymakers should adopt measures that take the huge advantage that offers the ICT to advance in the achievement of the SDG. This is especially relevant for those related to the environment preservation where important efforts are required to meet the 2030 goals. The European Green Deal plan announced by the European Commission is an important step forward in the right direction. All the agents involved must collaborate closely in the effort to achieve the goals, especially those involved in the development of digitalization technologies and services, since the proven disruptive capacity of these technologies can be of great help.

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