



Measuring the digital inclusion of women: a poset-based approach to the women in digital scoreboard

Filippo Damiani¹ · Paula Rodríguez-Modroño²

Accepted: 3 April 2023 / Published online: 17 April 2023
© The Author(s), under exclusive licence to Springer Nature B.V. 2023

Abstract

The participation of women in digital society is essential to achieving the objectives of Agenda 2030 and an essential component in the EU strategy for the digital transition. This article applies a poset-based approach to the European Women in Digital (WiD) Scoreboard, to examine the digital inclusion of women in EU Member States and in the UK. The poset methodology enables us to identify the most significant indicators for each of the dimensions of the Scoreboard, considering the EU-28 as well as different clusters of countries, and to construct a new ranking that deals with the shortcomings of the aggregative approaches, the pre-treatment of data and the full compensability effect generated by arithmetic means. Our results show that two indicators, STEM graduates and the unadjusted pay gap, are the most significant for achieving the digital inclusion of women. Our research contributes to better understanding the dynamics and the factors facilitating the digital inclusion of women in the EU-28 Member States, providing a clustering of EU countries into four performance groups depending on the digital inclusion of women. It also contributes to the design of more targeted and effective policies for integrating gender equality into the EU digital transition strategy.

Keywords Digital economy · Women's digital inclusion · Digital transition · Gender digital gap · Poset

1 Introduction

Recent decades have seen the spread of digital technologies transforming the world of work (JRC 2019). The ability to use digital technologies for professional purposes has become a prerequisite for the successful integration of workers into the digitalised economy. The COVID-19 pandemic has accelerated even further the pace of digitalisation in European

✉ Filippo Damiani
filippo.damiani@unimore.it
Paula Rodríguez-Modroño
prodmod@upo.es

¹ Marco Biagi Department of Economics, University of Modena and Reggio Emilia, Modena, Italy

² Department of Economics, Quantitative Methods and Economic History, Pablo de Olavide University, Seville, Spain

societies and economies. This digital transformation of the labour market not only creates opportunities for gender equality but also gives rise to risks. Although the gender gap in IT skills and the use of digital devices is gradually levelling out across the European Union (EU), women are still behind men in the use of various ICT technologies at work (EIGE 2020). A study by the EIGE (EIGE 2017) shows that closing the gender gap in the STEM subjects (Science, Technology, Engineering and Mathematics) would have a positive impact on employment, with total EU employment in ICT projected to rise by anything from 850,000 to 1.2 million jobs by 2050. As a result, the gender digital gap continues not only to prevent women from reaching their full potential, but also hinders EU Member States from achieving their full productive capacity (European Commission 2018; Norlén et al. 2019).

Gender equality needs to be considered as a primary objective in the EU strategy for the digital transition, incorporating the measurement of advances in digitalisation for women and men as an essential component of this strategy. The evaluation of public policies governing the digital transition (Bánhidi et al. 2020) is even more important in the post-COVID-19 economic recovery period, in which digital services are becoming a key driver of economic growth, making the Digital Europe program an essential part of the recovery plan. At least 20% of the Next Generation EU budget is intended to fund investments in digital, approximately €150 billion.

However, the statistical data on digital inclusion are scarce and usually not disaggregated by gender. The Women in Digital (WiD) Scoreboard, formulated in 2019, is one of the most recent mechanisms put in place by the European Commission to assess women's inclusion in digital jobs, careers and entrepreneurship. The WiD index, part of the Digital Economy and Society Index (DESI), consists of twelve indicators to assess the performance of Member States in the areas of Internet use, Internet user skills as well as specialist skills and employment (European Commission 2020b). The WiD Scoreboard presents a ranking of countries using a simple arithmetic mean of the twelve normalised indicators, thus, using an aggregative approach, which has been highly successful in the literature, but it has also been deeply criticised as inappropriate and inconsistent from a methodological point of view (Maggino 2017). In particular, the arithmetic mean implies full compensability, which means that a low performance of a country in some indicators could be compensated by a high performance in other indicators. Other aggregative approaches (i.e. the geometric mean) still present compensability (Alaimo et al. 2021b). In this paper we address the issue of compensability by constructing a new WiD ranking adopting one of the methodologies based on the non-aggregative approach: the poset-based approach (Alaimo 2020b), which is particularly suitable for the treatment of ordinal data (Alaimo et al. 2020), as demonstrated by many works in different research fields (Annoni and Brüggemann 2009; Carlsen, and Brüggemann 2016; Carlsen 2017; Iglesias 2017; Arcagni 2019; Fattore and Arcagni 2019). Poset permits to fully exploits all the information in the dataset, reducing the need for subjective choices (Badinger and Reuter 2015), avoiding the use of aggregation methods (Fattore 2016; Fattore et al. 2018; Ivaldi et al. 2020) and without pre-treatment of data: performance can be evaluated considering all the indicators simultaneously (Carlsen and Brüggemann 2017). Therefore, the poset methodology is useful to overcome the curse of dimensionality without using a parametric model or introducing subjective criteria (Silan et al. 2020). The poset methodology presents also some drawbacks, in particular it is highly computationally demanding; if the number of observations is very high, the computation complexity increases (Alaimo et al. 2020) and could bring to a high number of incomparabilities. However, the WiD dataset permits to adopt the poset methodology without computational problems.

By applying the poset-based approach, we can also identify the most significant indicators for each of the three dimensions that compose the WiD, considering both the EU-28¹ as a whole, and four macroregions. Our findings about the significance of indicators, depending on the region, contribute to identifying areas where policy intervention continues to be needed, and to the design of more targeted and effective policies for integrating gender equality into the EU digital transition strategy. Additionally, our analysis identifies a clustering of EU countries into four performance groups depending on their level of digital inclusion of women. We also compare our poset ranking and the one proposed by the Women in Digital Scoreboard for 2020, identifying similarities and differences. Although the poset methodology has already been applied to socio-economic issues, including gender discrimination (Di Bella et al. 2018; , Di Brisco and Farina 2018), it has not previously been applied to an analysis of the WiD.

The remainder of the article consists of five sections. Section 2 presents a literature review of women's digital inclusion within the framework of the European Union. Section 3 defines the data and methods, describing the Women in Digital (WiD) Scoreboard, its dimensions and the poset methodology. Section 4 presents the results of the application of the poset methodology to study the different dimensions of WiD in the EU-28 as a whole and in the four macroregions into which we divide the EU. Section 5 presents an overview of the findings as well as the limitations of the study.

2 From the digital gender divide to women's digital inclusion

Research on the digital gender divide and women's digital inclusion can be divided into three main phases. Early feminist and gender approaches to the digital revolution were largely optimistic about the potential of digital technologies as a tool for empowerment (Grau-Sarabia and Fuster-Morell 2021; Fuster 2022). Women were considered as a 'disadvantaged' group that just needed support to reach a level of access to ICT in line with the population as a whole. This first-order digital gender gap focused on the lack of access to ICT.

However, the second wave of digital divide studies from a gender perspective cast light on the fact that access to technology in itself does not lead directly to enhanced social opportunities, highlighting that the acquisition of digital skills and uses of the internet are also gender-stratified (Castaño et al. 2011; Helsper 2010; van Deursen and van Dijk 2019). The second-order digital gender gap represents ICT usage and proficiency of ICT usage. Technology is gendered, and digital technologies form part of the structure and performance of gender inequalities (Wajcman 2010; Wyatt 2008). Digitalisation holds the potential to reorganise gendered work relations, since the patterns of the gender division of labour are shaped, negotiated, or affected by digitalisation (Kohlrausch and Weber 2020). In fact, despite the measures implemented to enhance women's digital skills and to increase the participation of women in the ICT workforce, studies show that gender disparities in digital proficiency are still more evident at the higher levels of specialisation. Gender gaps in the EU are still wider at the higher and more specialised levels, which are widely considered to be key factors for future digital inclusion and employment (OECD 2018). Women are less engaged in digital technologies, information-seeking activities, content-sharing or

¹ The EU-28 is taken to include the United Kingdom as the UK was a Member State until December 2019.

the contribution to free/open collaborative platforms (Hargittai 2010; Hargittai et al. 2015; Helsper and Eynon 2013).

As a result, a third level of digital divide studies now focuses on quantifying the impact of the unequal distribution of the benefits of internet use (Quan-Haase et al. 2016; Meri-Tuulia et al. 2017; Sáinz et al. 2020; Scheerder et al. 2017; van Deursen and Helsper 2015). The third digital gender gap refers to this differentiated use of the most advanced ICT technologies and applications. The EU WiD Scoreboard shows that there is still a considerable gender gap in specialist digital skills. Even in those EU Member States where equality between women and men is closer to being achieved, stereotypes continue to act as barriers to women taking STEM degrees (European Commission 2019), and to prevent their career advancement, resulting in persistent gender digital gaps (Martínez-Cantos 2017). Women are still under-represented in ICT jobs, top management and academic careers. This pattern applies to almost all advanced countries and is largely independent of the country's level of economic development (Sorgner et al. 2017). Although 57% of university graduates in the EU are women, only 20% of tertiary graduates in ICT-related fields are women, and the proportion of women in ICT jobs is only 19% (EIGE 2020; European Commission 2021b). Even when women study STEM subjects, they come up against a glass ceiling preventing them from reaching senior positions. ICT companies require long hard working days with almost unlimited availability on the part of workers, which is incompatible with the inflexibility of care work and achieving a work-life balance (Rodríguez-Modroño et al. 2022; Vergés Bosch et al. 2021). The digital gender divide becomes even more pronounced when it comes to women as creators of technology or software developers. The majority of software packages are still authored by men. Finally, venture capital investment and start-ups tend to reveal a socio-cultural gender bias in equity financing: 93% of innovative start-ups seeking venture capital investments are founded by men, women-owned start-ups receive 23% less funding and are 30% less likely to have positive outcomes (OECD 2018; European Commission 2019). These figures have been stable in recent years, without showing significant improvements, in line with other longitudinal studies from particular contexts, where gender differences in digital skills have remained consistent in recent years (van Deursen and van Dijk 2015; van Deursen et al. 2015).

In short, STEM subjects do not seem to be able to include, retain and promote women properly. Although the 2030 Digital Compass has set the target for the EU to have 20 million ICT specialists in employment by 2030, with a convergence between women and men (European Commission 2021a; 2030). Gender inequalities remain and generate equity and efficiency problems that hamper economic growth and welfare for all, but especially for women (Vergés Bosch et al. 2021). While a number of positive policy developments may be noted, major challenges remain if gender parity in the digital world of work is to be achieved. One of the main challenges is the development of gender-specific and gender-sensitive indicators and indices that provide insights into the breadth and depth of women's digital inclusion, since ICT-focused indices which include gender dimensions have a relatively short history (Brimacombe and Skuse 2013). The EU digital strategy 'Shaping Europe's digital future' (European Commission 2020a) and the EU gender equality strategy 2020–2025 are the most recent steps taken by the EU for the promotion of a gender perspective in this area. These initiatives are placing greater emphasis on the collection of sex-disaggregated data and the development of indicators. However, the Women in Digital Scoreboard is still the only measurement framework to monitor the progress of European countries towards women's digital inclusion. As a result, in this study we analyse it using the poset methodology, to construct a more refined ranking and examine the differences by macroregion and cluster of countries.

3 Materials and methods

The Women in Digital (WiD) Scoreboard is part of the Digital Economy and Society Index (DESI) and monitors in detail women's participation in the digital economy in the EU-28 countries. It is based on 12 indicators divided into three dimensions (European Commission 2020c), namely internet use, internet user skills, and specialist skills and employment.

The first dimension (internet use) is composed of six indicators, listed as follows: *1.1% of women who use the internet at least once a week; 1.2% of women who never used the internet; 1.3% of women who used the internet in the previous three months to use online banking; 1.4% of women who used internet in the previous three months for doing an online course; 1.5% of women who used internet in the previous three months for taking part in on-line consultations of voting to define civic or political issues; 1.6% of women internet users who, during the previous year, needed to send filled in forms to the public administration.* The breakdown for the indicators of this dimension is all women aged 16–74, and the source of the data is the Community survey on ICT usage in households and individuals provided by Eurostat.

The second dimension (internet user skills) consists of three indicators, which are: *2.1% of women with basic or above basic digital skills in information, communication, problem-solving and software for content creation; 2.2% of women with above basic digital skills in information, communication, problem-solving and software for content creation; 2.3% of women who have used advanced spreadsheet functions, created presentation or document integrating text, pictures and tables or charts, or written code in a programming language.* The breakdown and the source of the data are the same as the ones of the first dimension.

The third dimension (specialist skills and employment) contains the last three indicators of the index: *3.1 Women graduates in STEM per 1000 individuals ages 20–29; 3.2% of women aged 15–74 employed ICT specialist based on the ISCO-08 classification; 3.3 Gender pay gap in unadjusted form, considering all employees working in firms with ten or more employees.* The source of the data of this dimension is the Eurostat questionnaire on education statistics, the Labour Force Survey, and the structure of earnings survey. Indicator 3.3 measures the difference between the average gross hourly earnings for men and women, as a percentage of average gross hourly earnings for men.

In the WiD index 2020, all the indicators are considered of equal importance, and the aggregation of the indicators into the three dimensions and the overall index is constructed as the simple unweighted arithmetic average of the normalised scores. The normalisation method used in the WiD 2020 index implies the choice of minimum and maximum values for each indicator. In this paper, adopting the poset-based approach, we do not need to normalise indicators, avoiding the subjective choice of the above-mentioned minimum and maximum values. No missing data are detected. The data matrix considered in this study consists of 28 countries and 12 indicators; hence, the total number of observations is 336.

In this study we apply the partial order theory, or poset-based approach, a discipline associated with discrete mathematics, in which the objects of a data set, consisting of multiple indicators, are compared and ordered to obtain a ranking (Brüggemann and Patil 2011). According to poset theory, one object can be considered better than another if and only if it achieves a better performance on all indicators of a data set, or, alternatively, if it performs better on just one indicator, and it ties in all the others. Furthermore, all the ordered pairs of objects can be graphically represented in the so-called Hasse diagram.

In the analysis presented in this study, the first step consists in the identification of the Hasse diagram, which represents the relations between the 28 countries according to their

Table 1 Example: three countries (a, b, and c) and three indicators (q_1 , q_2 , and q_3)

Country	q_1	q_2	q_3
A	4	3	2
B	3	2	2
C	4	2	0

Fig. 1 Example: Hasse diagram

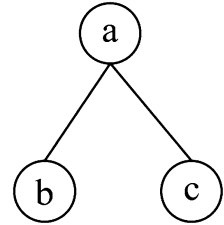


Table 2 Example: downsets and incomparabilities of the objects, in numbers

Country	D(x)	I(x)
A	3	0
B	1	1
C	1	1

scores considering all 12 indicators together. To better understand poset theory, consider the example in Table 1, identifying three countries (A, B, and C) and three indicators (q_1 , q_2 , and q_3).

In the poset analysis, it is crucial to compare all countries based on all indicators. As a result, it may be said that country A performs better than both country B and country C since, even if it ties in q_3 with country B and in q_1 with country C, it achieves a higher score on all other indicators. What is not possible to compare is country B with country C: country B shows a higher score in q_3 ($2 > 0$), but a lower score in q_1 ($3 < 4$); hence, country B is incomparable with country C. The relations between the comparable countries are country A > country B, as well as country A > country C. At the same time, country B || country C (where || is the sign indicating incomparability). Figure 1 shows the Hasse diagram of our example.

The second step of the analysis includes the identification of the downset of any country as well as the incomparabilities in order to construct the ranking of the countries. The downset of country x consists of those countries y such that $y \leq x$; its cardinality is denoted as $D(x)$. If $y < x$ for one or more indicators and $y > x$, then x and y are incomparable; the number of countries that are incomparable with a country x is denoted as $I(x)$. In our example, we obtain the results as shown in Table 2.

As shown in Table 2, the downset of country A consists of three elements (country A itself, country B, and country C). To rank the three countries considered in the example, it would be sufficient to look at the Hasse Diagram showed in Fig. 1 to realise that country A is first in the ranking followed by countries B and C (both with the same result). However, with larger dataset, as the WiD 2020 one, it may be difficult to elaborate the ranking due to the high number of incomparabilities between the analysed countries; consequently,

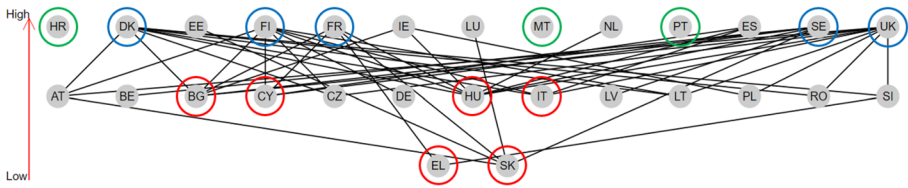


Fig. 2 Hasse Diagram, 28 countries and 12 indicators. Source: Authors’ own elaboration based on WiD data.

in such cases, it is possible to apply the Local Partial Order Model (LPOM), a ranking method through which the “final score” of the countries is a function of $D(x)$ and $I(x)$. The formula to compute the “final score” is as follows (Brüggemann and Patil 2011):

$$\delta(x) = D(x)[(n + 1)/(n + 1 - I(x))] \tag{1}$$

where x is the country of interest, and n indicates the total number of countries, in our example, $n=3$. To better understand how the LPOM method compute the final score, we can re-consider the banal example of Table 2. The score of country A, applying the formula, is: $3 * (3 + 1) / (3 + 1 - 0) = 3 * 4 / 4 = 3$. By contrast, the score of both countries B and C is: $1 * (3 + 1) / (3 + 1 - 1) = 1 * 4 / 3 = 1,33$. Thus, we obtain the following ranking: first position for country A and second position for countries B and C (tie). Otherwise, if we create a ranking by simply computing the unweighted arithmetic average, we obtain a different ranking, with country B better ranked than country C. In our analysis we use the LPOM to create the ranking considering first the entire dataset, and then we repeat the same process for each of the three dimensions of indicators.

The third step of the analysis consists in the detection of the most significant indicators for each of the three dimensions through the “attribute-related sensitivity” analysis. The aim is to examine how an indicator influences the position of the countries in the Hasse diagram by removing one indicator from the data matrix (Brüggemann and Patil 2011).

Our goal is to find the four out of six most important indicators of dimension 1, and the two out of three most relevant indicators of both dimension 2 and 3. We will conduct this analysis considering first the EU-28 countries then just the countries in each of the four European macroregions (northern, western, eastern, and southern Europe) for an in-depth examination of regional variations. The last step of the analysis is the comparison between our results and the results of the Women in Digital Scoreboard for 2020, identifying similarities and differences across the two rankings. The poset-based approach is applied using the online software PyHasse, available at <https://posets.pyhasse.org/>.

4 Results

In this section, we present the main results of the analysis, starting from the first step of the analysis, namely the Hasse Diagram of the 28 countries considering all the 12 indicators of the three dimensions (Fig. 2).

The Hasse Diagram shows the connections between the countries analysed according to their data. The lines connecting two countries reveal that the country at the higher level achieves better results than the country at the lower level, since it has higher scores in all the 12 indicators. On the one hand, the countries circled in blue (Denmark,

Rank	Country	downset	incomp	Score	Rank	Country	downset	incomp	Score
1	United-Kingdom	12	16	26.77	15	Austria	2	23	9.67
2	Denmark	11	17	26.58	15	Belgium	1	26	9.67
3	Finland	10	18	26.36	15	Germany	1	26	9.67
4	Sweden	7	21	25.38	15	Latvia	1	26	9.67
5	France	6	22	24.86	19	Poland	1	25	7.25
6	Ireland	4	24	23.20	19	Romania	1	25	7.25
6	Spain	4	24	23.20	21	Czechia	1	24	5.80
8	Estonia	2	26	19.33	21	Lithuania	1	24	5.80
8	Luxembourg	2	26	19.33	23	Cyprus	1	23	4.83
8	Netherlands	2	26	19.33	23	Greece	1	23	4.83
11	Croatia	1	27	14.50	23	Italy	1	23	4.83
11	Malta	1	27	14.50	26	Bulgaria	1	21	3.63
11	Portugal	1	27	14.50	27	Hungary	1	19	2.90
14	Slovenia	2	24	11.60	27	Slovakia	1	19	2.90

Fig. 3 Ranking of the countries according to their scores obtained as a function of the downsets and the incomparabilities Source: Authors' own elaboration based on WiD data.

Finland, France, Sweden, and the United Kingdom) are at a higher level compared to at least five countries; on the other hand, the countries circled in red (Bulgaria, Cyprus, Greece, Hungary, Italy and Slovakia) are low-performing states on all the indicators compared to at least five countries. The three countries circled in green (Croatia, Malta and Portugal) are incomparable with all other countries; this means that they perform well on at least one indicator, but not so well on others.

From the Hasse Diagram it is now possible to move on to the second step of the analysis: to compute the downsets and the number of incomparabilities of each country, for the purposes of calculating the final scores using the Local Partial Order Model (LPOM), and then constructing our own ranking, as shown in Fig. 3.

The countries are grouped into four categories depending on their final score. Blue represents the “leaders in the digital participation of women” (leaders, for short) with a final score greater than 20; green is the “medium-high digital participation of women” group (medium-high, for short) with a final score between 10 and 20; in yellow the “medium-low digital participation of women” group (medium-low, for short) is identified with a final score between 5 and 10; finally, red represents the “emerging digital participation of women” group (emerging, for short) a final score less than 5. All groups consist of seven countries except for the medium-low group (in yellow), which includes eight countries, since Czechia and Lithuania achieved the same score.

To analyse this ranking, we need to consider the downsets: 12 countries have higher scores on all indicators with respect to at least one country (downset greater than 1). The largest downset is that of the United Kingdom: the UK has higher scores than 11 countries on all indicators. Hence, the UK leads the ranking, thanks to its good performance on all indicators. By way of contrast, the countries with a downset equal to 1 were found to be underperforming on at least one indicator compared to all other countries; 16 countries are in this situation, and their final score drops as the number of incomparabilities decreases, resulting in an increase in the number of countries with better results on all the indicators in the dataset. According to our results, the last positions of the ranking are occupied by Hungary and Slovakia: they both present incomparabilities with 19 countries, meaning that eight different countries have higher scores on all indicators compared to them. These results are shown also in Fig. 4 by means of political maps, one for each of the four macroregions.

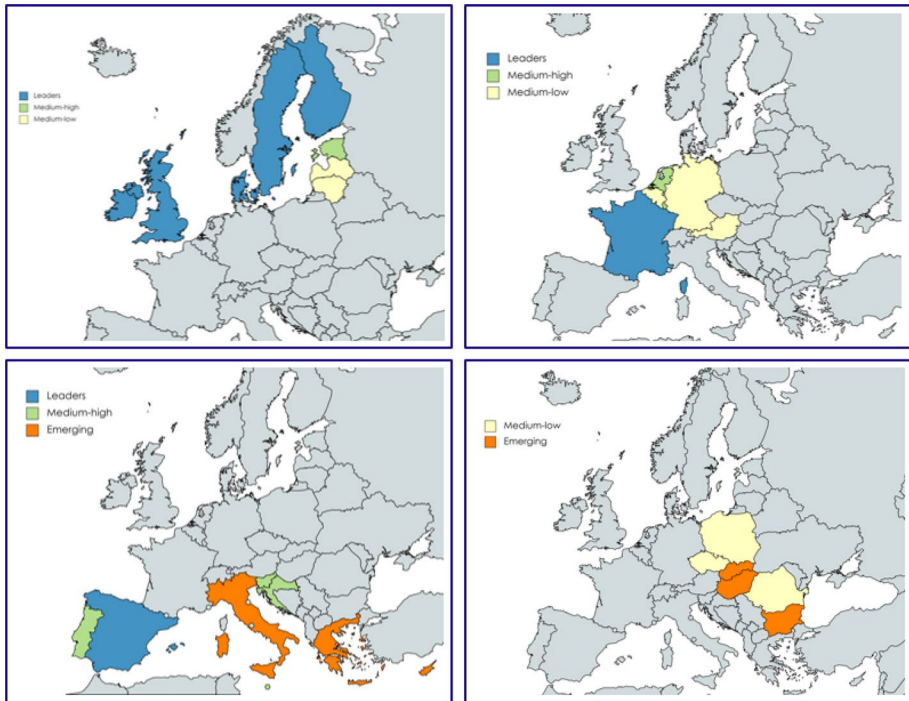


Fig. 4 Results of the poset analysis considering all three WiD 2020 dimensions. Clockwise from top left: northern Europe, western Europe, eastern Europe, southern Europe Source: Authors' own elaboration based on WiD data

Figure 4 shows that the results significantly differ among the macroregions. Northern European countries are all in the leaders' group, except for the Baltic countries (Estonia is in the middle-high group, Latvia and Lithuania are in the middle-low group). Western European countries range from the leaders (France) to the medium-low group (Austria, Belgium, and Germany). The Southern European countries include Spain among the leaders, whereas Cyprus, Greece, and Italy are in the emerging group. Finally, eastern European countries belong only to the last two groups of the ranking: Czech Republic, Poland, and Romania are in the middle-low group, whereas Bulgaria, Hungary, and Slovakia are in the emerging group. As a result, on the one hand, northern and western European countries are at the forefront in terms of the participation of women in the digital economy (especially the UK and the Scandinavian countries). On the other hand, certain southern and eastern European countries are characterised by significant shortcomings in this regard.

The third step of the analysis consists of attribute-related sensitivity analysis. We identify the two of the three most significant indicators for each dimension. Since the first dimension consists of six indicators, for this dimension we identify the four most important indicators. The analysis is replicated five times: first considering all the countries together, then considering one of the four macroregions at a time. The results are presented in Table 3, with the indicators listed following the enumeration presented in Sect. 3.

The indicators highlighted in the first column are the most significant ones for all the EU-28 countries. Regarding the analysis at a macro-regional level, it is important to

Table 3 Most impacting indicators according to attribute-related sensitivity analysis, both at EU-28 level, and at macro-regional level *Source* Authors' own elaboration based on WiD data

Indicator	EU-28	Northern EU	Western EU	Southern EU	Eastern EU
1.1	X	X		X	X
1.2	X				X
1.3			X		X
1.4					
1.5	X	X	X	X	
1.6	X				X
2.1					
2.2	X	X	X	X	X
2.3	X			X	X
3.1	X	X	X	X	X
3.2			X	X	
3.3	X	X	X	X	X

underline the following considerations: first, it was not possible to identify the two out of three indicators with the highest impact for all macroregions in all dimensions (for instance, the most important indicators considering northern European countries are just two out of six in dimension 1, and one out of three in dimension 2); second, in some cases it was not possible to find more important indicators than others in a particular dimension (for instance, all three indicators of dimension 3 have the same impact in western and southern European countries) and for this reason all indicators relating to that dimension are considered as equivalent.

The attribute-related sensitivity analysis then revealed eight of the 12 most significant indicators for the EU-28. Specifically, three indicators about internet user skills, specialist skills and employment have the highest impact in all four macroregions, namely: *2.2% of women with above basic digital skills in information, communication, problem-solving and software for content creation*; *3.1 Women graduates in STEM per 1000 individuals ages 20–29*; *3.3 Gender pay gap in unadjusted form, considering all employees working in firms with ten or more employees*. Furthermore, two more indicators of internet use are the most significant in three macroregions: *1.1% of women who use the internet at least once a week*; *1.5% of women who used internet in the previous three months for taking part in on-line consultations of voting to define civic or political issues*. Moreover, two indicators are significant in some macroregions even if they are not in the analysis of the EU-28: indicator 1.3 in western and eastern Europe; and indicator 3.2 in western and southern Europe. Only two indicators are left out of all the analyses: *1.4% of women who used internet in the previous three months for doing an online course*; *2.1% of women with basic or above basic digital skills in information, communication, problem solving and software for content creation*.

Another interesting aspect of the analysis that deserves attention is the ranking obtained considering the three dimensions individually. The ranking is expressed in the form of the four performance categories discussed above. The results are shown in the maps in Fig. 5.

With reference to Fig. 5 it may be noted that only a few countries are in the same performance category with regard to all the dimensions. On the one hand, Denmark, Finland, Sweden and the UK are the only four countries that are leaders in each of the three

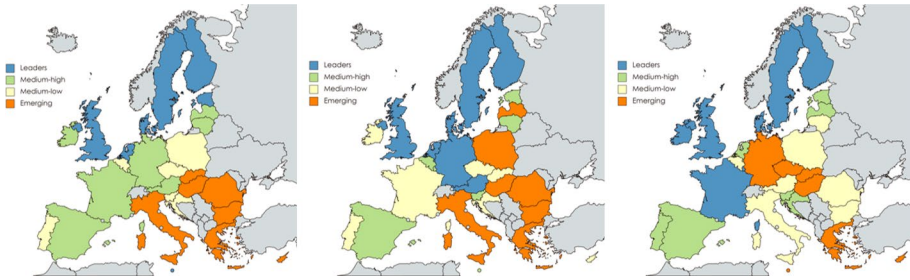


Fig. 5 Results of the poset analysis considering the three WiD 2020 dimensions singularly. From left to right: dimension 1, dimension 2, and dimension 3. Source: Authors’ own elaboration based on WiD data.

dimensions; on the other hand, Greece and Hungary are the only two countries at the bottom of the ranking in all three dimensions. Our findings identify the dimension in which certain countries could improve the most. For instance, Austria, Germany, Lithuania and Luxembourg have good results in the first two dimensions, but they have significant weaknesses (especially in the case of Germany and Luxembourg) in the dimension related to specialist skills and employment. Another example is represented by France, Ireland, and Latvia, that are in the middle-high category in both dimensions one and three, but could improve significantly in the dimension regarding internet user skills. Slovenia is the only country that has the most significant shortcomings in the first dimension (internet use).

The last step of the analysis concerns the comparison between the results and ranking proposed in the Women in Digital Scoreboard 2020 and our results obtained using the poset-based approach, by computing the Spearman correlation coefficient ρ , and the τ Kendall correlation as in Alaimo et al. (Alaimo et al. 2020; Alaimo et al. 2021a). First of all, to test the validity of our ranking we calculate the Spearman correlation coefficient ρ , using the following formula:

$$\rho = 1 - \frac{6 * \sum d_i^2}{n * (n^2 - 1)} \tag{2}$$

where d is the pairwise distance of the ranks of the different countries and n is the number of countries. The result (in a range between 0 and 1, where 0 is total discordance and 1 is total concordance) is 0.881 with a p value < 0.001 . We also calculate the τ Kendall rank correlation, applying the following formula:

$$\tau = \frac{c - d}{c + d} \tag{3}$$

where c is the number of concordant pairs and d the number of discordant pairs. The result (in a range between -1 and 1 , where -1 is total discordance and 1 is total concordance) is 0.687 with a p value < 0.001 . The high values of the coefficients mean that the results obtained in the two ranking are similar, even if there are some differences, which we try to explain starting from Fig. 6, which shows the scores of the 28 countries comparing our analysis and the score reported in the WiD Scoreboard 2020, and in Fig. 7, showing the countries that move at least three positions in the ranking.

Figure 6 shows that the ranking obtained with the poset-based approach is not the same as the one in the Women in Digital Scoreboard 2020. France, Spain and Ireland

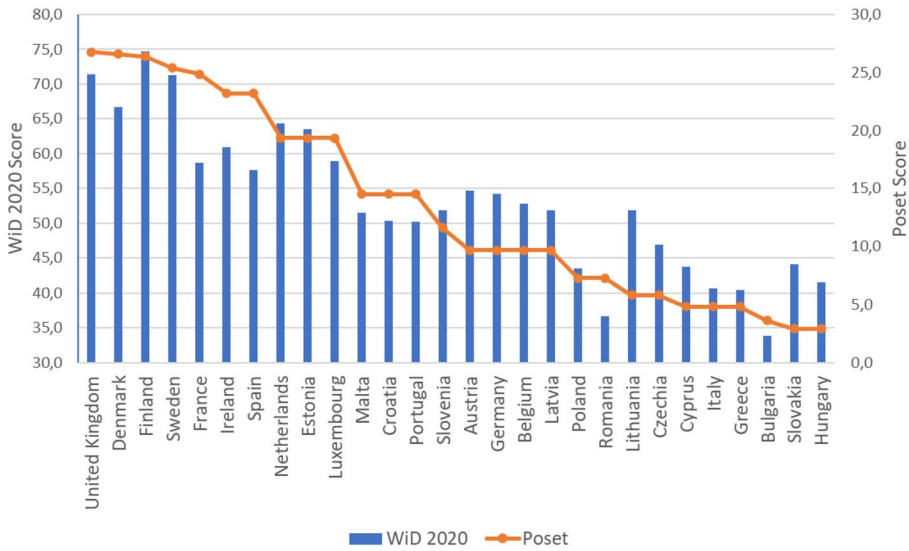


Fig. 6 Comparison between the scores of the 28 countries in the Women in Digital Scoreboard 2020 and in the poset-based approach analysis. Source: Authors' own elaboration based on WiD data

improve their ranking significantly with the poset methodology, while Lithuania, Slovakia and Hungary drop down in the ranking. Therefore, our results show significant differences in the ranking of the countries.

Figure 7 shows in green the countries that move up in the ranking by at least three positions in the poset-based analysis compared to the ranking in the Women in Digital Scoreboard: Portugal and Romania (8), Croatia (7), Malta (6), France, Poland, and Spain (4), and Greece (3). In red, the countries that move down at least three positions in the ranking: Lithuania (-7), Slovakia (-6), Austria (-4), Germany, Hungary, and Netherlands (-3). The explanation for the differences between the two rankings lies in the performance of these countries in relation to the most important indicators, particularly indicators 1.5, 1.6, 3.1, and 3.3 (the last two even more substantially). Good performances on these indicators led to the higher ranking in the poset-based analysis whereas deficiencies in relation to these indicators led to a lower ranking. To further understand this phenomenon, Fig. 8 shows the average ranking of the aforementioned countries considering only indicators 3.1 and 3.3.

In general, a better (or worse) ranking in the poset analysis depends on the downset and on the upset of each country according to Fig. 2. The ranking obtained from a simple unweighted average of the indicators, presented in the Women in Digital Scoreboard 2020, is led by Finland, whereas, in the poset analysis, the leader is United Kingdom since its downset, as reported in Fig. 3, is 12 and it is the highest, which means that UK has better scores in all the indicators (not just in the average) with respect to 11 out of 27 countries; moreover, the upset of UK is 1, which means that there is no country with better scores in all indicators than UK. At the same time, Hungary and Slovakia are in the last position of the poset ranking since their downset is 1, which means that every country has better scores in at least one indicator compared to Hungary and Slovakia, and their upset is 9; in fact, 8 countries perform better than Hungary and Slovakia in every indicator. For this reason, we believe that the ranking proposed in this paper, adopting the poset-based approach,

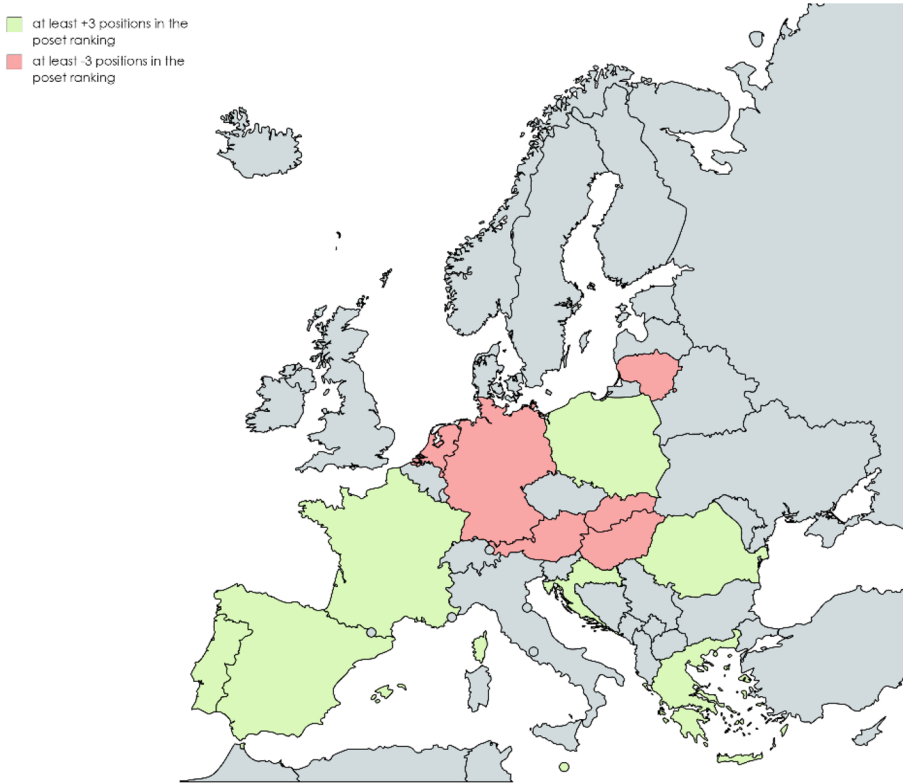


Fig. 7 Comparison between the poset-based approach analysis and the Women in Digital Scoreboard 2020 results. Source: Authors' own elaboration based on WiD data

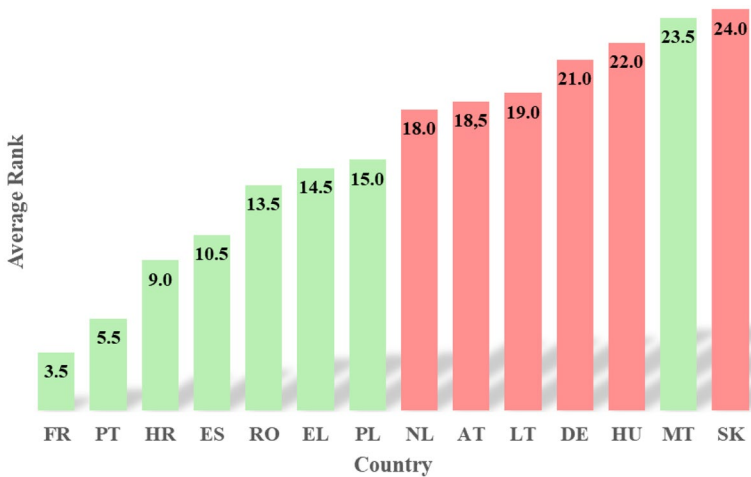


Fig. 8 Average ranking of the 13 countries underlined in Fig. 7, according to indicators 3.1 and 3.3 Source: Authors' own elaboration based on WiD data

permits us to claim that the position of a given country depends on its performance on all indicators compared to other countries and not just on the average.

In Fig. 8, we identify two groups of countries considering the results in relation to indicators 3.1 and 3.3, except Malta, which moves up in the ranking even though its results for the most important indicators of the third dimension are not good (25th in 3.1, and 21st in 3.3). However, as explained in the discussion above, Malta belongs to the small group of countries that cannot be compared with the rest, according to the poset-based approach theory, thanks above all to the positive results in relation to indicator 1.5, where Malta ranks second. It may be concluded that, in general, countries that have good results in the majority of indicators should see an improvement in their results for the most important indicators: *Women graduates in STEM per 1000 individuals ages 20–29* and *Gender pay gap in unadjusted form, considering all employees working in firms with ten or more employees*.

5 Discussion and conclusions

In this study we applied poset theory to analyse women's digital inclusion in the EU-28 countries using the data from the 12 indicators of the Women in Digital Scoreboard 2020. The poset methodology enabled us to construct a new ranking that deals with the shortcomings of the approach presented in the Women in Digital Scoreboard 2020, in which the ranking is constructed as the simple average of the indicators. A ranking computed with this method can provide just an overview of the aggregate performance of a given country; whereas, the application of the poset-based approach permits to obtain a ranking which already takes into account the comparison between countries and their scores indicator by indicator, introducing the concept of incomparability in case the performances of two given countries are not coherent among the indicators considered (country A is better than country B in the indicator 1, but is worse in the indicator 2). Moreover, the poset-based approach reduces significantly the loss of information thanks to its non-aggregative nature, permitting to go more in-depth in the study of the gender digital divide phenomena.

The analysis resulted in a classification of countries, according to a new ranking, in four groups depending on their performance level. The best performing group consists of the United Kingdom, Denmark, Finland, Sweden, France, Ireland and Spain (leaders); by contrast, the countries where women are most underrepresented are Slovakia, Hungary, Bulgaria, Italy, Greece, and Cyprus (emerging countries).

According to the poset-based approach, the leaders consist of those countries that achieve better results in relation to all indicators compared to at least three other countries. The United Kingdom is the country leading the ranking, since it achieves better scores on all the indicators with respect to eleven other countries; Ireland and Spain, the last two countries in the leaders' group, achieve better results on all indicators in comparison to three different countries. Similarly, the emerging group consists of the countries underperforming on all indicators compared to at least four different countries (as in the case of Cyprus, Greece, and Italy), and eight in the case of Hungary and Slovakia, at the bottom of the ranking. Moreover, three countries (Croatia, Malta, and Portugal) are incomparable with all the other countries, meaning that they present very good results on some indicators but very low scores on other indicators.

We also analysed the data by macroregion, and the results seem to confirm the socio-economic pattern among European countries: the northern countries are mostly in the leaders' group, the western countries are between the leaders and the middle group, the

southern countries are mostly between the middle and the emerging group, and the eastern countries are mostly in the emerging group. Thus, countries in a macroregion usually belong to the same group, with very few exceptions: the Baltic states are the only countries in northern Europe that are not in the leaders' group, whereas Spain is the only southern European country in the leaders' group.

Comparing our results with those proposed in the Women in Digital Scoreboard 2020 report, we found that half of the countries have equal or similar positions in the two rankings, while the other half move up or down the ranking by at least three positions. These differences depend mainly on the performance of countries on the most significant indicators revealed by the attribute-related sensitivity analysis² that we conducted, considering all countries first, then the countries in each macroregion. Among the most significant indicators, two belong to the first dimension, internet use (*% of women who used internet in the previous three months for taking part in on-line consultations of voting to define civic or political issues*, and *% of internet users who, during the previous year, needed to send filled in forms to the public administration*), and other two belong to the third dimension, specialist skills and employment (*Women graduates in STEM per 1,000 individuals ages 20–29*, and *Gender pay gap in unadjusted form, considering all employees working in firms with ten or more employees*). The last two indicators are even more important in the determination of the ranking. In fact, the countries that improved their ranking are those with good results on indicators 3.1 and 3.3 (except for Malta). The macroregional analysis provided results on various significant indicators for each European region. For instance, our analysis suggests that only for western and southern European countries, an important indicator is *% of women aged 15–74 employed ICT specialists based on the ISCO-08 classification*. As a result, our research contributes to a better understanding of the dynamics and the underlying causes of women's digital inclusion in the EU countries. The different significance of indicators in the EU and in the four macroregions helps to design more targeted and effective policies, showing the specific areas on which each country should focus to reduce the gender digital divide.

This study presents some limitations, both theoretical and methodological. From the theoretical point of view, the set of indicators is not exhaustive, and the data are collected just at country level. The methodological limitations are mainly related to the fact that, even in quite a large dataset, the application of the poset-based approach can lead to a large number of incomparabilities, generated in some cases by small differences in the performance on certain indicators.

For future research, it would be interesting to collect regional data in order to replicate the analysis at regional level, and explore in detail regional variances in the gender digital divide across Europe, as regional socioeconomic differences in some countries (such as Italy and Spain) are usually significant. Moreover, if more gendered data were available, the set of indicators could be further enlarged, including for example many of the other indicators of the Digital Economic and Society Index, which currently consists of 25 indicators. Finally, as data for other years is available, it should be possible to extend the study to include a longitudinal analysis.

Acknowledgements The authors wish to thank William Bromwich for his painstaking attention to the copy-editing of this paper.

² We decided to find the impact of each indicator by applying the method which is proposed in the poset theory (European Commission 2021a; 2030), in order to remain within the poset-based approach application concept.

Authors contribution The authors certify that they have NO affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter discussed in this manuscript.

Funding This work was supported by Spanish Ministry of Science and Innovation (Award number PID2019-105835RB-I00; Grant Recipient: Paula Rodríguez-Modroño).

Declarations

Conflict of interest None.

References

- Alaimo, L.S.: Complexity of social phenomena: measurements, analysis, representations and synthesis. Doctoral thesis. University of Rome "La Sapienza", Rome, Italy. (2020)
- Alaimo, L.S., Ivaldi, E., Landi, S., Maggino, F.: Measuring and evaluating socio-economic inequality in small areas: An application to the urban units of the municipality of Genoa. *Socio-Econ. Plann. Sci* **83**, 101170 (2020). <https://doi.org/10.1016/j.seps.2021.101170>
- Alaimo, L.S., Arcagni, A., Fattore, M., Maggino, F.: Synthesis of Multi-indicator System over Time: A poset-based Approach. *Soc. Indic. Res.* **157**, 77–99 (2021a). <https://doi.org/10.1007/s11205-020-02398-5>
- Alaimo, L.S., Ciacci, A., Ivaldi, E.: Measuring Sustainable Development by Non-aggregative Approach. *Soc. Indic. Res.* **157**, 101–122 (2021b). <https://doi.org/10.1007/s11205-020-02357-0>
- Annoni, P., Bruggemann, R.: Exploring partial order of European Countries. *Soc. Indic. Res.* **92**, 471–487 (2009). <https://doi.org/10.1007/s11205-008-9298-4>
- Arcagni, A., Barbiano di Belgiojoso, E.B., Fattore, M., Rimoldi, S.M.: Multidimensional analysis of deprivation and fragility patterns of migrants in Lombardy, using partially ordered sets and self-organizing maps. *Soc. Indic. Res.* **141**(2), 551–579 (2019). <https://doi.org/10.1007/s11205-018-1856-9>
- Badinger, H., Reuter, W.H.: Measurement of fiscal rules: Introducing the application of partially ordered set (POSET) theory. *J. Macroecon.* **43**, 108–123 (2015). <https://doi.org/10.1016/j.jmacro.2014.09.005>
- Brimacombe, T., Skuse, A.: Gender, ICTs, and indicators: Measuring Inequality and Change. *Gend. Technol. Dev.* **17**(2), 131–157 (2013). <https://doi.org/10.1177/0971852413488713>
- Brüggenmann, R., Patil, G.P.: Ranking and Prioritization for Multi-Indicator Systems. Introduction to Partial Order Applications. Springer-Verlag, New York (2011). <https://doi.org/10.1007/978-1-4419-8477-7>
- Bánhidí, Z., Dobos, I., Nemeslaki, A.: What the overall digital economy and society Index reveals: a statistical analysis of the DESI EU28 dimensions. *Reg. Stat* **10**(2), 46–62 (2020). <https://doi.org/10.15196/RS100209>
- Carlsen, L.: An alternative view on distribution keys for the possible relocation of refugees in the European Union. *Soc. Indic. Res.* **130**, 1147–1163 (2017). <https://doi.org/10.1007/s11205-016-1234-4>
- Carlsen, L., Bruggemann, R.: Fragile State Index: Trends and developments. A partial order data analysis. *Soc. Indic. Res.* **133**(1), 1–14 (2016). <https://doi.org/10.1007/s11205-016-1353-y>
- Carlsen, L., Brüggenmann, R.: Partial ordering and metrology analyzing analytical performance. *Partial Order Concepts Appl. Sci.* **1**, 49–70 (2017)
- Castaño, C., Martín, J., Martínez, J.L.: La brecha digital de género en España y Europa: Medición con indicadores compuestos. *Revista Española de Investigaciones Sociológicas* **136**, 167 (2011)
- Di Bella, E., Leporatti, L., Maggino, F., Gandullia, L.: A poset based indicator of gender equality at sub-national level. *ASMOD 2018*. in: Proceedings of the International Conference on Advances in Statistical Modelling of Ordinal Data. (2018). <https://doi.org/10.6093/978-88-6887-042-3>
- Di Brisco, A.M., Farina, P.: Measuring gender gap from a Poset Perspective. *Soc. Indic. Res.* **136**, 1109–1124 (2018). <https://doi.org/10.1007/s11205-017-1582-8>
- EIGE: Gender Equality Index 2020—Digitalisation and the future of work. (2020). <https://eige.europa.eu/publications/gender-equality-index-2020-digitalisation-and-future-work>
- EIGE: Economic Benefits of Gender Equality in the EU: EU and EU Member States Overviews. Publications Office of the European Union, Luxembourg (2017)
- European Commission: Women in the digital age: Final report Directorate General for Communications Networks, Content and Technology. Publications Office. (2018). <https://data.europa.eu/doi/10.2759/526938>

- European Commission: Women in Digital - Shaping Europe's digital future (2019). <https://digital-strategy.ec.europa.eu/en/library/women-digital>
- European Commission: *2030 Digital Compass: the European way for the Digital Decade*. (2021a). <https://eufordigital.eu/wp-content/uploads/2021/03/2030-Digital-Compass-the-European-way-for-the-Digital-Decade.pdf>
- European Commission: Women in Digital Scoreboard 2021. (2021b). <https://digital-strategy.ec.europa.eu/en/news/women-digital-scoreboard-2021> (accessed 1 December 2021)
- European Commission: *Shaping Europe's Digital Future*. (2020a). https://ec.europa.eu/info/sites/info/files/communication-shaping-europes-digital-future-feb2020_en_4.pdf (accessed 3 February 2021)
- European Commission: Women in Digital Index 2020. Methodology. (2020b). <https://comunic.ro/wp-content/uploads/2021/03/WomeninDigitalIndex2020-methodology.pdf>
- European Commission: *Women in Digital Scoreboard 2020*. (2020c). <https://bit.ly/3CPgXnH> (accessed 3 April 2022)
- Fattore, M.: Partially ordered sets and the measurement of multidimensional ordinal deprivation. *Soc. Indic. Res.* **128**(2), 835–858 (2016). <https://doi.org/10.1007/s11205-015-1059-6>
- Fattore, M., Arcagni, A.: A reduced posetic approach to the measurement of multidimensional ordinal deprivation. *Soc. Indic. Res.* **136**(3), 1053–1070 (2018). <https://doi.org/10.1007/s11205-016-1501-4>
- Fattore, M., Arcagni, A.: F-FOD: Fuzzy first order dominance analysis and populations ranking over ordinal multi-indicator systems. *Soc. Indic. Res.* **144**(1), 1–29 (2019). <https://doi.org/10.1007/s11205-018-2049-2>
- Fuster, M.: The gender of the platform economy. *Inter. Policy Rev.* **11**, 27 (2022)
- Grau-Sarabia, M., Fuster-Morell, M.: Gender approaches in the study of the digital economy: A systematic literature review. *Humanit. Social Sci. Commun* **8**(1), 201 (2021). <https://doi.org/10.1057/s41599-021-00875-x>
- Hargittai, E.: Digital na(t)ives? Variation in internet skills and uses among members of the “Net generation. *Sociol. Inq.* **80**(1), 92–113 (2010). <https://doi.org/10.1111/j.1475-682X.2009.00317.x>
- Hargittai, E., Shaw, A.: Mind the skills gap: The role of internet know-how and gender in differentiated contributions to Wikipedia. *Inform. Communication Soc.* **18**(4), 424–442 (2015). <https://doi.org/10.1080/1369118X.2014.957711>
- Helsper, E.J.: Gendered Internet Use Across Generations and Life Stages. *Communication. Res* **37**(3), 352–374 (2010). <https://doi.org/10.1177/0093650209356439>
- Helsper, E.J., Eynon, R.: Distinct skill pathways to digital engagement. *Eur. J. Communication.* **28**(6), 696–713 (2013). <https://doi.org/10.1177/0267323113499113>
- Iglesias, K., Suter, C., Beycan, T., Vani, B.P.: Exploring multidimensional well-being in Switzerland: Comparing three synthesizing approaches. *Soc. Indic. Res.* **134**(3), 847–875 (2017). <https://doi.org/10.1007/s11205-016-1452-9>
- Ivaldi, E., Ciacci, A., Soliani, R.: Urban deprivation in Argentina: A POSET analysis. *Papers Reg. Sci.* **99**(6), 1723–1724 (2020). <https://doi.org/10.1111/pirs.12555>
- JRC: The Changing Nature of work and Skills in the Digital age. Publications Office of the European Union (2019). <https://doi.org/10.2760/679150>
- Kohlrausch, B., Weber, L.: Gender relations at the Digitalised Workplace: The interrelation between digitalisation, gender, and work. *Gend. výzkum / Gend. Res.* **21**(2), 13–31 (2020). <https://doi.org/10.13060/gav.2020.010>
- Maggino, F.: Developing indicators and managing the complexity. In: Maggino, F. (ed.) *Complexity in Society: from Indicators Construction to Their Synthesis*. Social Indicators Research Series, vol. 70. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-60595-1_4
- Martínez-Cantos, J.L.: Digital skills gaps: A pending subject for gender digital inclusion in the European Union. *Eur. J. Communication.* **32**(5), 419–438 (2017). <https://doi.org/10.1177/0267323117718464>
- Meri-Tuulia, K., Antero, K., Suvi-Sadetta, K.: Differences between the genders in ICT skills for finnish upper comprehensive school students: Does gender matter? *SEMINAR.NET.* **13**(2), 17 (2017)
- Norlén, H., Papadimitriou, E., Dijkstra, L.: The Regional Gender Equality Monitor. Measuring female disadvantage and achievement in EU region. (2019). <https://doi.org/10.2760/472693>
- OECD: Bridging the digital gender divide. Include, Upskill, Innovate, (2018). <https://www.oecd.org/digital/bridging-the-digital-gender-divide.pdf>
- Quan-Haase, A., Martin, K., Schreurs, K.: Interviews with digital seniors: ICT use in the context of everyday life. *Inform. Communication Soc.* **19**(5), 691–707 (2016). <https://doi.org/10.1080/1369118X.2016.1140217>
- Rodríguez-Modroño, P., Pesole, A., López-Igual, P.: Assessing gender inequality in digital labour platforms in Europe. *Internet Policy Review.* **11**(1) (2022). <https://doi.org/10.14763/2022.1.1622>

- Scheerder, A., van Deursen, A., van Dijk, J.: Determinants of internet skills, uses and outcomes. A systematic review of the second- and third-level digital divide. *Telematics Inform.* **34**(8), 1607–1624 (2017). <https://doi.org/10.1016/j.tele.2017.07.007>
- Silan, M., Boccuzzo, G., Arpino, B.: Matching on poset-based average rank for multiple treatments (MAR-MoT) to compare many unbalanced groups. *Stat. Med.* **2021**, **40**(28), 6443–6458 (2020). <https://doi.org/10.1002/sim.9192>
- Sorgner, A., Bode, E., Krieger-Boden, C.: The Effects of Digitalization on Gender Equality in the G20 economies, Kiel Institute for the World Economy. (2017). https://www.ifw-kiel.de/pub/e-books/digital_women-final_report.pdf
- Sáinz, M., Arroyo, L., Castaño, C.: Mujeres y digitalización. De las Brechas a los Algoritmos. Instituto Andaluz de las Mujeres, Madrid (2020)
- Vergés Bosch, N., Freude, L., Almeda Samaranch, E., González Ramos, A.M.: Women working in ICT: Situation and possibilities of progress in Catalonia and Spain. *Gend. Technol. Dev.* 1–19 (2021). <https://doi.org/10.1080/09718524.2021.1969783>
- Wajcman, J.: Feminist theories of technology. *Camb. J. Econ.* **34**(1), 143–152 (2010). <https://doi.org/10.1093/cje/ben057>
- Wyatt, S.: Technological Determinism is dead; Long Live Technological Determinism. in Hackett et al. (eds.) In: *The Handbook of Science and Technology Studies*, pp. 165–180. The MIT Press, Cambridge, Mass. (2008)
- van Deursen, A.J.A.M., Helsper, E.J.: The Third-Level Digital Divide: Who Benefits Most from Being Online? in L. Robinson, S. R. Cotten, J. Schulz, T. M. Hale, & A. Williams (Eds.), *Studies in Media and Communications* (Vol. 10, pp. 29–52). Emerald Group Publishing Limited. (2015). <https://doi.org/10.1108/S2050-206020150000010002>
- van Deursen, A.J.A.M., van Dijk, J.A.G.M.: Toward a multifaceted model of Internet Access for understanding Digital divides: An empirical investigation. *Inform. Soc.* **31**(5), 379–391 (2015). <https://doi.org/10.1080/01972243.2015.1069770>
- van Deursen, A.J., van Dijk, J.A.: The first-level digital divide shifts from inequalities in physical access to inequalities in material access. *New. Media & Society.* **21**(2), 354–375 (2019). <https://doi.org/10.1177/1461444818797082>
- van Deursen, A.J.A.M., van Dijk, J.A.G.M., ten Klooster, P.M.: Increasing inequalities in what we do online: A longitudinal cross sectional analysis of internet activities among the dutch population (2010 to 2013) over gender, age, education, and income. *Telematics Inform.* **32**(2), 259–272 (2015). <https://doi.org/10.1016/j.tele.2014.09.003>

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.