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ORIGINAL

Access to intensive care in 14 European countries: a spatial analysis of intensive care need and capacity in the light of COVID-19

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Abstract

Purpose: The coronavirus disease 2019 (COVID-19) poses major challenges to health-care systems worldwide. This pandemic demonstrates the importance of timely access to intensive care and, therefore, this study aims to explore the accessibility of intensive care beds in 14 European countries and its impact on the COVID-19 case fatality ratio (CFR).

Methods: We examined access to intensive care beds by deriving (1) a regional ratio of intensive care beds to 100,000 population capita (accessibility index, AI) and (2) the distance to the closest intensive care unit. The cross-sectional analysis was performed at a 5-by-5 km spatial resolution and results were summarized nationally for 14 European countries. The relationship between AI and CFR was analyzed at the regional level.

Results: We found national-level differences in the levels of access to intensive care beds. The AI was highest in Germany (AI = 35.3), followed by Estonia (AI = 33.5) and Austria (AI = 26.4), and lowest in Sweden (AI = 5) and Denmark (AI = 6.4). The average travel distance to the closest hospital was highest in Croatia (25.3 min by car) and lowest in Luxembourg (9.1 min). Subnational results illustrate that capacity was associated with population density and national-level inventories. The correlation analysis revealed a negative correlation of ICU accessibility and COVID-19 CFR ($r = -0.57$; $p < 0.001$).

Conclusion: Geographical access to intensive care beds varies significantly across European countries and low ICU accessibility was associated with a higher proportion of COVID-19 deaths to cases (CFR). Important differences in access are due to the sizes of national resource inventories and the distribution of health-care facilities relative to the human population. Our findings provide a resource for officials planning public health responses beyond the current COVID-19 pandemic, such as identifying potential locations suitable for temporary facilities or establishing logistical plans for moving severely ill patients to facilities with available beds.

Keywords: Access, Intensive care, Europe, COVID-19

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Introduction

The coronavirus disease 2019 (COVID-19) poses a major global challenge to health-care systems despite the warnings vocalized following the severe acute respiratory syndrome (SARS) pandemic in 2003 [1, 2]. This pandemic demonstrates the consequences of situations where the need for health care is greater than the health-care capability. However, other situations can also confront the health-care system with similar problems such as mass casualties after terrorist attacks, as was the case in Paris in 2015 [3]. With regard to COVID-19, several European countries have been at the center of the pandemic since the beginning of 2020 [4], with Italy, Spain, and the UK having among the highest numbers of reported cases and deaths worldwide as of May 2020. Ensuring universal access to diagnostics and treatment during such situations is crucial [5]. The current pandemic demonstrates the scale of the possible increase of need for intensive care units (ICU) if national case counts are translated into health-care demand. The European Centre for Disease Prevention and Control (ECDC) estimated that 32% of COVID-19 cases in the European Union (EU) require inpatient care and 2.4% require intensive care as of April 2020 [6].

The need for health care is met by different health-care systems across Europe. Some countries seem to be well placed to implement the necessary actions to cope with increased health-care needs, but others are struggling [7]. One important aspect affecting the efficacy of national responses is the capacity to endow the health-care system with necessary resources in a timely manner. Previous research identified substantial differences in the number of ICU beds among European countries, which range from 4.2 ICU beds per 100,000 people in Portugal to 29.2 in Germany (EU mean: 11.5) [8]. The proportion of the population aged 65 years and over also differs among European countries, as this age group accounted for a low of 14.1% and a high of 22.8% of the national population, respectively, in Ireland and Italy in 2019 (EU mean: 20.3%) [9]. It is important to take demographic differences into account, as the need for health care increases with patient age due to the increased morbidity among the elderly population.

To ensure universal access to health-care resources, adequate health-care resources must be available (in terms of number and capacity of hospitals) and accessible (in terms of travel distance) [5]. Availability and accessibility are commonly merged under the term 'spatial accessibility' [10], and relevant national and regional differences in spatial accessibility to health care were known long before the COVID-19 pandemic [11, 12]. It is important to assess the heterogeneous patterns of spatial accessibility to specific health-care resources that are required to adequately manage an increased need of intensive care. Such regional patterns of spatial accessibility cannot be reliably derived from simple provider-to-population ratios justifying the necessity of more sophisticated measures [10]. This is clearly in line with the 'COVID-19 strategic preparedness and response plan' of the WHO (World Health Organization), which states that one of the first public health measures is to 'map existing preparedness and response capacity' [7]. Within this context, this study assessed the spatial accessibility of intensive care beds in Europe. However, in the light of the COVID-19 pandemic, a focus is put on the impact on the COVID-19 case fatality ratio (CFR). We start from the hypothesis that accessibility varies between European countries and that a low accessibility is related to higher COVID-19 CFR.

Take-home message

Our results suggest substantial pre-existing subnational- and national-level differences for spatial accessibility to intensive care units. Furthermore, lower accessibility of intensive care is associated with higher COVID-19 case fatality ratios. In conclusion, some countries (e.g., Germany) are particularly well positioned to manage a swiftly increased need for intensive care, whereas others (e.g., Denmark, Italy or Sweden) have lower numbers of intensive care beds that are also spatially more concentrated, and thus localized shortages are possible during a locally increased need for intensive care.

Materials and methods

This study included 14 European countries, for which the required health-care inventory and location data were available. To assess the accessibility of ICU beds, the need for intensive care as well as the capacity of intensive care must be modeled. Regarding the capacity of intensive care, we collected the following data at hospital level for each country: (1) address of the hospital, (2) number of ICU beds, and (3) total number of inpatient beds. Since the definition of 'hospital' was not consistent in the European countries, we applied the definition based on the classification of health-care providers of the System of Health Accounts (SHA) provided by the WHO. As such, hospitals are defined as health-care facilities providing acute (curative) inpatient care beds for internal medicine, and excluding hospitals providing solely psychiatric beds, long-term care beds, or rehabilitative care beds. Furthermore, it was not possible to apply a common definition of ICU as the definitions differ slightly in the European countries. The data were mainly obtained from national government health departments and cover the most recent reference periods between 2017 and 2019. For detailed information regarding the definitions and data sources for each country, see Online Appendix 1.

Regarding the need for intensive care, we used the adjusted total population counts of the countries to model the need for care as provided by the 'gridded population of the world' raster (GPWv4) as of 2020 at the resolution of approximately 5 km (2.5 arc-min) [13]. We excluded all locations with a population of zero. For a sub-analysis, we excluded patients aged 80 years and over, since this age group has been shown to have poor outcomes from acute admissions to an ICU [14]. This different dataset was based on the GPWv4 as of 2010, since more recent data were not yet available. This sub-analysis was performed to model intensive care provision for the section of the population with higher outcomes from ICU care.

Using the modeled need for intensive care as well as the capacity of intensive care, we calculated two accessibility measures: (1) a regional ratio of hospital beds to 100,000 population capita (accessibility index, AI), and (2) the distance to the closest hospital providing intensive care. The AI is a measure of both availability and accessibility of hospital beds that accounts for population sizes, whereas the distance to the closest hospital is a simple and easier to interpret measure of accessibility. We included both measures to provide a more comprehensive assessment of access to intensive care across European countries. For both measures, we calculated the distance from each centroid of the gridded population raster to hospitals providing ICU beds. The distance calculation is based on TomTom Multinet data (TomTom N.V., Amsterdam, The Netherlands) as of 2016 using ArcGIS Pro 2.5 (ESRI Inc., Redlands, USA). The closest hospital approach only considers one hospital (i.e., the closest one), whereas the AI considers all hospitals within a certain catchment area. For the calculation of the regional ratio (AI) we applied the 'enhanced two step floating catchment area' methodology (E2SFCA) [15]. This well-established method is based on a gravity model, which considers the declining probability to see a health-care provider with increasing travel distance. By using this approach, it was possible to disaggregate the national ratio of hospital beds to match the 5-by-5 km spatial resolution of the population raster. Population weighting was used when deriving the national mean of the AI and the distance to the closest hospital. For a detailed description of the E2SFCA method, see Online Appendix 2. To quantify any regional clustering of the AI, we applied a hot spot analysis (based on the Getis-Ord Gi* statistic) using ArcGIS Pro. This metric was used to identify areas of significant high or low AI.

Finally, we used the crude CFR (proportion of cumulative COVID-19 deaths to cumulative COVID-19 cases) on NUTS-1 level ('Nomenclature of Territorial Units for Statistics' defined by the European Union) until 28 July 2020 to assess the relationship of accessibility to an ICU and the mortality of COVID-19 across all included countries. The relationship was analyzed using spearman's Rho (non-parametric data) using the statistical analysis software SPSS version 23 (IBM, Armonk, USA). We further included the positivity rate (proportion of cumulative COVID-19 cases to cumulative number of tested people until 28 July 2020) as the measure of the countries testing strategy, since differing strategies are reported to be an important source of bias regarding the CFR [16].

Results

For 14 countries, necessary data could be retrieved, with the other European countries excluded due to either (1) missing regional data on national level (e.g., in Spain, data are managed locally by autonomous regions) or (2) data protection policies (e.g., Portugal). Among the 14 European countries included, the analysis revealed distinct national and regional differences in the provision of intensive care resources.

Intensive care on national level

On national level, the crude number of ICU beds varied between 28,031 in Germany and 130 in Luxembourg (see Table 1). The average accessibility index as the measure of availability and accessibility of ICU beds was highest in Germany (AI = 35.3), followed by Estonia (AI = 33.5) and Austria (AI = 26.4), and lowest in Sweden (AI = 5.0) and Denmark (AI = 6.4). These first findings were further analyzed with the average distance to the closest hospital providing ICU beds. Among all 14 countries, the average travel distance was 13.1 min by car. Croatia had the highest average travel time with 25.3 min, while Luxembourg (9.1 min) and Germany (9.3 min) had the lowest travel times to the nearest facility with ICU beds.

Regarding the sub-analysis excluding patients aged 80 years and over, the analysis revealed overall higher AI with an average absolute increase of 1.4 (SD: 1.6), which was due to the smaller population size compared to the total population. In Estonia and Luxembourg, the AI showed the highest absolute increase (+4.6), followed by Slovenia (+2.8). On the other hand, in Croatia, the AI did not change substantially (+0.1) and in Lithuania AI decreased (− 1.4).

Intensive care on regional level

Subnational variations of health-care provision were further analyzed using high-resolution maps of AI (Fig. 1). In Germany, with one of the highest national AI levels, access to ICU beds was high throughout the country. Likewise, AI for ICU was high across Luxembourg and

Table 1 Overview intensive care beds

Country	Hospitals (*n*)	ICU beds[a] (*n*)	ICU beds/total beds at the hospital (%)	Average travel time to closest hospital (min)	Average accessibility index[b]	Area of significant AI[c] (%)	
						High	Low
Austria	118	2,369	5.9	12.7	26.4	54	1.1
Croatia	25	396	3	25.3	9	2.6	43.4
Denmark	29	382	3.5	15.4	6.4	0.5	36.3
England	194	3999	4.1	12.5	7	0	40.7
Estonia	15	483	9.4	16.9	33.5	47.5	4.6
France	343	5,671	4	16.6	8.2	0.8	31.6
Germany	1161	28,031	5.9	9.3	35.3	95.2	0.3
Italy	428	5184	3.7	12	8.1	0	18
Lithuania	57	644	3.7	16.2	22.7	54	0.3
Luxembourg	9	130	6.3	9.1	21.1	63.6	0
Poland	534	4391	2.7	12.7	11.1	4.4	3.5
Slovakia	52	814	4.4	16.7	14.4	40.5	0.2
Slovenia	15	539	8.6	15.7	24.2	47.2	2.6
Sweden	55	522	3	22	5	1	82.9
All countries ($n = 14$)	3035	53,555	4.9	13.1	16.6	29.4	18.9

ICU intensive care unit, *AI* accessibility index

[a] Different definitions of ICU were applied (Online Appendix 1)

[b] AI was calculated per 100,000 people

[c] Area of significant AI was calculated by the hot spot analysis using a 99% confidence interval. 'High' represents hot spots, whereas 'low' represents cold spots

also, but to a lesser degree, in Estonia, Lithuania, Slovenia, and Austria.

In Italy, England, France, and especially Sweden, the patterns were more clustered, indicating that spatial accessibility to ICU beds was high near some population centers, but lower across rural areas of these countries. In Sweden, for example, there were vast areas of low spatial accessibility, especially in the northwest. Looking at clusters of high accessibility (see Table 1; Fig. 2), the hot spot analysis revealed that 95.2% of all populated locations in Germany had high spatial accessibility (confidence interval: 99%) in contrast to Italy (no significant high accessibility) or Sweden (1%).

Regarding the sub-analysis excluding patients aged 80 years and over, the findings of the regional analysis did not substantially vary substantially from the patterns shown in Figs. 1 or 2. Therefore, the spatial distribution shown in these figures can be transferred to the results of the sub-analysis.

Accessibility of ICU and case fatality ratio (CFR) of COVID-19

Except for France, the CFR could be calculated on NUTS-1 level for all countries included. For France, we used the national numbers to calculate the CFR, since regional data were only available for the inpatient sector. The average CFR across all 14 countries was 7.4% (SD: 5.3) with the lowest CFR in the NUTS1 Region Slovakia (1.2%), followed by Luxemburg (1.8%) and 'Południowy' in Poland (2.3%). All the three highest NUTS1 Regions were located in England with 'London' having the highest one (19.4%), followed by 'West Midlands' (19.1%). The correlation analysis on NUTS1 level revealed a significant negative correlation of ICU accessibility and CFR with $r = -0.57$ ($p < 0.001$). Therefore, in NUTS1 regions with low ICU accessibility, the CFR was higher.

For England and France, the positivity rate was not available on NUTS-1 level. Therefore, we used the rate on country level for both countries. The positivity rate varied across the included countries from 0.4% in Lithuania to 15.8% in 'Östra Sverige' in Sweden with a mean across all included countries of 3.3% (standard deviation: 3.0). Regarding the relationship of the cumulative positivity rate and the CFR, the analysis revealed no significant correlation.

Discussion

We mapped spatial accessibility for intensive care beds in 14 European countries. A heterogeneous geographical distribution was present both within and between the analyzed countries. At the national level, Germany and Estonia had the highest accessibility indices for intensive care beds. Subnationally, the geographical pattern of accessibility indices was more clustered, especially

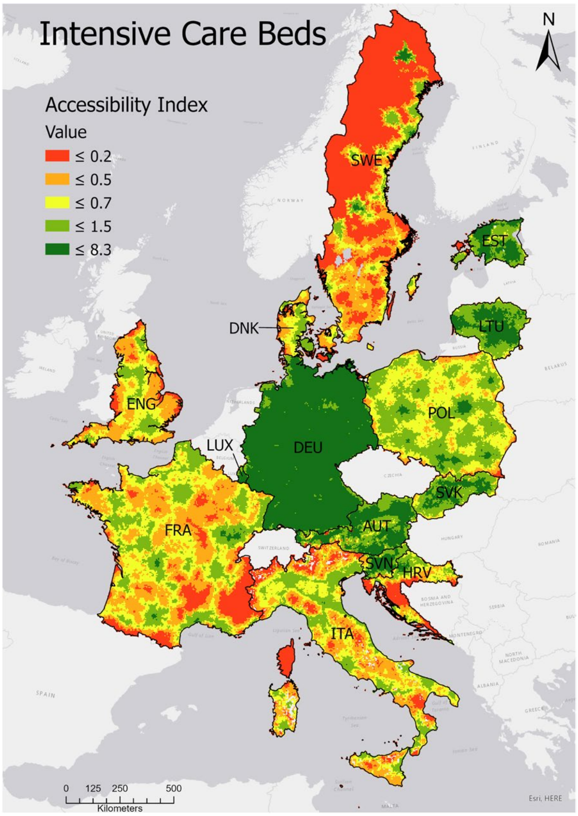

Fig. 1 Regional analysis of accessibility indices (AI) for intensive care beds in 14 European countries. The AI was calculated per 100,000 people. *AUT* Austria, *DEU* Germany, *DNK* Denmark, *ENG* England, *EST* Estonia, *FRA* France, *HRV* Croatia, *ITA* Italy, *LTU* Lithuania, *LUX* Luxembourg, *POL* Poland, *SVK* Slovakia, *SVN* Slovenia, *SWE* Sweden. Data source of administrative boundaries: ©EuroGeographics

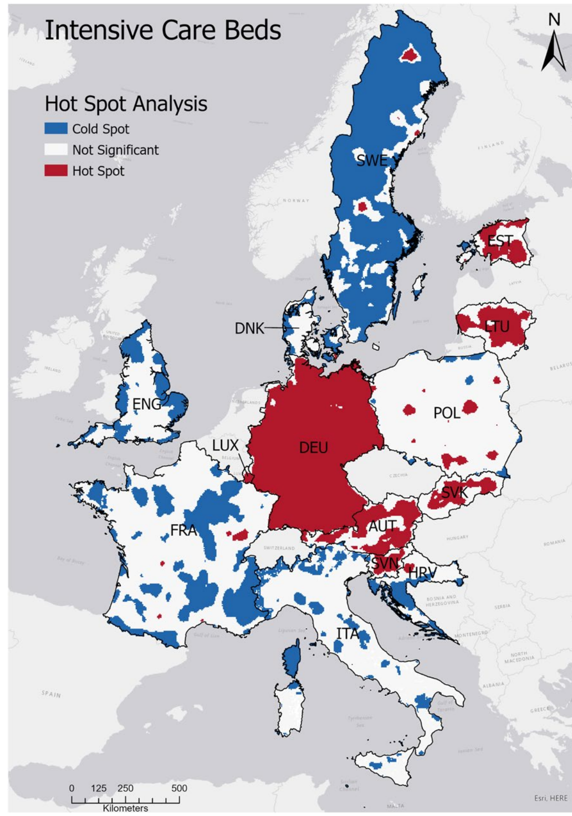

Fig. 2 Hot spot analysis of accessibility indices (AI) for intensive care beds in 14 European countries. *CI* confidence interval, *AUT* Austria, *DEU* Germany, *DNK* Denmark, *ENG* England, *EST* Estonia, *FRA* France, *HRV* Croatia, *ITA* Italy, *LTU* Lithuania, *LUX* Luxembourg, *POL* Poland, *SVK* Slovakia, *SVN* Slovenia, *SWE* Sweden. Data source of administrative boundaries: ©EuroGeographics

in Sweden, Italy and France, whereas in Germany and Luxembourg, high accessibility indices were present throughout the country. At the regional level, we further found that in regions with low ICU accessibility, the CFR of COVID-19 was higher.

The findings suggest that low accessibility of ICU beds is associated with a higher proportion of COVID-19-related deaths to the number of cases (higher CFR). In general, a lack of adequate access to health care is known to be associated with negative health outcomes [17–19], which stem from various spatial and non-spatial dimensions of access [20]. In this study, we only included the spatial dimension of access, which ignored other aspects that influence health-related outcomes such as the socioeconomic status or the affordability of health services [21]. To further evaluate the impact of variable accessibility indices on health outcomes, morbidity data should be included in future studies as the need for health care is best modeled using the treatable morbidity. Looking at the average travel time to the closest hospital among the countries included (from 9.1 up to 25.3 min), it may be questioned whether a difference of about 15 min in travel time really makes a difference regarding the outcome of a disease like COVID-19. However, there are multiple factors possibly influencing the CFR besides spatial factors that have not been accounted for in this study (e.g., morbidity of the population or COVID-19 testing strategies) [22]. For example, at the peak of the first wave, people in the UK were specifically told not to come in for a test, but rather self-isolate if they were ill but not in an at-risk group. Such testing strategies affect the documented case count, leading to an increased apparent CFR. If different countries followed alternative testing strategies, this could be a confounding factor, especially since testing strategies has been changed over time [16]. The positivity rate as reported in our study varied greatly among the included countries which further strengthens the different testing strategies followed in the included countries. The highest positivity rate was present in 'Östra Sverige' in Sweden (15.8%) which suggests rather restrictive testing (i.e., only testing high risk patients with high pretest probabilities). However, the positivity rate showed no significant association with the CFR on NUTS-1 level. Therefore, on this aggregated regional level, an influence of the testing strategy on the CFR was not present. This may be due to the geographical level of the analysis (NUTS-1 level) and an influence may be present on more detailed analysis levels (i.e., NUTS-2 or NUTS-3). Even though our results did not reveal an association, the testing strategy is still likely a relevant source of bias regarding the potential influence of the accessibility on the CFR [16].

The crude CFR also does not account for changes in the demography of positive cases and deaths during the different stages of an epidemic. However, as reported by the European Commission, demographic factors alone cannot explain the high number of fatalities reported for example in Italy [16]. Furthermore, the incidence of COVID-19 follows infection clusters and is therefore not equally distributed within countries. In the 21 counties of Sweden, for example, the highest incidence as of 18 August 2020 was in the county Jönköping with 1336, and the lowest in Skåne with 307 cases per 100,000 residents [23]. These differing incidences represent a bias regarding the analysis of the CFR. Also, the AI accounts for availability of ICU beds and not only the travel distance. This is especially important since it also accounts for in-hospital transfers to an ICU where the travel time to the hospital is not the major issue. Therefore, the AI represents more than just the travel distance and the negative correlation found with CFR should prompt a critical discussion regarding the current intensive care provision in certain countries. However, due to the numerous potential sources of bias, we are not able to fully explain the differing CFR reported in this study, especially since we performed a correlation analysis, and therefore, are not able to draw conclusions regarding causality. This requires further research which should include individual level data on the location and the morbidity of the patients admitted to the ICU to support the findings. However, the reported findings may provide additional insights into spatial factors that influence the CFR.

In this study, both AI and travel time to the closest facility were calculated, and in some case these results led to outcomes that appear contradictory. These differences emerge because AI incorporates the number of beds relative to the population potentially needing them, in addition to travel distance. For example, Italy and Austria had similar travel time to the nearest facility with intensive care beds (12.0 vs. 12.7 min), but dissimilar AI for the same health-care service (AI = 8.1 vs. AI = 26.4). These results suggest that the key difference between these countries is the local demand for intensive care beds and not the time it takes patients to reach them. In this regard, it has to be noted that geographically isolated locations such as rural parts in Sweden are at higher risk of longer travel times to an ICU, but are probably also at lower risk of being exposed to diseases like COVID-19. However, for other diseases (such as major trauma and cardiovascular or neurologic diseases), the probability of requiring intensive care in such isolated regions due to a medical emergency may be as high as in more populated areas. Since the results represent the overall access to intensive care regardless of the etiology of the disease, the consequences drawn from low accessibility may differ depending on the medical focus. However, even though studies analyzing in-hospital delays from the general ward to intensive care units have shown that ICU transfer delays are associated with higher mortality, necessary to that end were delays of at least 1 or 2 h [24, 25]. This being said, the average difference of 15 min travel time reported in our study may not be relevant for the majority of medical emergencies.

In general, both AI and travel time measures have advantages and disadvantages [10, 26]. The major advantage of the travel distance is that it is simple and easy to communicate. In contrast, AI is more complex, but provides more informative results by accounting bypassing the closest provider, population size, resources available, and distance decay [10, 27]. Alternative measures and thresholds have also been applied when assessing spatial accessibility, such as in a study in Scotland, which revealed that 94% of the population could access an intensive care unit within a 45-min drive time by car [28]. The method applied in our study (E2SFCA) has limitations despite being a widely used measure of spatial accessibility [26]. The limitations include the user-defined catchment size and distance decay function. For these elements of E2SFCA, we relied on parameters established in previous studies [15, 21].

Looking at the analysis excluding very old patients, the findings do not alter the conclusions stated above. Therefore, looking at the population with a higher probability of a better outcome from an acute ICU admissions (i.e., patients aged 79 years and younger), altering of policy planning based on the reported findings may help to provide better treatments for the population with better outcomes [14]. However, the ethics of admission to an ICU have to be acknowledged [29]. Therefore, policy planning based on the probable outcome of intensive care should be accompanied by a social debate on end-of-life decisions.

The numbers of hospital beds used in this study were comparable to the numbers reported in earlier studies [8, 30]. However, different definitions for hospital or intensive care were used among the European countries, making direct comparisons challenging. For example, in Estonia intensive care is classified into levels I–III, with level I and II being comparable with high dependency units or intermediate care units in other countries. However, due to data restrictions, it was not possible to include only the highest level of intensive care (e.g., level III units in Estonia) for most European countries. This may explain the exceptionally high spatial accessibility in Estonia compared to previous studies [8]. In addition, the criteria for an ICU transfer may differ in the analyzed countries. For example, in many Scandinavian countries, a patient may be of an FiO_2 (fraction of inspired oxygen) of up to 60% on a general ward before being transferred to an ICU to get mechanical ventilation, whereas in Germany the criteria for an ICU transfer are often less strict, which may be due to the high availability of ICU beds in Germany as shown in our study. Although the authors tried to harmonize the retrieved data, the lack of a common definition should be noted, and conclusions should be drawn with caution (Online Appendix 1: detailed information for each country).

It should be noticed that low accessibility indices are not equivalent to a low quality of care or the result of inadequate planning. They rather display the distribution of care provision at subnational levels that results from the interplay of national public health strategies and the spatial distribution of the underlying population. As such, if health polices prioritized centralization of health-care services, AI will tend to cluster spatially, as was the case in Sweden [31]. Additionally, centralizing certain health-care services may improve the quality of specialized care. For example, centralizing neonatal care in fewer facilities has been shown to reduce mortality in very-low-birth-weight infants [32]. Furthermore, in some countries the focus of the health-care system has been put on primary health care (e.g., in Nordic countries), whereas in other countries like Germany attention has been turned toward specialized care, which may explain the findings reported in this study.

During pandemic outbreaks such as COVID-19, scarcities of health-care resources are a primary concern due to the increased mortality that can occur when health-care systems are overwhelmed. The planning of hospital beds for intensive care as well as for other specialties is usually based on planning models that include relevant information such as demographic data, average length of stay, admission rates, and bed occupancy rates [33]. In many situations (e.g., terrorist attacks or the COVID-19 pandemic), intensive care resources may be needed beyond existing capacity, and therefore capacity of these critical services has to be expanded to meet the increased demand [3, 34, 35]. Hospitals are urged to utilize existing response plans or modify them to address health-care demands. While many European countries have made a tremendous effort to increase the number of intensive care beds in response to COVID-19, our results suggest substantial pre-existing national- and subnational-level differences for spatial accessibility to needed services. Accessibility to intensive care beds, in particular, is of concern as their availability was more limited at the start of the pandemic and rapid expansion in capacity will be challenging. For example, the expansion of hospital capacity is simplest when built upon existing infrastructure and workforces, but such health-care system assets varied greatly among European countries. Therefore, besides the number of ICU beds, the major issues regarding intensive care provision are the adequately trained workforce and the number of mechanical ventilators. Among both, the workforce represents the more difficult asset to be rapidly increased. Therefore, in many countries the number of ICU beds must be differentiated by physical and staffed ICU beds. In our analysis, the data did not allow for this differentiation. Another aspect of the expansion of intensive care capacity is the temporal aspect. The increased capacity will likely be reduced once the issue leading to the increased demand has been resolved. Therefore, many countries use temporary infrastructures (such as operating rooms or other hospital spaces) to increase the number of hospital beds in such situations. Our results may also help optimize locating such temporary facilities in case of an increased need for intensive care. In this regard, the findings suggest that Germany is particularly well positioned to manage an increased need for intensive care due to a large number of intensive care beds that are distributed throughout the country. In contrast, Italy and France have more lower numbers of intensive care beds that are also more spatially concentrated, and thus localized shortages are possible, for example, during a local COVID-19 outbreak [36]. However, provision of a large number of ICU beds that may not be needed for routine care (i.e., aside from situations like the current pandemic) increases health-care expenditures. Therefore, aspects of health economics should also be considered. Simply increasing the number of ICU beds may not always be the best approach to achieve better outcomes for the severely ill.

In conclusion, our results provide novel insights into the distribution of intensive care resources in Europe and also suggest that low accessibility of intensive care is related with higher CFR of COVID-19. The results may help to contextualize the spatial dynamics in situations where demand for care exceeds capacity, as was the case in northern Italy in early 2020 [36]. Finally, our findings may provide a resource to public health officials by helping to define areas where increased health-care capacity is most needed in case of an increased need for intensive care.

Electronic supplementary material

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Author contributions

JB designed the study, monitored the data collection, cleaned and analyzed the data, prepared cartographic material and drafted the paper. DB, DK, WM, LS, DW and DG revised the paper. DW, LS and WM contributed to the methodological aspects of the study. All authors discussed the results and contributed to the final manuscript.

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