Evaluation by accessibility index differences of the cross-border potential for general inpatient care in the Ems-Dollart Region, a Dutch-German cross-border area

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Abstract

Access to healthcare in border regions is hampered by the very existence of the border and the limitations of cross-border cooperation between healthcare systems. This work examined the status quo of access to inpatient care at a high level of spatial detail and the potential impact of a cross-border cooperation in the Ems-Dollart border Region (EDR), a region located in the northern Dutch-German border area. A cross-border data model of inpatient care for Germany and The Netherlands was created using hospital beds as supply and 1-km² gridded population data as demand. The enhanced the two-step floating catchment area (E2SFCA) algorithm was applied to match supply and demand using road accessibility as intermediary. The model was calculated both for national and cross-border accessibility scenarios, with results standardised against national averages to account for systemic differences between German and Dutch healthcare settings. The resulting maps of spatial access to inpatient care capacity showed that the region has access rates below the national averages, with access rates in The Netherlands showing greater spatial variation than seen in Germany. The border appeared to be less important as cause of low access rates than other factors, such as the presence of the North Sea coast. The model results for cross-border hospital care showed a very local potential with access gains for only 2.2% of the population in the EDR, mostly in The Netherlands. This increase was drawn from wide areas with average and high access rates from both Germany and The Netherlands.

Introduction

National borders can cause social, economic and administrative disruptions and, as a result, produce spatial disparities for the areas surrounding the border. Regions close to borders may therefore be characterised as areas of limited effectiveness of institutions of public services (Winder, 2009). This also applies to healthcare systems and services, where accessibility and availability of providers are impaired by the existence of the border.

Improvement of spatial disparities in border regions has long been a goal of the European Union (EU). In this context, EU Directive 2011/24/EU (European Parliament, 2011) addresses access to healthcare in border regions and aims to "facilitate closer cooperation in a number of areas of medicine and healthcare" (Belet, 2019, p. 3). The directive facilitates access to healthcare benefits for European citizens, including treatment when abroad, planned care in another country and treatment for rare diseases not available in the home country (Wismar *et al.*, 2022). The EU Directive contains several limitations, such as restrictions on reim-

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bursement and the exclusion of nursing care. However, even though cross-border access of care may be crucial for patients residing in border regions with limited access to healthcare (Mullan *et al.*, 2022), there is little information about the impact of this EU Directive.

The Ems-Dollart Region (EDR), a cross-border organisation representing a EU border region located in the northern Dutch-German border, is named after the Ems River and the Dollart Estuary. In the following, we use the term in a geographically extended sense to include the districts of Osnabrück, Grafschaft Bentheim and the city of Osnabrück and not in relation to the aforementioned organisation. EDR is largely characterised by economic and demographic stability, even long-term economic prosperity, but includes also areas characterised by economic and demographic decline, deindustrialisation and an ageing population. The latter is especially true for the Dutch region adjacent to the border, creating a notable contrast to the German side (Velthuis *et al.*, 2024). With regard to the provision of healthcare, a systemic contrast lies in the different roles that inpatient care plays in German and Dutch healthcare. For example, the German healthcare system has 2.6 times as many hospital beds per capita as the Dutch one. This stark difference, which is one of the largest between the countries of the EU, invites the question of the spatial distribution of inpatient healthcare capacity in the immediate vicinity of the border within the EDR; e.g., is the proximity of the national border in EDR associated with low levels of access to inpatient care? With the idea of cross-border access to healthcare in mind, one wonders if the opening of the systemic healthcare border would change access to inpatient care and which regions would benefit from improved healthcare provision.

In this paper, we created a spatial cross-border model of inpatient care using publicly available aggregated data for Germany and the Netherlands, with inpatient hospital beds as the supply-side capacity and gridded population data as the demand-side. Supply and demand would be matched by an algorithm from the Floating Catchment Area (FCA) family, utilising road accessibility as an intermediary. We aimed to compare the resulting maps of inpatient care capacity heuristically within the national healthcare systems of the EDR, both in absolute measures and relative to the national healthcare system. Finally, the model was modified to include inpatient capacity across the Dutch-German border. The resulting map of differences between a national and a cross-border healthcare scenario would be used to assess the potential impact on the population of the region.

Materials and Methods

Background information

The different roles that inpatient care plays in the two national healthcare systems, and the resulting expectations and decisions of patients, are not reflected in a simple supply-demand ratio so an examination of the differences between the two healthcare systems is needed. The methods section explains our choice of an FCA algorithm and the modification required to account for the situation in the border region. The results, both in maps and in the descriptive statistics of the model, represent a spatially detailed analysis of the differences in the accessibility of general inpatient care for to the population within the EDR. This work would identify areas in the northern Dutch-German border region that could be strongly affected by the integration of inpatient care across the national border. The resulting change in accessibility rates were analysed in terms of the number of people affected in the border region.

Comparison of the inpatient care in The Netherlands and Germany

As pointed out by Schwettmann *et al.* (2023, p. 3), the German and Dutch healthcare systems are "classic examples of the Bismarckian health system which have adopted some competitive elements". The Dutch system can be characterized as decentralized, with healthcare delivered by private providers and operated by private health insurers, whereas the German one follows a corporatist model with a stronger role for self-government (Kroneman *et al.*, 2024). Hospital care in the Netherlands and Germany is differently organized along a number of structural and organisational dimensions (Schwettmann *et al.*, 2023). For better comparability, here we focus on acute care hospitals providing inpatient and emergency care only.

Financing and health expenditure

Dutch citizens purchase health insurance from private insurers; for curative care they pay 50% according to a community-rated premium, while 50% is paid by the employer via an income-dependent premium. For children under 18 other regulations apply (Kronemann *et al.*, 2016). In addition, out-of-pocket payments play an important role in the context of cost sharing for inpatient care. Most of the health expenditures (27.7%) in The Netherlands are for long-term care, while inpatient care plays a less important role (16.8%) in comparison to outpatient care (24.7%) (Kroneman *et al.*, 2024).

German citizens are legally required to have health insurance, either in Statutory Health Insurance (SHI) or in substitutive Private Health Insurance (PHI). Most of the German population is covered through SHI (87%), with 10.8% is covered through PHI or other health insurance forms (2%) (Blümel *et al.*, 2020). Contributions to health insurance are equally shared between employer and employee and out-of-pocket payments are lower in comparison to most of the European countries. In Germany, more than a quarter of the health expenditures is spent on inpatient care (27.9%), while less money is spent on outpatient care (26.1%) or long-term care (14.8%) (Blümel *et al.*, 2020).

Hospital type

In the Netherlands, three types of hospitals provide inpatient care, emergency care, and all outpatient care: general hospitals, top clinical centres, and university hospitals (Kronemann et al., 2016). There also exist specialized hospitals, which provide care for one condition only. For a better comparison, these hospitals are excluded. General hospitals offer general medical services, while the university hospitals form medical centres together with the medical, university faculty and offer a broad range of specialist care. In contrast, top clinical centres are part of a university hospital or specialized in certain care (*e.g.*, treatment of specific cancers or organ transplants) in the form of a consortium of a number of hospitals. Most hospitals in the Netherlands are foundations and non-profit institutions, while private for-profit hospitals only play a minor role in the Dutch healthcare system (Götze, 2010).

In Germany, hospital types differ depending on their size, functionality or ownership. One typology can be made according to the range of healthcare services hospitals offer (German

Hospital Association, 2022): hospitals with basic and regular care typically provide general medical services such as internal medicine, surgery or gynaecology; hospitals with specialised care offer more healthcare services than basic and regular hospitals and also focus on providing specific treatments for certain medical conditions; and hospitals that offer maximum care, provide the highest level of care and deal a wide range of specialities (German Hospital Association, 2022). Most academic hospitals in Germany are affiliated with a university, but not all of them are hospitals providing maximum care. In addition, there exist three types of hospital ownerships: public, private not-for-profit (so-called charities), and private for-profit; public hospitals usually owned by local or regional governments; and private (for-profit and not-for-profit) hospitals owned by foundations, churches, charities or companies. In the last few years, the German hospitals sector has gone through great changes due to hospital mergers and privatization schemes (Varabyova *et al.*, 2016). Currently, the German Government has introduced a major reform in the hospital sector aiming at the updating of the existing payment system by assigning hospitals into service groups based on certain quality criteria (German Federal Government, 2024).

Hospital access

General Practitioner (GP) or hospital selection appears mainly unbiased by the form of insurance in both countries. In Germany, public servants and persons with high income can opt-out of the statutory health insurance and choose fully private insurance (Schwettmann *et al.*, 2023). Nevertheless, all forms of funds and insurance use the same providers (Blümel & Busse, 2020).

In The Netherlands, the majority of the population extends the statutory coverage with a voluntary insurance. This does not entitle the insured to increased choice among hospitals. However, it should be added that insurers may favour certain provider networks on the basis of contracts (Wammes *et al.*, 2020).

In The Netherlands, the GP has a key role in the healthcare system and hospital care is generally only accessible after consulting one. This is controlled by service fees, which have to be paid for each consultation with a specialist up to a mandatory annual deductible (Wammes *et al.*, 2020). Even in the case of an emergency, patients are encouraged to get in contact with their GP or the GP out-of-hours service if possible. However, patients can also go to the emergency ward directly. Although there exist urban-rural differences, most of the Dutch population (99%) can reach their nearest hospitals within 30 minutes by car (OECD, 2021). Longer travel times mostly occur in the North. More and more hospitals are also opening outpatient clinics on the outskirts of their catchment area to compete with surrounding hospitals (Deuning, 2024), something that also increases the accessibility of hospitals in certain regions. In the German healthcare system, the GP does not have such a strict function as gatekeeper as in The Netherlands. Patients can freely choose and access hospitals in two ways: with a referral from a GP or specialist, or without a referral via after-hours and emergency care (Blümel *et al.*, 2020). In comparison to The Netherlands, the hospital density in Germany is higher, which is also visible in the accessibility of hospital care. Although there is regional differences, i.e. 97% of the German population need less than 24 minutes to reach a hospital featuring emergency care (Neumeier & Osigus, 2024).

Potential for cross-border inpatient care

Overall, quantitative data about cross-border care is scarce and despite its importance for border regions, the number of patients using cross-border healthcare is still limited (Wismar *et al.*, 2022). For example, in the German-Polish border region, cross-border emergency services are still rare and mental, financial, political and communicative borders prevent people accessing the nearest provider (Kuntosch *et al.*, 2024). Meanwhile, insurance data from the Meuse–Rhine Euro area (the Belgium-Germany-Netherlands border region) estimates that up to 2404 patients crossed the border to receive health care between 2019 and 2020. This number is reported to be relatively high compared to other EU border regions (it should be noted, however, that the data is incomplete due to inconsistent reporting practices; Mullan *et al.*, 2022). During the first wave of the COVID-19 pandemic, cross-border activities in healthcare were revived, especially with regard to intensive care. To reduce the pressure on overburdened Dutch intensive care wards (Intensive Care Units, ICU), 100 patients per day were transferred across regions within the Netherlands and 55 patients in total were transferred across the border to Germany. Later preparation plans included the use of German ICU capacity (Winkelmann *et al.*, 2022). In search of existing barriers, qualitative research suggests that complex routines, such as insurance-related administration, patient handover or patient involvement, become even more complex in cross-border settings (Beuken *et al.*, 2020). Furthermore, effective communication among healthcare professionals as well as between healthcare professionals and patients can be impeded by various factors, such as language barriers and discrepancies in available information (Beuken *et al.*, 2020). Other differences in care processes and practices, e.g., with respect to preoperative screening for methicillin-resistance or post-operative physical therapy (Schwettmann *et al.*, 2023), further complicate cross-border care. Related to these barriers, a European Commission report (Mullan *et al.*, 2022) states that better health data are needed to facilitate access to cross-border healthcare.

Nevertheless, the criteria developed by Kuntosch *et al.*(2024) suggest a potential for a mutual cross-border use of inpatient care capacity in the rural parts of the northern Dutch-German border region: there is no significant economic disparity between the countries, both systems are very capable and both are rural border regions with relatively sparse healthcare structures in some areas (Schwettmann *et al.*, 2023). However, language barriers and legal and reimbursement issues for patients may hinder this potential in this border region too. At first sight, the relation of the hospital-bed indicator listed in Table 1 suggests that there is a one-way potential for cross-border inpatient care, *i.e.* that Dutch patients are treated in German hospitals and not the other way round. This impression is reinforced by the excessive waiting times that patients experience in some care situations in the Netherlands (OECD, 2021). However, not only the absolute hospital-bed capacity but also the utilisation of hospital capacity (hospital discharge, occupancy rate, days of in-patient treatment) is consistently and profoundly higher in the German healthcare system. The number of hospital discharges and the number of hospital days of inpatients are further indications of the different roles of hospitals within the national healthcare systems. Given that the average length of stay is twice as long in Germany, it is unlikely that the 2.6 times higher hospital-bed capacity represents a major overcapacity compared to the Netherlands. Instead, the difference is more a result of the Dutch preference for outpatient care and day treatments (Schwettmann *et al.*, 2023) as reflected in the lower health expenditures for inpatient care (Table 1).

General approach

Against this background, we decided to focus on the geospatial perspective of accessibility and availability, but with a relative understanding of inpatient hospital capacity. Our assumption was that both healthcare systems fully cover the demand for inpatient care. We mapped the two systems at a regional level with high spatial detail across borders, while using the relative measures of difference, standardised against national averages in identifying the cross-border potential and the respective areas of potential along the border.

Study site

We first calculated a national accessibility index and then the cross-border accessibility index for inpatient care based on data for the whole area of each country. This large area was needed to account for the "edge effect" of any catchment-based method (Wan *et al.*, 2012). We restricted our following analysis to the northern Dutch-German border region, *i.e.* the EDR (Figure 1). The difference between these two indices was used to investigate the cross-border potential of inpatient care. The accessibility difference revealed areas in the region affected by the counterfactual removal of the border between the two national care systems. However, there was no change in supply or demand between these scenarios.

Data

Population

Population distribution with higher detail than administrative regions is required for local or regional models of accessibility. Population grids are well-suited because of their regular geometric representation (Burgdorf & Göddecke-Stellmann, 2014). As our work did not consider demographic properties, we considered the Eurostat GISCO GEOSTAT 1-km² population grid (Eurostat, 2021; Table 2) The distribution of the population was modelled using an approach that aggregates the population by area and considers the aggregates as geometric points (centre of the 1-km² squares) for further processing.

Hospitals

The hospital locations (Table 2) were determined by geocoding the visitors' addresses available in the dataset. For this purpose, the Nominatim service for OpenStreetMap (2022) data was used with the help of the GeoPy library (https://geopy.readthedocs.io/en/stable/). For the German hospitals, structured quality reports (G-BA SQB) provided detailed data on individual hospitals, including their location, number of beds, number of cases and other indicators (Joint Federal Commitee, 2020). The hospitals transmit these reports to the federal and state authorities responsible for quality assurance (Joint Federal Commitee, 2016). Our selection excluded hospital locations offering psychiatric, psychotherapeutic, neurological or paediatric care only and included hospital locations providing inpatient number of cases and with a minimum of 50 beds.

Data on the function of Dutch hospitals as well as the number of hospital beds were taken from the DigiMV2020 survey available from CIBG, an executive organization of the Ministry of Health, Welfare and Sport offering transparent and reliable data and information in healthcare and welfare (CIBG, 2023). In this survey, care providers reported data to the CIBG on the organisational level for the year 2020. The reported total number of beds was corrected to exclude ambulant and neonatal capacity.

Road network

The calculation of accessibility isochrones was based on OpenStreetMap (OpenStreetMap, 2022; Table 2)

Statistical methodology

The enhanced two-step FCA (E2SFCA) method (Luo & Qi, 2009) was used to calculate the accessibility index based on data regarding hospital locations, their function and capacity, as well as

Table 1. Differences between the Dutch and the German hospital system in 2021.

Parameter	Germany	The Netherlands	Reference
Population	83 155 031	17 475 415	Eurostat, 2024
Hospital beds (per 1 000 population)	7.76	2.95	OECD, 2024
Hospital discharges (per 100 000 population)	21 790	7 779	OECD, 2024
Occupancy rate - curative care (% of beds)	69.90	61.2	Eurostat, 2024
In-patient average length of stay (days)	8.9	4.3	Eurostat, 2024
Hospital days of in-patients (per capita)	57 059 090 (1.9)	5 573 805 (0.3)	Eurostat, 2024
Health expenditures for inpatient care (% of budget)	27.9	16.8	Blümel *et al.*, 2020 Kroneman *et al.*, 2024

Table 2. Sources for the cross-border data model on inpatient care.

Indicator	Germany	The Netherlands
Population distribution	EuroStat GISCO JRC, 2021; 1-km^2 Grid, 2021	EuroStat GISCO JRC, 2021; 1-km^2 Grid, 2021
Hospital locations	G-BA SQB (2020), OpenStreetMap (2022)	DigiMV, 2020, OpenStreetMap, 2022
Hospital beds	G-BA SQB (2020)	DigiMV, 2020 & 2021, other
Hospital function	G-BA SQB (2020)	DigiMV, 2020
Road network	OpenStreetMap (2022)	OpenStreetMap, 2022

data on population distribution. Routable traffic network data were used to generate potential catchment areas around hospital locations. The travel costs between medical supply and demanding population were expressed through the travel time.

In the absence of empiric data on patient visits to hospitals in the region (realized access), we modelled the concepts of potential accessibility (Humphreys & Smith, 2009; Luo & Qi, 2009) through FCAs, which are regional accessibility measures that model spatial interaction between service and demand (Luo & Wang, 2003). From a geographic perspective, they are essentially a mathematical interpretation of Tobler's First Law of geography (Tobler, 1970), which stresses the role of spatial distance and proximity as influential factor for natural and social processes. FCAs provide acceptable predictions of patient utilization patterns of hospital visits (Bauer *et al.*, 2020; Delamater *et al.*, 2019).

The gravest limitations of the early FCA and 2SFCA algorithms, namely the absence of a notion of distance and the dichotomous model of catchment that this entails, are addressed by the modified 2SFCA (M2SFCA (Delamater, 2013) or the E2SFCA method. The strength of the latter is the introduction of a spatial distance decay function to apply weights to travel time zones around healthcare sites (catchment zones). This accounts for a

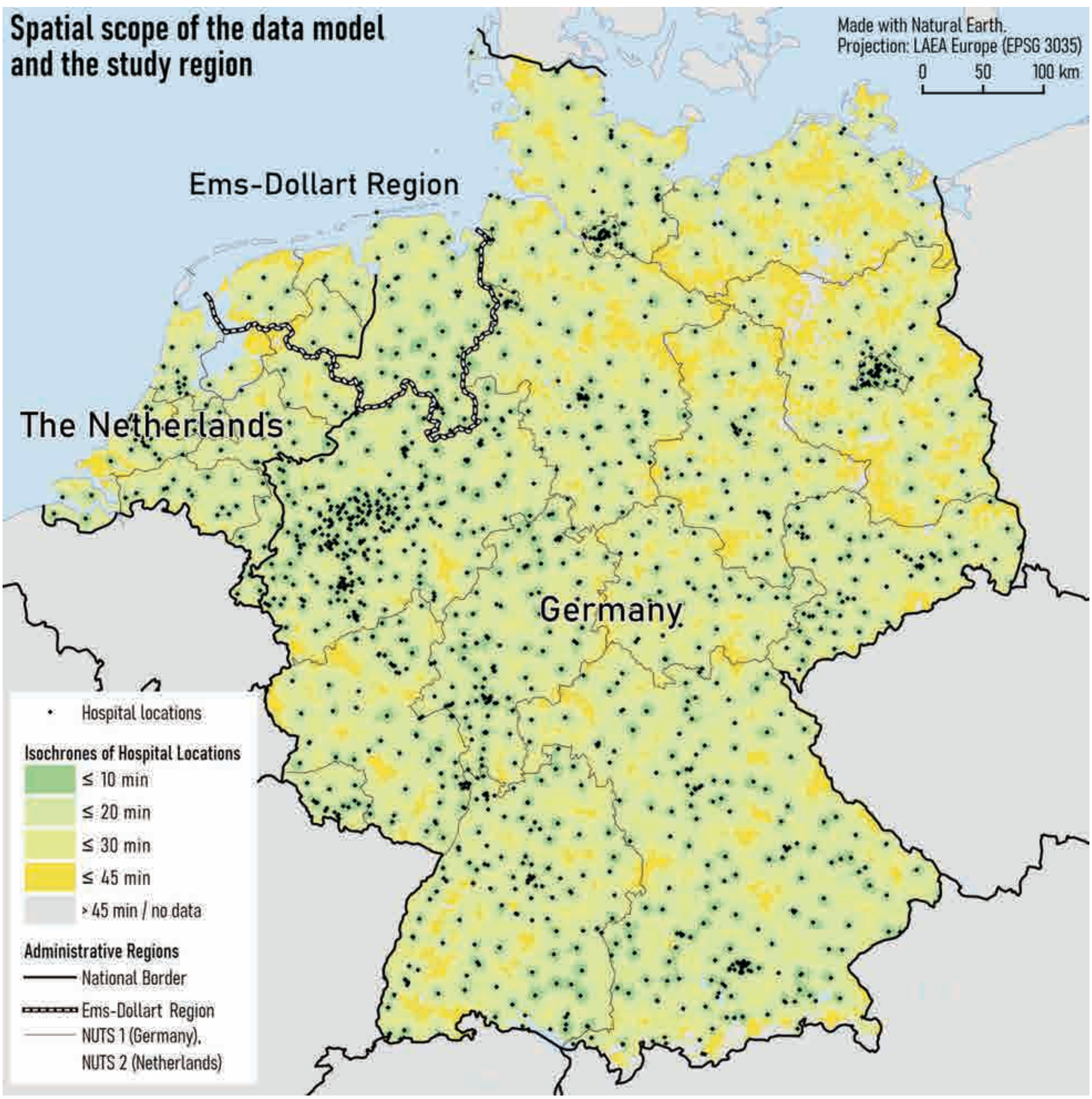

Figure 1. Scope of the data model in the study with hospital locations and potential hospital catchment areas through isochrones of travel time by car. The border of the Ems-Dollart Region marks the spatial scope of the analysis.

more realistic model of demand for service. Despite some shortcomings of the E2SFCA method (mentioned under Limitations in the Discussion), we preferred to use this method for our analysis due to its mathematical simplicity and ability to provide a simple computational representation of both national and cross-border scenarios. In addition, it is still considered in many recent studies (Bauer *et al.*, 2020; Bauer & Groneberg, 2016; Jörg & Haldimann, 2023). The catchment zones for the 1.530 Dutch and German hospital locations were generated using OpenStreetMap data from 2022 utilizing OpenRouteService (https://openrouteservice.org/). The process has been described in (Specht *et al.*, 2022) in greater detail. We used catchment zones with distances of 10, 20, 30 and 45 minutes travel time by car. The corresponding weights of 0.92, 0.48, 0.13 and 0.01 result from a decay parameter of the Gaussian distance weight function of β = 306 (Figure 2). The choice was based on the fact that 99% of the Dutch population and more than

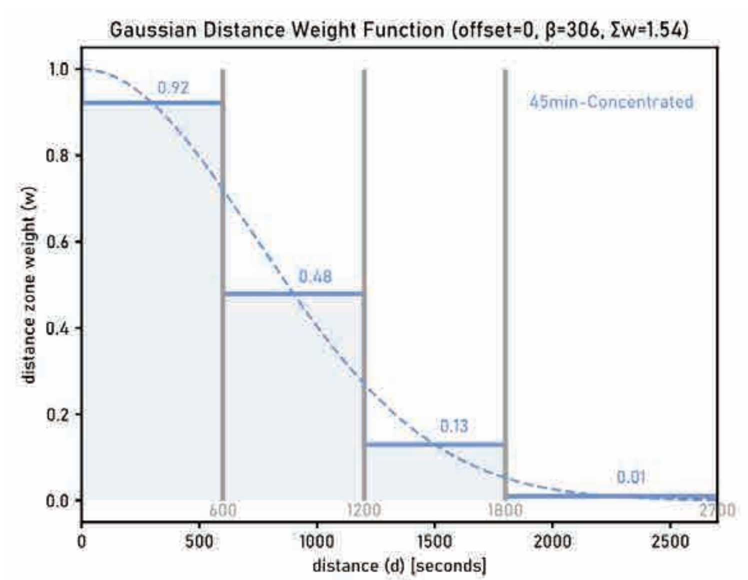

Figure 2. Distance decay function used as E2SFCA model parameter. Distance given in travel time by car on the road network; E2SFCA, the enhanced two-step floating catchment area.

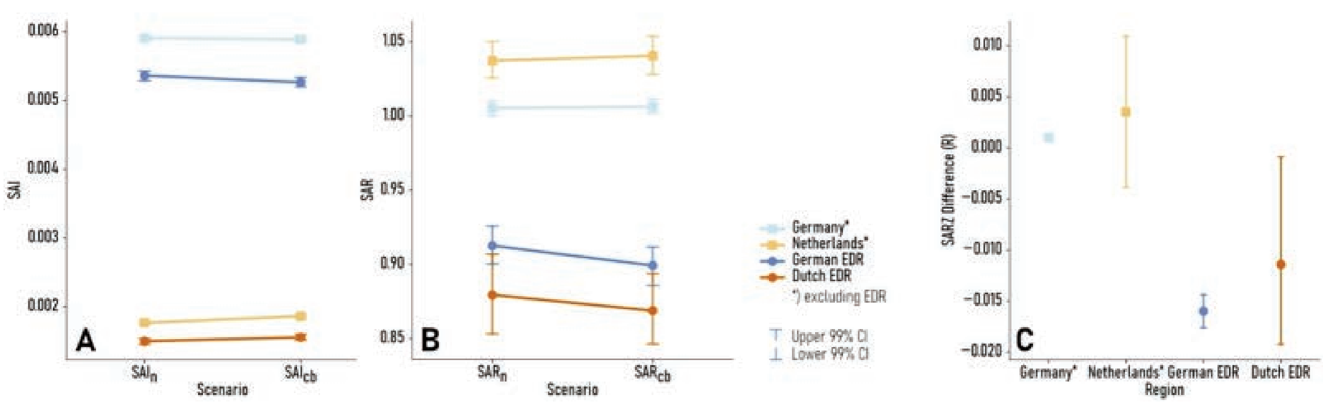

Figure 3. Changes of the regional mean SAI, the SAR and the difference of the standardized SAR between the national (SAI_n, SAR_n) and the cross-border scenarios (SAI_{cb}, SAR_{cb}). **A**) Change of the regional mean SAI between the national (SAI_n) and the cross-border scenarios (SAI_{cb}); **B**) change of the regional mean SAR and the national (SAR_n) and the cross-border scenario (SAR_{cb}); **C**) Differences of the standardized SAR between the national ($SARZ_n$) and the cross-border scenario ($SARZ_{cb}$). SAI, the spatial access index; SAI_n, the national spatial access index; SAI_{cb}, the cross-border spatial access index; SAR, the spatial access rate; SAR_n, the national spatial access rate; SAR_{cb}, the cross-border spatial access rate.

97% of the German population can reach a hospital within 30 minutes (see above). The 45 minutes zone with a low weight of 0.01, a best practice suggested by (Wan *et al.*, 2012), was added to minimize the total exclusion of population in rural areas of our study region (the orange areas in Figure 1). The population outside of the 45-minute zone (0.60% of the German and 0.86% of the Dutch total population) was excluded from the analysis in favour of a more concentrated weight function.

The 1-km² population cells defined the spatial dimension of the accessibility measures. The population within the catchment area of a hospital was determined mathematically using the point-in-polygon test for each travel time zone on the population grid (242.542 populated grid cells). This and all following calculations were implemented in Python utilizing the Pandas and the GeoPandas libraries (https://geopandas.org/).

We then used the E2SFCA algorithm to calculate the spatial access index (SAI), an essentially a distance-weighted bed-to-population ratio for each grid cell. As an absolute measure in relation to the EDR cross-border situation, it summarises two different healthcare systems on a uniform supply-demand scale. While this enables cross-border comparison of systems, it does so at the expense of the differences in the role of inpatient care described above. The SAI is in fact the unprocessed result of the E2SFCA analysis and therefore combines the two health systems into one numerical dimension (Figure 3A; Table 3).

In order to account for the differences between the healthcare systems, the SAI for each country was standardised with the average national SAI of all grid cells. The resulting Spatial Access Rate

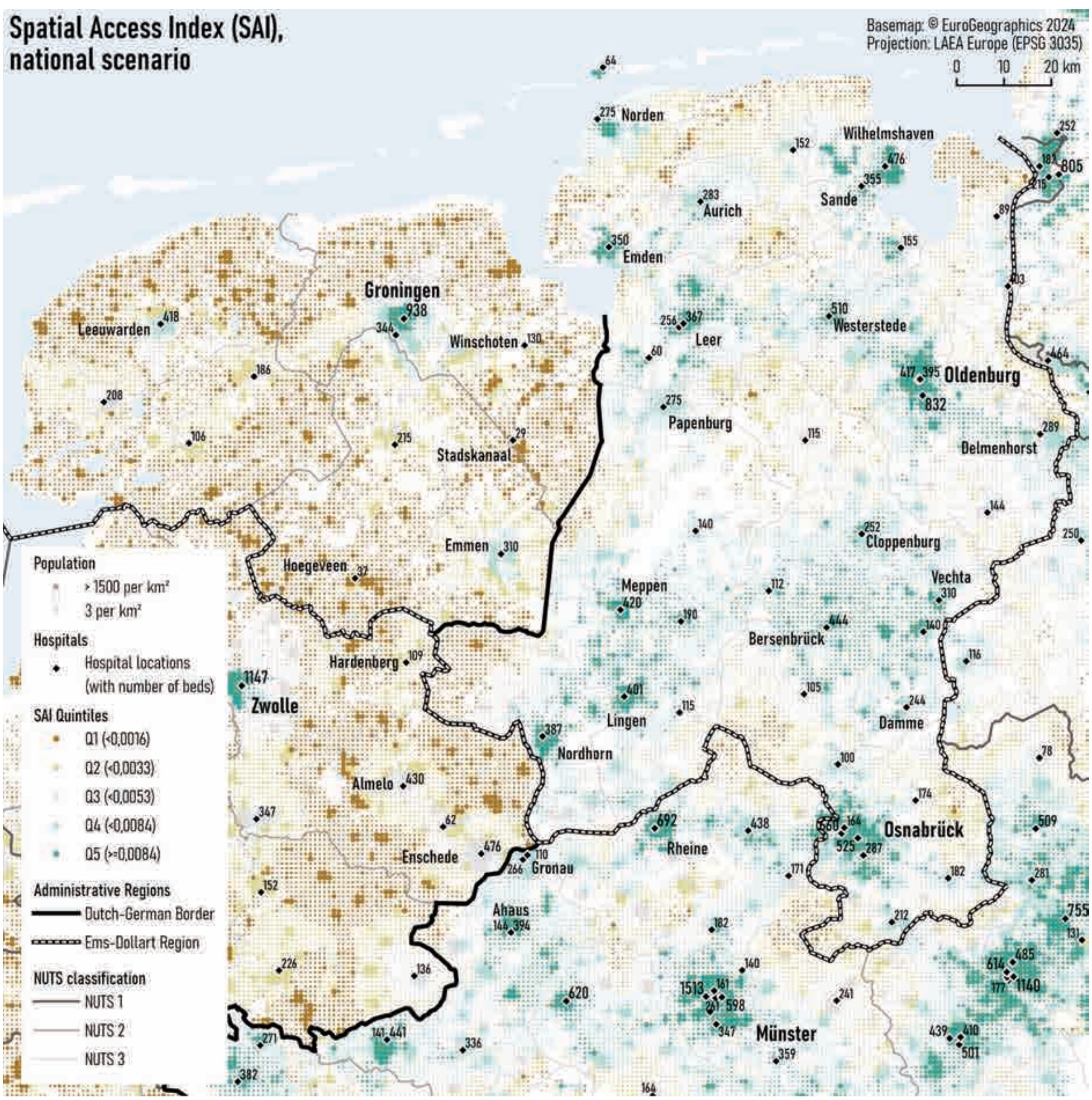

Figure 4. National scenario: spatial access index quintiles applied to a map of the population based on proportional 1-km² grid symbols of the study area. SAI, spatial access index.

Table 3. Average spatial access index (SAI) and spatial access rates (SAR) showing national scenarios and access differences

	SAI × 10^{-3}			SAR_n			Cross-border rate difference		
Spatial unit	M	CI(99%)	SD	M	CI(99%)	SD	M	CI(99%)	SD
Germany	5.87	[5.85, 5.90]	4.85	1.000	[0.995, 1.005]	0.825	0.000	[-0.0002, 0.0002]	0.036
German EDR	5.36	[5.29, 5.43]	3.14	0.913	[0.900, 0.925]	0.534	-0.016	[-0.0176, -0.0144]	0.068
Netherlands	1.70	[1.68, 1.72]	1.33	1.000	[0.988, 1.012]	0.783	0.000	[-0.0059, 0.0059]	0.395
Dutch EDR	1.50	[1.45, 1.54]	1.46	0.879	[0.853, 0.906]	0.854	-0.011	[-0.0206, -0.0023]	0.295

EDR, Ems-Dollart Region; SAI, spatial access index; SAR_n, national spatial access rate; Cross-border rate difference, with standardized SAR (R = $SARZ_{cb}$-$SARZ_n$); R, access difference; M, Mean; CI, confidence interval; SD, standard deviation.

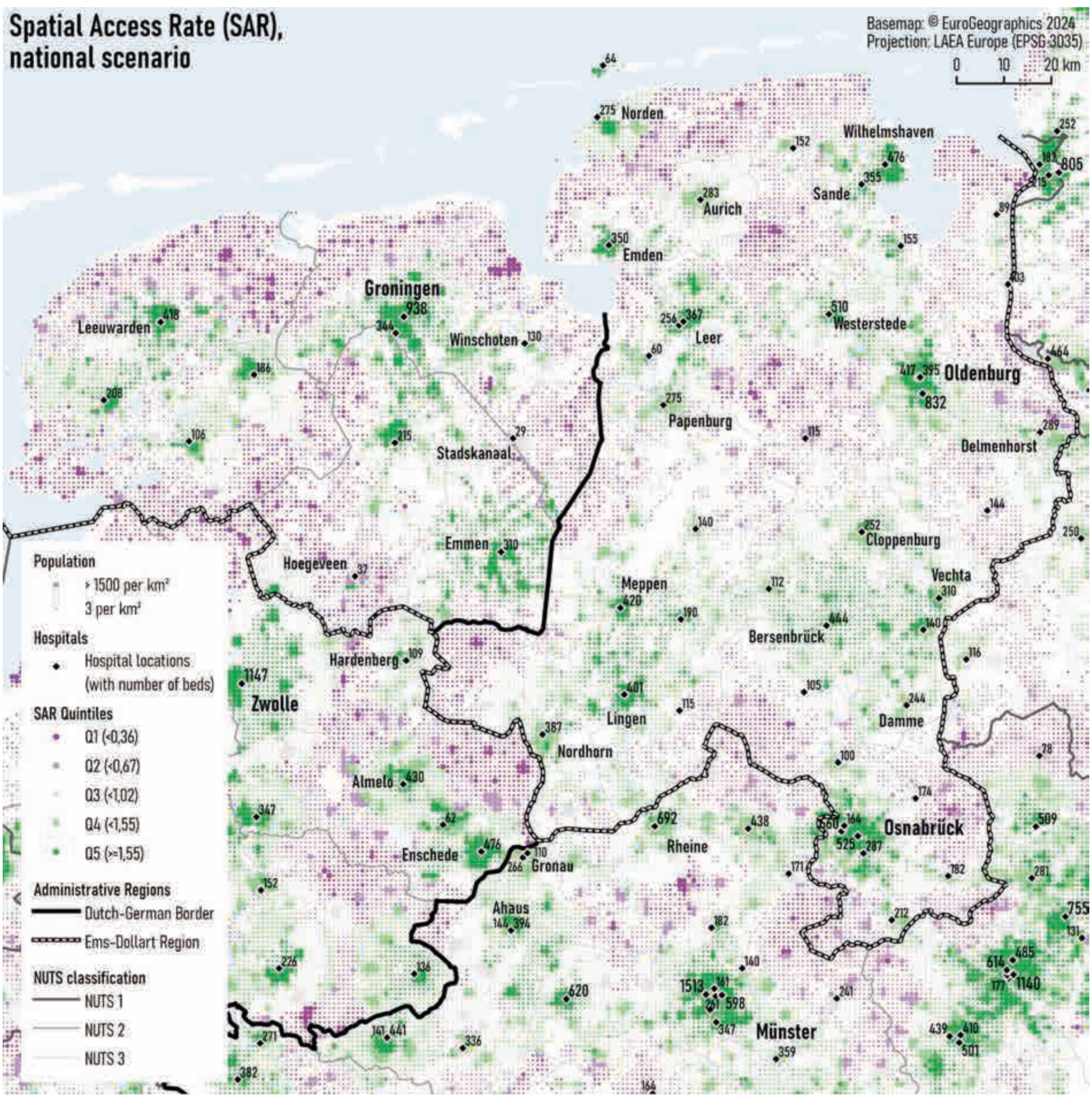

Figure 5. National scenario: spatial access rates quintiles applied to a map of the population based on proportional 1-km² grid symbols of the study area. SAR, spatial access rate.

(SAR); Figure 3B; Table 3 is a relative accessibility measure that accounts for systemic differences in inpatient care supply (Figure 4). As outlined by Wan *et al.* (2012), this rate provides more stable spatial patterns than the absolute SAI values and is less sensitive to the parameters of the distance decay function. Consequently, it was employed for the purpose of cartographic comparison of hospital accessibility too (Figure 5). A z-scored modification of the SAR (SARZ) for a populated grid cell was employed for identification of border-related effects. It was derived from the difference between its SAI and the mean SAI of all grid cells within the same nation, divided by the standard deviation of the SAI of all grid cells within the same nation. SAI and SAR maps were produced to categorize the *status quo* accessibility of regions for the final evaluation of the cross-border effects (Table 4), with Q1 representing lowest and Q5 the highest accessibility rates.

Winder (2009) describes border regions as "sites in which difference is produced and disrupted", resulting in "weakened or partial state effectiveness". Kuntosch et al. (2024) developed a conceptual framework of such effects of a national border in relation to the health care system. They located the border region by Thiessen polygons (a.k.a Voronoi cells) around healthcare sites being divided by the national border. This geometric approach identifies areas, where the shortest path to a hospital leads to the other side of the border.

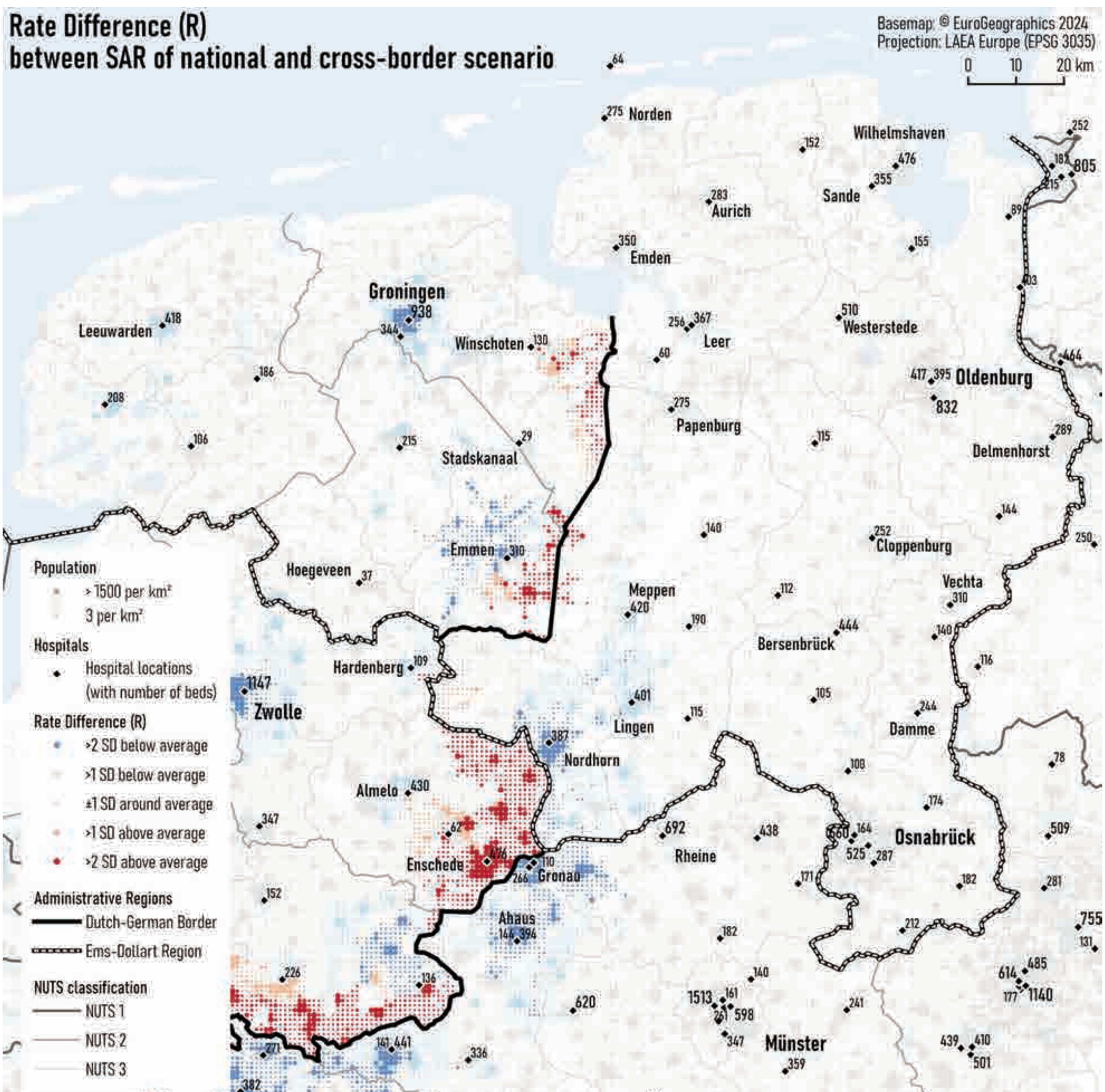

Figure 6. National and cross-border scenarios: affected population by rate difference between spatial access rates. R, rate difference; SAR, spatial access rate; SARZ, z-scored modification of SAR; $SARZ_{cb} - SARZ_n$, rate difference between national and cross-border scenario.

We used an approach based on the difference between two FCA models, which allowed us to quantify the effects in the border region, compare different healthcare systems and analyse for the consequences of an integrated cross-border care. As our approach involved a numeric analysis of the local capacity, we felt that this approach was more helpful for our objectives than a heuristic analysis on the basis of maps of accessibility ratios (Wan *et al.*, 2012) or the geometric approach of Kuntosch *et al.* (2024). Rauch *et al.* (2023) used a similar differential approach in a slightly different context, where they subtracted index values between car and public transport accessibility models. The E2SFCA algorithm was employed to generate two distinct SAIs for the joint area of Germany and the Netherlands under two distinct scenarios. In the 'national' scenario, the population is served exclusively by national hospitals. In the 'cross-border' scenario, the border is completely permeable, allowing the population to access any healthcare facility regardless of the border. Both scenarios are hypothetical, but the 'national' scenario closely reflects the current *status quo* with limited cross-border transfer. These scenarios were realised during the calculation of the SAI by a filtering operation based on a match between the country of the hospital and the country of the population. This ensured that only the population matching the scenario criteria would be aggregated within a given catchment area in the first step of the E2SFCA. The identical filter was employed during the subsequent phase of the E2SFCA as well, ensuring that only hospitals aligning with specified scenario criteria were accessed.

We expressed the potential change that the cross-border scenario would cause at a given population grid point (i) as the Rate Difference (R; Figure 3C, Table 3) between the national and the cross-border $SARZ_i$ of that population grid point. We apply a classification based on the mean (M) and multiples of the standard deviation (SD) to the distribution of R to classify the change in areas under the cross-border scenario (Figure 6). We defined areas with positive access rate differences (R_i>M+1SD, R_i>M+2SD) and negative ones (R_i<M-1SD, R_i<M-2SD) and regarded areas around the mean of the distribution (M-1SD< R_i<M+1SD) as unaffected.

Finally, the magnitude of the cross-border effect was expressed in terms of the number of inhabitants within the affected areas. The previous measures and classifications are variants of supply ratios attached to grid cells. This is an assessment from a spatial perspective only. In the last step, we wanted to consider the affected population (P) within those border areas with higher and lower access rates under the cross-border scenario. We differentiated the population between the SAR of the *status quo* (columns of Table 4) and the rate difference R resulting from the cross-border scenario (rows of Table 4). From a spatial perspective, we differentiated the affected population on the basis of the nations within the EDR. The resulting population figures are listed in Table 4.

Results

Status quo of inpatient care

Given the differences between the systems, the average SAI in the Netherlands was, as expected, lower than in Germany. The average SAI of both parts of the EDR were significantly lower than the respective national SAIs (Table 3, Figure 3A). It is worth noting, that the SD of the German EDR was found to be lower than the German national one, while the SD of the Dutch EDR was higher than the one at the Dutch national level.

Figure 4 shows the spatial distribution the SAIs. The Dutch areas in the western part of the map are dominated by the two SAI quintiles with the lowest accessibility index (Q1 and Q2 in brown shades). In contrast, the populated areas in close proximity to the larger hospitals (Groningen, Leeuwarden and Scheper) are included in the higher quintiles (Q4 and Q5 in turquoise shades). The German area east of the border is dominated by areas with these higher SAI quantiles as well as some areas around the median (Q3 in grey). In contrast to the Dutch side, only few areas in the German part (mostly coastal or other peripheral areas) have lower accessibility indexes.

The SAR standardizes the SAI against the national average and enables a comparison of the regions with respect to the differences of the healthcare system. The SARs of the EDR given in Table 3 are significantly below the national averages on both sides of the border. Again, the SD of the German EDR is lower than the German one, while the SD of the Dutch EDR is higher than the national one.

Table 4. Number of inhabitants in the Ems-Dollart Region affected by the cross-border scenario.

	EDR population the Netherlands					EDR population Germany					Total (%)
Status quo (SAR_n quintiles)	Q1	Q2	Q3	Q4	Q5	Q1	Q2	Q3	Q4	Q5	
CHANGE (Cross-Border Rate Difference) R = SARZcb-SARZn											
-2 SD	0	0	0	0	222 807	0	0	475	18 037	30 913	272 233
					5.2			*0.0*	*0.4*	*0.7*	*6.3*
-1 SD	0	0	0	14 843	252 105	0	362	23 185	13 298	83 688	387 482
				0.3	*5.9*		*0.0*	*0.5*	*0.3*	*1.9*	*9.0*
Unaffected	209 717	263 359	215 534	227 159	225 398	121 499	326 424	497 116	740 884	719 153	3 546 244
	4.9	*6.1*	*5.0*	*5.3*	*5.2*	*2.8*	*7.6*	*11.6*	*17.2*	*16.7*	*82.5*
+1 SD	4 158	4 973	19 478	0	17 181	3 552	3	184	7	0	49 538
	0.1	*0.1*	*0.5*		*0.4*	*0.1*	*0.0*	*0.0*	*0.0*		*1.2*
+2 SD	5 759	3 532	1 864	1 107	27 596	1 053	1 087	613	307	17	42 936
	0.1	*0.1*	*0.0*	*0.0*	*0.6*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*1.0*
Total	219 635	271 864	236 876	243 110	745 087	126 105	327 876	521 574	772 533	833 771	4 298 433
%	*5.1*	*6.3*	*5.5*	*5.7*	*17.3*	*2.9*	*7.6*	*12.1*	*18.0*	*19.4*	*100.0*

EDR=Ems-Dollart Region; Percentages of total EDR population in italics; The effective change is expressed as SD multiples of the rate difference (R); The *status quo* of hospital care is expressed in terms of access quintiles (SAR_n), with Q1 being the lowest and Q5 the highest.

A visual inspection of the spatial distribution of SAR quintiles (Figure 5) gives a more balanced impression of the difference between the two parts of the EDR than the SAI map (Figure 4). Firstly, most of the densely populated areas in the Dutch part have access rates above the median (Q4 and Q5 in green shades). In Germany, these higher access rates even extend to large areas with a lower population density. As with the SAI map, there are few areas within the region with rates around the median (Q3 in grey). In contrast, the Dutch EDR shows a higher spread with larger areas well below the median (Q1 and Q2 in indigo shades). As the higher standard deviation of the Dutch EDR in Table 3 suggests, the lower hospital density in the Netherlands results in larger contiguous areas of very high (Q5) and very low (Q1) access rates. Conversely, the strong presence of the middle quintiles (Q2-Q4) in the German EDR is a visual representation of the SD below that of the national distribution.

Cross-border potential and effects

A free access to inpatient hospital care across the borders results in slight gains in the average cross-border access indexes (SAI_{cb}) in The Netherlands and leads to a slight decrease of the average access index in Germany (Figure 3A). However, this movement of the indices towards the mean of both nations is not surprising considering the "blur effect" of the FCA method along the border. However, the fully integrated cross-border supply scenario changes the SARs significantly within the EDR. The average SAR_{cb} within the region is even lower than the national averages of the access rates (Figure 3B) resulting in rate differences (R) and their confidence intervals moving below zero (Table 3). The SD of R in the region now becomes higher than the national one in Germany and lower than the national average in the Netherlands.

Figure 6 shows the spatial distribution of the rate differences of the cross-border scenario with the national scenario. Areas with both higher and lower accessibility rates can be found on both sides of the border, but with a different distribution and quantity. While regions with higher and much higher accessibility rates, *i.e.* +1SD and +2SD (shown in red shades) are located quite close to the border and mostly on the Dutch side, e.g., east of Emmen and Winschoten, the care capacity is seen as withdrawn from other nearby areas, i.e. -1SD and -2SD (shown in shades of blue). In some areas of the Netherlands, accessibility rates decrease even in the densely populated areas further away from the border (e.g., in Leeuwarden and Zwolle). In the context of averages, as shown in Figure 3C, the Netherlands benefits from a cross-border scenario, while on average, the EDR does not benefit. The German side of the EDR also provides capacity to regions outside of the region (e.g., the area around Nordhorn to the area north of Enschede).

Table 4 shows the aggregated number of people affected or unaffected by a cross-border scenario. Most of the people (82.5%) living in the EDR remain largely unaffected (M-1 SD < R <= M+1 SD) by cross-border integration of inpatient care. Except for a few people (<0.1 %) in Germany, there is no additional loss in access rates (-2 SD, -1 SD of R) for people living in regions with already low access rates (Q1 or Q2 of the national SAR (SAR_n). However, for 15.3 % of the population living in regions with access rates around the median and above (Q3-Q5 of SAR_n), a loss of access rates can be observed in a cross-border scenario. A comparatively small number of people (2.2 %) benefit from gains (+1 SD, +2 SD of R) in accessibility to inpatient care. These gains occur almost exclusively on the Dutch side.

Discussion

Both national healthcare systems rank high among other countries (Schwettmann *et al.*, 2023) and most people in the EDR do profit from good access to inpatient care capacities. According to our analysis, around 78.1 % of the population there live in areas with access rates around the median or higher (Q3-Q5 of SAR_n). At the same time, however, the current accessibility of inpatient care is below the national average for large areas of the region (Q1+Q2 of SAR_n). Figure 5 shows where these 21.9% of the EDR population are located on the Dutch (11.4% of EDR population) and on the German side (10.5% of EDR population). Some of these areas are close to the border, but for the most part they are spread over the whole region. In fact, lower access rates are more consistently located in the vicinity of the North Sea coast. Together, this results in significantly lower average access rates in both the German and the Dutch parts of this region compared to the national means.

The variation of access rate SDs and the spatial distribution of quintiles on the map is worth a second look. The German EDR area may have access rates below the national average, but with the lower SD it is more homogeneous than the German reference distribution with its metropolitan clusters in North Rhine-Westphalia and more rural regions in Bavaria and eastern Germany (not visible on the maps). In the Netherlands, the opposite direction was found, where the higher SD indicates a more heterogeneous distribution of SAR in the Dutch EDR, even still below the national average. This is supported by the SAI map (Figure 4), which allows an absolute comparison with the German system. Only the populated areas close to the larger hospitals (Groningen, Leeuwarden and Emmen) are included in the higher SAI quintiles, giving the impression of a system with a more concentrated inpatient care.

The cross-border integration of inpatient care could provide opportunities for border regions, especially for areas with low accessibility. The SAR map (Figure 5) shows where this is particularly the case for people living in the Dutch part of the EDR. Looking at the map, the influence of the border as a cause of low accessibility rates in the region under consideration is put into perspective. There are certainly areas with low accessibility rates along the border, even adjacent to both sides of the border. But there are also areas with above average accessibility rates. Larger contiguous areas with low accessibility rates are more likely to be found along the German and the Dutch North Sea coasts.

Effects of cross-border integration of inpatient care seen in Figure 6 localises the gains and losses in accessibility rates, with areas of gain located exclusively in close proximity to the border. In total, only 2.2 % of the EDR population live in these areas benefitting from cross-border integration. Most of the beneficiaries are located on the Dutch side of the border. However, almost half of them (about 1%) already benefit from good accessibility in the status quo scenario, so it is debatable whether this represents a true improvement. In The Netherlands, only 0.4 % of the EDR population and in Germany about 0.1 % of the EDR population live in areas with below-average accessibility and benefit from accessibility gains. As the cross-border model involves spatial redistribution under constant amounts of supply and demand, these gains come at the expense of other regions within the area, especially those with higher access rates. Those providing areas are found in Germany and The Netherlands. Under the cross-border model, there is no loss of access rates in regions with already low accessibility rates. Although our specific results are limited to the EDR, the method can be applied in a variety of ways and is also of interest in other regions and for other purposes. The FCA analysis on the 1-km² grid reveals small-scale aspects of processes that may remain hidden in accessibility analyses using area-based population models. Care researchers can use this additional spatial detail to identify underserved areas and select interesting study areas or specific providers for mixed methods studies. Similarly, public health officials or health care planners can identify areas for local interventions to strengthen primary care or existing outpatient care facilities (as is already done in the Netherlands). The method of calculating differences in (standardised) FCA rates is particularly interesting for this purpose, as health care planners can estimate the small-scale effects of alternative scenarios when changing the location or capacity of care providers. Similarly, slow changes in demand, for example due to demographic changes, or sudden regional changes, such as those caused by the COVID-19 pandemic, can be better understood in terms of their spatial impact on the matching of supply and demand. According to Winkelmann *et al.* (2022, p. 44) "the transfer of COVID-19 patients across borders has been shown to be an important tool and symbol of European solidarity with the potential to be expanded". In this way, the calculation of accessibility index differences can help to identify and visualise the local potential of such preparedness across European borders.

Strengths and limitations

Figure 6 demonstrates the advantage of our approach to calculate rate differences between two scenarios using the E2SFCA method on gridded population data: With high spatial detail, we can locate areas of loss and gain in access rates. It clearly shows where and how many people bear the burden of a low access to care, particularly due to boundary effects in access. At the same time, the map highlights where the potential for cross-border integration of inpatient care is the greatest. Gains in accessibility rates through a cross-border integration of care can be found, but these effects appear to be a more local phenomenon. On the other hand, the selected data on hospital function and capacity provides only a very general understanding of the provision of inpatient care without any consideration of specific treatments or the requirements of specific risk groups within the population. The formal differences of access between the healthcare systems are complex and the different roles of inpatient and outpatient services limit the generalisability of the findings. Further studies should examine cross-border differences along barriers to specific treatments.

Any study considering cross-border comparisons of the accessibility and availability of healthcare for specific diagnosis or treatments would require data on population demographics and socioeconomic status, specialization of healthcare sites and epidemiological variations in demand (*e.g.*, data on prevalence, incidence or mortality). Measures of regional deprivation together with annually updated demographically structured gridded population data, including daytime population, could serve as demand estimate for diagnosis-related questions about accessibility to healthcare facilities to specific demographic or socioeconomic subgroups of the population. Unfortunately, no publicly available population dataset readily combines these desired characteristics at the European levels. However, a meaningful analysis of specific aspects of access to specialised therapy locations requires empirical data on realised access. Such sensitive patient-provider treatment relationships can be found, e.g., in cancer registries on both sides of the border. Another source of more general data on treatments is the patient records kept by individual hospitals or from insurance data. Working exclusively with publicly available aggregated data, as in our study, has its limits but can be supportive within a larger mixed methods approach. Finding quantitative data sources with a similar scope and semantics for hospitals across the border proved to be a challenge. However, we are confident that the number of reported inpatient beds is of acceptable quality for our purpose. The use of the German SQB data for certain applications in care research has been criticised (Kraska *et al*., 2017). However, this criticism relates to older editions and more specific quality indicators than the ones we used. In contrast to this data source, the work with the Dutch DigiMV 2020 data revealed some ambiguous reporting habits of providers even for general indicators. The reporting of capacity per hospital site was inconsistent between organisations. Manual case-by-case disambiguation of site capacity was performed through consistency checks with information from within the data source (n=7), imputation with data from the more recent DigiMV 2021 (n=6), linear distribution of reported organisational capacity (n=4), or other sources such as annual reports (n=4) or website information (n=2).

The identification of hospital catchment areas is based on isochrone polygons derived from a road network model. The reduction of accessibility to travel times by car is a limitation of many accessibility-based analyses. Nevertheless, we regard this a valid estimator as the split of transport modes in the year 2020 has been in favour of cars with numbers as high as 88.4% in Germany and 89.7% in the Netherlands (European Environment Agency, 2024). This modal split has been consistently above 80% in both nations even in the years before the Covid pandemic.

Finally, the E2SFCA method has a number of limitations. First, there is the absence of a notion of competition among healthcare sites, which can lead to an overestimation of demand (Jörg & Haldimann, 2023). Another limitation is the insensitivity to spatial disparities between urban and rural areas, as described by McGrail *et al.* (2015). The E2SFCA and other methods of this generation of FCAs do not consider the distance-related complexity created by spatial disparities, as both the global catchment area and the distance decay functions are constant parameters. Algorithms such as 3SFCA (Wan *et al.*, 2012), FCA+Huff (Luo, 2014), iFCA (Bauer & Groneberg, 2016; Bauer *et al.*, 2020), as well as MHV3SFCA (Jörg & Haldimann, 2023) attempt to address either one of these limitations (3SFCA and FCA+Huff address competition) or both (iFCA and MHV3SFCA). Still, we believe that the choice of FCA method is of secondary importance for the results of our study. Any systematic limitations of a specific method will be consistent across national and cross-border scenarios and will have limited impact on the relative measures used to evaluate the resulting accessibility indices.

Conclusions

On average, the German and the Dutch people living in EDR share the disadvantage of having access rates to inpatient care below the national average. However, the cartographic analysis of the spatial access rates reveals differences in the spatial distribution resulting from two differently organised and structured healthcare systems. The analysis of access to inpatient care capacity with high spatial detail within a border region provides interesting insights into the spatial heterogeneity of the resulting situation. Within the limitations of our study, it cannot be claimed that the immediate vicinity of a national border constitutes a poorly served area. The map and the analysis of the effects of an integrated inpatient access answer the question of where the potential for such cross-border integration of inpatient care is located within the region. It does not appear that minimising border effects will generally and widely improve access to inpatient care capacity along the border in the region. However, there are very local positive effects for a few citizens in the rural areas of the EDR. This limited impact for only a minority of patients may provide an additional explanation as to why cross-border care is not a common practice between the two nations and why already known barriers persist. At the same time, however, the FCA rate differences may help decision-makers and health care planners to decide whether to invest either in supply-side capacity or in the removal of systemic and functional barriers within border regions as part of a European preparedness for future challenges.

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