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# Living spaces, flows and structures across the EU internal borders

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# Contents

# Abstract

Knowing where, how, and for what purposes people frequently cross borders has significant policy implications. However, limited data availability often hinders effective decision-making. This contribution highlights key issues related to cross-border flows in EU border regions and their spatial implications. The lack of granular, reliable, and comparable data frequently leads to an underestimation of the true scale of cross-border movements within the EU. Additionally, the assessment of the socioeconomic potential of border regions typically does not consider the hypothetical elimination of obstacles, be they legal, administrative, infrastructural, or linguistic. This study addresses two research questions: can methodological innovations help accurately quantify existing and potential cross-border interactions, thereby overcoming current limitations in data availability and accessibility? And how can a data-driven approach support the definition and delimitation of cross-border functional areas? The contribution begins by defining cross-border areas as living spaces. It then examines conventional data sources such as administrative records, surveys, and transport data to enhance understanding of existing cross-border interactions. Following this, the study explores non-conventional data sources and methods, including mobile big data, web scraping and geospatial artificial intelligence. Lastly, new methodologies for defining cross-border functional areas are presented, along with interoperability challenges to enhance the integration of global data.

# Foreword by Themis Christophidou, Director-General of Regional and Urban Policy, European Commission

The EU is home to 150 million citizens living in border regions. Every day, they cross borders to work, study or access essential services such as healthcare. These interactions are vital to individual livelihoods and regional cohesion.

Yet, invisible barriers often persist: different administrative systems, gaps in service provision, fragmented transport systems, inconsistent data collection and limited interoperability across jurisdictions.

Addressing these challenges is not an administrative exercise, but a political and strategic imperative to ensure that EU citizens living in border regions have the 'right to stay'.

This *Science for Policy* report marks a key step forward. It draws on advanced methodologies – using sources such as GPS and mobile phone data, web scraping and cross-border surveys – combined with tools such as gravity models and functional region delineation. Together, they provide insights into how people move, work, access services and interact across EU borders. These evidence-based findings allow us to accurately map needs, identify practical barriers and target solutions where they matter most.

To unlock the full potential of our regions, we must continue to boost our cross-border cooperation. Strong inter-services collaboration is paving the way for targeted investments and policies that deliver concrete improvements – from improving transport connectivity to enhancing service provision and simplifying cross-border administration.

Let this report serve as both a guide and a catalyst for action, inspiring decision-makers at all levels to embrace the potential of cross-border cooperation.

I extend my deepest gratitude to all the contributors whose dedication made this report possible. Their efforts help us shape policies that respond to the realities on the ground – making a tangible difference in the lives of millions.

Together, let us build living spaces that reflect the unity and strength of our Union.

**With best regards,**

**Themis Christophidou**

# Acknowledgements

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# Executive summary

This report addresses the challenges and opportunities in measuring flows across EU internal borders. The main objective is to provide insights into how methodological innovations, based on both traditional and non-traditional data sources, can enhance the quantification of existing and potential cross-border interactions. These innovations may also support the definition and delimitation of cross-border functional areas.

Having accurate mappings of the cross-border flows of people 'from where to where' is thus essential to plan investments in services and to design policy and territorial strategies. However, too often the limited availability of data hampers adequate decision-making. As early as 2017, the European Commission stated that 'the limited availability of statistical and geospatial data on cross-border flows reduces the scope for genuine cross-border policy development and decision-making'. The deeper exploration of existing statistics, along with new data sources and methodologies, may be crucial, especially for policymakers in border regions. There are three key considerations in this study, as follows.

The lack of granular, reliable and comparable data often leads to an underestimation of cross-border flows. Additionally, even the available data can be challenging to access, complicating the understanding and quantification of these flows.

- To quantify the socioeconomic potential of border regions, studies should analyse how flows would occur across national borders in the absence of obstacles, be they legal, administrative, infrastructural or linguistic. Such counterfactual analyses could inform policy on the impact of removing these barriers.
- Mapping cross-border flows 'from where to where' encounters challenges in defining the spatial boundaries of cross-border living areas.

These considerations raise two research questions, which this study addresses.

- Can methodological innovations accurately quantify existing and potential cross-border interactions and overcome current data limitations?
- How can a data-driven approach aid in the precise definition and delimitation of cross-border functional areas?

The report first conceptualises cross-border regions as living spaces that foster EU territorial cohesion, also offering a broader perspective beyond EU borders through the dyad approach. **Chapter 22** acknowledges conventional data sources that enhance our understanding of existing cross-border interactions. **Chapter 3** investigates non-traditional data sources and methods, such as mobile app data, web scraping, phone data and geospatial AI, to identify existing and potential cross-border flows. **Chapter 4** presents new methodologies for defining cross-border functional areas at various territorial scales and in various sectors. Lastly, **Chapter 5** highlights data interoperability challenges to enhance the integration of global data.

These contributions are of paramount importance to support the policymaking process in border regions, particularly in sectors like the provision and accessibility of public services. For instance, a public transport and healthcare accessibility analysis reveals that border regions face longer driving times to access services than national averages. A border closure scenario further illustrates how these disparities could worsen without targeted policy interventions that ensure individuals

have access to services near their residences but across a border. In this sense, a deeper analysis of cross-border mobility could support targeted infrastructure investments and the design of ad hoc cross-border cooperation projects.

This report is a result of the **workshop on measuring cross-border flows held on 15 and 16 May 2025 at the Joint Research Centre site in Ispra**, which brought together scholars and policymakers to discuss conventional and innovative analytical methods for collecting and analysing data on flows across EU internal borders. Both the manuscript and the workshop were conducted under the data and analysis for cross-border regions (ACROSS) project, an initiative run by the European Commission's Directorate-General for Regional and Urban Policy and the Joint Research Centre. The project aims to collect, harmonise and display geospatial data on cross-border interactions and robust socioeconomic indicators in the EU, which are useful for comparing border regions and supporting research in border studies. It covers a variety of domains including public transport, public services, healthcare, cross-border governance, border obstacles and solutions. Data and more information are available on the data hub for EU border regions.

# 1. Setting the scene

## 1.1. Policymakers' open questions regarding cross-border regions in the EU

**Ricardo Ferreira**

Research and policymaking are different in many ways yet share a common ultimate goal. In these two fields, we encounter highly differentiated jargon, procedures, administrative and organisational cultures, and modes of communication. Even the channels through which results are disseminated are clearly distinct. Researchers publish in peer-reviewed academic journals and present at academic forums that are rarely attended by policymakers. Conversely, policy papers, position papers, reports, press releases or formally adopted acts of soft law (e.g. European Commission communications or staff working documents) are unfamiliar to the research community. Nonetheless, both worlds are bound by the same ultimate aim: to contribute to better lives for people and stronger societies.

Decision-making should be underpinned by scientific knowledge wherever possible. The perception is that this view is shared by most individuals operating in these two spheres. Contrary to the often-heard criticism that 'they do not care', researchers frequently seek to ensure the societal relevance of their work, and policymakers regularly request data and information to underpin difficult decisions. However, the substantial differences between the two environments often impede the bridging that would facilitate this sort of collaboration.

The aim of this *Science for Policy* report is to provide an overview of questions that are frequently present in political debate yet remain unanswered. Across various forums related to cross-border cooperation involving different levels of administration and policy- and decision-making, certain open questions persist. While some have not been addressed at all, others may be approached from various angles in specialised academic literature yet the debate on them remains open. The purpose of this chapter is not to propose a research agenda; it is merely to contribute to better interactions between academia and policy, with the ultimate goal of promoting the development of cross-border regions.

Beyond raising awareness of these open questions, we advocate for a greater intersection between research and policymaking, perhaps through the more regular participation of policy practitioners in academic publications and forums or through the more systematic use of political documents – frequently classified as 'grey literature' – as both objects of and inputs for research. The work carried out by the Joint Research Centre (JRC) in relation to cross-border interactions is noteworthy in this regard, as it brings both sides to the table. The launch of the data hub for EU border regions stems from a European Commission policy initiative. As early as 2017, the European Commission noted that 'the limited availability of statistical and geospatial data on cross-border flows reduces the scope for genuine cross-border policy development and decision-making' (European Commission, 2017, p. 14). Concurrently, the data available have brought together researchers who create datasets and those who draw upon such data in their work on cross-border interactions.

This *Science for Policy* report illustrates how it is possible to bridge research and policymaking. The debate preceding this publication demonstrated a convergence of interests and underscored the need for enhanced communication on the open questions that must be addressed to better inform decision-making in cross-border contexts. This list of questions is by no means exhaustive

and inevitably reflects a degree of observer bias; it is nonetheless hoped that these questions will contribute to the debate and stimulate research with direct relevance to political decision-making at various administrative levels – the local, regional, national and European.

When considering cross-border cooperation in Europe, the European Union initiative that funds cross-border, transnational, or interregional cooperation projects between countries and regions (Interreg) naturally comes to mind. Given its considerable value and uniqueness on the world stage, it serves as an essential source of a large body of research on border regions; some scholars even use 'Interreg' as exchangeable with 'cross-border cooperation'. The wealth of data available on the programme's implementation contributes to the topic's prominence in the literature – one might reasonably posit that there is a correlation between the availability of data and the frequency of research on a topic. Nevertheless, it is our contention that research on cross-border cooperation ought to extend beyond this EU public funding scheme and be oriented towards the broader goal of cross-border territorial development. Accordingly, this list of open questions does not focus on Interreg but on topics less frequently addressed in the academic literature.

The questions are grouped according to three broad areas of challenge; given the highly multidisciplinary nature of cross-border interactions, a disciplinary division did not seem appropriate. These groups merely serve as a structural device, as the topics naturally span across categories.

While acknowledging the conceptual distinction between cross-border 'cooperation' and 'collaboration', this chapter uses only the former, given its formal grounding in legal instruments and its predominance in policy discourse. In some of the questions raised below, however, the term may have connotations closer to the concept of collaboration, implying a deeper level of joint action. The scope of this report is also limited to the internal borders of the EU; while many of these questions are equally pertinent elsewhere, a focus on external borders would necessitate the inclusion of additional factors.

### 1.1.1. Territorial potential and measuring flows

#### What are the current flows of people in border regions, and what potential flows may develop?

Where, how and for what purposes people regularly cross a border has direct policy implications. Given that one of the functions of public policy is the provision of public goods, it is essential that the various levels of administration have reliable knowledge of the demand for such goods. The provision of public services – public transport being a case in point – is ordinarily planned on the basis of demand analyses derived from existing statistics, which are generally constrained to within national borders. The accurate mapping of cross-border flows of people is therefore essential for planning service investments.

A problematic cycle arises in this context. Limited data availability too often hampers adequate decision-making: an inaccurate perception of relatively modest flows results in insufficient effort being directed towards the provision of cross-border public services, while the absence of such services in turn suppresses the potential of those very flows. This could be addressed through a deeper understanding of commuting flows from two angles: (a) their real intensity and (b) their potential.

As regards the current intensity of cross-border flows, there is a widely held perception that they are frequently underestimated. The already scarce official data – based solely on individuals who complete the often-cumbersome administrative processes of formally registering both their place of residence and their place of employment – are themselves likely to represent a significant undercount, owing to the prevalence of incomplete official records. This challenge could be addressed through the use of alternative methodologies for modelling real flows.

Regarding potential flows, there is little to no information available. Were one to consider a Europe free of border obstacles, it might reasonably be assumed that cross-border commuting flows within a contiguous region would be proportionate to intra-country, interregional commuting flows, subject to language barriers. This reasoning could underpin the modelling of potential commuting flows and, by contrasting these with observed flows, yield estimates of the extent to which borders are hampering people's natural territories.

Such knowledge would enable decision- and policymakers to better align investments in border territories with actual needs. The supply of public services – such as public transport or information services for cross-border commuters – could thus be more effectively matched to demand.

### How big are border effects? What are the costs and impacts of border obstacles?

Even within the Schengen area and the single market, borders continue to hamper interactions between contiguous regions. The resulting unrealised potential is commonly referred to as the border effect. However, its true scale and impact remain insufficiently understood. The existing literature includes various modelling exercises, although these remain limited in scope: many focus on a narrow set of variables – most frequently trade – without addressing broader implications such as gross domestic product (GDP) loss. Many also examine a specific border in isolation and, given that methodologies are not consistently applied across borders, that makes it difficult to determine where negative effects are most pronounced. Establishing the causal relationship between particular types of obstacles and their impacts would be essential to informing effective obstacle-reduction policies.

A complementary line of inquiry concerns the extent to which borders impose a structural disadvantage on border regions relative to non-border regions. One may ask whether the economic impact of border obstacles places economic agents in these regions in a less competitive position than their counterparts elsewhere. Consider, for instance, small and medium-sized enterprises seeking to explore their local markets within a given radius: a firm located in a border region must contend with two licensing procedures, as its catchment area spans two countries, thereby incurring higher administrative costs than competitors based in non-border regions.

Such knowledge would enable decision- and policymakers to improve policies aimed at reducing border obstacles and would support more robust cost–benefit analyses of investments in cross-border cooperation.

### What are the potential gains of the effective cross-border provision of services?

The cross-border provision of public services is identified by the European Commission (European Commission, 2022a) as one of the ways to ensure the resilience of border regions. Across the EU, regional and local authorities face budgetary constraints that hamper their capacity to provide higher-quality public services. The joint provision of services in partnership with the administration of neighbouring countries or regions has the potential to generate efficiency gains – notably through economies of scale. This opens up a number of research avenues: modelling the scale of

the potential benefits of such cooperation, identifying their main explanatory factors, differentiating between the types of services with the most to gain and modelling optimal territorial configurations for different types of services.

Such knowledge would enable decision- and policymakers to better appreciate the potential of cross-border cooperation in the provision of public services and thereby promote greater efficiency in their delivery.

### What is the potential effect of an increase in access to services and better responses to public needs?

This complement to the preceding question concerns the accessibility of public services. Too frequently, public service provision is planned solely within the boundaries of a given country, which results in border regions becoming peripheral and their residents having poorer access to services than those in more central areas. In addition, public services located just across a border may often be physically accessible – in terms of road connections – while remaining legally inaccessible to residents of the neighbouring country. To what extent would legal access to existing cross-border services improve living conditions in such regions? And for which types of public service would this improvement be most significant?

Such knowledge would enable decision- and policymakers to better exploit the latent potential of public services situated across a border to the direct benefit of the populations in those regions.

### Can cross-border cooperation contribute to overcoming territorial and demographic challenges?

Regions across Europe face diverse yet significant challenges, such as demographic pressures ranging from depopulation and ageing to over-congestion, which gives rise to, among other things, housing difficulties. While these challenges are not unique to border regions, the nature of cross-border regions may represent an opportunity to at least alleviate them in these areas.

Depopulation, for instance, is both a cause and a consequence of a diminishing educational offer. As a region ages and loses some of its population, it may fall below the minimum demand required to sustain schools; their closure, in turn, discourages young families from settling or remaining in the area. The joint provision of education by two neighbouring regions could, however, generate the critical mass necessary to maintain an adequate educational offer. The Hospital of Cerdanya provides a well-known illustration of how the joint provision of public services across borders can sustain the provision of a public service that neither side alone could support.

In the case of over-congested border regions, facilitating smoother cross-border interactions may help to alleviate housing pressures by enabling people to live on one side of a border and work on the other. At the same time, increased cross-border housing demand may affect affordability and land use on the residential side of the border. Realising this potential, however, is contingent upon addressing the legal barriers to cross-border work and education – including those arising from differences in taxation, social security and healthcare systems. Cross-border mobility in particular, including but not limited to public transport, must also be better understood, especially the extent to which jointly coordinated transport services could unlock cross-border commuting and, conversely, the extent to which such commuting might exacerbate congestion. A clearer understanding of the potential – and the limitations – of unimpeded joint access to services could allow the full benefits of cross-border interactions to be realised.

Such knowledge would enable decision- and policymakers to conduct more robust cost–benefit analyses for the planning of joint services, taking due account of the externalities associated with addressing territorial and demographic challenges.

#### What are the missing sector-specific opportunities to be taken from cross-border cooperation?

The opportunities arising from cross-border interactions vary across sectors. Some sectors receive more attention than others by virtue of their visibility – healthcare, transport and employment being prominent examples. Other sectors, however, hold considerable potential for cross-border cooperation, while presenting contextual particularities that call for different analytical approaches. A more systematic assessment of the specific cross-border challenges and opportunities within each sector would help to unlock the potential of these sectors during cross-border territorial development. Pertinent examples include the impact of cross-border commuting on housing markets, the potential for the joint cross-border management of natural areas and the effectiveness gains to be derived from cross-border spatial planning.

Such knowledge would enable decision- and policymakers in sectors where the awareness of cross-border dynamics is typically limited to better incorporate the specificities and potential of border regions into their sector-specific policies.

### 1.1.2. Structuring and financing cross-border governance

#### What are the optimal delimitations for a border region?

Defining the boundaries and extent of a border region is a perennial challenge. Theoretically, no single answer exists, as the appropriate delimitation of these regions depends on the function under consideration; different functional areas may thus be defined for different purposes. Nevertheless, clear delimitations are necessary for many administrative and legal purposes – for instance, to determine where a given set of financial resources may lawfully be deployed. Decisions on the size of border regions could be better informed by an understanding of where the impact of limited resources is likely to be greatest. Examining the correlations between the size of border regions and public spending multipliers – particularly when paired with increased cooperation and reduced border effects – would contribute to the optimisation of public investment. Pinpointing the location of different territorial functions could also help establish whether different policy interventions ought to be based on different delimitations of border regions.

Such knowledge would enable decision- and policymakers to better allocate investments – notably Interreg funding – to the territories where their impact on society would be greatest.

#### Can the funding of cooperation costs be made sustainable by internalising its economic gains?

There are two recurrent and interrelated topics in border studies that are rarely discussed together. On the one hand, there is the question of the costs of implementing cross-border cooperation, which are frequently examined through the lens of Interreg expenditure; on the other hand, there is the question of the potential economic gains from increased cooperation – notably the estimated 2 % increase in GDP for border regions that is derivable from resolving one fifth of the existing obstacles (Capello et al., 2018). However, these two strands of analysis are typically addressed in

isolation. Bringing them together would allow for an assessment of how those potential gains might be distributed and the extent to which they could contribute to offsetting the costs of cooperation.

A related avenue of inquiry concerns the link between the public budgets of local and regional administrations and the economic performance of their territories. For instance, what would the effect on cross-border cooperation be if local and regional public budgets were to benefit fiscally from improved economic performance in border regions? To what extent could such gains form part of the funding base for cooperation costs?

Such knowledge would enable decision- and policymakers to explore new mechanisms for the governance and financing of cross-border cooperation.

### How do differences in the national distribution of competences impact cross-border governance, and how can the associated challenges be overcome?

The distribution of legal competences across different levels of public administration varies significantly between countries. In principle, this merely reflects differing constitutional frameworks and need not impact the form that cross-border cooperation takes. In practice, however, it does. Analyses of legal and administrative obstacles to cross-border cooperation regularly identify discrepancies in the distribution of competences as a source of additional difficulty. Where legal competence over a given matter rests at the regional level in one country and at the national level in another, establishing cooperation becomes considerably more complex. Administrative cultures – and, in some cases, constitutional requirements – create an expectation that administrations should engage only with their equivalent-level counterparts, whether that is at the national-to-national or regional-to-regional level. Yet in certain sectors, cooperation may need to be implemented across different levels – regional on one side, national on the other – which can prove particularly challenging when bilateral agreements are required, given that legal impediments may prevent administrations from negotiating with counterparts of a different level.

This challenge gives rise to several questions concerning how its impact might be minimised: to what extent, and through what mechanisms, does this asymmetric allocation of competences hamper cross-border cooperation? What arrangements might be explored to overcome such limitations? And to what extent is administrative culture – namely, the assumption that negotiations should only take place between bodies of equivalent levels – the primary driver of this challenge?

Such knowledge would enable decision- and policymakers, principally at the national and regional levels, to adapt their processes for implementing cross-border cooperation strategies and projects.

### What is the best way to define the governance structure of a given project, strategy or territory?

The sustainability of cross-border cooperation actions beyond the duration of the projects through which they are funded is a recurrent challenge. Too frequently, activities are bounded by project timelines, diminishing the broader societal benefits that might otherwise be realised. While the lack of sustainability is often attributed primarily to insufficient funding, a closer examination suggests that the failure to establish appropriate governance structures in a timely manner may be the more fundamental cause. Identifying suitable governance arrangements and making them operational before a project concludes may be key to maintaining the project beyond its initial impetus. Establishing such structures entails the attribution of mandates, the delegation of competences and the definition of budgets – steps that may prove decisive in ensuring the continuation of cooperation beyond the project that triggered it.

Such structures may, however, take many forms. The most advanced forms, such as the European Grouping of Territorial Cooperation (EGTC), entail the attribution of a legal personality under EU law. Other forms of legal personality recognised under national law – such as associations – may also be considered, as may arrangements that do not require a legal personality, such as intermunicipal agreements.

This raises several questions: to what extent is the establishment of a legal personality essential? What are the key factors for success when designing a governance structure? Is it possible to establish a causal relationship between some of those factors and project success across different types of projects? What are the critical factors underpinning the success of specific structures, such as the EGTC?

Such knowledge would enable decision- and policymakers operating at the level of the project beneficiaries to improve these projects' design by giving due consideration to governance structures from the outset. At the EU level, it could inform improvements to existing legal instruments – such as the EGTC Regulation – to render them better suited to aiding cooperation.

### How can we achieve and sustain the multilevel commitment needed for cooperation?

Cross-border cooperation frequently depends on multilevel commitment from political actors and other stakeholders. At the same time, the regular turnover of individuals in these roles – owing, for instance, to political cycles – poses challenges to maintaining continuous commitment. It is, furthermore, essential to secure simultaneous engagement not only across different administrative levels, but also from both sides of a border. This is a recurrent challenge not only in the design of cooperation projects and strategies, but also for their implementation and long-term sustainability.

Several questions arise in this regard: what factors are conducive to sustained multilevel commitment? Is there a direct relationship between this commitment and the types of actors involved – for instance, the simultaneous engagement of civil society alongside political actors? Are there specific processes for securing such commitment that yield higher rates of success? Or do certain forms of governance structures generate better outcomes? In short, what are the key factors for ensuring successful long-term multilevel commitments?

Such knowledge would enable decision- and policymakers to lay the necessary groundwork for their cooperation strategies and projects, ensuring that all requisite actors are engaged in a sustainable and meaningful manner.

### What are the potential and limitations of tax compensation schemes among neighbouring countries with significant cross-border commuting?

The existing models for taxing the income of cross-border commuters may give rise to disparities between territories and lead to certain statistical distortions. In principle, the income taxes paid by individuals to a state are offset by the public goods that state provides to its residents; the implicit assumption is that the state collecting the taxes is the same as the one providing the public goods. This assumption breaks down, however, in the case of cross-border workers, who live on one side of a border but work on the other. Their income tax is paid to the public budget of their country of employment, while some or all of the relevant public goods they use are provided by their country of residence. This asymmetry may generate friction between the administrations of the two countries.

The same issue also produces a statistical distortion in certain indicators, most notably GDP per capita. The added value generated by a cross-border worker is attributed to the GDP of their country of employment, without that individual being counted in its population – thereby inflating the GDP per capita on that side of the border. Conversely, on the other side of the border, the individual is counted in the population without their added value being included in the GDP – thereby depressing the GDP per capita.

While this issue has received some attention in policy debates, its implications remain insufficiently quantified. Several questions warrant further investigation: to what extent does this effect constitute a genuine problem? To what extent do the public goods provided by the country of employment offset the alleged distortion? If compensation were deemed appropriate, how might its value best be calculated and what factors should be taken into account? What alternative forms of compensation – beyond financial transfers – might be considered, such as the provision of cross-border public goods, including free public transport or education? And could such alternatives generate a multiplier effect by simultaneously reinforcing cross-border cooperation?

Such knowledge would enable decision- and policymakers to partake in a more informed debate on this issue and, ultimately, to develop equitable solutions. At the same time, it could also provide an impetus for strengthening the provision of cross-border public services.

### 1.1.3. Identities, reconciliation, EU integration and law

#### What are the impacts of history on trust among border peoples?

Political action on cross-border cooperation is frequently driven by economic considerations – namely, overcoming border effects in order to realise socioeconomic gains through increased market efficiency and reduced disparities. The reconciliation aspect, however, which is inherent to the cooperative process, ought not to be overlooked. Borders have shifted throughout history, and conflicts have divided peoples both literally – through the drawing of borders that separated communities into different territories – and in terms of trust and social cohesion. A related question concerns the extent to which unequal power relationships between countries and regions, and the political narratives that accompany them, shape people's perceptions of their neighbours and translate into more or less favourable conditions for cooperation.

Trust is simultaneously a precondition for and a consequence of cooperation. To what extent can cross-border cooperation contribute to reconciliation and the rebuilding of trust? This question is of considerable importance for policymaking, as it impacts how policies can best be tailored to territories with differing historical backgrounds. Can the same instruments be equally well suited to long-established borders and to those redrawn in the aftermath of the Second World War?

The application of instruments such as the EGTC varies considerably across different parts of the EU. To what extent is this a reflection of differing levels and forms of trust rooted in the experiences of the last five or six generations, or indeed of earlier generations? To what extent must the element of reconciliation be more explicitly integrated into cross-border cooperation processes, including as a means of unlocking their socioeconomic potential? Conversely, to what extent might certain forms of cooperation – such as educational mobility – exert a significant long-term influence on reconciliation?

Such knowledge would enable decision- and policymakers to better adapt policy instruments to the specific needs of cross-border territories. At the national and programme levels, a deeper

understanding of the relationships between history, trust and cooperation processes could also enhance the alignment of cooperation programmes with territorial realities.

### What are border peoples' identities? How can national and border identities co-exist?

Understanding the sociological dimensions of people's identities is essential to understanding how individuals, organisations and communities can engage in cross-border cooperation. Existing analyses of cross-border commuting and border effects frequently indicate that borders continue to exert a considerable dampening influence on flows. Cross-border commuting within the Schengen area and the EU, for instance, appears to be substantially lower than interregional commuting within national borders. While the existence of legal obstacles accounts for part of this disparity, identity also plays a significant role.

Understanding how individuals relate to a given territory is essential both for promoting citizen engagement and for determining how legal frameworks can best be made applicable to cross-border territories. Several questions arise in this context: do individuals identify as coming from a cross-border territory? Do they perceive the neighbouring region to be part of their natural territorial sphere? What factors give rise to a cross-border identity? Do residents of border regions exhibit a stronger sense of European identity than those from non-border regions? And to what extent do individuals identify more strongly with their local cross-border territory than with their country of citizenship?

Such knowledge would enable decision- and policymakers to design more effective cross-border strategies by better incorporating the identities of the people concerned and to foster more meaningful citizen participation.

### Are people living in border regions more European?

The European Commission identifies border regions as living laboratories of European integration (European Commission, 2021a). In these territories, individuals and organisations interact regularly with their counterparts in other EU Member States, lending a stronger European dimension to their daily lives than is experienced by those living far from a border.

Yet to what extent does proximity to a border actually have this effect on individuals and organisations? Beyond more frequent border crossings, what is it that makes border peoples more European? Is there a genuine element of identifying and perceiving one's self as European, or is that perception oriented towards the neighbouring country rather than towards the EU as such? Are such individuals more inclined to vote for pro-EU political parties as a result of their daily contact with their neighbouring country, or does their distance from national capitals and decision-making centres engender a sense of marginalisation, leading them instead to vote against EU institutions as an expression of anti-establishment sentiment?

A related line of inquiry concerns civic engagement at the European level. A stronger European identity might reasonably be expected to manifest as higher participation in, or use of, EU-level civic tools – such as European Parliament petitions, Europass, SOLVIT (the informal problem-solving network provided by the national administration in each Member State and in Iceland, Liechtenstein and Norway), or the Europe Direct network. To what extent is this the case among border peoples?

Such knowledge would enable decision- and policymakers to better adapt these tools to the specific contexts of border regions. At a broader level, greater political awareness of the effects of borders on people's perceptions and sense of belonging would inform more targeted policies to address potential disparities and strengthen EU integration.

## Should there be overlapping legal frameworks in cross-border territories?

National borders represent a rigid delimitation of the territorial applicability of legal frameworks. Yet, in principle, the law ought to apply to the area of influence of the issue it regulates – a hydrological plan, for instance, should apply to a river basin, and solid waste disposal regulations to a given urban catchment area. Where such areas of influence are bisected by a national border – as in the case of a twin-city urban area – two legal frameworks apply to different parts of what is, in functional terms, a single territory, and these frameworks frequently conflict on specific points.

From a normative perspective, this situation may appear unavoidable, given that local law is subordinate to regional law, which is in turn subordinate to national law. Yet the question arises as to whether it might be possible to develop legal frameworks that are applicable to a cross-border territory without calling into question the national legal frameworks of either country. Could urban spatial planning norms for a cross-border urban node, for example, be jointly developed and rendered equally applicable on both sides of a border, while remaining coherent with the national and regional law of both countries? What conditions would need to be met to establish a framework in which certain norms apply beyond a national border? And is it possible, on the basis of existing examples, to infer the necessary conditions for such a normative system?

Such knowledge would enable decision- and policymakers to explore synergies in cross-border territories through deeper cross-border integration, while also creating the conditions for strengthening the cross-border provision of public services.

## Are specific legislative changes needed to overcome border obstacles?

The reflection process conducted as part of a cross-border review – a consultation exercise that preceded the European Commission communication on boosting growth and cohesion in EU border regions – alongside the work done towards implementing territorial impact assessments (Ferreira et al., 2020) demonstrates that the need to interact with several legal frameworks simultaneously in a cross-border territory frequently hampers cross-border interactions. The B-solutions initiative has also provided evidence of the incompatibility of some legal frameworks (Medeiros et al., 2023).

Within a cross-border territory, it is possible to find both horizontal and vertical deficits in the articulation of co-existing legal frameworks. For a given cross-border issue, the need to navigate two national legal systems points to the need for horizontal articulation. The complex legal architecture of the EU, with its division of competences across European, national and regional frameworks, meanwhile points to the need for vertical articulation – a need that becomes particularly evident when approached from a sectoral perspective, such as through the lens of transport law.

To what extent should legislative changes be pursued – with full respect to the principles of conferral, subsidiarity and proportionality – in order to better articulate these frameworks, both vertically and horizontally, to overcome and prevent cross-border legal obstacles? In which sectors is this need most acute? And what specific amendments to national or EU law in a given sector could enable deeper cross-border integration?

Such knowledge would enable policymakers at the regional, national and EU levels to consider targeted legal amendments to address the specific problems that hamper cross-border interactions and regional development.

This list of questions is by no means exhaustive. It represents a modest attempt to systematise some of the challenges faced by border peoples in the EU, yet falls well short of capturing their full breadth. Indeed, research has already demonstrated that, the more cooperation advances,

the more obstacles come to light, which implies that policy-relevant questions are inherently dynamic. The overarching goal is to contribute to better lives in border regions and to ensure that the existence of a border does not prevent individuals and organisations from fully exploring their natural territories – that is, all areas in their immediate proximity.

With this perspective in mind, one general question might ultimately suffice: in what ways does one's research contribute to policy- or decision-making that is in the service of improving lives?

## 1.2. Flows through the lens of border economics

**Mattia Albertini**

Every day, millions of workers live in one country and cross into another to work. These cross-border workers create some of the most dynamic labour markets in the EU. In 2022, approximately 1.8 million such workers were reported across the EU and European Free Trade Association (EFTA) (European Commission, 2024). This phenomenon is typical of border economies, which are regions where geographical proximity, regulatory alignment and institutional cooperation allow labour, goods and services to flow across national borders more intensively than elsewhere. Border economies lie at the core of border economics and offer a unique interplay between migration, taxation, labour markets, innovation and much more.

Despite the importance of this mobility, there is still a striking lack of detailed microdata on cross-border workers that would help us characterise border economies. This shortage limits our ability to understand how border economies function and, more importantly, how to design policies that sustain them. In particular, without reliable information on who cross-border workers are, where they live and how they move, policymakers risk misjudging the true scale of cross-border integration. The purpose of this section is to argue for stronger cooperation and better cross-referencing of data on the flows of goods, people and cross-border workers in particular.

The first matter is how to define a border economy. In some cases, bilateral agreements specify the commuting zones in which workers can live, work and benefit from special taxation or service arrangements. For example, until 2023 Italy defined international commuting zones as areas within 20 kilometres of the Swiss border, a definition that directly shaped tax incentives for Italian workers in Switzerland ([1]). In other cases, such as Germany's border with Switzerland, the bilateral agreement in place does not establish commuting zones, making it harder to understand their economic geography. Switzerland represents a best-practice case study, where granular data on residents' place of work allow researchers to estimate commuting distances, but this level of detail is more of an exception than a rule within the EU.

Data on flows of people are pivotal because they help us understand not only the scale but also the nature of border economies. Even if we can delimit a commuting zone geographically, what matters is the intensity and character of the economic activity within it. Borders differ in type: some lie between two Member States, others between a Member State and a non-EU country, and others between two non-EU countries. Each configuration brings with it different institutions, incentives and social distances, and therefore different challenges. Bilateral agreements are one

([1]) The Italian Revenue Agency's Resolution No 38/E of 2017 stated that Italian municipalities within 20 km of the border with the cantons of Ticino, Valais or Grisons were to be designated as border regions.

way to classify border types, but deeper data on cross-border workers, places of work and places of residence would reveal much more. For example, Switzerland has only recently started to track the municipality of residence of its cross-border workers. Not long ago the data accessible typically covered only the municipality in which they worked in Switzerland. Observing flows of people from this perspective alone ignores the economic footprint of these workers in their country of residence in terms of the demand for housing, local taxation and their use of public services. Without this information, the real extent of cross-border integration and the degree of direct and indirect economic activity across borders remain invisible.

Furthermore, the study of border economies is also crucial because border migration flows differ fundamentally from inland ones and can conceal complex dynamics that current statistics are unable to grasp. Albertini et al. (2022) demonstrate that increases in cross-border flows in Switzerland, often interpreted as an expansion of labour supply, also reflect residential choices rather than new workers entering the market. For example, a worker employed in Switzerland who moves their place of residence from Switzerland to Italy is recorded as an emigrant in Swiss statistics and an immigrant in Italian ones, but in practice nothing changes in terms of labour supply. The individual keeps working in Switzerland, paying Swiss income taxes and only alters their residential status. Before 2023, this person would not have been liable to Italian income tax, highlighting the fiscal implications of such residential arbitrage. Without precise information on these dynamics, policymakers risk systematically misinterpreting border flows and treating statistical artefacts as real changes in labour supply or fiscal contributions. This misreading is not a mere technicality: it can distort debates on wage competition, fiscal fairness or the sustainability of welfare systems and fuel political tensions in border regions. In highly integrated areas, where cross-border workers may account for a significant share of the labour force, such as Switzerland or Luxembourg, the absence of reliable data means that policies are too often based on perceptions rather than facts. Investing in better cross-border data collection is therefore not just a matter of statistical refinement, but of ensuring that political and policy debates are grounded in evidence rather than rhetoric.

The scientific literature further underscores the importance of better data collection. Bello (2020), for example, used traffic flows between northern Italy and the Swiss canton of Ticino to show that cross-border commuting responds strongly to changes in the exchange rate: when the Swiss franc appreciates, workers cross more often. Beerli et al. (2021) found that the liberalisation of cross-border work expanded Switzerland's border-region labour markets. These are just some of the studies that centre the cross-border dynamics and that often highlight the important limitations of current data.

For policymakers, the implications are clear. First, labour market data that do not distinguish between genuine increases in supply and changes in residence lead to misjudgements about wage pressure or labour competition. Second, residential integration means that border regions share responsibility for housing, education, healthcare and infrastructure. Policies focused only on commuting or taxation underestimate these broader fiscal and social systems. Third, exchange rate shocks and regulatory reforms affect borders asymmetrically, depending on the institutional and economic conditions of the countries involved. EU policy must therefore recognise the heterogeneity of borders: integration across an internal EU border looks very different from integration across a border with a non-EU neighbour.

In sum, cross-border workers play a vital role in the EU's economic integration, but their importance is not fully understood because of inadequate data. A stronger framework for collecting, harmonising and sharing information on cross-border mobility is essential. Only then can policymakers design fair tax regimes, coordinate social security systems, invest in infrastructure and manage demographic

pressures effectively. Border economies are not peripheral; they are central to the EU's cohesion and competitiveness.

## 1.3. A new framework for EU cross-border interactions – the data hub for EU border regions

**Matteo Berzi and Benedikt Herrmann**

Since the adoption of the communication on boosting growth and cohesion in EU border regions (European Commission, 2017), the Directorate-General for Regional and Urban Policy (DG Regional and Urban Policy) has compiled a broad range of data on cross-border interactions in EU border areas. This DG Regional and Urban Policy inventory covers public transport, public services, missing rail links, healthcare, crisis management agreements, energy communities, cross-border management structures and legal–administrative obstacles. The data vary in format, granularity, the precision of their geolocation and source – ranging from official statistics to non-official contributions from the European Committee of the Regions and the European Observation Network for Territorial Development and Cohesion (ESPON). Until now, no single publicly accessible platform has existed to gather, harmonise and visualise these datasets, nor to host additional data contributions. In line with the objectives set out in the first section of this report, DG Regional and Urban Policy launched the ACROSS (data and analysis for cross-border regions) project in collaboration with the JRC. The project is geographically focused on the internal land borders of the Member States ([2]) and EFTA countries and pursues three interlinked goals:

1. the assessment and transformation of the DG Regional and Urban Policy inventory into relevant indicators and geospatial datasets;
2. the development of a single open-access platform to display the assessed data and more data on cross-border interactions, serving multiple audiences: EU policymakers, national authorities, regional and local administrations, cross-border organisations and scholars;
3. the fostering of research on existing and potential cross-border interactions.

### 1.3.1. Data processing and indicator design

The data were processed in the following ways (and in this order): through data availability checks, stakeholder consultations, data cleaning, geospatial analysis, indicator building and data visualisation. After processing the data, three groups of datasets were identified:

- feasible datasets, which include layers with high geographical coverage and frequently updated data, suitable for transformation into indicators at various scales, such as indicators of cross-border public transport (rail stops), public services, cooperation in healthcare, management structures (e.g. EGTCs) and border obstacles;

([2]) https://european-union.europa.eu/principles-countries-history/eu-countries_en

- potentially feasible datasets, which consist of layers that partially meet the criteria and require further cooperation, data cleaning or harmonisation, such as indicators of cross-border energy communities; crisis management; Euroregions and Eurocities; the Euroregions, excellence and innovation across EU borders initiative; and missing rail links;
- unfeasible datasets, which are those still lacking the necessary georeferenced or systematised data to become indicators, although they are static resources like PDFs, maps and tables that are available as tools, such as cross-border reviews, transport obstacles, solutions to border obstacles and healthcare cooperation toolkits.

Given the varying geographical scopes of cross-border interactions, identifying appropriate geospatial layers and administrative boundaries is essential. Three main layers were selected: cross-border areas (46 units), defined as 25 km buffers from borders that may overlap; NUTS 3 ([3]) border regions (359 units), which are based on proximity to land borders and the population distribution; and local administrative units (LAUs) within cross-border areas (16 854 municipalities).

Once the feasible datasets were aligned with the three main layers, they were used to build indicators that reflect the significance of cross-border interactions at various scales. Ratios and shares were preferred over absolute values because they enhance comparability, normalise data, provide contextual insights and are more relevant for policymaking.

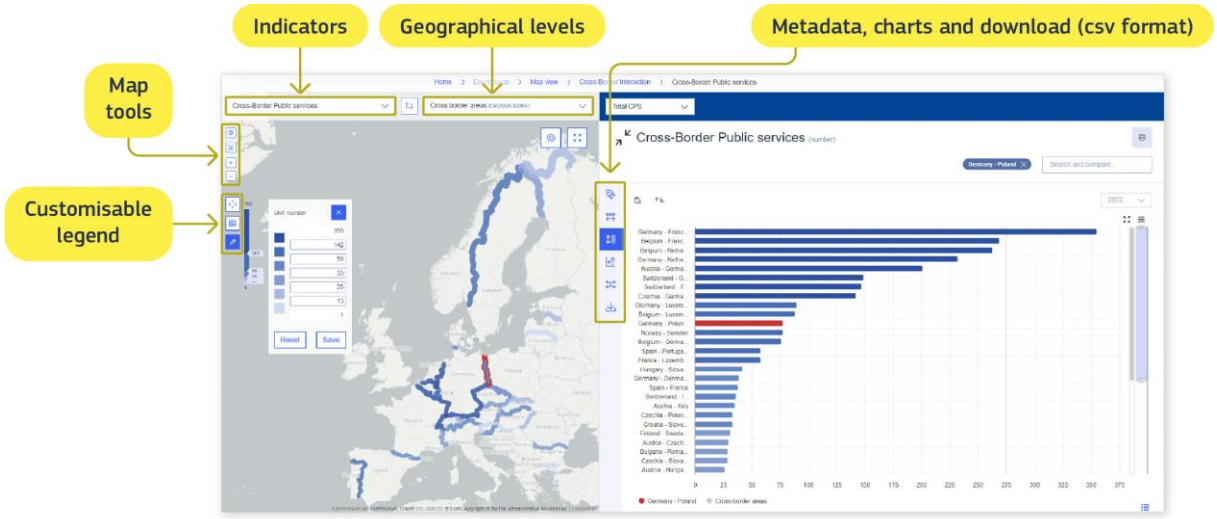
### 1.3.2. Developing a single platform for multiple target audiences

After the processing phase, the results were made publicly available through a new section of DG Regional and Urban Policy's website for territorial development. This section, called the data hub for EU border regions, was created to be accessible to all stakeholders involved in, or interested in, cross-border cooperation at the regional, national and EU levels. The hub has been enriched with a set of robust, high-quality socioeconomic indicators that highlight disparities along internal EU borders (Berzi et al., 2025). These indicators cover demographics, employment, regional economies, tourism and energy and are mainly sourced from JRC Territorial Development Unit platforms such as the Annual Regional Database of the European Commission (Ardeco), the urban data platform, the Rural Observatory and the EU Tourism Dashboard (provided by the statistical office of the European Union (Eurostat)). Ardeco provides harmonised data at the NUTS 3 level; the urban data platform supplies indicators on tourism, transport, education and demographics; and the Rural Observatory offers multidimensional rural statistics. To meet the different needs of its audiences, the hub presents the data in a range of formats.

**Map view.** This offers an EU-wide perspective on any chosen indicator (**Figure 1**). Charts allow users to understand a specific cross-border interaction or regional statistic across all internal borders at the scales for which it is available (regional, local or border area). The view can support EU policymakers in evaluating performance.

([3]) Nomenclature of territorial units for statistics; see https://ec.europa.eu/eurostat/web/nuts.

**Figure 1.** Map view of the data hub for EU border regions.

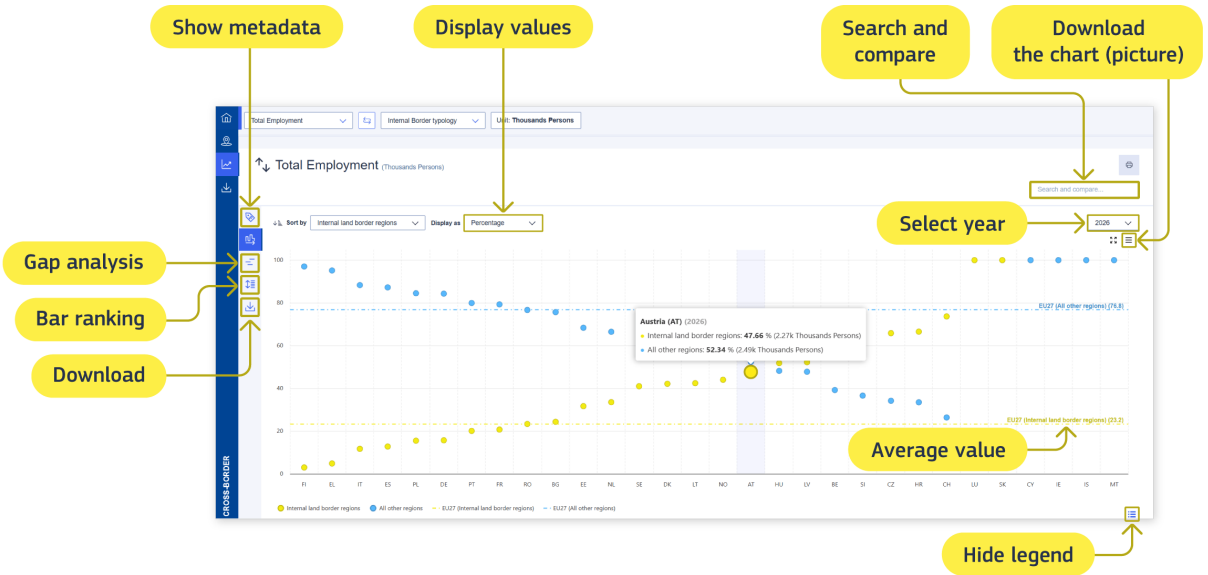



*Source: Authors' elaboration.*

**My border region.** This enables the comparison of a selected region, border area or border municipality with its counterparts along the same border or elsewhere in the EU and EFTA. The tool provides the same cross-border interactions and regional statistics as the map view and aims to help regional and local authorities with benchmarking, the development of territorial strategies and the identification of cooperation synergies.

**Border-focused view.** This format aggregates the indicators of regional statistics in one country, allowing national authorities to compare border regions with the rest of the country (Figure 2). This view could assist in monitoring the performance of border regions within each Member State and in each EFTA country.

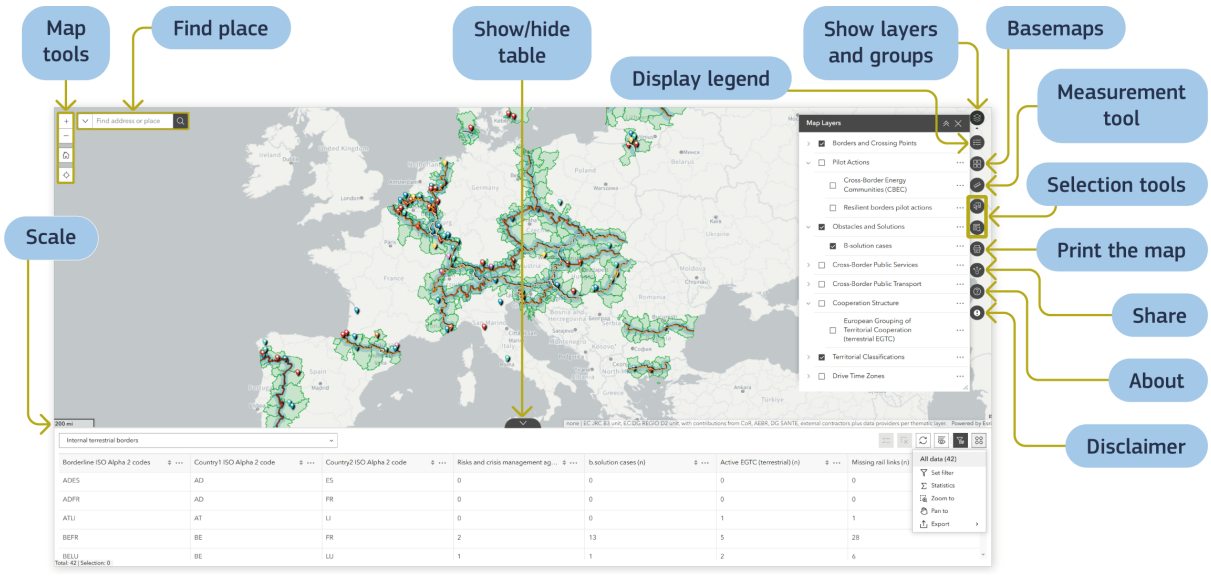
**Figure 2.** Border-focused view of the data hub for EU border regions.




*Source: Authors' elaboration.*

**Web map of geolocalised interactions.** This is an interactive map for a broad audience (Figure 3). It displays the spatial distribution of all DG Regional and Urban Policy inventory items. Datasets that already contain geospatial information (e.g. those on public services, public transport, missing rail links) are shown directly, while others (e.g. those on EGTC structures, B-solution initiatives) have been processed and integrated into the map through geographical information system (GIS) analyses in collaboration with data providers. Each map item is enriched with additional qualitative information. The lines of the borders show the counts for specific dataset items – such as the number of EGTCs, bilateral disaster management agreements or missing rail links – following the dyad approach described in Section 1.5. The complete data and accompanying metadata can be downloaded as a geodatabase, and a web feature service is available for direct import into GIS software.

**Figure 3.** Web map of geolocated cross-border interactions in the data hub for EU border regions.




*Source: Authors' elaboration.*

All assets in the data hub are free to download either from the hub itself or via the JRC Data Catalogue. The repository will be updated annually; following each update, a dissemination phase will collect feedback and recommendations for visual improvements from stakeholders and data providers. Simultaneously, new cross-border interaction data will be incorporated to ensure that the hub remains a living, responsive resource for the cross-border community in the EU and beyond.

## 1.3.3. Fostering research on cross-border interactions

The ACROSS project also aims to extend the DG Regional and Urban Policy inventory with data-driven evidence on existing cross-border interactions in sectors that are not yet covered. Current work, for example, maps existing cross-border protected areas. However, research on potential cross-border interactions is being pursued in close collaboration with scholars and cross-border experts from across the EU and beyond (Berzi et al., 2026). The preliminary findings of this research are presented in Section 3.3 (tourism in cross-border regions), Section 4.3 (mapping prospective functional rural areas (FRAs)) and Section 4.4 (assessing access to healthcare services across borders). All these studies start by examining the counterfactual statement that border obstacles do not impede the provision of services and flows. Their results are of paramount importance because they illustrate the added value of more integrated border regions and, by making these insights

visible, can stimulate stronger, targeted cooperation among the competent authorities in each sector. When new datasets are harmonised and spatially aligned, they provide valuable additional insights for understanding and improving cross-border cooperation throughout the EU.

Nevertheless, reliable and granular data on the cross-border flows of people and goods remain scarce. Incorporating such data into the DG Regional and Urban Policy inventory would enhance the cross-border planning of public services and help identify further opportunities for cooperation. Combining the existing DG Regional and Urban Policy information with innovative, low-cost methods for collecting data on mobility and freight flows (e.g. mobile phone records, transport–operator application programming interfaces or satellite-derived traffic indicators) could make these flows more measurable. The following chapters review both official statistics and non-traditional data sources used for mapping cross-border flows, opening up new avenues for interdisciplinary discussion within the academic community. A key challenge highlighted is how this flow data can be used to refine the definition of functional cross-border regions and to deepen our understanding of cross-border living spaces, a topic explored in the following section.

## 1.4. What exactly is a cross-border living space?

**Olle Järv and Lewis Dijkstra**

### 1.4.1. Border regions as living labs of EU integration

Border regions in the EU are seen as a key sign of progress towards achieving balanced and sustainable territorial cohesion within the EU. Broadly speaking, the goal of territorial cohesion is to mitigate social and spatial disparities in the interactions between, cooperation across and integration of communities located in different regions. Therefore, border regions are inherently linked to the spatial materialisation of EU cohesion policy. Moreover, cross-border regions are seen as living laboratories (i.e. indicators) of EU integration.

With internal borders open for citizens and entities of the EU, people cross borders for work, study, shopping and tourism and to visit friends and family. Companies and organisations are advancing their collaboration across borders in order to be more successful, while the public sector seeks collaborations to better plan, develop and govern cross-border regions to support cross-border interactions, the engagement of people, and cooperation between entities across Member State borders. These interactions, collaborations and cooperation contribute to the formation of one functioning system – a functional cross-border region or **a cross-border living area.**

Border regions are generally defined as regions that are geographically close to a state border and that interact with and are influenced by regions on the other side of that border. But where do these cross-border interactions and collaborations take place? Regardless of the growing importance of border regions in both policy and academic debate, we lack comprehensive and up-to-date information on border regions and the cross-border interactions of people. Finally, how should we define and delineate cross-border living areas? This popular concept is used in policy and academic debate without a clear definition and without an explanation of how it is associated with the concept of a functional (urban) region.

### 1.4.2. Defining cross-border living spaces/areas

What are the theoretical underpinnings of the concept of a cross-border living space? In brief, a cross-border living space is a territory where various cross-border interactions of a social, cultural, economic, governmental and political nature take place, and that forms an additional functional system that connects two (or more) existing nation states separated by a border. Here, people and their daily lives – especially the spatial mobility and social practices defining individuals' spheres of activity – play a central role in the production of a common cross-border living space (Järv et al., 2023). These living spaces are therefore dynamic in nature and evolve over time depending on the interplay between structure (society) and agency (people). The construction of a cross-border living space occurs through the practices of people, while their practices are in turn shaped by the societal setting (e.g. history, culture, regulations, economy, politics, events) of a given territory.

Cross-border living spaces transcend the concept of the state and reimagine the logic of territorialisation and core–periphery thinking, as the starting point when defining a living space is the border rather than the capital. Instead of contradicting the nation state system, it forms an additional layer that blends with and complements to that system, while supporting border regions in becoming a resource (Sohn, 2014).

Given that the process of cross-border integration is multilayered by nature (Durand, 2015), as it includes both material and immaterial aspects, it is also the case that the construction of a cross-border living space is equally complex (Medeiros, 2020). Therefore, cross-border living spaces should be understood and defined from various dimensions to better capture their complexity, similarly to cross-border integration (Durand, 2015). According to Durand, a cross-border living space can be approached from four dimensions: the structural, functional, institutional and ideational.

**Structural dimension.** Defining a cross-border living space through the structural dimension means taking a place-based view and paying attention to the spatial characteristics of a given space, including its structure and degree of urbanisation, the distribution of economic activities and the density and composition of the population living on both sides of the border.

**Functional dimension.** Defining a cross-border living space from the functional dimension is linked to the characteristics cross-border flows and taking a flow-based view of both people and entities. Here, flows between areas includes all types of interactions across borders that contribute to the formation of a functioning interconnected society. That is, it is not only about working across borders, but includes cross-border social practices that are linked to education, shopping, leisure, tourism, interacting with friends and relatives (i.e. social networks) and residential mobility, in addition to economic interactions (flows of goods, money, information) taking place between companies.

**Institutional dimension.** Defining a cross-border living space from the institutional dimension involves assessing the characteristics of cross-border cooperation between entities and organisations in the public sector. Here, a spatial perspective of a cross-border cooperation network and the locations of the actors involved highlight the territory in which public policies and public service provisions are jointly planned and developed, ultimately leading to the formation of joint cross-border governance – consolidating the territorial cross-border project.

**Ideational dimension.** Defining a cross-border living space through the ideational dimension involves assessing immaterial individual and collective representations of cross-border integration, including a sense of belonging to a given cross-border living area, sharing similar social and political

values and perceptions and having common symbols and images that are associated with the area. The ideational dimension of this space can be delineated based on the spatial distribution of the daily practices of people with an active engagement in and sense of belonging to a given cross-border living area.

All these dimensions are relevant (see **Section 4.1**). However, to better acknowledge the lived experience of people and how people, goods and social interactions take place and move across borders, more emphasis should be put on the functional and ideational dimensions when defining cross-border living spaces in the EU.

### 1.4.3. Linking functional urban and rural areas to cross-border living spaces

Functional areas can help map cross-border living spaces in two distinct ways. The first way is through the creation of daily systems, or areas that are relatively self-contained and offer their residents most of the daily services they need in terms of work, education, healthcare, retail, recreation and socialising. NUTS 3 regions found along national borders and 25 km buffers along borders do not provide logical subdivisions into smaller geographical units and thus may combine places that are hundreds of kilometres apart. In this way, a single EU border region may combine urban areas in a flat valley with dense road networks and rural, mountainous areas with few people and roads. Functional areas can help to split these border areas into different living spaces with different characteristics.

The second way is through the construction of functional areas around specific functions. Functional urban areas (FUAs) consist of a city and its surrounding commuting zone. Although the definition only considers the function of work, the analysis of FUAs in the EU shows that they also contain most, if not all, the public and private services that people use frequently. In other words, FUAs are self-contained daily systems. FRAs are based on potential flows to a regional centre, namely the largest town or village in an area. While FUAs are based on observed commuting flows, FRAs rely on potential flows, as data on this wide variety of trips are currently not available. Our analysis indicates that most FRAs provide most of the daily services people need and thus function as daily systems. Some, however, lack certain services. Because FRAs are based on potential trips, we can identify these missing services. Although neither FRAs nor FUAs take into account the data on economic interactions between companies, the close proximity of companies is likely to lead to more frequent exchanges of goods, funds and information.

Defining cross-border functional areas presents a challenge, as cross-border commuting data are often lacking. Eurostat is working on defining the FUAs of cross-border cities, which are cities that cross a national border; but this work does not yet cover cross-border commuting zones. For example, Luxembourg City does not cross a national border, but many of the people working there live in one of the three countries neighbouring Luxembourg. In contrast, cross-border FRAs can easily be defined as they rely on potential, not actual, flows. This method can also be applied to the entire territory, meaning both urban and rural functional areas can be defined in the same way.

One last aspect to consider is that potential flows rely on the existing road network, tunnels and bridges. If a border has few crossings, some areas along the border will not be part of a cross-border functional area because the crossing points are too far from these areas to be part of a daily system.

### 1.4.4. Operationalising the functional dimension of cross-border living spaces

Currently, functional cross-border regions, or living spaces, are quantitatively measured in four ways. The most common approach stems from the nation-state perspective, where a cross-border living space is constructed according to the top-down administrative division of a country, where border regions in the EU are officially defined as administrative units that are next to a country's border at the NUTS 3 level. This is how border regions are officially recognised at the institutional level and has been operationalised through the Interreg programme.

Another, less common, approach stems from the border perspective, where cross-border living spaces are identified according to a predefined distance from a border. Currently, the most frequently used distance is 25 km from the border. More advanced measurements use a predefined travel time to a border. Here, the distance from which it is possible to reach a border in 30–90 minutes (predominantly with a private car) is used to delineate cross-border living spaces (see Section 2.2). However, having the proximity and potential ability to visit the other side of a border does not mean that people cross these borders in practice. Further, the spatial scope of a cross-border living space does not have to be equal on both sides of a border, as borders may be crossed for different reasons.

The final approach stems from the observation of the cross-border interactions and flows of people, yet it is the most challenging one to implement due to the absence of relevant data and suitable methodologies to collect such data. In some cross-border regions, it has been possible to measure the flow of cross-border commuting for work and use it in delineating cross-border living spaces. Measuring other types of cross-border interactions is even more challenging; however, the first attempts to measure such interactions (Section 3.1), based on new data sources, are discussed in Chapter 3. Certainly, the perspective (Member State or border) used to measure the flows of interactions affects how a functional cross-border living space is delineated. In many areas, within-country flows may be the most prominent ones and cross-border flows may remain second in size. However, they might be meaningful flows for the border region community, creating an additional cross-border living space that blends with and complements the nation-state system.

In essence, the optimal way to define cross-border living spaces and measure cross-border integration for both policy and research is to simultaneously consider both current functional living spaces and potential cross-border living spaces. Today some of the EU's internal borders are easy to cross, but others need more crossing points. These points will in turn create new potential and de facto cross-border living spaces. This will help us to monitor, evaluate and adjust EU policies and instruments for the development and governance of border regions in the EU.

### 1.4.5. Future outlook of the concept and its operationalisation for policy and planning

Does a one-size-fits-all approach to defining and delineating cross-border living spaces make sense? The notion of a cross-border living space remains multilayered and its definition depends on the dimension that is focused on. For policy and governance, simple definitions are sought for their easy and universal operationalisation. However, if the main aim is to support society with more effective measures and policies, then the emphasis should be more on people and their daily lives and thus the functional (Järv et al., 2026) and ideational (Decoville et al., 2018) dimensions of cross-border living spaces should be given more attention in policy and research.

To move in this direction, more research is needed in order to reimagine cross-border living spaces, compare how various definitions affect the delineation of these spaces and find optimal solutions for policymaking.

Several topics needs to be examined. Conceptually, these include how to better examine cross-border flows from a border perspective, as an additional layer to the Member State perspective, and how to delineate functional cross-border living spaces.

Methodologically, further research is needed on what data sources can provide feasible and reliable information on the various cross-border interactions people have beyond work and residential mobility and the cross-border interactions between companies and other entities.

Practically, another consideration is what the optimal solutions and workflows are to put this information into practice and to support policymaking and governance.

To tackle the abovementioned questions, we need to pay more attention to border regions and cross-border interactions through scholars adding such topics to their research agendas and decision-makers allocating resources to this research.

## 1.5. Dyads as the first step towards a global common denominator for border studies

**Emmanuel Brunet-Jailly, Maria Sigridur Finnsdottir and Helga Kristín Hallgrímsdóttir**

### 1.5.1. Why not 'borders', 'boundaries', 'frontiers', 'borderlands' or 'border regions'?

There are many debates regarding the terminologies used for borders, and there are methodological issues regarding the use of 'dyads'. In this short section we review these issues and debates to justify the adoption of the term 'dyad' in the Borders in Globalization (BIG_Dyads) Database.

Questions about what is understood by the words 'borders', 'boundaries' and 'frontiers', but also 'border regions' and 'borderlands' have been discussed by social scientists for over a century (Ancel, 1938; Anderson, 1996; Brunet-Jailly, 2005; Lapid, 2001; Minghi, 1963; Newman et al., 1998; Parker et al., 2009; Walker, 2010; Walters, 2006). Similarly, questions about the explanatory force of dyads in international relations have existed since Rudolf Rummel's 'Dimensions of Dyadic War, 1820–1952' (1967). Methodological concerns about dyadic pairing within (often) national datasets, however, were almost settled for students of borders by Paul Poast of the University of Chicago when he wrote 'Dyads are Dead, Long Live Dyads!' (2016), a study that was further strengthened by Jacob Carlson et al. in 'Dyadic Clustering in International Relations' (2024). Interestingly, these authors point to the over-exploitation and thus methodological complications related to the multiple dyadic inferences resulting from dyadic clustering; in our work we restrain our usage of dyads to non-multiway dyadic clustering, which limits the likelihood of cluster-robust standard error (Carlson et al., 2024, pp. 187; 192; 196).

For the purpose of this very short statement on research in the era of data-driven border studies – instead of elaborating on these debates extensively, and because they have been dealt with elsewhere – it will suffice to state that the Borders in Globalization Research Laboratory (BIG_Lab) team at the University of Victoria, British Columbia, Canada, in all its research work, understands

'border' to be a general term that points to an area between two countries. BIG_Lab also defines a boundary line as a legally recognised line often enshrined in an international agreement; it is often delineated on a map and demarcated across the land between a country and its (sometimes many) neighbours. A frontier (Turner, 1920) is an area/zone between two countries, but when it is a space it is then understood to be distinctly cultural, and it is likely to have emerged from conquests or the process of colonisation in a region of the world where many cultures are not necessarily delineated or demarcated by a border. Hence, BIG_Lab takes 'dyad' to be the most specific and precise manner of understanding the division, and the relationship across that division, between two countries. A country always has more than a single dyad (unless it is an enclave); a dyad exists only between two countries that are adjacent to the same part of a boundary line, therefore multiple dyads form the boundary line between country A and neighbours B, C, D (for instance). A frontier does not necessarily stop at a dyad but may straddle a dyad. The term 'border' refers to all dimensions of a bordering territory.

The fundamental reason for this level of precision in the definition of what a dyad is in relationship to a border, a boundary or a frontier is our interest in collecting data that would provide a view from the perspective of the border, analogous to James Scott's Seeing like a State (1998) or Warren Magnusson's *Politics of Urbanism: Seeing like a city* (2011). Focusing on each dyad, and in particular on each dyadic relationship of the member states of the United Nations, allows researchers and policymakers to have a view of the world from the perspective of a single standardised unit of analysis: the dyad. The dyad then also allows for measuring many varied forms of relationships across dyads.

This single standardised unit of analysis has been used by BIG_Lab researchers to measure activities on dyads, away from the dyad and on either side of a dyad. Furthermore, the dyadic division of the United Nations' member states is duly recorded in the United Nations treaty archives, where a dyad is the legally dividing line between two contiguous states that are both fully fledged members of the United Nations. Thus, in law, dyadic analysis is the basic unit of analysis between pairs of countries. The dyad is treated as the basic unit of analysis by researchers examining interactions between countries. In other words, while the term 'dyad' is perhaps unfamiliar and/or uncommon to some readers, it is broadly understood to be more precise than 'boundaries' 'frontiers', 'borders', 'border regions' or 'borderlands'.

The foundational dataset of the BIG_Dyads Database has documented all the world's dyads. Today they are at the core of the BIG_Dyads Database, which is much larger in scope than other existing datasets, such as the Boundary Dataset used by Furlong et al. (2003), the International Border Agreements Dataset researched by Owsiak et al. (2018) or the correlates of war project by Sinnett et al. (2002), in part because the project focuses on wars alone.

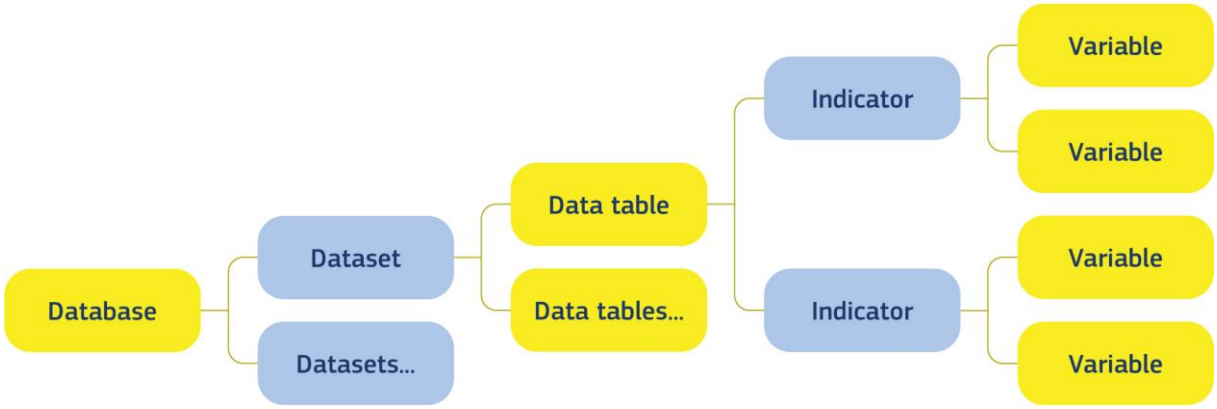
The BIG_Dyads Database is unique because it is the first database to present a diverse range of indicators – extending beyond those used for peace and conflict studies – in terms of dyads and is also the first comprehensive and multidisciplinary collection of comparative data on dyads. Indeed, the BIG_Dyads Database is a collection of several datasets covering a diverse set of indicators/variables. The choice and development of these indicators is informed by the six BIG_Lab research themes: (a) border culture, (b) sustainability across borderlands, (c) border security, (d) border history, (e) the governance of borders and (f) border flows / mobility.

Because the dyad is a shared territorial line between two current neighbouring United Nation member states, each dyad is also (in most cases) recognised by an international agreement that is registered by the United Nations and recorded in the United Nations Treaty Collection. In this UN depository, the status of all treaties is available and is often complemented by a depositary

notification with certified true copies. Also available are the titles of treaties, including those that are League of Nations treaties (established between 1921 and 1931) and multilateral treaties deposited with the Secretary-General of the United Nations between 1959 and 2009. Thus, for each≤one of the world's dyads, we have (a) a record the date of the establishment of the dyad, (b) a dyadic treaty, (c) the date of any dyadic disputes and (d) the date of all dyadic disputes' settlement. These are contained in the dyad characteristics dataset within the BIG_Dyads Database.

The BIG_Dyads Database is structured as a relational database, facilitating the easy and fast accessing, querying and updating of stored data. One key strength of the relational database structure is that different tables are allowed to have different organising principles, allowing for greater flexibility in dataset design and data analysis. By organising principle, we mean the combination of variables or values that represent a unique row. These unique rows are marked by primary keys (generally, by ID numbers). The primary key of one table can be used as a variable value in another table to relate the two; in this scenario, it is described as a foreign key. As a result of this structure, not only are records (rows) in the database crossed by attributes (columns), but multiple tables can also be related to one another. As of July 2025, the database contains 74 indicators and 216 variables representing data on 771 dyads; ultimately, our goal is to expand the numbers of indicators and variables on all dyads. Furthermore, the database is structured hierarchically (**Figure 4**); the database contains many datasets, and each dataset includes a set of thematically linked data tables that are organised by their primary keys and related to one another through foreign keys. These data tables, in turn, include some number of conceptual indicators. Each indicator is made up of a series of simple variables.

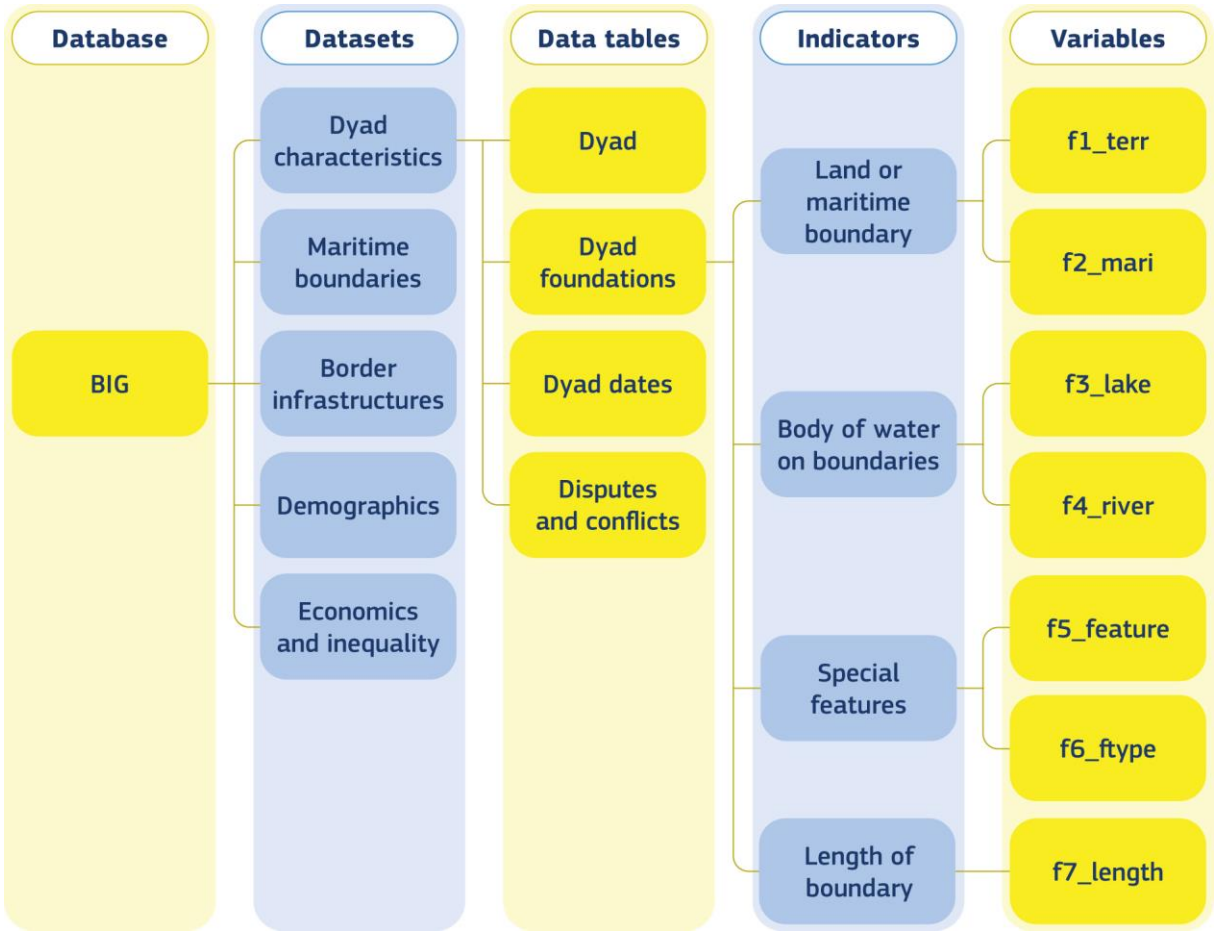
**Figure 4.** Hierarchical structure of the BIG_Dyads Database.




*Source: Authors' elaboration.*

Take the dyads foundations data table as a concrete example of this hierarchical design. The foundations data table (**Figure 5**) is one of four that make up the dyad characteristics dataset, along with the dyads data table (the list of dyads and their ID numbers), the dyad dates table and the dyad disputes and conflicts table. Within the foundations data table, there are four indicators: (a) whether it is a land or maritime dyad; (b) whether the dyad is over a body of water; (c) special features; and (d) the length of the dyad. Each of these conceptual indicators is then made up of a set of variables.

**Figure 5.** Structure of the BIG_Dyads Database and the dyad foundations data table.




*Source: Authors' elaboration.*

The dyadic approach offers great potential for mapping cross-border flows and treating EU border regions as dynamic 'living spaces', but further research is required. The BIG_Dyads Database already provides a standardised, dyad-level, multidisciplinary resource for the systematic analysis of cross-border interactions. Its relational–hierarchical architecture covers every UN member state dyad, drawing on UN treaty archives, national statistics and specialised research datasets, and it offers flexible, low-cost comparability worldwide. Consequently, scholars and policymakers can rely on a robust, scalable evidence base for designing policies on cooperation, security, trade and environmental management. A promising example of EU-wide synergy is the data hub for EU border regions, which adopts the dyad as its reporting unit and visualises geolocated cross-border interactions on an interactive web map; however, additional synergies and methodological integration remain necessary.

# 2. Conventional data

## 2.1. The unexplored treasure of data on employment-related movements across borders – an overview of data availability in the Member States

**Johan van der Valk, Roland Gaugitsch and Claire Duvernet**

### 2.1.1. Potential of administrative data

Administrative data can be a highly valuable source of information on cross-border flows. For administrative purposes, it is relevant whether a person (employee) or an enterprise that is active in their country is a resident or non-resident, as economic activities often come with financial or legal obligations or eligibility for social benefits. These rules or procedures differ if the actor is a host or a native. As a result, administrative records usually include information about country of residence and/or citizenship.

A breakdown by country of residence produces insights on cross-border activities. Regarding people, clear examples of themes where administrative data provide such information are demography, work, education and healthcare. With these data, one can produce indicators like migration, cross-border work, cross-border studying or cross-border healthcare consumption. Regarding businesses, potential data sources are data regarding value added tax and enterprise records, which can provide information on the delivery of cross-border services or goods or enterprises that have local units across borders.

The key advantages of administrative data compared, for example, with survey data are the comparatively low production cost and the high regional granularity and measurement of small populations. In addition, data production is relatively straightforward, building only on existing data. Administrative data are thus a source with high reward for low costs and effort.

Administrative data, however, pose two main challenges. They are collected by government agencies or other entities for administrative purposes and not for statistical ones. As a consequence, national statistical institutes (NSIs) generally do not own the data. This creates organisational challenges, as in most cases NSIs have to involve outside entities in data production. Furthermore, in some cases data from several sources and different owners have to be combined in order to produce the required information. This could raise issues from an organisational or legal perspective. The second challenge is providing international comparable data. Administrative data are fully defined by national circumstances and are subject to changes based on national legislation or procedures. This could affect their consistency over time and across countries.

To what extent the challenges are serious differs by subject or field of study, with each subject or field requiring a different data source related to specific administrative procedures. For some it is more problematic than for others. This means that for every topic one must investigate what is possible from a practical point of view. Secondly, the seriousness of the challenges differs by country. In some countries, NSIs have, by law, access to all governmental administration data. In addition, some countries are organised as federal states, where certain administrative

responsibilities are given to a level lower than the federal level. This could make it more complicated to achieve full coverage.

Despite of these challenges, we deem administrative data to be the most promising source from which to gather pan-European information on cross-border flows in the near future. As the data are there in principle, the main objective is to make them available. Three elements are essential for the process to be successful:

- strong international coordination is required;
- a pragmatic and practical approach is needed, which accepts limited flaws in the data collected;
- it is essential that NSIs collaborate to learn from each other to develop effective methods in the presence of limited resources.

## 2.2. Public transport data for cross-border accessibility analysis

**Claire Duvernet and Philipp Gareis**

### 2.2.1. General transit feed specification data for cross-border accessibility analysis

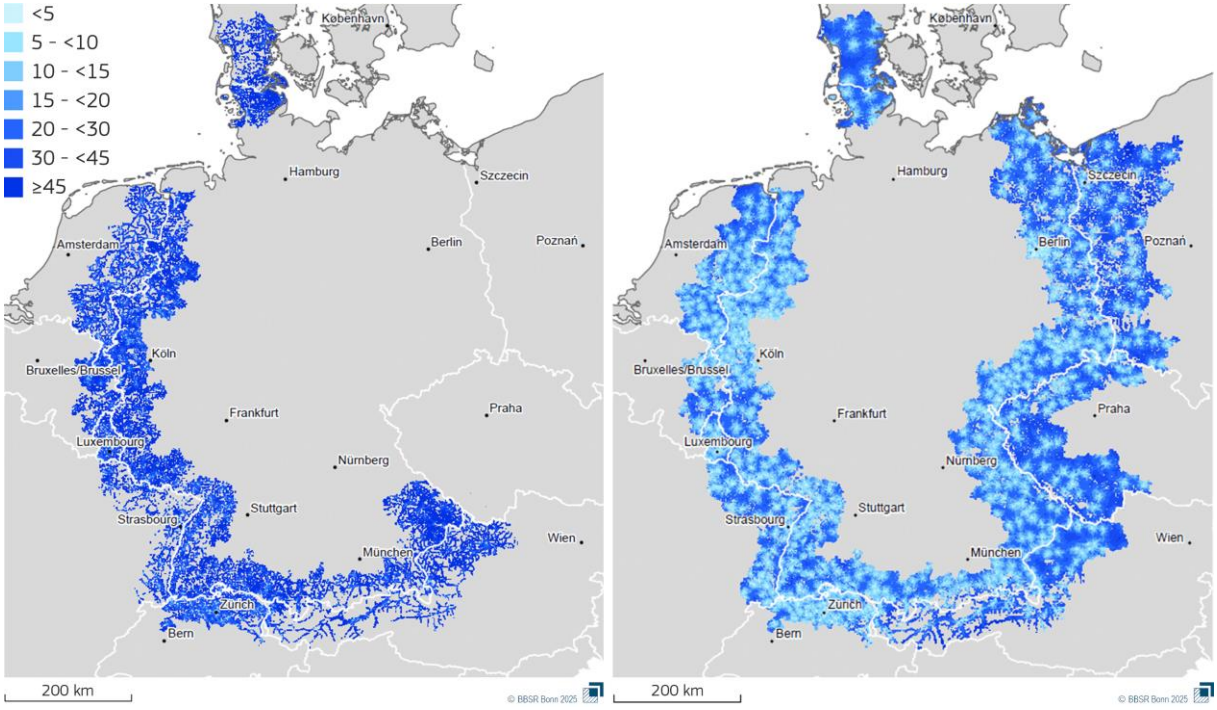
Public authorities or planners willing to analyse territorial dynamics in a cross-border functional area face several challenges: one the one hand, data on cross-border flows from national or regional statistical offices are limited and not directly comparable from one country to another; on the other hand, using data from commercial providers requires substantial financial resources. In this context, general transit feed specification (GTFS) data, when available on both sides of a border, are a powerful tool for analysing accessibility and mobility across national boundaries.

The GTFS 'is a standardized data format that provides a structure for public transit agencies to describe the details of their services such as schedules, stops, fares, etc.' (GTFS, 2025). It started in 2005 with a partnership between the Tri-County Metropolitan Transportation District of Oregon and Google. The goal was to develop a format for public transport data that would allow them to be imported into Google Maps. The partnership quickly extended to other transport agencies, and the data were made public, so that other developers could use them (McHugh, 2013). Now, according to MobilityData, the non-profit organisation behind the GTFS, the format is used by over 10 000 public agencies over 100 countries, making it the largest source of public transport data.

The development of GTFS datasets over the past 20 years represents a major innovation for transport studies and spatial analysis (Antrim et al., 2013; Park et al., 2021). GTFS data support the construction of time-based accessibility maps and origin–destination matrices. Associated with road networks and geoinformation about points of interest, they can be used to build multimodal accessibility models that simulate how easily residents can reach key destinations – such as jobs, schools, hospitals or administrative centres – using public transport (Verduzco Torres et al., 2024). These models can incorporate transfers, walking times and service frequency. While most studies are based on schedules, the GTFS also provides real-time information, making it possible to take into account travel time uncertainty in accessibility analysis (Javanmard et al., 2025).

When it comes to border regions, the potential of GTFS data remains largely untapped. Border regions have unique transport characteristics. They often suffer from fragmented transit services, lack of coordination between different national or regional transit authorities and asymmetric infrastructure investment (European Commission, 2022b). EU regional policy promotes territorial cohesion (Article 174 of the Treaty on the Functioning of the European Union) and is aimed at 'ensuring equal opportunities wherever people live through access to jobs, services, transport and connectivity' (European Commission, 2025). As the only source of transport data from official service providers, comparable across several countries, and with an open-standard format, GTFS data provide essential information to support this goal. By calculating accessibility indicators (e.g. hospitals reachable across the border by car or public transport within a certain time) (see **Section 4.4**), analysts can compare how accessible services are to residents on either side of a border (**Figure 6**) and identify areas where residents are closer to infrastructures across a border (**Figure 7**). It is also possible to assess the catchment area of an infrastructure, including population across the border, or to compare travel time by public transport and by car, highlighting potential investment needs.

**Figure 6.** Accessibility of hospitals by public transport (A) and by car (B) in minutes.



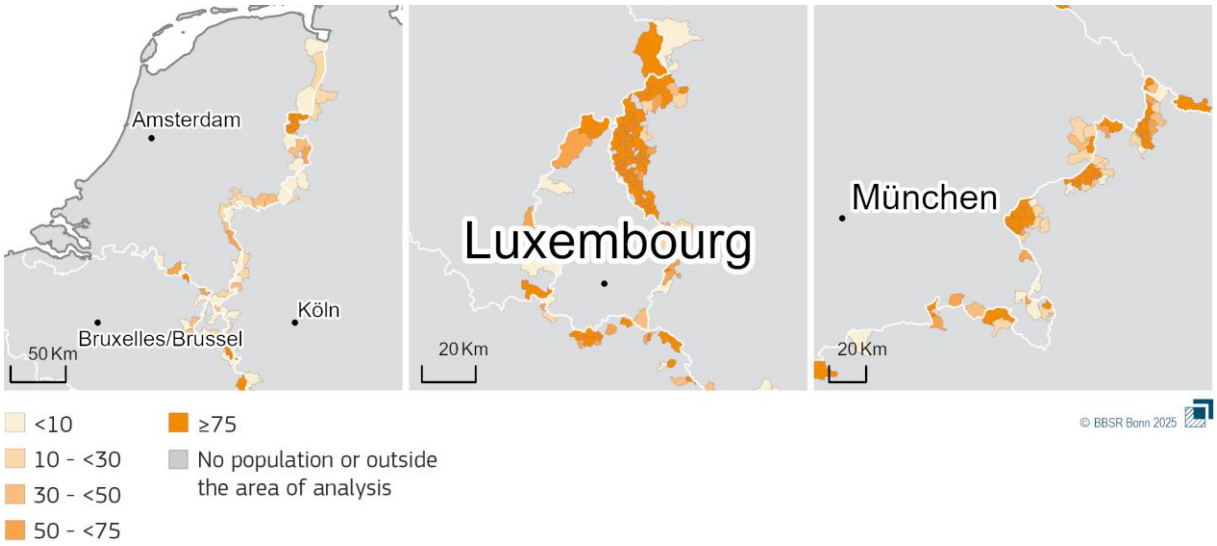

*Sources: Authors' elaboration, based on data from Geofabrik (https://www.geofabrik.de), GTFS for Germany (https://gtfs.de), data.public.lu (https://data.public.lu/fr/), GTFS Belgium (https://gtfs.be/index_en.html), the French Ministry of Transport (https://transport.data.gouv.fr), opentransportdata.swiss (https://data.opentransportdata.swiss), Rejseplanen Labs (https://labs.rejseplanen.dk/hc/en-us) and Mobilitätsverbünde Österreich (https://data.mobilitaetsverbuende.at/en/data-sets) and OVapi GTFS (https://gtfs.ovapi.nl) (all data from 17 March 2025). Geometrical basis: 2024 data from GfK Geomarketing and the geographic information system of the Commission (GISCO) (Eurostat).*

While the widespread use of GTFS data opens up undeniable opportunities for territorial analysis in a cross-border context, there is still room for improvement. Just like any other open-standard format, the quality of the data varies according to the way they are maintained and published by each service provider. Transport agencies have to make sure that the feeds are up to date and consistent with information on schedules and routes published elsewhere. Furthermore, GTFS data

are not built exactly the same way: not all countries and regions provide the exact same information, meaning a lot of harmonisation is required in order to combine the data. Some provide one file with all transport-related information; in other countries, each provider has its own data feed.

In border regions, the fragmentation of transport systems and the reintroduction of border controls in some parts of the Schengen area may have a strong impact on real-time operations and thus differences when compared with official schedule data. In this context, GTFS schedule data may require some adjustment in order to measure socio-spatial inequalities in accessibility accurately (Braga et al., 2023). And even though the format is conceived to be accessible to a wide audience, one should not underestimate the technical and computational resources necessary to process the data.

**Figure 7.** Cross-border accessibility of hospitals.




*Sources: Authors' elaboration, based on data from Geofabrik (https://www.geofabrik.de), GTFS for Germany (https://gtfs.de), data.public.lu (https://data.public.lu/fr/), GTFS Belgium (https://gtfs.be/index_en.html), the French Ministry of Transport (https://transport.data.gouv.fr), opentransportdata.swiss (https://data.opentransportdata.swiss), Rejseplanen Labs (https://labs.rejseplanen.dk/hc/en-us), Mobilitätsverbünde Österreich (https://data.mobilitaetsverbuende.at/en/data-sets) and OVapi GTFS (https://gtfs.ovapi.nl) (all data from 17 March 2025). Geometrical basis: 2024 data from GfK Geomarketing and GISCO (Eurostat).*

In an iterative approach, creating accessibility maps for border regions is possible with the r5r tool (Pereira et al., 2021). While calculating accessibility at the level of large administrative boundaries is not recommended, because of the modifiable area unit problem (Jasso Chávez et al., 2025), grid-based accessibility measurement can lead to accurate estimates. However, analysis at the grid level comes with other difficulties, such as high computational resource demand, overlapping of grids with administrative boundaries during upscaling and difficulties snapping from certain grids to the nearest streets or walking, cycling or public transport facilities. However, when GTFS and points of interest data are available, accessibility matrices are calculable using r5r for various transport modes and modal splits, including walking, cycling, public transport and car travel times. Now it is time to shed light on the neglected topic of accessibility of points of interest in border regions by public transport to discuss topics like accessibility injustice, which became explicitly visible during the COVID-19 pandemic (Karacan, 2025). The European Accessibility Act, a directive from 2019, contains a call to facilitate cross-border mobility (Directive (EU) 2019/882). Now it is possible to monitor the state of accessibility in cross-border areas and progress in the upcoming years, using available GTFS data.

Nevertheless, it is necessary to develop a common framework for analysing accessibility in the future. Policymakers, statistics providers, regional and transport planners, and research institutions in border areas could benefit from partnerships focused on developing key indicators and methodologies tailored to cross-border functional areas. Having common indicators on accessibility available on a regular basis and taking into account cross-border flows can significantly improve cross-border monitoring and support evidence-based policymaking.

### 2.2.2. Key takeaways and next steps

- The GTFS offers an open, standardised data source that can underpin EU-wide analyses of public transport accessibility across borders.
- Its practical use is often limited by inconsistent data quality, varying levels of detail and the substantial effort required for harmonisation and processing.
- Full exploitation of its potential depends on adopting common metadata standards, sharing tools such as r5r and establishing a jointly funded repository to keep cross-border data feeds up to date.

## 2.3. Cross-border movements – the case of France and its hidden issues

**Jean Rubio**

France is located in a unique position in Europe, bordered by eight countries and encompassing a wide variety of cross-border dynamics. Each day, thousands of people cross into or out of French territory – commuting to work, access services, visit relatives or engage in economic and cultural exchanges. While the benefits of this mobility are widely acknowledged (ranging from economic dynamism to EU integration), less attention is paid to the complex, often hidden challenges that underpin these flows.

This section explores the case of cross-border movements in France, with a focus on the structural and institutional issues that make border areas both vital and vulnerable. Drawing on recent work by Mission Opérationnelle Transfrontalière (MOT), we unpack the specificities of border territories, obstacles to proper observation and emerging challenges to governance and data collection.

### 2.3.1. France's border regions – strategic yet marginal spaces

French border territories are paradoxical spaces. On the one hand, they serve as gateways to Europe, acting as daily corridors for labour, trade and interaction. On the other hand, they are often located on the fringes of national systems, suffering from relative neglect in national policy frameworks.

Several factors contribute to the distinctiveness of these areas, namely:

- regulatory differentials between France and its neighbours (e.g. with regard to labour, taxation and healthcare access);
- socio-demographic contrasts, such as population ageing or urban–rural imbalances;
- spatial asymmetries, with dense urban centres on one side of the border and rural or peri-urban zones on the other;
- shared but differently managed natural resources, such as cross-border rivers or mountain ecosystems.

This complexity means that border areas cannot be understood using standard territorial categories. They are fundamentally hybrid zones, shaped by dual influences and multiple layers of governance.

### 2.3.2. The realities of cross-border mobility

Cross-border mobility in France is quantitatively significant (Table 1). According to recent data compiled by the MOT:

- in 2024, more than 500 000 cross-border workers were estimated to commute daily between France and neighbouring countries;
- the largest flows are with Switzerland (over 230 000 workers) and Luxembourg (over 120 000);
- other important destinations include Belgium, Germany and Monaco;
- flows to Italy and Spain are not specified – their number is an estimate of flows of workers to other countries.

**Table 1.** Differences in data by source and type of source.

| Destination | 2021 (INSEE) | 2023 and later (other if available) | Source | Type |
|---|---|---|---|---|
| Belgium | 46 369 | 39 252 | INAMI | Administrative |
| Luxembourg | 104 723 | 122 768 | STATEC | Statistical |
| Germany | 50 125 | See 2021 | | Statistical |
| Monaco | 33 467 | 48 977 | | Statistical |
| Switzerland | 223 966 | 234 619 | OFS | Administrative |
| Other (Italy, Spain) | 20 053 | See 2021 | | Statistical |
| Total | 478 703 | 515 794 | | |

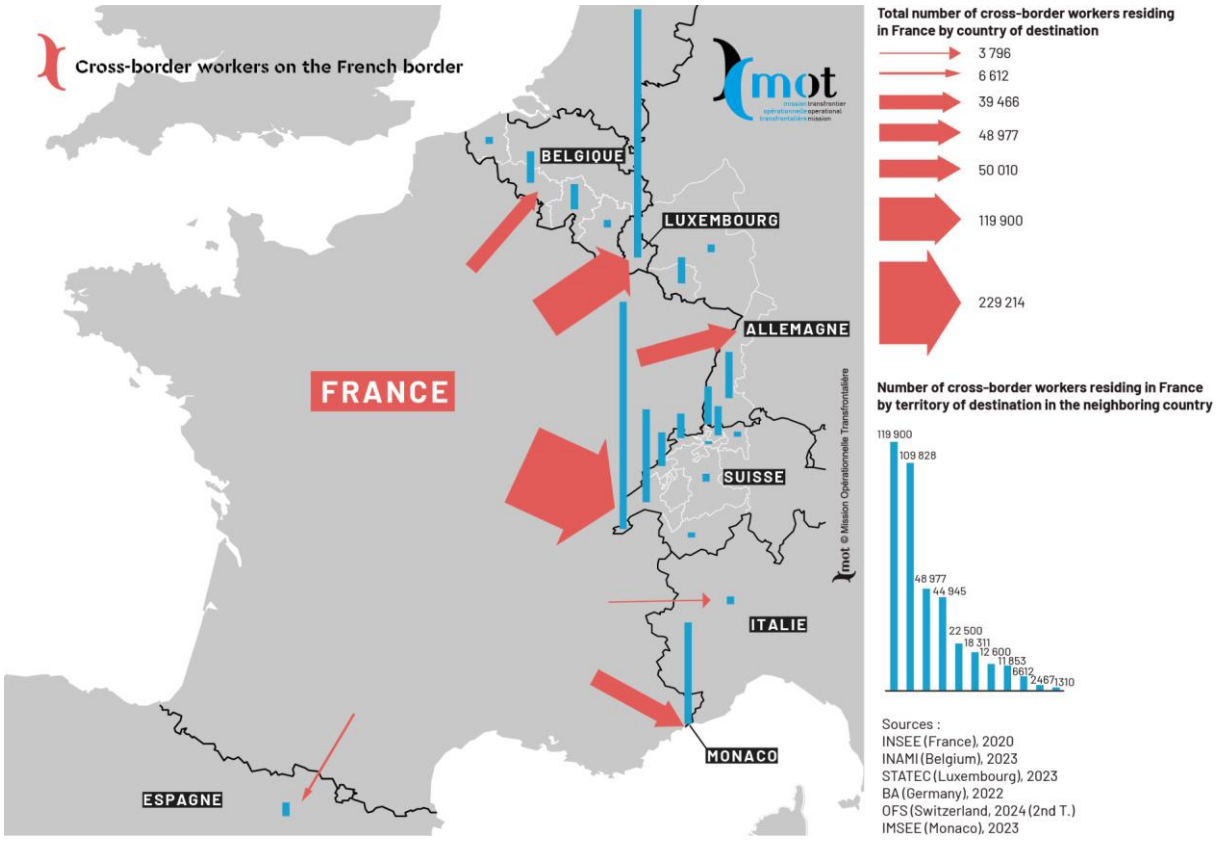
*NB:* INAMI – National Institute for Health and Disability Insurance (Institut national d'assurance maladie invalidité); OFS – Federal Statistical Office (Switzerland); STATEC – National Institute of Statistics and Economic Studies of Luxembourg.
*Source: Author' elaboration.*

However, the sheer scale of mobility often hides more nuanced realities.

- These movements are highly concentrated. Most workers live in border-adjacent departments, with commuting corridors becoming spatially extended over time.
- There are socio-professional stratifications. Higher-income workers tend to be over-represented among cross-border commuters, while less qualified workers face greater obstacles.
- The daily traffic generates strong pressures on infrastructure (roads, public transport) and public services (childcare, healthcare, housing) in French border communities.

The benefits of mobility – access to higher wages, diversified job markets and better purchasing power – are undeniable. But they are not evenly distributed and often mask growing local tensions (**Figure 8**).

**Figure 8.** Cross-border workers on the French border.




*Source: MOT, 2024.*

## 2.3.3. Main obstacles to cross-border observation

Cross-border observation faces persistent and multifaceted obstacles that hinder the development of coherent territorial analyses. One of the core challenges is that statistical data collection and dissemination remain under national responsibility, leading to a lack of access to comparable data on both sides of borders. Administrative units used for observation often lack symmetry, making territorial comparisons difficult. At the local level, data availability is especially poor (particularly at the LAU 1 and LAU 2 levels), while census periods are not aligned across countries, further

complicating temporal analyses. Differences in the definition of indicators reduce the relevance and accuracy of cross-border comparisons. For some borders, no centralised platform exists providing basic territorial data, and access to geospatial information remains limited or fragmented. Moreover, local actors frequently lack the technical capacity to carry out observation tasks, limiting the quality of ground-level insights. These issues are exacerbated by weak cooperation between data providers and users, both within and across countries. Without stronger collaboration – as recommended in a recent ESPON policy brief (ESPON, 2021) – efforts to harmonise or converge datasets will remain stalled. Strengthening communication and intensifying exchanges between local, regional and national actors is essential to build a robust and usable cross-border observation framework.

### 2.3.4. Multi-level responses and the emerging architecture of observation

To address these challenges, a multi-level observation framework is gradually taking shape in France and across the EU. Several initiatives illustrate this trend.

- Local observatories. Many have been created under Interreg programmes and are now institutionalised (e.g. GeoRhena ([4]), the Geographic Information System of the Greater Region ([5]), Observatoire Statistique Transfrontalier de l'Arc Jurassien ([6])). New ones are emerging, such as Observ'Alp ([7] ) on the Alpine border and observatories on the French–Spanish and French–Belgian borders.
- National coordination. The MOT–Agence nationale de la cohésion des territoires working group brings together institutional actors (MOT, Agence nationale de la cohésion des territoires / Observatoires des Territoires, INSEE), regional planning agencies and border stakeholders. It monitors progress, coordinates surveys and promotes the creation of harmonised indicators.
- European networks. France participates in platforms such as the European Cross-Border Monitoring Network ([8]) (led by the Federal Institute for Research on Building, Urban Affairs and Spatial Development), the ESPON governance mechanisms for cross-border functional areas (ESPON, 2026) and the European Commission Data Hub for EU border regions ([9]).

These structures aim to bridge the gaps between levels of governance and to promote the use of shared data platforms, including open data and cross-border GISs.

([4]) www.georhena.eu
([5]) www.sig-gr.eu
([6]) www.arcjurassien.org/ostaj
([7]) www.observalp.eu
([8]) www.bbsr.bund.de/BBSR/EN/research/specialist-articles/spatial-development/network-crossborderdata/main.html;jsessionid=DC558754E92C86506291391200FFF222.live21304
([9]) https://territorial.ec.europa.eu/across

### 2.3.5. The broader picture – beyond commuting

While commuting flows dominate cross-border mobility debates, the real picture is broader. Other hidden forms of cross-border interaction include:

- cross-border consumption – shopping across borders due to differences in the price of fuel, alcohol, healthcare, etc.;
- access to public services such as schooling, hospitals or cultural facilities;
- second-home ownership and tourism, which alter demographic dynamics and service provision;
- informal mobility and 'grey zones' (i.e. undeclared work), especially along the Franco-Italian border or Pyrenean corridors.

These dimensions are rarely captured in official data but are crucial for understanding territorial cohesion and planning needs.

### 2.3.6. Towards more resilient and equitable cross-border governance of monitoring

What emerges from the French case is a need for a deep rethinking of cross-border governance, grounded in evidence and collaboration.

To that end, several priorities stand out, namely:

- investing in permanent observation systems, not only project based but institutionalised within public agencies and intergovernmental partnerships;
- promoting interoperability of statistical systems through coordinated surveys, harmonised indicators and shared methodologies;
- building territorial intelligence at the local level, ensuring that municipalities and intermunicipalities have access to data, tools and training;
- making cross-border mobility inclusive by addressing the social divides that it reinforces, ensuring that access to mobility is not determined by wealth, proximity or digital access;
- integrating observation into policymaking – data collection must be linked to planning, transport strategies, housing policy and environmental resilience, especially in light of climate risks and border closures.

### 2.3.7. Key takeaways and next steps

- Cross-border movements in France reveal a complex and often invisible world of interdependence, inequality and institutional fragmentation. While the image of European citizens seamlessly crossing borders is appealing, the reality is more fragmented. Gaps in data, mismatches in governance and asymmetries in opportunity all point to a system that still needs substantial reworking.
- Thanks to initiatives like those led by the MOT and its partners, a new architecture of cross-border observation is emerging – one that recognises the specificities of border territories and strives to make them visible, measurable and governable.

— For France, embracing this challenge is a matter not only of territorial equity but also of European responsibility.

## 2.4. Not numbers, but motivations – the power of surveys in research on cross-border commuting

**Viktória Jánosi**

Understanding the socioeconomic and spatial dynamics of any region fundamentally relies on accurate data (Musikhin et al., 2023) and information. This principle applies to border regions as well, but a distinguishing factor is the significant influence of cross-border movements. While these cross-border dynamics extend their impact beyond the immediate vicinity of the border, their role is important for the borderlands themselves (Sohn, 2014). Here, citizens regularly engage in daily activities that involve crossing open borders, transforming these lines from administrative divisions to one shared space of daily life. However, a significant challenge currently facing the EU is the persistent lack of readily available and accurate data concerning these cross-border movements (Chilla et al., 2019). This data deficit inherently complicates the tasks of policymakers, preventing them from making adequately informed and evidence-based decisions essential for effective regional development and cooperation.

### 2.4.1. The distinctive power of survey methodology

Survey-based data collection offers numerous advantages, particularly in identifying unique patterns (Smyth, 2018) that are difficult or impossible to uncover through other data collection methods.

One of the most critical issues, which is invisible in statistics but can be answered through survey data, is the motivation behind cross-border movements, specifically the reasons why individuals choose to cross borders (Delloye et al., 2024). This aspect is of paramount importance to policymakers and development initiatives, as the underlying purpose of cross-border activity significantly influences regional dynamics. It makes a substantial difference whether individuals commute for study, work, shopping or leisure activities on the other side of the border, as each motivation necessitates distinct policy responses and development strategies.

Another advantage of this methodology lies in its capacity to precisely determine individuals' movement patterns. Their exact origin and destination already indicates the extent of the journey, but surveys can further enquire about the precise route taken and the specific border crossing point used and the reasons for these choices. This level of detail enables the identification of more accurate commuter patterns and catchment areas within border regions.

Furthermore, surveys enable inquiry at the individual level into the frequency of cross-border travel, as Salamońska et al. (2013) found in a European Union at the Crossroads of Global Order (EUCROSS) working paper, allowing for the refinement and appropriate weighting of observed patterns. A common weakness of many other data collection methodologies is their inability to link individual trips directly to specific individuals, thereby limiting the nuance of the patterns identified. In contrast, data gathered from surveys provide precise and concrete answers in this respect.

One of the greatest advantages of surveying is its adaptability to include any kind of question, especially if the given research project uses an adaptive survey design (Schouten et al., 2017). Any specific enquiry we may have concerning cross-border movement can be directly addressed within the questionnaire. The questions asked can be modified shortly before implementation. For instance, we can enquire about difficulties encountered during commuting, to gather highly valuable supplementary information when researching obstacles present at borders.

Considering all these aspects, surveying offers numerous advantages that are either unattainable or significantly more challenging to extract from data analysed using other collection methods. The result is a detailed and, most importantly, adaptable database, a feature that truly distinguishes this methodology from others.

### 2.4.2. Challenges and limitations of survey methodology

While survey-based data collection offers numerous advantages, it also entails several inherent disadvantages and complexities that must be considered during its application. These aspects require thorough consideration to ensure the robust application and accurate interpretation of survey findings, particularly in complex domains such as cross-border research.

The most significant difficulties associated with survey methodology are 'establishing clear definitions and boundaries for… the target population' (Willie, 2024, p. 75) and subsequently reaching them with questionnaires. Although various options are available today, ranging from online platforms to in-person approaches, it remains challenging to achieve full coverage of the relevant audience.

A further challenge arises in the actual distribution of the questionnaires. In special cases, for example when monitoring cross-border movements, on-site data collection becomes unavoidable. However, this method is highly resource intensive, as it requires a physical human presence on-site, and the distribution and completion of questionnaires.

A subsequent, non-negligible factor is that a significant proportion of people are reluctant to complete questionnaires (Patten, 2014). Various reasons contribute to this, such as individuals begrudging the time it takes or fearing that their personal data will not be kept private. This reluctance substantially reduces the quantity of incoming data, thereby affecting the overall sample size.

Furthermore, it must not be overlooked that data processing itself is time-consuming, with the time taken depending highly on the number of open-ended questions (Brookover et al., 1992). While these can yield valuable qualitative data, they can also significantly increase the time required to process questionnaires.

In summary, the primary disadvantage of surveying lies in the significant difficulty of collecting an adequately sized and representative sample. Typically, only a fraction of the relevant target population can be reached, and, even then, the resulting sample often lacks adequate representativeness.

### 2.4.3. Case study – survey insights from the promotion of legal accessibility in the Slovak–Hungarian border project

The strategic project promotion of legal accessibility across the Slovak–Hungarian border (#ACCESS) was initiated on 1 May 2023 and will run until 30 April 2029. The two implementing partners, the Budapest-based Central European Service for Cross-border Initiatives (CESCI) and the Košice-based CESCI Carpathia, aim to identify and remove as many legal and administrative obstacles as possible that hinder cross-border movements and affect the lives of border residents.

In order for the #ACCESS project to achieve its goal of promoting Hungarian–Slovak cross-border cooperation, the legal and administrative problems that people living in the border area experience in their cross-border activities need to be identified. A survey was a particularly important part of this exploratory data collection work.

In order to obtain as much information as possible, the survey was conducted covering five topics relevant to the Slovak–Hungarian border region, covering cross-border shopping, employment and learning, permanent settlement on the other side of the border and the implementation of cross-border projects.

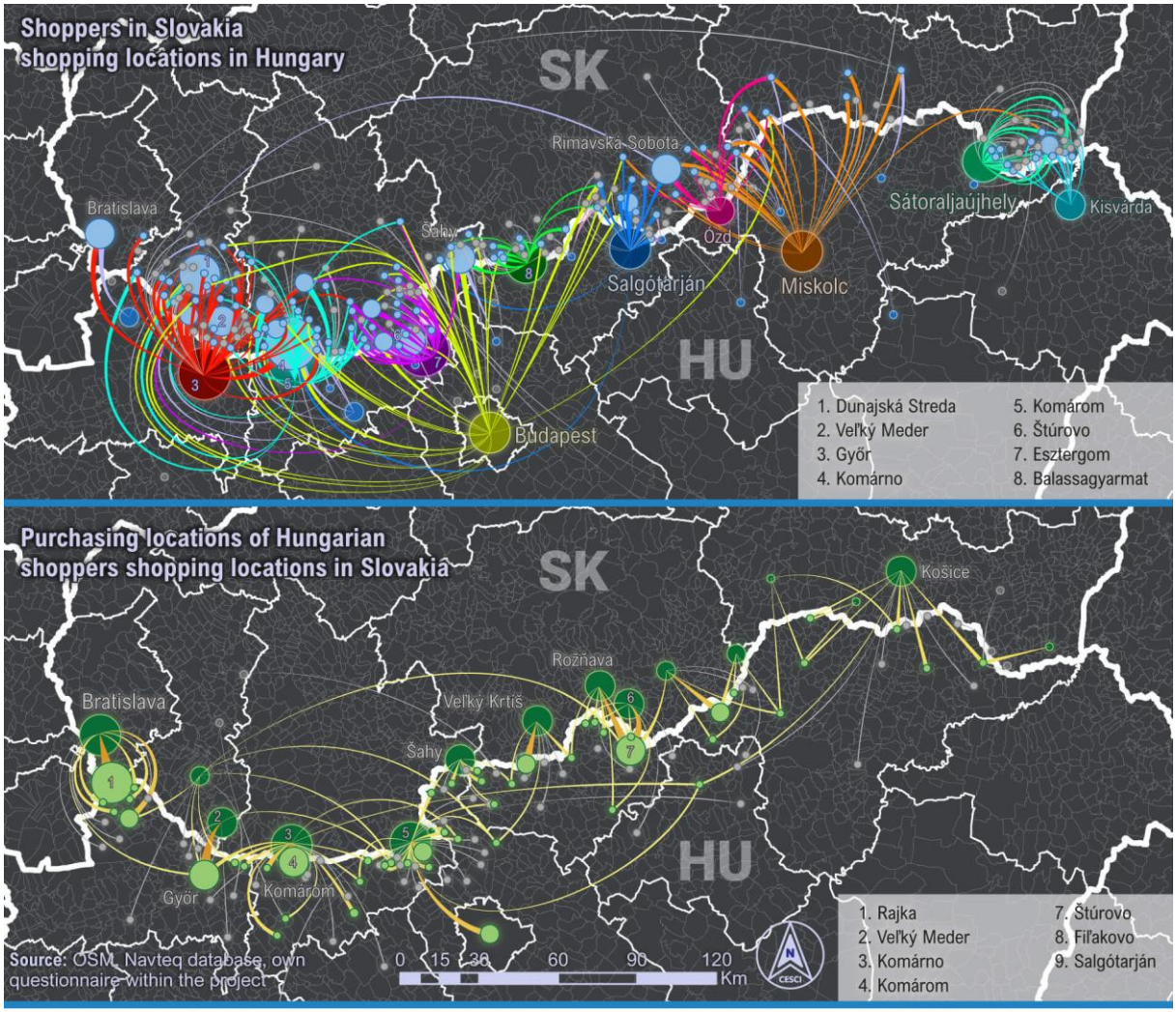
The survey was conducted from November 2023 to January 2024. The territorial focus of the collection of experiences was the Slovak–Hungarian border area (defined as a 30 km zone on both sides). To ensure successful information collection, the questionnaires were mainly available online, but were also promoted in several ways: through paper leaflets distributed in relevant locations in the affected municipalities, an online campaign, direct emails and social media platforms, and a two-round prize draw among those who filled out the questionnaires, to incentivise participation.

### 2.4.4. Results for cross-border shopping mobility

The questionnaire focused on the shopping habits of residents living near the Slovak–Hungarian border, offering insights into the cross-border dynamics of consumer behaviour. A total of 833 people completed the questionnaire. Some 17 responses were excluded because the respondents did not participate in cross-border shopping.

The spatial pattern of cross-border purchases, and several characteristic centres, networks and directions, can be identified from the responses received (Figure 9). On the Hungarian side, Győr, Komárom and Esztergom are absolutely outstanding as cross-border shopping destinations (each mentioned between 110 and 150 times). Respondents residing in Hungary named nearly 25 different shopping destinations in Slovakia, of which three had between 40 and 50 mentions: Štúrovo, Komárno and Bratislava.

**Figure 9.** Spatial pattern of cross-border shopping.



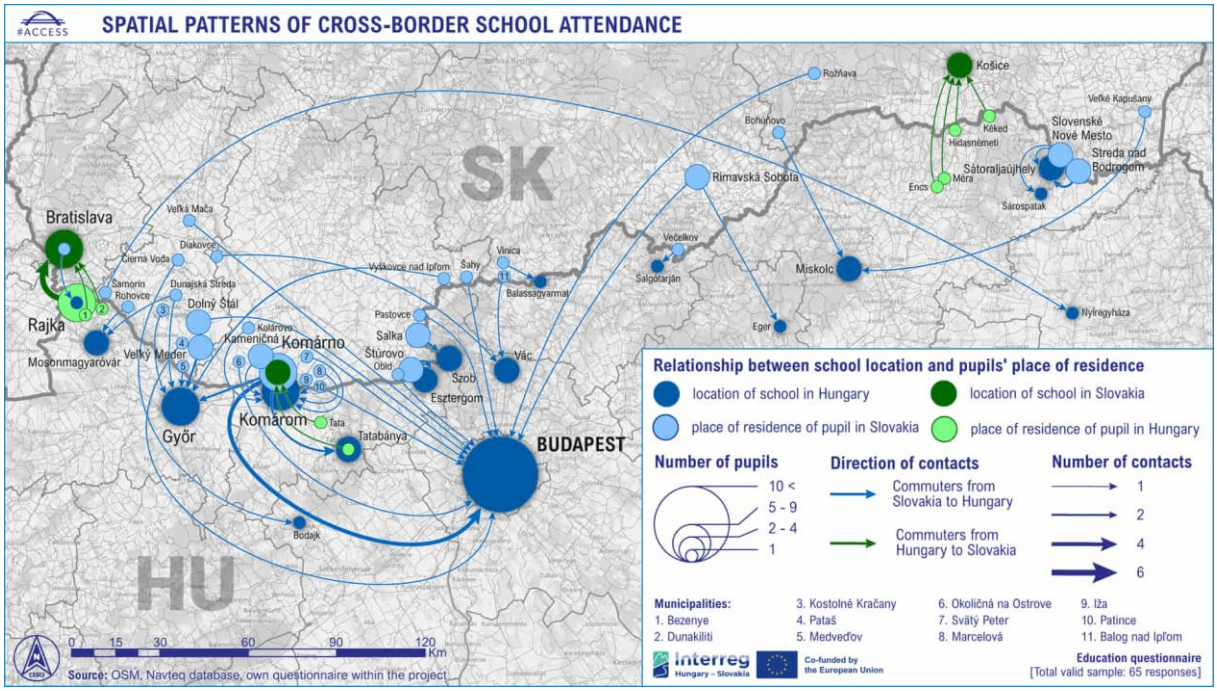

*Source: CESCI et al., 2024.*

## 2.4.5. Results for cross-border student mobility

The target groups of the questionnaire were students living in Slovakia and studying in Hungary and students living in Hungary and studying in Slovakia. A total of 65 respondents filled in the questionnaire.

In terms of student mobility, the most important commuting activity in the border region is from Slovakia to Hungary (Figure 10). Travel in the other direction is less common and is spatially concentrated: the cross-border metropolitan areas of Bratislava account for 57 % of all student residents in Hungary who study in Slovakia. Another area with a high level of cross-border mobility of students is the Hungarian catchment area of Košice. Budapest (31 %), Győr (16 %), Komárom (10 %) and Sátoraljaújhely (6 %) are the cities where Slovak residents most often choose to continue their studies in Hungary.

**Figure 10.** Spatial pattern of cross-border school attendance.




*Source: CESCI et al., 2024.*

### 2.4.6. Key takeaways and next steps

- A comprehensive understanding of cross-border commuting, a pivotal aspect of the evolving landscape of EU internal border regions, requires an innovative approach to data collection. Surveys are uniquely suited to capturing individual motivations, precise movement patterns and the nuanced daily experiences of commuters – information that is indispensable for effective policy formulation.
- Despite the inherent challenges of surveys, such as difficulties in achieving full sample representativeness and resource-intensive implementation, their advantages remain profound. They yield detailed, adaptable databases capable of providing granular insights unattainable through other methods, like motivations for cross-border movements. This allows policymakers to move beyond reactive measures, enabling the development of more targeted, human-centric interventions.
- It is important to acknowledge that numerous methodologies exist for measuring cross-border movements, yet none currently provide a perfect, all-encompassing database. Therefore, the most effective solution at present is combining multiple, innovative methods, for example the analysis of cellular data (Silm et al., 2021), or even metro card usage data (Liu et al., 2021). This approach enables the strategic utilisation of the strengths of various methods while simultaneously mitigating their individual disadvantages using complementary insights provided by others.

# 3. Non-traditional data sources

## 3.1. First findings captured to measure cross-border flows and map border regions based on digital traces

**Olle Järv**

### 3.1.1. Conventional data – what is missing?

To quantify a functional cross-border region we need information about the interactions of people across the border, including cross-border practices with regard to work, education, shopping, public services, leisure and meeting friends and relatives. Inherently, these social interactions are linked to physical activity in a location and therefore spatial mobility, which reveal the complex connectedness of areas between both sides of a border and the functioning of a cross-border society. From a spatial perspective, these are aspects of a functional cross-border region, also referred to as a cross-border living space.

In the EU, information about cross-border interactions is very limited. We do have some knowledge about cross-border working. Surveys revealing detailed commuting information do exist, but are only available for some countries, like Luxembourg and Switzerland (Drevon et al., 2018), and some advances have been made to combine country-level surveys (Sallard et al., 2024). Interactions at the EU level have been captured repetitively over a long time by labour force surveys, but beyond overall flows they do not enable the assessment of functional cross-border regions due to spatially inaccurate data. Other types of interactions are even less understood, and associated data cover either certain interactions, like shopping, or certain border regions (see **Sections 2.3** and **2.4**). There exists a valuable border-region-specific Eurobarometer survey (Flash Eurobarometer 422) on cross-border mobility and the motives behind it. However, the survey design predefines the border regions, which do not necessarily represent the fully functional border regions. Hence, it may not capture the full picture of flows and their motives.

Overall, existing information based on conventional data is certainly relevant to understanding cross-border interactions; however, it lacks three crucial aspects. First, data collection relies on official predefined border regions and potentially omits the actual functional border regions. Second, almost all existing data are collected from one point in time, thus omitting the temporal perspective of cross-border interactions – weekly and seasonal rhythms, and yearly trends. Third, data may be detailed in certain study areas, but EU-level information on functional cross-border regions is still scarce.

Therefore, we should look beyond traditional data sources to reveal cross-border interactions. One promising avenue is to use mobile big data to produce digital traces of people, as many sources, like social media and mobile application data, are inherently transnational – data collection and/or processing is not confined to countries, and can uncover cross-border traces (see **Section 3.2**).

### 3.1.2. Mobile big data – how can they reveal cross-border interactions?

To use mobile big data to study cross-border interactions and border regions, we have to make three underlying assumptions (Järv et al., 2023). Initially, digital traces from mobile big data can be linked to unique mobile devices, in most cases our smartphones, and reveal both physical mobility and social networks. The first underlying assumption is that smartphones contain highly sensitive personal information. For this reason, individual mobile devices are not shared between people and can therefore be considered proxies for anonymous individuals.

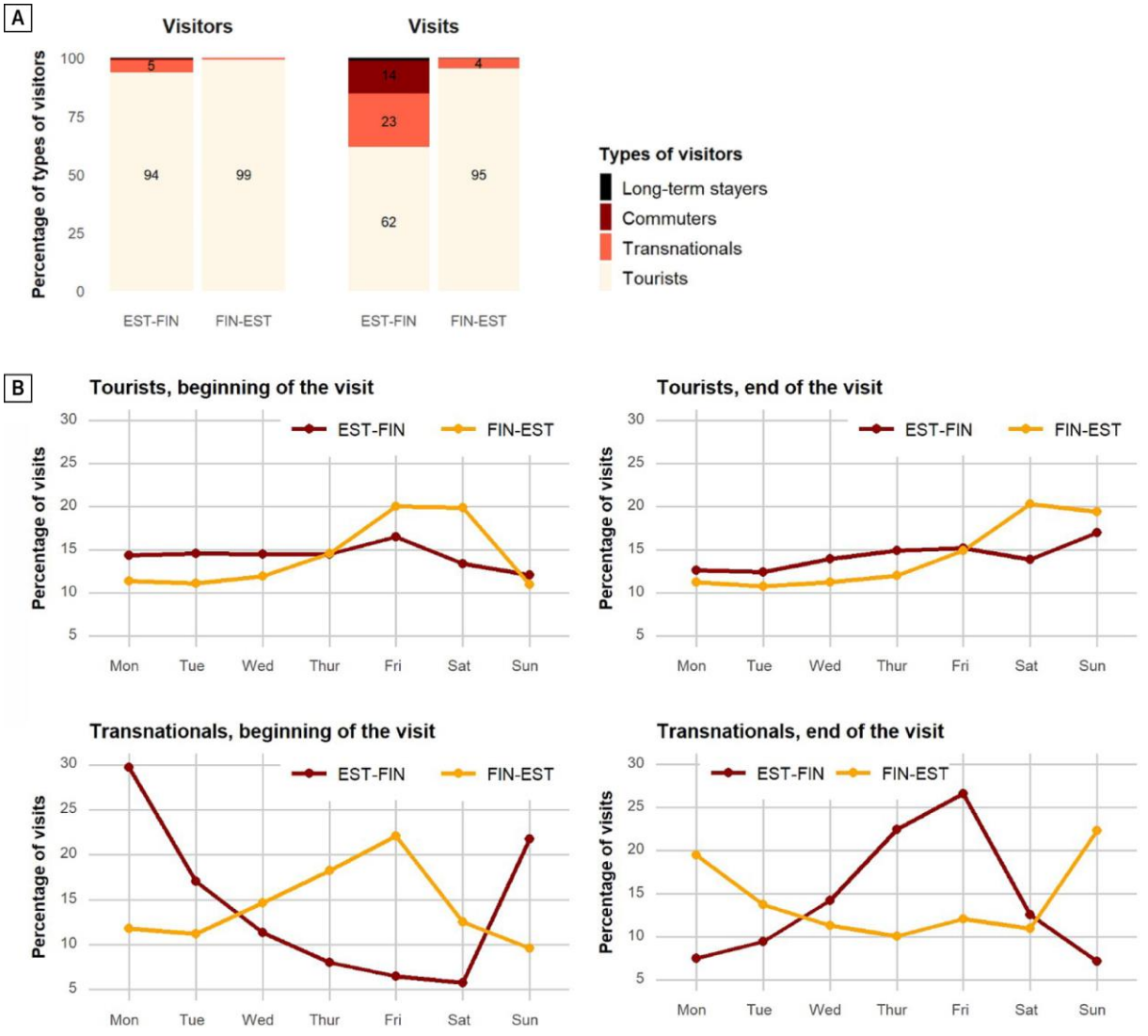
Mobile big data as an umbrella concept includes various data sources, from precise mobile application usage and network operator records to less accurate user-generated data (see Section 3.2). Therefore, the second underlying assumption is that, regardless of how spatially and temporally precise (or imprecise) these digital traces of devices are, they still capture mobility and interaction. In this context, the definition of movement may not always reflect the very detailed act of a device moving from one place (e.g. in country A) to another (e.g. in country B) along a certain trajectory in a road network, due to data scarcity. Yet digital traces can reveal when a border between two countries is crossed by a device (i.e. person) and provide useful information for policy and practice (Järv et al., 2026).

The third underlying assumption is that the capturing of mobility flows and social networks across borders not only provides insights about transport demand and friendship networks, but more broadly reveals the functioning of a cross-border society in terms of spatial extent and intensity of interactions and indicates the degree of social integration of a cross-border region.

### 3.1.3. Revealing cross-border mobility flows

Cross-border interactions can be measured empirically using digital traces from either an individual or an aggregated perspective depending on the level of data processing and analytical approach. For example, the studies by Silm et al. (2021), regarding the Estonia–Finland border (Figure 11), and Järv et al. (2023), regarding the Greater Region of Luxembourg (Figure 12), processed individual-level data to obtain additional cross-border characteristics from digital traces.

**Figure 11.** Cross-border mobility between Estonia and Finland by visitor type and visit count (A), and weekly variation in visits by two visitor groups (B).

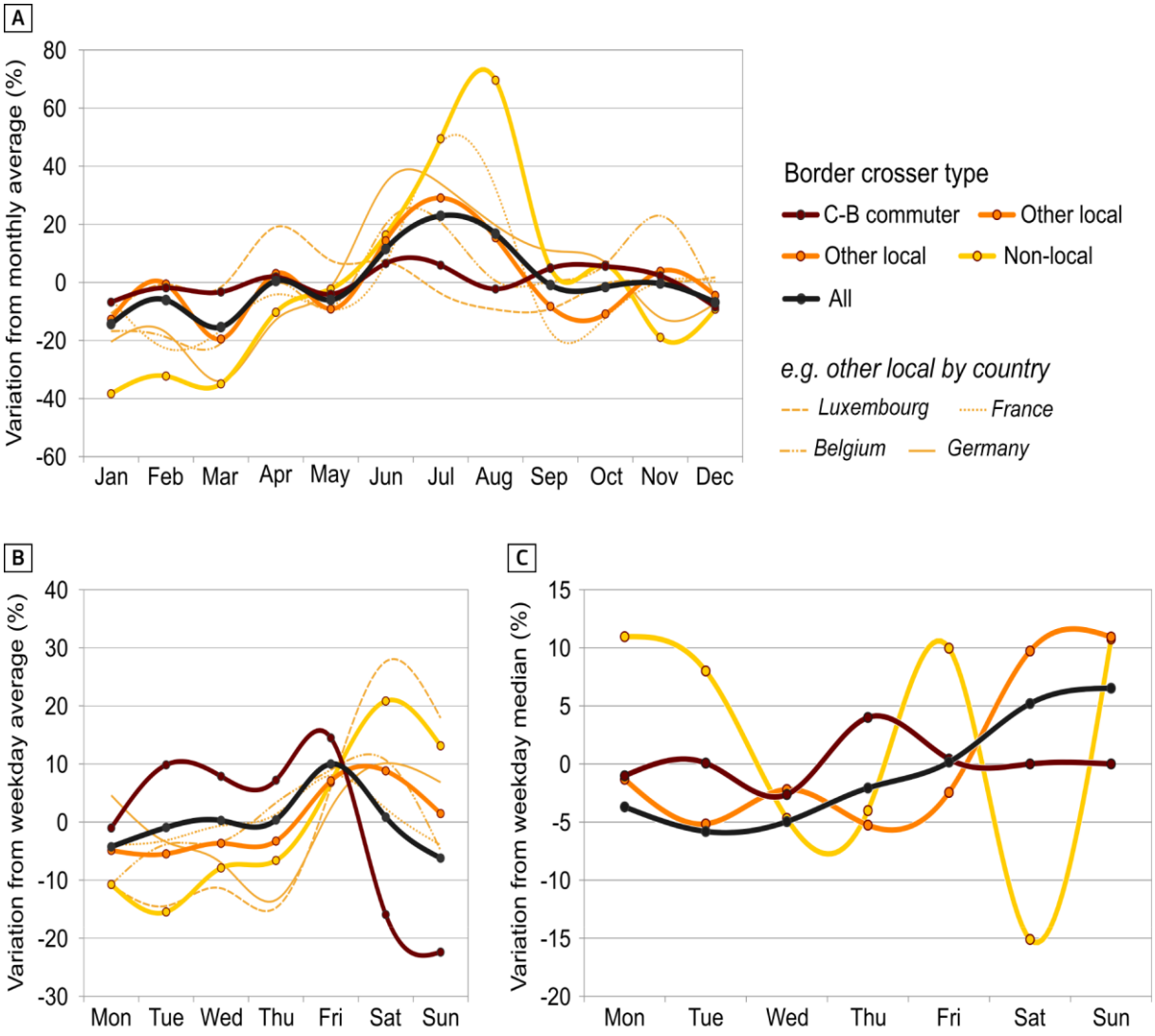



*Source: Silm et al., 2021.*

Both studies used individual-level cross-border mobility patterns (e.g. frequency, duration) to separate the study population into certain groups of people crossing borders, including local visitors, international tourists and cross-border commuters. The results provide insights on temporal rhythms of flows, travel distances and mobility volumes by population group.

Other studies have examined aggregated cross-border mobility networks and flows without focusing on individual spatial behaviour. A study by Blanford et al. (2015) explored overall cross-border connectivity between countries in eastern Africa. Two studies assessed how the COVID-19 pandemic influenced cross-border mobility flows between neighbouring countries: Docquier et al. (2022) examined daily cross-border commuting in Europe and Wallin Aagesen et al. (2023) evaluated the overall mobility flows between the Nordic countries.

**Figure 12.** Monthly (A) and weekly (B) variations in visits to Luxembourg and weekly variation in distance travelled across the border (C), by border crosser type.




*Source: Järv et al., 2023.*

The most recent study by Järv et al. (2026) examined aggregated cross-border mobility flows between all neighbouring countries in Europe, while focusing on frequent mobility by users with multiple border crossings in a border region. The frequent mobility flows exclude tourist behaviour (which is more sporadic and irregular) and address the spatial behaviour of local communities. The clustering of border regions by weekly and monthly mobility rhythms reveals the underlying characteristics of interactions.

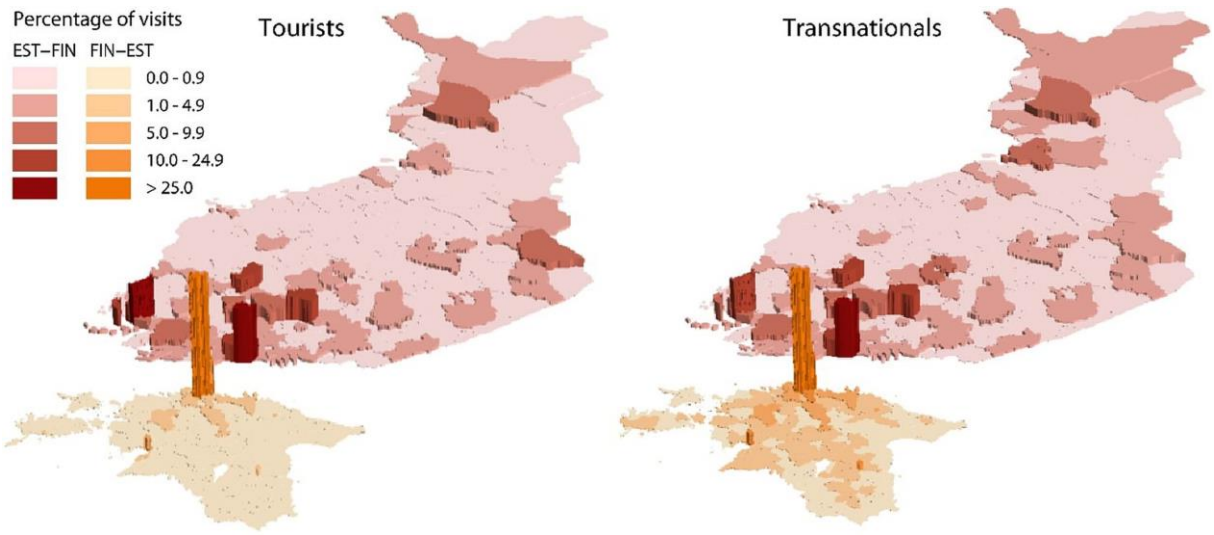
For example, the concentration of interactions in border regions on working days indicates commuting-dominant behaviour, while the concentration of flows on weekends reflects established leisure and shopping practices across the border. Seasonal variation, in general, reveals border regions with stable year-round interaction, while frequent mobility with significant seasonal variation indicates significant seasonal cross-border working and leisure practices. Analysing these temporal characteristics of cross-border interactions can reveal predominant motives and reasons behind the functioning of cross-border regions from a people perspective.

### 3.1.4. Mapping functional cross-border regions

Spatial information about cross-border interactions based on digital traces can also unveil the territorial extent of such interactions and provide new insights about functional cross-border regions. In most cases, cross-border interactions are mostly secondary to within-country interactions; however, these interactions can be meaningful and relevant to the border region community and to its functioning (**Section 1.4**). Therefore, as cross-border interactions contribute to the formation of additional cross-border living spaces, we need to focus on cross-border interactions from a border perspective to capturing the phenomenon holistically.

Studies by Silm et al. (2021), Wallin Aagesen et al. (2023) and Järv et al. (2026) are the first attempts to territorialise functioning cross-border regions using digital traces from mobile big data sources. Based on simple choropleth mapping, Silm et al. (2021) showcase how cross-border visits are linked to distance from a border (**Figure 13**). That said, frequent cross-border mobility flows can also change depending on other factors, including settlement hierarchy, labour market opportunities and leisure destinations across borders. In other words, meaningful and significant cross-border interactions may not always be distributed in one uniform space along the border but could potentially be clustered and/or fragmented.

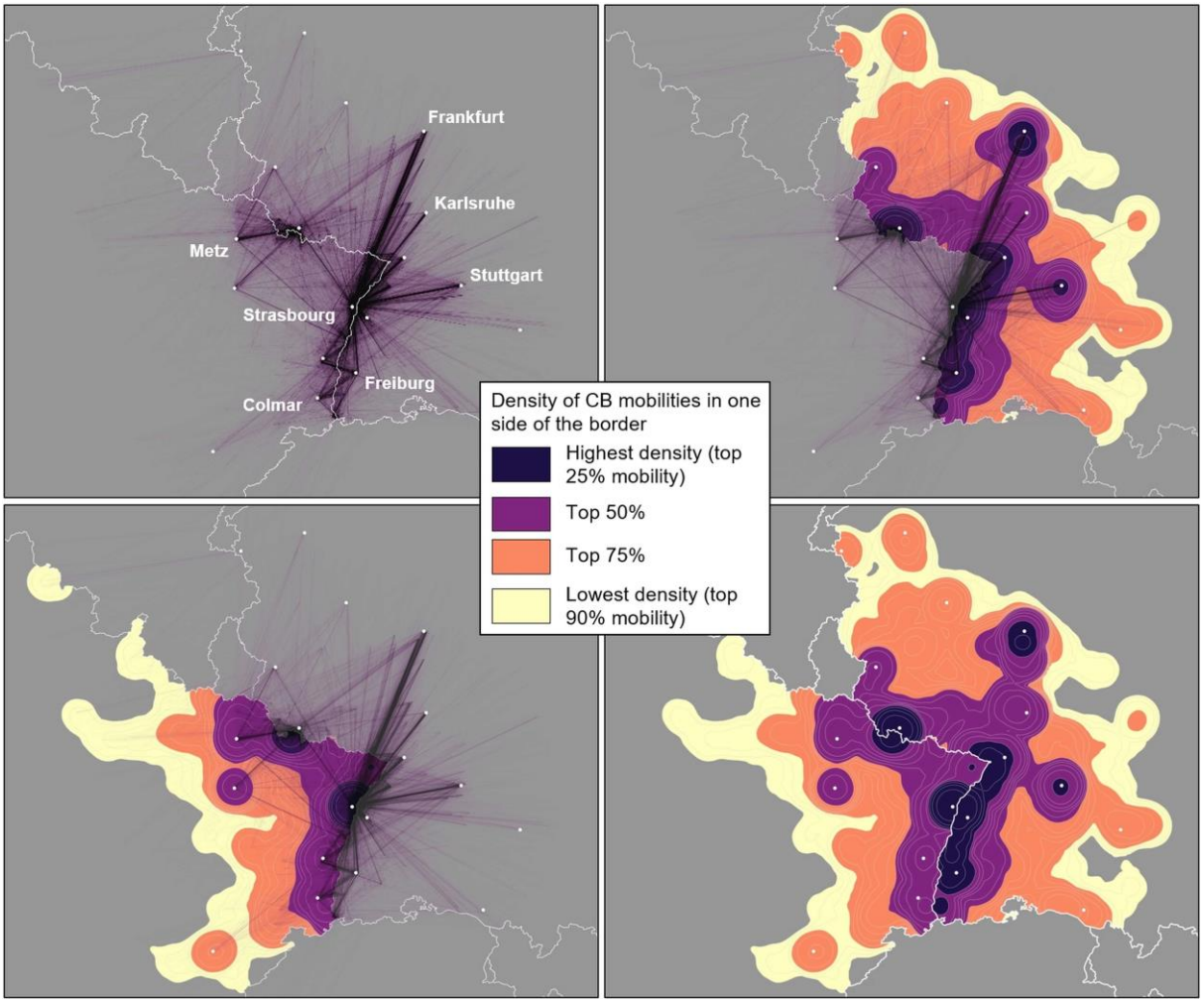
**Figure 13.** Spatial distribution of cross-border mobility between Estonia and Finland by country of origin and visitor type.




*Source: Silm et al., 2021.*

More advanced attempts by Wallin Aagesen et al. (2023) and Järv et al. (2026) used the kernel density estimation (KDE) approach to estimate functional cross-border regions based on mobility in Europe. The approach enables the mapping of both the areas likely to have the highest densities of cross-border interactions and the geographical extent of cross-border regions. Technically, the spatial density of cross-border interaction is estimated separately for both sides of the border and then combined to obtain a holistic overview of the functional cross-border region (**Figure 14**).

**Figure 14.** An example of KDE mapping of a functional cross-border region based on mobility across the France–Germany border.

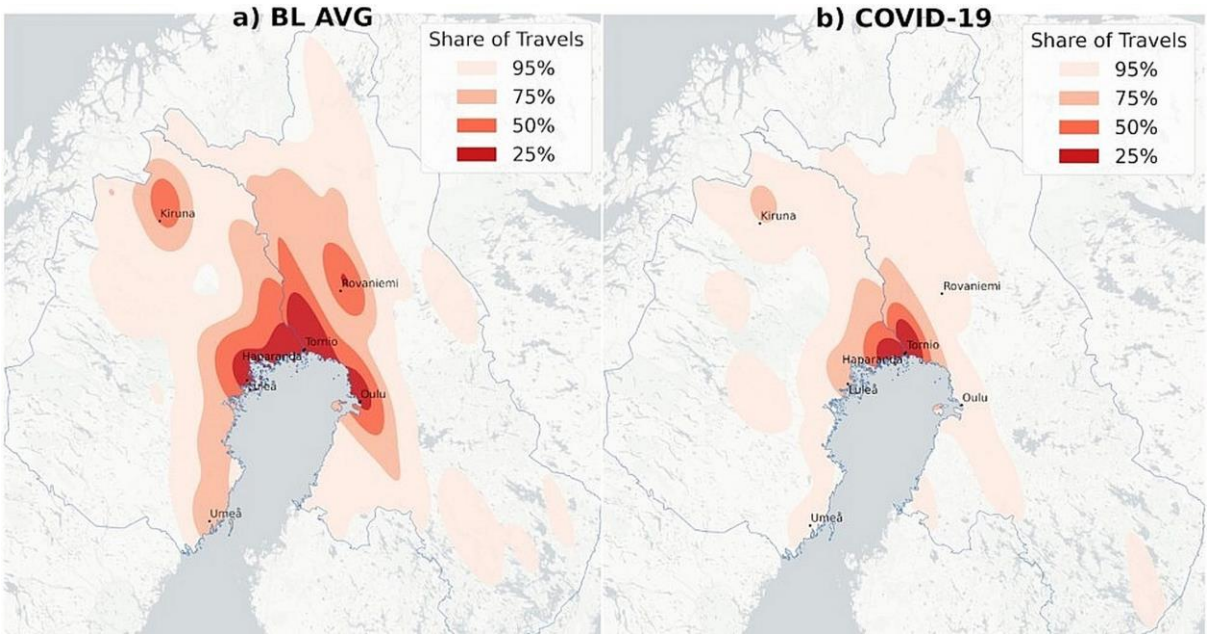



*Source: Adapted from Järv et al. (2026).*

A study by Wallin Aagesen et al. (2023) demonstrated how the spatial extent of a functional cross-border region may change over time along with the spatial structure of cross-border interactions (**Figure 15A**). The influence of the COVID-19 pandemic was examined as a case study; the unexpected social disruption not only decreased the overall volume of travel across the borders, but also its spatial structure.

To use the KDE approach, an open-access tool was developed for mapping cross-border regions (Söderholm et al., 2023). The approach does not automatically define the functional cross-border region, as it involves mathematical estimation and therefore requires a set of input parameters, all of which can affect the final outcome. Therefore, and most importantly, certain KDE threshold criteria (or a set of thresholds) have to be set for defining the spatial extent of a cross-border region. For example, the functional cross-border region can be defined as the territory that sees 25 % or 75 % of all cross-border interactions between two (or more) neighbouring countries (**Figure 15B**).

**Figure 15.** The functional cross-border region based on cross-border mobility flows between northern Sweden and northern Finland before (A) and during (B) the COVID-19 pandemic.




*Source: Wallin Aagesen et al., 2023.*

It is important to note that the studies mentioned above and the associated figures are the first attempts to empirically test the feasibility of the proposed conceptual frameworks and the suitability of potential data sources for deriving cross-border mobility flows.

### 3.1.5. Key takeaways and next steps

- The first studies using various types of mobile big data demonstrate how a mobility-based approach can provide new insights on defining and analysing functional cross-border regions in Europe, and the kinds of cross-border interactions that exist there.
- Current empirical findings should be treated with caution. Nevertheless, they provide a solid foundation for conceptual and methodological advancements, testing various data sources and revising existing frameworks. This knowledge can be applied to future practice and policy.
- Conceptual and methodological next steps should incorporate the idea of functional cross-border regions as multilayered spaces that host various functions (e.g. work, services, shopping, leisure, meeting family and friends). Therefore, to capture functional cross-border regions better, we need to measure cross-border interactions separately for each function and combine the 'layers' of interaction to gain a more holistic perspective. Not least, we need to acknowledge that cross-border interactions are not uniform from both sides of the border – the directionality of interactions and their asymmetry should be addressed when measuring and analysing cross-border interactions and functional border regions.

## 3.2. Perspectives for future research – data from mobile apps and public transport connectivity

**Vít Pászto, Ate Poorthuis and Francisco Rowe**

The widespread adoption of mobile phones over the past two decades has created many new opportunities for researchers to analyse the large-scale, high-resolution data generated by these devices – either actively (e.g. through calls or social media posts) or passively (e.g. through location 'pings') (Rowe, 2023). This development has been especially valuable for studying flows of people, which are traditionally difficult to capture. Conventional sources such as population registers, commuting statistics or mobility surveys offer useful insights but often lack spatial and temporal granularity or coverage and focus only on one specific aspect of human mobility. As such, comprehensive or near-real-time analysis of the flows of people on both national and multi-country scales is a particularly promising application of mobile phone data (see, for example, Rowe et al., 2023).

Today, research can draw on more than 15 years of experimentation and methodological development using mobile phone data. Both call data records and passive positioning data from mobile network operators (MNOs) enable the tracking of anonymised users across space and time (Rowe et al., 2022). These data have been used to estimate daytime populations (Ahas et al., 2010), map functional regions (Ratti et al., 2010) and explore social dynamics in urban contexts. Similarly, social media posts, which, when sent from mobile devices, can also be used to trace platform users through space and time, can be used to study urban phenomena such as segregation (Hristova et al., 2016; Müürisepp et al., 2022) and gentrification processes (Chapple et al., 2021). While most applications to date have focused on urban or national contexts, similar approaches hold promise for analysing cross-border mobility. For example, Docquier et al. (2022) analysed Facebook data to analyse how cross-border commuting in Europe was affected by COVID-19, and Järv et al. (2023) showed how Twitter could be leveraged similarly to analyse cross-border mobility in the Greater Region of Luxembourg.

### 3.2.1. Sources of mobile phone data and opportunities for use

Despite the promise of mobile phone data for studying cross-border mobility, there are several specific challenges to realising its potential to study cross-border flows at the European level. To understand these, we need to differentiate between three different sources of mobile phone data (MNOs, social media and mobile application data), as each presents distinct opportunities and limitations.

MNO data are created and archived by the mobile network operators in a country. They consist of both call data records (i.e. detailing when and where a call is made or a data packet is sent) and positioning data (i.e. pings sent by devices to and from a network) (Rowe et al., 2022). Such data usually offer broad, nationwide coverage and can potentially capture the movements of nearly all mobile phone users who subscribe to a specific provider. This results in potentially fewer issues with demographic or behavioural biases than other sources. However, MNO data often stop at the edge of a provider's network, making it difficult to observe cross-border movements unless the same operator is active on both sides. Spatial resolution varies and is usually coarser outside urban areas.

Furthermore, MNO data cannot be freely accessed; obtaining them requires negotiating agreements with operators, which can be challenging, especially when detailed flow data are sought.

Social media data, however, capture the (geotagged) content that people produce on specific online platforms (Mason et al., 2025). In addition to locations and timestamps linked to specific activities, posts can include rich contextual information such as text and images, providing the potential for additional, qualitative depth in mobility analyses. Yet these data are often demographically skewed, as they only represent users of a specific platform, and each platform has its own specific user base. Furthermore, open access to online platforms has diminished over time due to changes in platform policies and increasing awareness of privacy, which makes it extremely challenging to collect and analyse large-scale datasets unless specific agreements with a platform are made or provisions of the Digital Services Act can be leveraged.

In recent years, mobile app data have gained prominence as a third source of mobility data. Such data consist of location information and timestamps passively collected from a range of applications (e.g. weather, news or navigation apps) while the user is active using each app. The data are aggregated and then sold by third-party brokers to commercial parties and researchers alike. App-based datasets can be vast, often including millions of users within a single country, and they offer high spatial and temporal resolution by leveraging the positioning sensors within mobile phones. However, they also come with major caveats. Who is included in the data (and who is not) is quite unclear, and data quality can be inconsistent from country to country, provider to provider and even period to period. Third-party brokers often do not provide – or simply do not have – enough information to fully gauge the reliability of these data. While the use of these data is increasingly common in academic research, and data are readily available in some markets, the data and its third-party brokers seem, for now, less prevalent in the EU, where the absence of clear legal and ethical frameworks remains a significant barrier to wider adoption.

### 3.2.2. Towards wider transnational use of mobile phone data

Although the use of mobile phone data is becoming more common in human mobility analysis, it is hardly **routine** in analysing migration flows, let alone cross-border flows. Such analysis is rather limited for various reasons, such as technical limitations (switching to a foreign network), legal issues (data protection, data anonymisation) or practical regulatory and policy barriers (e.g. data sharing, bi- and multilateral agreements between states). However, several studies have worked with mobile positioning data and have focused specifically on non-domestic subscriber identity module (SIM) cards, which indicate a degree of cross-border or international movement or the presence of non-residents. Examples of these analyses include work in the field of tourism, for instance focusing on visits of international travellers to various types of mass events (Altin et al., 2022) or the COVID-19 pandemic (e.g. Choi et al. (2020) used roaming data collected from Korea Telecom to forecast imported COVID-19 cases). Mobile phone data have also been used to analyse cross-border movements; for example, passive mobile positioning data and call detail records have been used to assess transnationalism – people operating actively in two or more countries – in Estonia (Ahas et al., 2017).

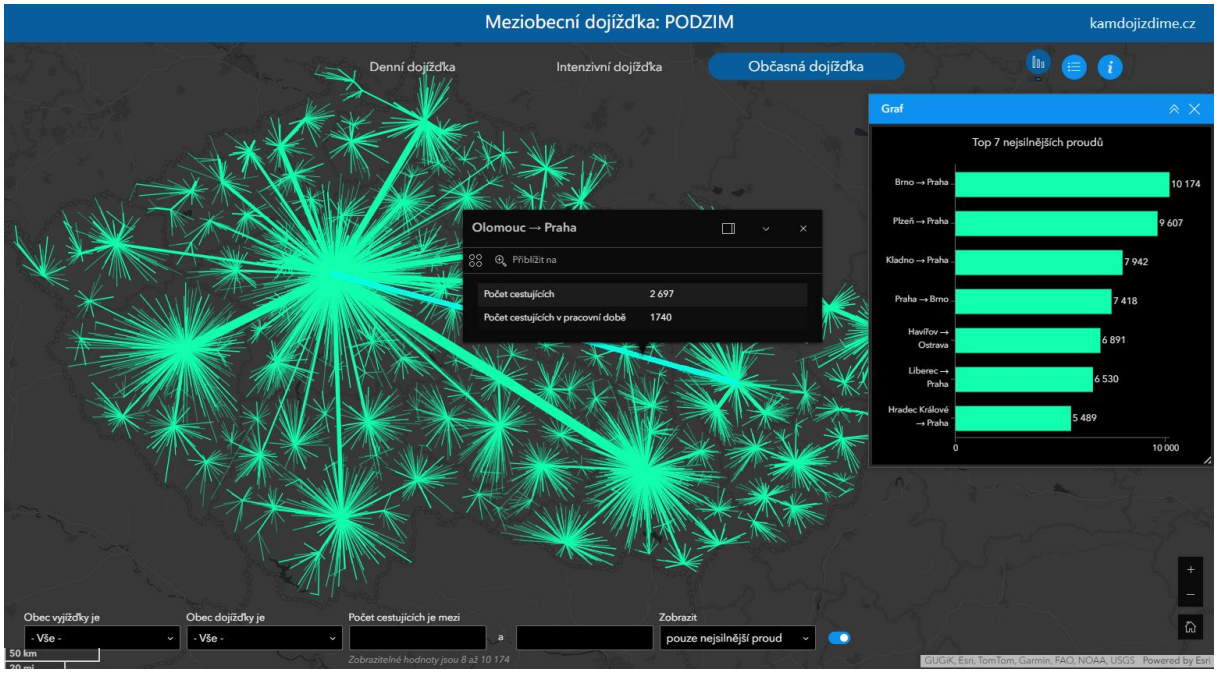
The use of mobile positioning data **within single countries** is becoming more widespread and, importantly, is not limited by inter-country differences in access to such data. However, research leveraging the data is still relatively costly, with the only option being to purchase the data directly from MNOs. However, the potential that would be unlocked by a change in the policies of individual states, or a unified approach (both legal and technical) to accessing the data in order to monitor

cross-border flows, is very large. This is true from several perspectives, compared with conventional methods of detecting cross-border flows – temporal (actual data), spatial (level of detail and geographical scale), dynamic (trend monitoring, flow peaks) and representativeness (in terms of sample size) (Iradukunda et al., 2025).

### 3.2.3. Case study – spatial analysis and visualisation of mobile phone data in Czechia

In 2024, the Ministry of the Interior of the Czech Republic launched a portal ([10]) featuring comprehensive insights from the analysis and geovisualisation of data (**Figure 16**) from all three major mobile operators in the country. The portal allows users to search for geolocation data for a specific LAU in four monitored periods, and to display intermunicipal commuting and other details from geolocation data on maps. In addition, it offers animations showing the daily movements of the resident populations of all municipalities by region, methodological documents, data specifications, settings for monitored parameters and the methodology for collecting geolocation data. The unique aspect of this project is that it comprehensively covers the entirety of Czechia.

**Figure 16.** A screenshot from the Ministry of the Interior of the Czech Republic's portal showing inter-LAU commuting.




*Source: Ministry of the Interior of the Czech Republic, 2024.*

More detailed territorial analyses are also being carried out by the Department of Geoinformatics at Palacký University Olomouc using data from one of the country's main mobile operators. The department's latest results and presentation of the possibilities of spatial analysis were published online ([11]) and highlight the rhythm between day and night, along with the 'emptying'

([10]) https://www.kamdojizdime.cz

([11]) Mobile Positioning Data (https://storymaps.arcgis.com/stories/a1c5a1328e4846679583484409895137)

of small villages and, conversely, the 'inflation' of important towns and cities in the region during the day compared with official statistics. Both case studies demonstrate the potential of mobile phone data for identifying, measuring and analysing the temporal and spatial patterns of actual human mobility, which would be very useful for cross-border flow assessment in general, provided that such datasets are harmonised across borders and made available within the EU (of course, under specific conditions ensuring personal data privacy).

### 3.2.4. Key takeaways and next steps

- To fully unlock the potential of mobile phone data for analysing cross-border mobility, the primary challenges are not technical per se. Much of the methodological groundwork has already been laid through years of applied research at the urban and national levels. What is needed to truly enable the use of mobile phone data for this purpose are regulatory and institutional frameworks that enable secure, privacy-preserving and interoperable data sharing across countries and data providers.
- While bilateral agreements with individual MNOs or mobile app data providers may offer useful starting points right now, they are probably insufficient for sustained and scalable cross-border analysis. Instead, the development of EU-level data governance mechanisms, drawing inspiration from existing practices of NSIs and at the European level, will be essential.
- These frameworks should facilitate access, ensure comparability across borders and safeguard individual privacy, thereby making it possible to harness the full analytical power of mobile phone data to assess transnational mobility and integration challenges.

## 3.3. Web scraping as a tool for research on cross-border regions

**Ricardo Barranco**

Tourism represents a significant and long-standing socioeconomic driver within the EU, contributing substantially to economic growth, employment and cultural enrichment (Butler, 2015; Carneiro et al., 2018; Ivlevs, 2017; Nawijn et al., 2012; Tokarchuk et al., 2017). In 2023, the sector accounted for over 2.9 billion tourist nights and 9 % of total employment in the EU (Eurostat, 2024), with its total contribution to GDP reaching approximately 10 %. However, these benefits are unevenly distributed, with direct economic impacts varying from nearly 12 % of Croatia's GDP to just 1.81 % in Romania in 2023, highlighting significant regional disparities.

Despite the socioeconomic importance of tourism, traditional tourism statistics often fail to capture the sector's spatial and temporal complexities, lacking the granularity and timeliness required for effective evidence-based policymaking and research (Batista e Silva et al., 2018). Official datasets frequently overlook smaller accommodation providers and short-term rentals, offering limited insight into dynamic market trends. To address these limitations, researchers are increasingly turning to non-traditional data sources, such as those derived from web scraping – the automated extraction of information from websites (Del Vecchio et al., 2018; Mitchell, 2018; United Nations, 2020). This method allows for the large-scale collection of user-generated content from online

platforms, providing valuable data on tourism supply, consumer behaviour and pricing trends that were previously difficult to obtain (Fang et al., 2016).

Despite its potential, web scraping presents notable challenges. The reliance on online platforms can introduce sampling bias: these sources may not represent the entire tourism landscape, potentially skewing results (Shafiee et al., 2016). Furthermore, the accuracy and reliability of scraped data can be compromised by inconsistencies, missing information and the technical complexities of navigating dynamic website structures and anti-scraping measures (Brenning et al., 2023a; Glez-Peña et al., 2014).

Still, the use of online platforms aligns with the EU's broader data strategy, which aims to foster data-driven innovation through the creation of sector-specific data spaces (Kotsev et al., 2020). This strategy is underpinned by a robust legal framework. The proposed EU Data Act (Regulation (EU) 2023/2854) seeks to unlock data's value while upholding stringent data protection standards (Brenning et al., 2023b; de Carvalho et al., 2020). Concurrently, the General Data Protection Regulation (Regulation (EU) 2016/679) establishes a comprehensive framework for personal data protection, ensuring individual control and harmonising regulations. Finally, the Directive on Copyright in the Digital Single Market (Directive (EU) 2019/790) provides a legal basis for text and data mining for scientific research purposes by research organisations, thereby facilitating academic inquiry while respecting intellectual property rights.

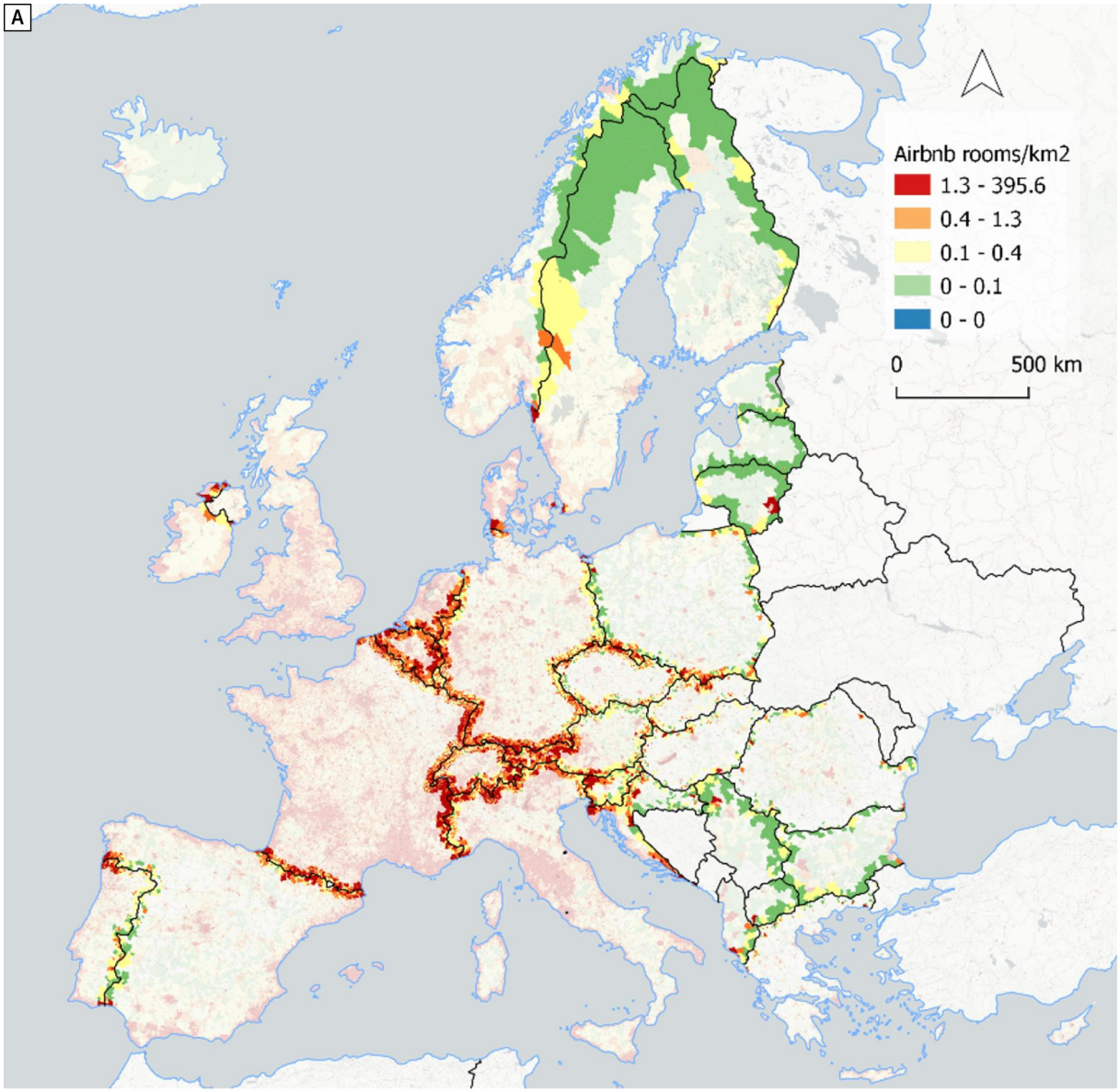
### 3.3.1. Short-term rentals in cross-border municipalities

A central element of this section was the development of a high-resolution EU dataset encompassing the locations and characteristics of short-term tourism accommodation. By web scraping Airbnb – the main online platform for short-term rental – as a primary data source, the dataset captured not only the geographical coordinates (latitude and longitude) of each short-term rental but also additional attributes. The type of accommodation (e.g. entire place, private room, shared room), number of rooms, number of guests accommodated, user rating, number of reviews, average daily rate, occupancy and availability were collected for a total 4.3 million listings.

The room count, an indicator of tourism capacity, offers a critical measure of the absolute scale of tourism destinations from a supply perspective. Cross-border municipalities represent around 12 % of the overall short-term rental capacity of the EU. On average, the capacity, revenue and daily rate of cross-border municipalities are 80 % of the EU levels. Notably, the values drop to around 40 % when normalised per $km^2$ (in order to account for the different municipality sizes). Taking a step further, when considering the degree of urbanisation, cross-border cities account for 8.9 % of the EU's total capacity, towns and suburbs 14.5 % and rural areas 17.3 %. Cross-border cities have, on average, 47.2 % of the EU's capacity per $km^2$, towns and suburbs 69.5 % and rural areas 92.6 %. From these values emerges the idea that, while border cities, towns and suburbs are lagging, border rural areas are on par with remaining European rural municipalities in terms of short-term rental capacity and room density (**Figure 17**).

**Figure 17.** Airbnb room density distribution in European border municipalities (A), with capacity and density data aggregated by degree of urbanisation (B).

A




B

**Short-term rentals capacity**

| Number of rooms | Border regions | All regions | Share (%) |
|---|---|---|---|
| Cities | 142,152 | 1,581,959 | 8.9 |
| Towns & Suburbs | 251,165 | 1,728,377 | 14.5 |
| Rural areas | 354,705 | 2,048,389 | 17.3 |

**Average municipality values**

| Rooms/km² | Border regions | All regions | Share (%) |
|---|---|---|---|
| Cities | 15.1 | 32.0 | 47.2 |
| Towns & Suburbs | 3.8 | 5.4 | 69.5 |
| Rural areas | 1.7 | 1.8 | 92.6 |

*Source: Author's elaboration.*

### 3.3.2. Detecting differences in short-term rentals in border regions

Using a 25 km distance from national borders as a delimitation criterion, we compared the differences in values across borders. The resulting map and differences are pictured in **Figure 18**. By far the highest difference in short-term rental density (rooms/km$^2$) is between Denmark and Sweden, at 61 rooms/km$^2$. This value includes Copenhagen, the capital of Denmark and the country's main tourist destination. The magnitude of the difference in this particular case makes it an outlier compared with the rest of the cross-border regions, leading to its the exclusion from the following analysis.

When compared with all neighbouring countries, France exhibits the highest difference in density of Airbnb rooms at its border (with around 1.5 more rooms/km$^2$, followed by Croatia (+ 1.4 rooms/km$^2$). The remaining countries have considerably lower values, with Switzerland (– 0.6 rooms/km$^2$) and Spain (– 1.8 rooms/km$^2$) on the opposite side of the spectrum with the lowest negative values. Focusing on Italy, an intricate pattern emerges in the Alpine regions. Although the country has a lower room density at the border than France (– 7.6 rooms/km$^2$) and Austria (– 0.2 rooms/km$^2$), it has more rooms/km$^2$ at its border than Switzerland (+ 1.1 rooms/km$^2$) and Slovenia (+ 0.1 rooms/km$^2$).

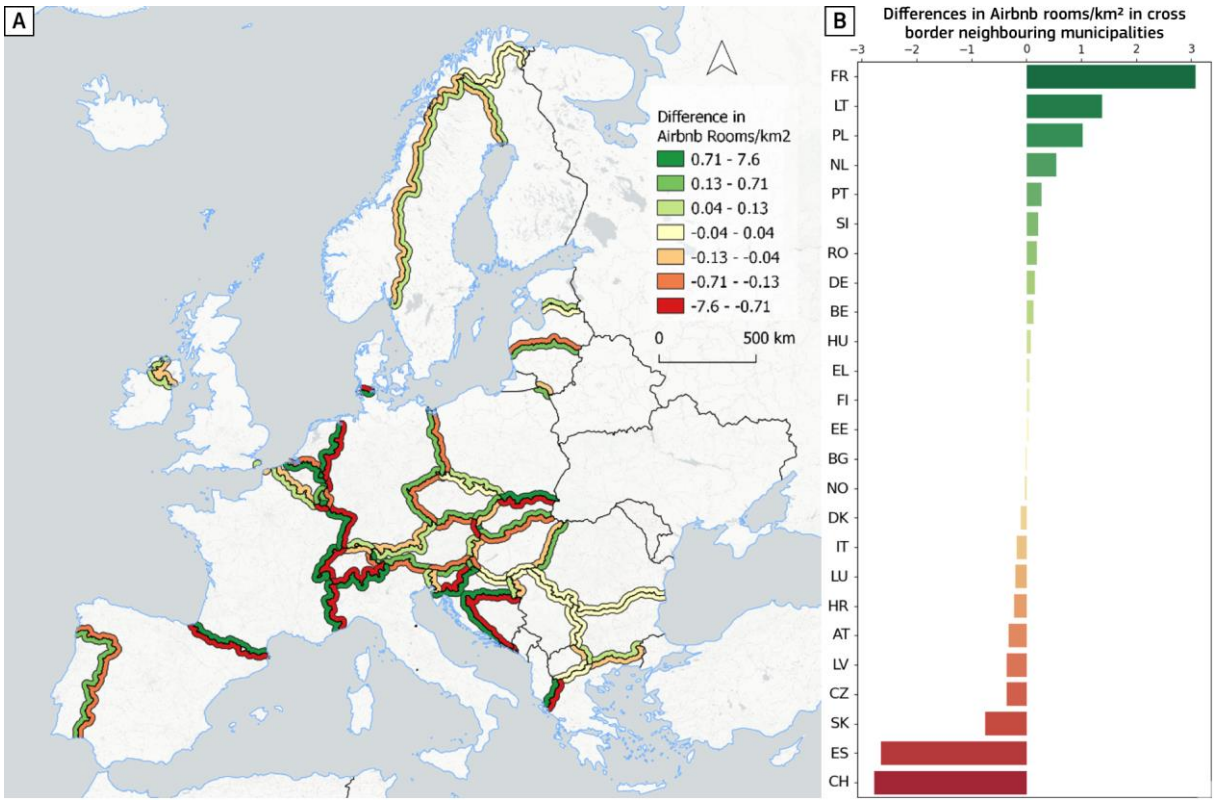
In many other countries, the values can also be positive or negative depending on the neighbouring country, supporting the idea that the distribution of short-term rentals is very much driven by very specific local geographical characteristics. Border regions with big differences from their neighbours have the potential to further develop tourism levels, by attracting cross-border tourists. This could help shape local policies and planning.

Building on the same methodology at a more detailed level, we examined each municipality individually and identified its directly adjacent neighbours. However, we only considered neighbouring municipalities located across a national border, that is in a different country. For each municipality, we computed the average difference in Airbnb room density compared with its cross-border neighbours.

This average value provides an indication of how Airbnb activity varies across national boundaries. It helps to identify patterns – such as whether one side of a border tends to have a higher density of Airbnb listings than the other – that may reflect differences in tourism demand, regulatory environments or housing markets, or even the potential to attract visitors from nearby foreign municipalities.

The results reveal that municipalities in France, the Netherlands and Portugal exhibit the highest positive differences, suggesting greater Airbnb density than their cross-border counterparts. Conversely, municipalities in Italy, Spain and Switzerland have the most negative values, indicating a lower Airbnb density than their neighbours (**Figure 18**).

**Figure 18.** Differences in Airbnb room density (rooms/km$^2$) in cross-border areas (A) and cross-border neighbouring municipalities (B).




*Source: Author's elaboration.*

### 3.3.3. Combining official and non-traditional data sources

Web-scraped high-resolution information, when merged with official statistics, can allow its disaggregation to higher spatial resolutions using a technique called dasymetric mapping. Following this principle, we can use the web-scraped accommodation capacity as spatial proxy, providing a sound estimate of how regional official statistics are spatially distributed at the municipal level. In our particular case, data from the official Eurostat dataset 'Guest nights spent at short-stay accommodation offered via collaborative economy platforms by NUTS 3 region – experimental statistics' ([12]) were disaggregated and analysed at the municipality level, using as a spatial proxy our high-resolution Airbnb capacity data.

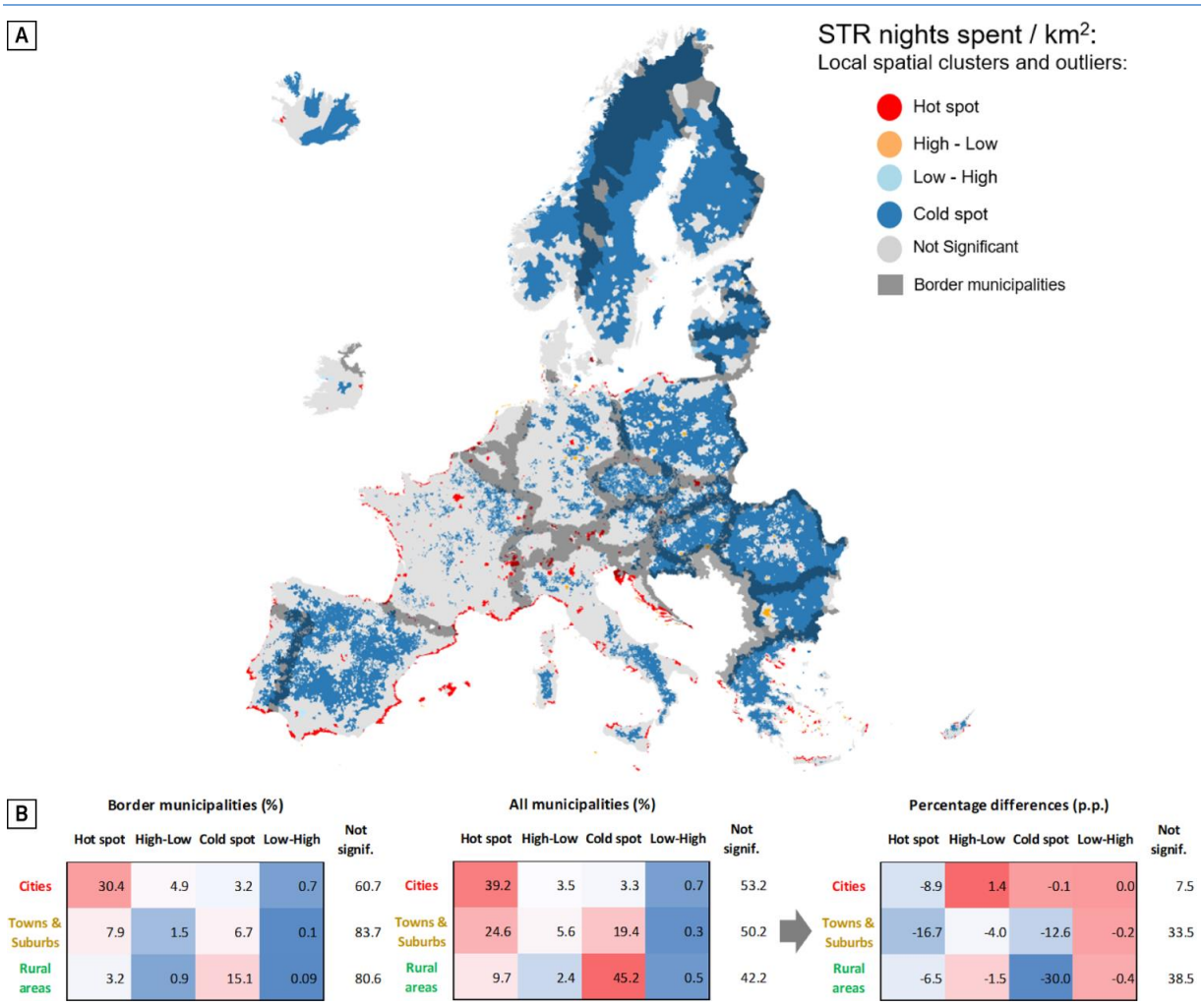
With the estimated municipal nights spent in short-term rentals per km$^2$, we can then test for spatial clusters and outliers. The hypothesis is that high values and/or low values are more spatially clustered than would be expected if underlying spatial processes were random. The appropriate statistical test value (global Moran's I of 0.57) confirmed our hypothesis of a global clustered pattern.

Next, we move from the global level to identify local spatial clusters and outliers. At the local level, Moran's I provides a more detailed view by examining each location individually, indicating whether a location has neighbouring locations with similar or dissimilar values. Municipalities were then classified into the following five groups and mapped in **Figure 19**:

([12]) https://ec.europa.eu/eurostat/databrowser/product/view/tour_ce_oan3

- **hotspot** (municipalities with a high number of nights spent in short-term rentals per km$^2$ surrounded by municipalities with a high number of nights spent in short-term rentals per km$^2$);
- **cold spot** (municipalities with a low number of nights spent in short-term rentals per km$^2$ surrounded by municipalities with a low number of nights spent in short-term rentals per km$^2$);
- **high–low** (municipalities with a high number of nights spent in short-term rentals per km$^2$ surrounded by municipalities with a low number of nights spent in short-term rentals per km$^2$);
- **low–high** (municipalities with a low number of nights spent in short-term rentals per km$^2$ surrounded by municipalities with a high number of nights spent in short-term rentals per km$^2$);
- **not significant** (municipalities with a number of nights spent in short-term rentals per km$^2$ that is not statistically significantly different from surrounding municipalities).

**Figure 19.** Local spatial clusters and outliers of nights spent in short-term rentals per km$^2$ in EU and EFTA municipalities (A), with percentage values for border and all municipalities and percentage point differences for all municipalities (B).




*Source: Author's elaboration.*

The contrast between border municipalities and all municipalities considered shows that border rural areas have a considerably lower share of cold spots (– 30 percentage points) and towns and suburbs a lower share of hotspots (– 16.7 percentage points). The remaining municipality types are fairly aligned with absolute values (within ± 9 percentage points).

### 3.3.4. Key takeaways and next steps

- Non-traditional data sources, like web scraping, have been proven to complement official statistics and increase territorial knowledge.
- Short-term rental capacity and density in rural border municipalities seems to be aligned with all other European rural municipalities. Big differences between border regions and their neighbours may reflect differences in tourism demand, regulatory environments or housing markets, but regions could potentially increase their tourism levels by attracting cross-border tourists through reshaping local policies and planning.
- This analysis reinforces the idea of tourism as an important economic sector in rural and remote areas. Tourism in rural border regions can serve as an alternative income source and help retain the local population, providing younger generations with viable employment opportunities beyond traditional agricultural activities.

## 3.4. New ways of measuring cross-border movements in the EU

**Nico Van de Weghe**

### 3.4.1. Data fusion challenges

Capturing cross-border human movement is inherently challenging due to limitations of traditional data sources. Many mobility data streams (e.g. censuses, surveys, phone data, social media) have unique biases in spatial/temporal coverage and population representativeness (Cabrera et al., 2025). This leads to the selective superiority problem, whereby different data sources can yield divergent mobility insights depending on context. For example, an epidemic modelling study showed that using mobile phone data rather than census-based travel data produced markedly different outcomes, with each data source performing best under different conditions (Panigutti et al., 2017). No single data source is uniformly superior; instead, each excels selectively, underscoring the need for intelligent data fusion across sources (Graells-Garrido et al., 2023).

Intelligent data integration has therefore become a priority in mobility analysis. Recent years have seen an explosion of heterogeneous mobility datasets (e.g. internet of things traffic sensors, transit feeds, mobile apps), but these are often siloed in incompatible formats. Integrating such multi-source data is not easy, due to interoperability issues and partial overlaps between data models (Bellini et al., 2024). Developing integrated data ecosystems is vital so that cross-border mobility can be monitored holistically rather than through isolated streams. Without such integration, important movement patterns (especially those spanning national borders) may go undetected because each individual dataset provides only a narrow view.

The EU is actively working towards bringing together interoperable mobility data. The concept of a common European mobility data space, along with national access points for sharing transport data, reflects this push (Scrocca et al., 2024). Research initiatives have also emerged: for instance, the enhanced data processing techniques for dynamic management of multimodal traffic (Tangent) project developed a semantic data platform to harmonise multi-city traffic datasets. By using knowledge graphs and standardised ontologies, Tangent enabled the integrated consumption of several data sources across European regions, proving the feasibility of cross-border data fusion in real time (Scrocca et al., 2024).

### 3.4.2. Geospatial artificial intelligence and hybrid modelling approaches

Advances in geospatial artificial intelligence (GeoAI) are opening up new possibilities for cross-border mobility analysis. In particular, hybrid AI models that combine data-driven learning with geographical domain knowledge can address the selective superiority of purely statistical models. Traditional black-box AI may miss critical spatial context or violate known geographical rules. New approaches therefore inject symbolic geographical knowledge (e.g. topological relationships, travel network rules) into neural models, aiming to achieve the best of both worlds: predictive power and rule-based interpretability.

One promising direction is neuro-symbolic GeoAI, which integrates machine learning with formal spatial reasoning. For example, Zhu et al. (2022) demonstrated a neural network that learns to reason about qualitative spatial relations (e.g. 'A is between B and C') by incorporating relation constraints into its architecture. By making the model 'spatially explicit' (i.e. embedding higher-order geographical constraints, such as the conceptual neighbourhood of spatial relations), the hybrid model achieved around 20 % better accuracy than a purely data-driven baseline (Zhu et al., 2022). This shows that encoding geographical rules (a symbolic component) alongside learning can markedly improve performance on spatial tasks. Such neuro-symbolic methods may be especially relevant to cross-border mobility, where movement patterns must obey geography (e.g. border geometries, network connectivity).

Beyond individual models, geospatial knowledge graphs and ontologies are being used to fuse data and inject context. By linking diverse mobility datasets (traffic sensors, points of interest, transport networks) in a common graph with well-defined relationships, AI systems can reason about the integrated knowledge. For instance, knowledge graphs have been used for semantic route planning and to ensure AI predictions do not violate fundamental geographical laws like connectivity (Blanford et al., 2015). These approaches improve both the interpretability and the robustness of mobility analytics, since the AI's decisions can be cross-checked against known geographical relationships.

An emerging example at the frontier of GeoAI is the Geo-R2LLM project (2025–2028). Geo-R2LLM is a multinational EU-funded effort to develop geographical large language models that are grounded in geographical reasoning and multimodal data. Instead of treating language models as purely text based, Geo-R2LLM rethinks them to incorporate map data, remote sensing imagery, and domain rules through retrieval and reasoning components. The goal is to build an AI system that can, for example, understand and answer questions about cross-border movement by consulting both its learned knowledge and external geographical databases. By integrating reasoning engines with the retrieval of up-to-date spatial information, such a system can remain consistent with real-world geography and adapt to new scenarios. Geo-R2LLM's planned evaluation is a context-aware navigation assistant in a complex urban environment (Helsinki), a use case that demands blending live location data, user context and logical spatial rules. If successful, this hybrid GeoAI approach

could be extended to cross-border mobility scenarios (e.g. guiding travellers across multiple transit systems and countries, while accounting for each region's rules and geography). It exemplifies how neuro-symbolic AI and integrated data can come together in next-generation mobility solutions.

### 3.4.3. Adaptive and privacy-preserving learning for mobility

Cross-border mobility patterns are anything but static. They evolve with seasons, policies, crises and human behaviour changes. Thus, adaptive learning systems are crucial for monitoring and predicting movement in real time. Models must handle concept drift, where the underlying patterns change over time (e.g. a new border policy suddenly reroutes migration flows, or a pandemic disrupts travel). Traditional static models can quickly become obsolete in such cases. Recent research emphasises online and continual learning techniques that update models as new data arrive, ensuring predictions remain accurate under shifting conditions.

For example, Meese et al. (2024) developed an online traffic prediction framework that continuously retrains a model at the network edge using streaming data from road sensors. By detecting changes on the fly and adapting the learned parameters, the system maintains performance even as traffic patterns evolve daily or in unforeseen ways. Importantly, this approach outperformed non-adaptive baseline models, illustrating the value of adaptivity for mobility analysis. In an EU cross-border context, adaptive learning could allow traffic and mobility management systems to respond to events (e.g. sudden surges at a border crossing or diversions due to weather) in near real time.

At the same time, the push for data-driven mobility intelligence raises privacy and data governance concerns, especially when combining data across borders. Mobility data (e.g. smartphone location traces, travel histories) are often personal and sensitive. Privacy-preserving machine learning techniques are therefore a key part of new mobility measurement methods in the EU, which has strict data protection regulations.

One prominent technique is federated learning (FL), where models are trained collaboratively across multiple data sources or devices without centralising the raw data (Ezequiel et al., 2022). Instead of pooling all traveller data in one place (which could violate privacy or data sovereignty laws), each data node (e.g. a country's dataset or an individual's device) computes model updates locally; only the updates (gradients) are shared and aggregated. This enables the construction of a global mobility model while personal data remain decentralised.

FL has been successfully applied to human mobility modelling to achieve privacy-aware insights. For instance, Ezequiel et al. (2022) used FL to train next-place prediction models on smartphone location data spread across users, avoiding any transfer of individuals' global positioning system traces to a central server. The federated approach could almost match the accuracy of a central model while keeping personal data on the associated device, demonstrating a viable trade-off between privacy and performance.

The EU's interest in cross-border mobility analysis makes FL especially attractive: Member States or companies can collaboratively build models (for traffic forecasting, migration trend detection, etc.) without breaching data-sharing restrictions across jurisdictions. Research by Meese et al. (2024) shows that FL can be combined with adaptive learning. They integrated FL with online training to continually improve a traffic model across a network of roadside units, with each unit keeping its data locally. Such approaches align with EU principles of data minimisation and sovereignty, allowing innovation in mobility analytics that respects privacy.

### 3.4.4. Key takeaways

- New methodologies for measuring cross-border movement in the EU centre on intelligent integration of diverse data sources, GeoAI models that hybridise learning with geographical knowledge, adaptive learning systems that keep pace with changing mobility dynamics and privacy-preserving techniques that uphold data protection standards.
- These research fronts are complementary: a future EU mobility observatory may fuse telecommunication data, transit records and social media signals in a common framework, use hybrid AI to analyse and reason about the fused data, and adapt its predictions continuously as conditions change, all without compromising individual privacy.
- The projects and studies cited (covering topics from semantic data integration platforms to GeoAI reasoning systems and FL trials) collectively sketch the blueprint of an advanced cross-border mobility measurement ecosystem. Each piece of research addresses a facet of the selective superiority problem: no single data source, model or static snapshot is sufficient. But together, and with careful design, they will offer a powerful toolkit for understanding and managing the flows of people across the EU's borders in the coming years.

# 4. Functional structures across borders

## 4.1. Understanding of the multifaceted nature of cross-border functional areas

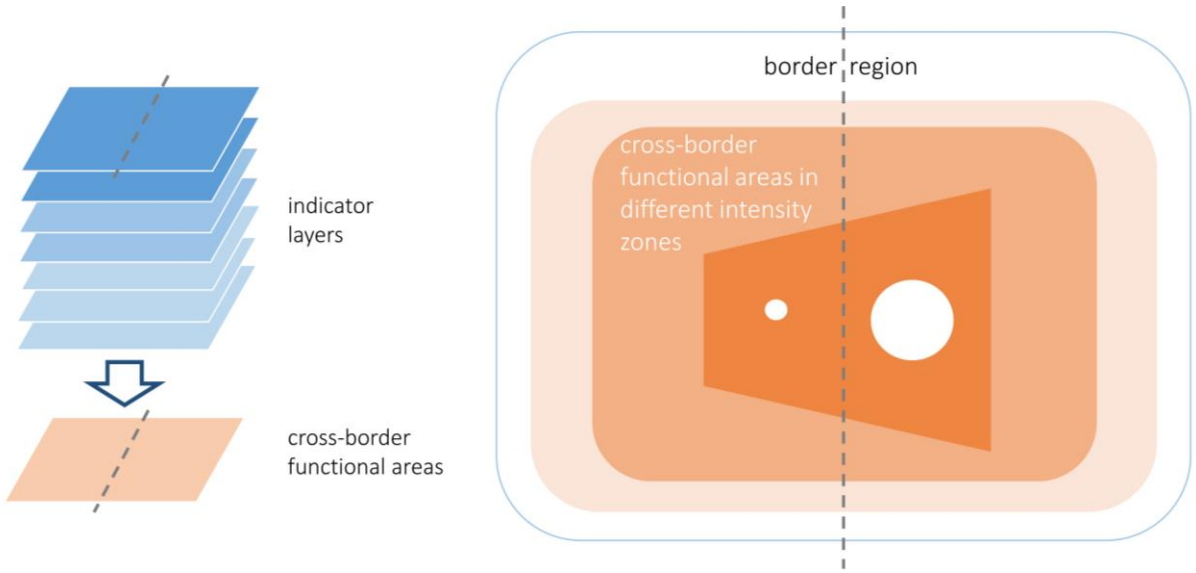
**Tobias Chilla, Elias Günther and Stefan Hippe**

### 4.1.1. Cross-border functional areas as a result of EU integration

The general idea of cross-border functional areas is obvious: the liberalisation of border regimes within the EU has led to new spatial patterns. Interactions and movements across borders increase continuously and lead to new territorial entities (Bertram et al., 2023; MOT, 2017). This spatial dynamics across established administrative and statistical units are well known from processes of urbanisation: in the domestic context, FUAs are the dominant concept, comprising cities and their commuting zones. In principle, this classification can also be applied to border regions. Almost two decades ago, the ESPON programme laid important foundations in this direction (through the study on urban functions and Metroborder; see ESPON, 2007, 2010). Section 3.1 of this report describes the current state of the debate.

Cross-border functional areas go beyond simple commuter zones, taking into account the multilayered nature of societal dynamics (Decoville et al., 2018; Jakubowski et al., 2021). This ambition immediately leads to concerns around data availability and methodological regionalisation challenges. Figure 20 describes this in a simplified way: the challenge is to combine a meaningful set of data that is available on either side of the border and – at best – contains cross-border flow information. On this basis, zones of integration intensity can be identified as differentiated cross-border functional areas.

**Figure 20.** The logic of cross-border functional areas.




*Source: ESPON, 2026.*

### 4.1.2. Data issues and methodological challenges

The availability of data for border regions is rather limited – in particular in the following dimensions.

- Data regarding flows across borders are hardly available. Cross-border commuting data are not available at a granular level in harmonised formats. Origin–destination information in mobility data is an exception, but rather difficult to obtain.
- Even if static data are available on either side of the border, they are (mostly) not harmonised at a meaningful scale. Data at the NUTS 2 level and sometimes the NUTS 3 level are available. However, LAU and geolocalised data would be much more relevant.
- Some topics and sectors are rather well covered, as in particular demographic data at the local (or grid) level and environmental data. Others, like economic information, are hardly available. These sectoral asymmetries of data availability should not lead to biased analyses.

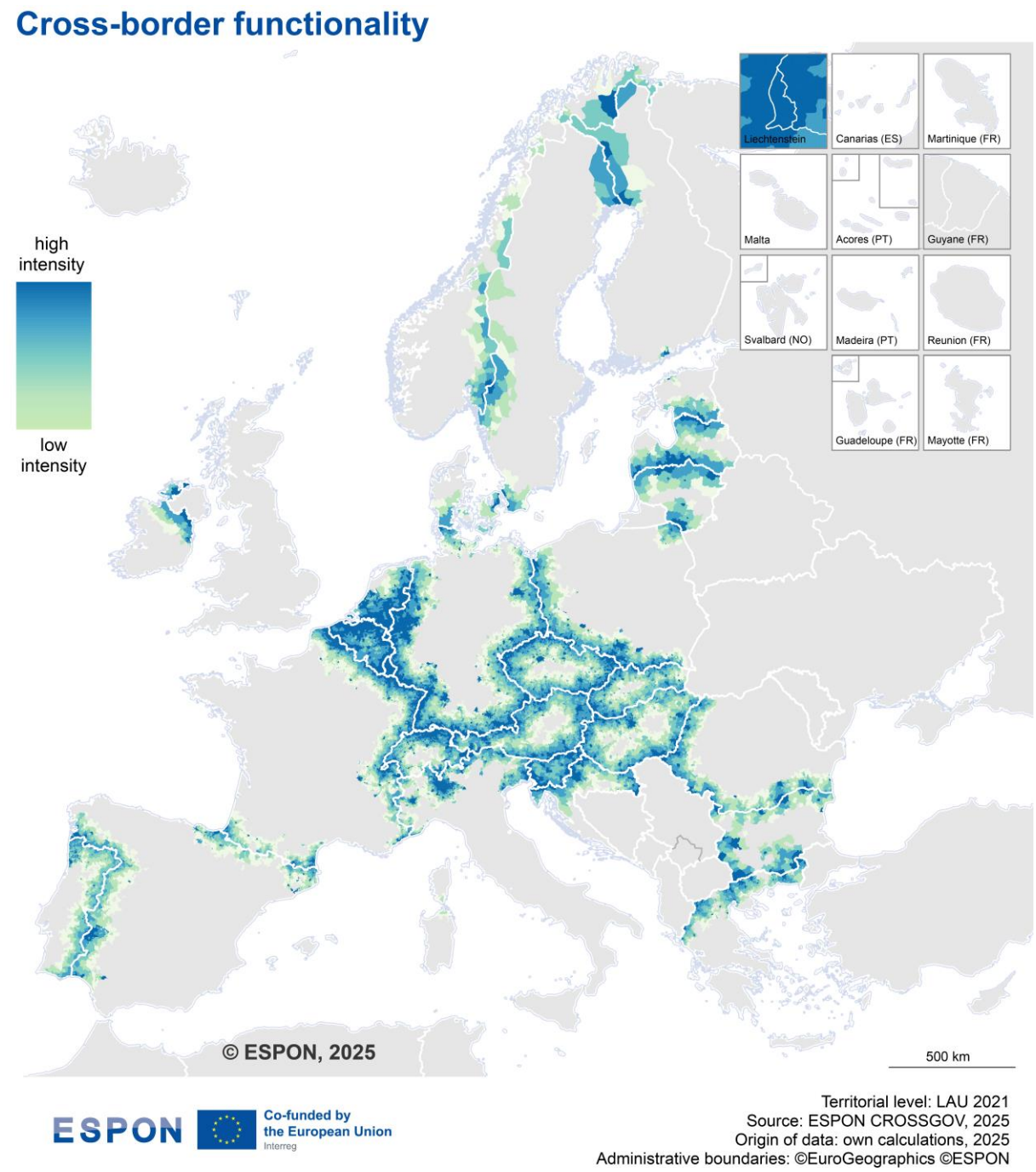
To make a long story short, the definition of cross-border functional areas needs granular data with a certain thematic balance. This can be achieved in a rather sophisticated way in single regions where fresh empirical data can be collected. At the EU level, collecting empirical data is not a systematic option. Official statistics and information derived from them have to be the main basis.

The methodological challenge lies in data integration. It is obvious that a combination of several indicators is required to generate a more realistic and multifaceted picture of border regions. This, however, means addressing even larger challenges than those faced when working on only one indicator.

To overcome the data integration challenge, the ESPON Crossgov project (ESPON, 2026) has recently adopted a new approach: the pan-European multi-indicator approach (Hippe et al, 2026). More concretely, the project has put together an indicator set at the municipal level of five data layers for all European borders (EU and EFTA), including population density (for LAUs), cross-border travel time accessibility (of LAUs), mobility flows (based on a raster dataset derived from residential Twitter ([13]) users who crossed the border), cross-border connectivity (derived from Facebook friendship connections) and natural risks (based on grid data). These data layers were weighted in order to balance the economic, social, environmental and geographical characteristics of European border regions (**Figure 21**).

([13]) Data extracted in 2023 before the rebranding to X.

**Figure 21.** Intensities of cross-border functionalities based on a multi-indicator approach




*Source: ESPON Crossgov, 2026.*

Furthermore, a multi-step procedure was developed that allows us to define and delimitate cross-border functional areas. The key criteria include a certain relevance within the settlement system, a minimum level of activity in socioeconomic terms on both sides of the border and a certain level of interaction (not shown on the map). This procedure enables us to define cross-border functional areas at the European level with a fully harmonised dataset and methodological approach (Hippe et al., 2026). Future studies will no doubt further extend the database, the methodological steps or delimitations at the municipal level. However, the Crossgov project has shown that it is possible to provide an evidence base for cross-border functional integration in Europe.

### 4.1.3. Key takeaways and next steps

- Cross-border functional areas need granular, theme-balanced data that are harmonised across borders; current gaps in flow statistics and inconsistent static indicators constitute the main methodological obstacles.
- The ESPON Crossgov project has shown that a multi-indicator, municipal-level framework (population density, travel time / accessibility, mobility-derived flows, digital connectivity and natural-risk layers) can reliably delineate pan-European cross-border functional areas.
- Scaling up this approach will require strengthened data-sharing mechanisms, the inclusion of additional economic indicators, and an institutionalised, jointly-funded governance structure to keep the dataset up to date to enable policy-relevant monitoring.

## 4.2. Defining cross-border functional urban areas

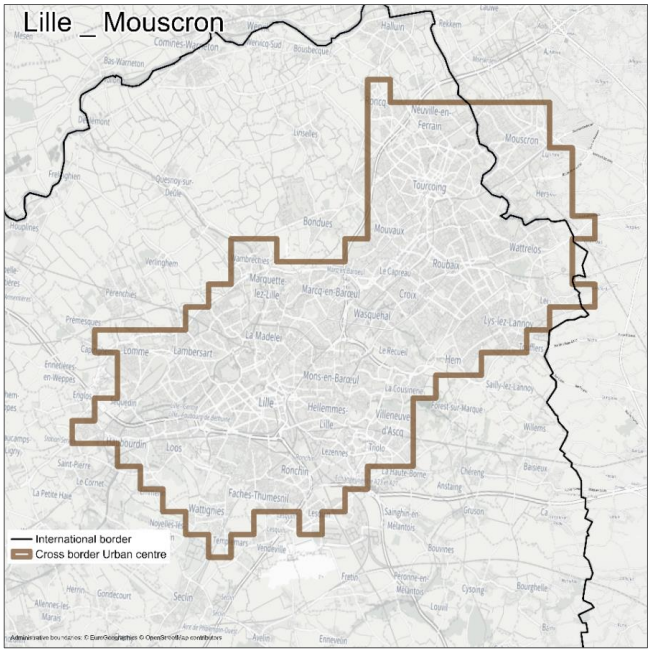
**Aleksandra Galic**

EU and EFTA cities at or near national borders often have deeply interconnected economies, labour markets and services, reflecting the high degree of cross-border integration in these areas. Statistical data collected on these spaces is often limited to regional and national data (which are confined to one side of the border) and diverse local administrative data, resulting in heterogeneous sources and variable definitions, along with insufficient granularity. Eurostat, together with NSIs, initiated a work process in 2021 in order to establish the methodological basis for the definition of cross-border cities and FUAs. This partnership soon became a subgroup of the Regional Statistics Working Group. The main objectives of the subgroup are to establish cooperation and coordination and to facilitate the exchange of experiences and good practices between the Commission and Member States on issues relating to cross-border cities and FUAs with EU/EFTA relevance. Moreover, the subgroup will assist Eurostat in establishing and promoting a harmonised methodology and collaborate to aid the collection, storage and dissemination of statistics on cross-border cities and FUAs.

In the definition of cross-border cities, during the current pilot phase, only the cities that are connected by land borders are considered. Due to its international relevance, the methodology of the degree of urbanisation classification was followed (Eurostat, 2025a). To define a city, first, a cluster of contiguous grid cells of 1 $km^2$ with a population density of at least 1 500 inhabitants per $km^2$ and a collective minimum population of 50 000 inhabitants (high-density cluster or urban centre) is identified. In the case of cross-border cities, the urban centre is calculated across the national land border (**Figure 22**). Concerning LAUs, in order to be part of a city, at least 50 % of their population needs to be in a cross-border urban centre. However, NSIs or countries have the freedom to decide if a particular LAU is part of a cross-border city, depending on national needs.

The result of the EU and EFTA pilot delineation was 11 cross-border cities: Aachen (Germany) / Vaals (Netherlands), Basel (Switzerland) / Saint-Louis (France) / Weil am Rhein (Germany), Como (Italy) / Chiasso (Switzerland), Frankfurt (Oder) (Germany) / Słubice (Poland), Geneva (Switzerland) / Annemasse (France), Görlitz (Germany) / Zgorzelec (Poland), Irun (Spain) / Hendaye (France), Kerkrade (Netherlands) / Herzogenrath (Germany), Konstanz (Switzerland) / Kreuzlingen (Germany), Lille (France) / Mouscron (Belgium) and Strasbourg (France) / Kehl (Germany). These results were based on the population counts in the most recent EU census round, of 2021, and the LAU boundaries of the same year.

**Figure 22.** Example of an urban centre of cross-border city Lille (France) / Mouscron (Belgium).

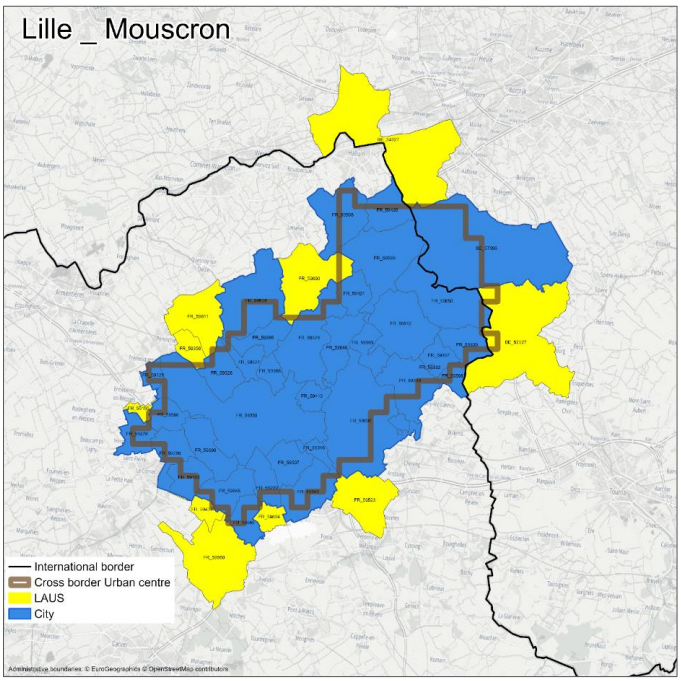



*Source: 2024 data from GISCO (Eurostat).*

The cities are coded using Eurostat's city database nomenclature, taking the general format CBXXXC or CBXXXF, where CB indicates that the territory is a cross-border city, while C and F designate the type of territory: C for city or F for FUA. XXX is a numeral code specific to each city. The codes for the 11 pilot cities have been already proposed and agreed on by the subgroup.

The FUA of a city is composed of an urban centre, defined by a high population density, and a commuting zone, defined by strong functional links through daily commuting flows (**Figure 23**).

**Figure 23.** Example of a cross-border urban centre overlaid on LAUs of the cross-border city Lille/Mouscron.




*Source: 2024 data from GISCO (Eurostat).*

Defining the cross-border FUAs has been an inherently difficult task, due to the need for cross-border commuting data at the LAU level. Where these data exist, there is often a problem in harmonising definitions from different (national) administrative registers. Therefore, adjustments need to be made for data to be comparable. Nonetheless, the research on LAU-to-LAU cross-border commuting flows has been advancing. The delineation of cross-border FUAs has been tested for Basel / Saint-Louis / Weil am Rhein, Como/Chiasso, Geneva/Annemasse, Konstanz/Kreuzlingen, Lille/Mouscron and Strasbourg/Kehl. It is important to note that in these cases the commuting data were extrapolated from administrative registers and are not bound to yearly commuting data.

In further work, some methodological adjustment will be needed, as the definition of employees and commuting flows may differ from country to country. As yearly cross-border commuting data at the LAU level may not be available, the subgroup will discuss the possibilities of aggregating and harmonising data. Moreover, the subgroup will continue to provide support and hold discussions among its members to foster cross-border cooperation. The methodological work on data needs and variable choices for cross-border statistics will be guided by the standards of official statistics while reflecting the realities of cross-border areas.

### 4.2.1. Key takeaways and next steps

- Eurostat's operational definition of cross-border cities and cross-border FUAs applies the degree of urbanisation criteria (≥ 1 500 inhabitants/km$^2$, ≥ 50 000 total population) and incorporates LAUs when at least 50 % of their residents live in a cross-border urban centre, resulting in 11 pilot cases.
- The main limitations result from the scarcity and inconsistent harmonisation of LAU-level cross-border commuting data, largely owing to divergent national definitions of employment and commuting flows, which limit the production of comparable cross-border FUAs.
- Upcoming priorities include standardising commuting registers, harmonising methods for aggregating regular LAU-level flow statistics, expanding the pilot to further cross-border cities and establishing a permanent EU-wide coordination platform to improve the methodology and facilitate data exchange.

## 4.3. Exploring hypothetical cross-border functional rural areas

**Chris Jacobs-Crisioni**

Presently, national borders are still a major obstacle in the lives of EU citizens, especially in border regions. National borders limit commuting (Rietveld, 2001), housing markets (Micheli et al., 2014) and local growth (Jacobs-Crisioni et al., 2017), and prevent cross-border public service uptake. Despite the far-reaching international economic integration achieved within the EU, national borders are still a cause of inefficiencies. The main reasons for the obstacles that borders cause may be, for example, coinciding language differences (Persyn et al., 2015) and uncertainties regarding contract enforcement (Rodrik, 2000).

This section explores a hypothetical functional geography of Europe. This functional geography is a fundamentally 'fuzzy' concept that one may obtain if the Hägerstrandian activity spaces

(Hägerstrand, 1970) of all citizens of Member States and EFTA countries were plotted on top of each other. Some people have large activity spaces; some have smaller spaces. Some activity spaces are very dispersed, while some are very focused on a single point in space. What the spaces mostly share is that, owing to travel times, they are bound geographically around places of residences, and that, according to the available evidence, they are cut quite drastically by national borders. Prior research on local centres (Jacobs-Crisioni et al., 2023) and corresponding FRAs (Dijkstra et al., 2024) offer a pragmatic, discrete characterisation of Europe's rural functional geography.

In this section, we extend existing research on local centres and FRAs by describing functional geographies in the hypothetical case that borders are not an obstacle to functional integration. We then explore potential efficiency gains from functional integration. The work on local centres and FRAs consists of a sequence of spatial analysis steps by which settlements, as defined by degree of urbanisation criteria, are transformed into an inferred hierarchy of central places; subsequently, a set of catchment areas are created around local centres; and, finally, a set of FRAs are created by combining those catchment areas. In earlier studies, only domestic linkages and catchments were considered. In this extension, the consequences of full international integration are mapped for central place hierarchies and FRAs.

### 4.3.1. Cross-border centres

The referenced works start by inferring a hierarchy of settlements, based on settlement population size and travel time to other settlements. We identify three levels of hierarchy and consider a settlement a centre at a certain level if it is the biggest in a specific drive time. We thus identify local centres (which are the biggest in a 15-minute drive), regional centres (30-minute drive) and national centres (60-minute drive). In the reference case, we only compare settlements within a certain driving time if both settlements are in the same Member State or EFTA country. For the purpose of this section, the definition of centres has been extended to take cross-border settlements into account.

We use four variables to identify central places. These are two dummy variables that indicate whether a settlement is the largest within $t$ minutes, either only considering domestic settlements $L(t)^d$ or considering all settlements, both domestic and cross-border $L(t)^a$; and two variables that indicate the total population of settlements within $t$ minutes, either only considering domestic settlements $M(t)^d$ or considering all settlements, both domestic and cross-border $M(t)^a$.

The cross-border dimension of some settlements must be considered. A settlement can therefore be classified as:

- not a centre, so $L(t)^d = 0$;
- a centre far from borders, so $L(t)^d = 1$ and $M(t)^d = M(t)^a$;
- only a centre domestically, so $L(t)^d = 1$ and $L(t)^a = 0$;
- a cross-border centre, so $L(t)^a = 1$ and $M(t)^a > M(t)^d$.

Note that $L(t)^a$ is more restrictive than $L(t)^d$, so that $L(t)^d$ is always 1 if $L(t)^a$ is 1, but the reverse does not hold true – that is, any settlement considered a cross-border centre will always be considered a centre if only domestic markets are concerned, but not all settlements that are considered centres in a domestic-only market would retain their status as centres in the event of full cross-border market integration.

So what would the implications of cross-border market integration be? Table 2 indicates that 90 local centres (0.5 % of all local centres), 81 regional centres (2.0 % of all regional centres) and 46 national centres (4.4 % of all national centres) would lose their central role to a larger centre in the vicinity. This may signal potential efficiency gains, as service providers that benefit from economies of scale (Jacobs-Crisioni et al., 2023) could concentrate in larger cross-border centres, enjoying agglomeration benefits (de Groot et al., 2016).

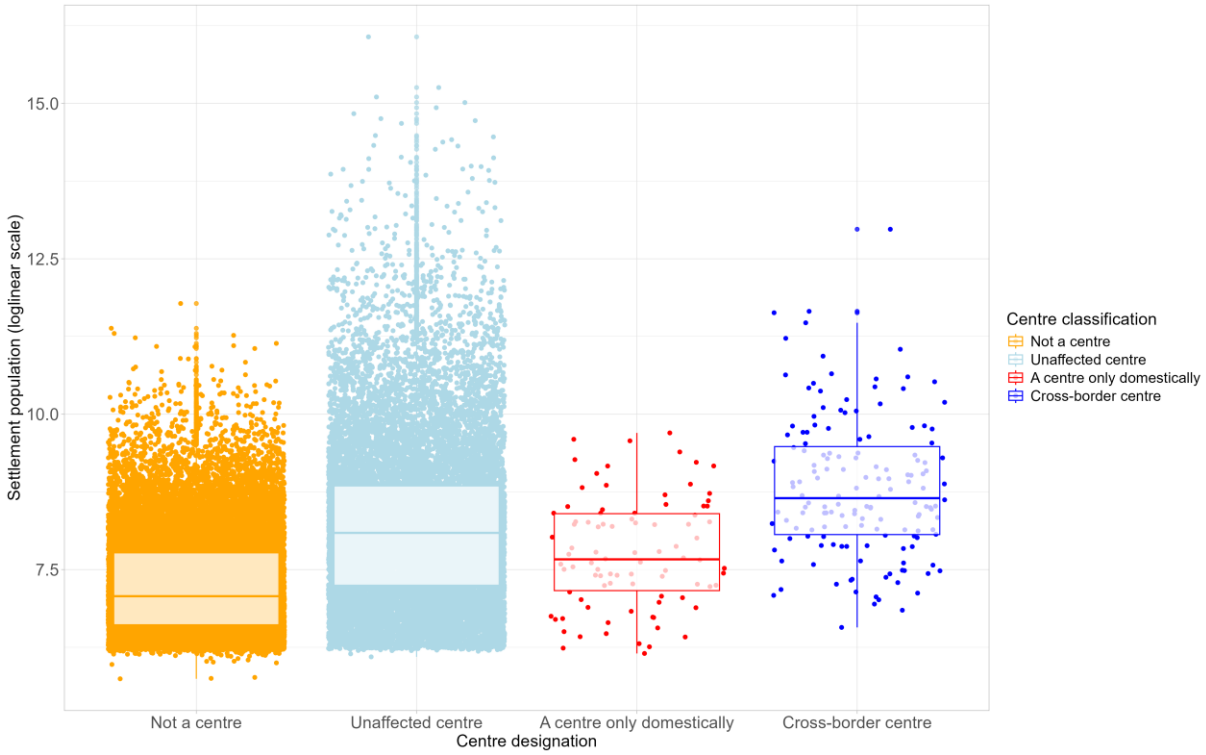
**Table 2.** Total number of domestic and cross-border centres.

| | ***t*** | | |
|---|---|---|---|
| | **15 minutes** | **30 minutes** | **60 minutes** |
| Not a centre | 24 956 | 37 675 | 40 717 |
| Centre far from borders | 16 480 | 3 754 | 817 |
| Only a centre domestically | 90 | 81 | 46 |
| Cross-border centre | 152 | 168 | 98 |

*Source: Author's elaboration.*

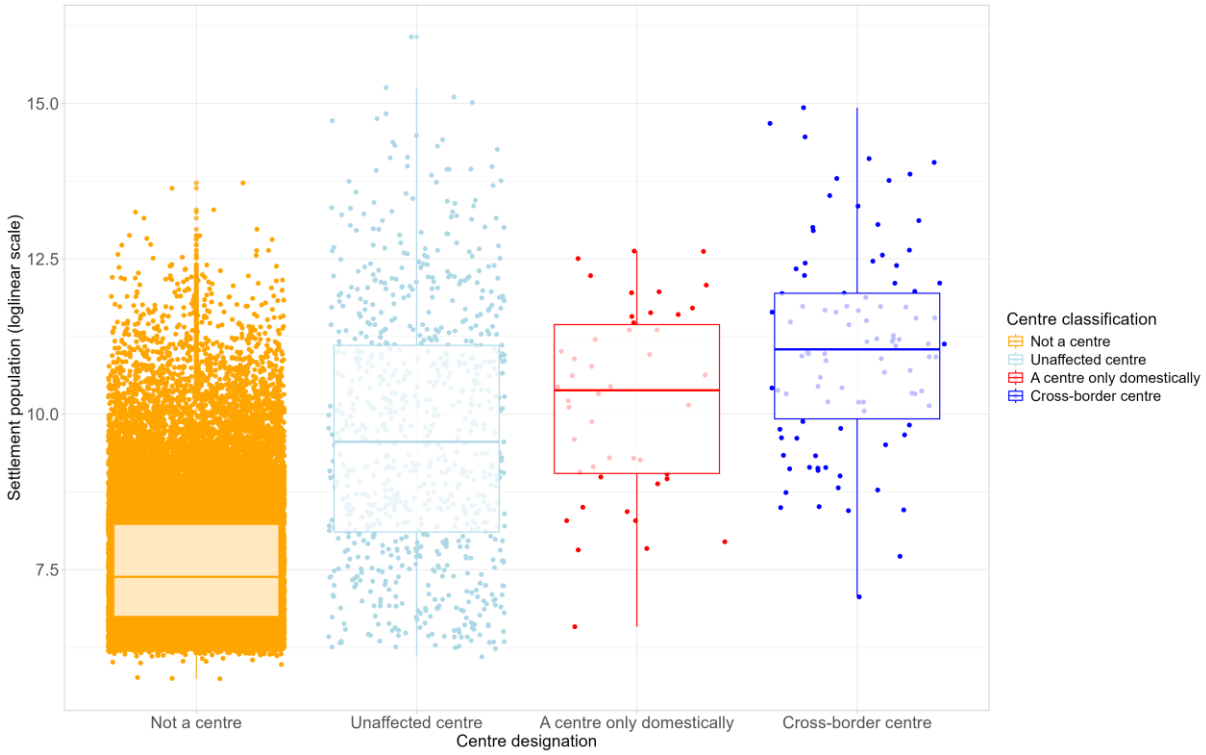
To this end, we plot settlement sizes by their designation (Figure 24, Figure 25 and Figure 26). These plots show that cross-border centres are larger than centres that would lose their status in the event of cross-border market integration. In fact, cross-border centres tend to be larger than the median size of centres far from national borders. This is especially clear in the case of national centres, where cross-border centres are considerably larger. Domestic centres that would lose their central role in the event of cross-border market integration tend to be smaller than those that would not. These centres are small settlements that, in terms of service provision, presumably punch well above their weight.

**Figure 24.** Settlement size by cross-border local centre designation.



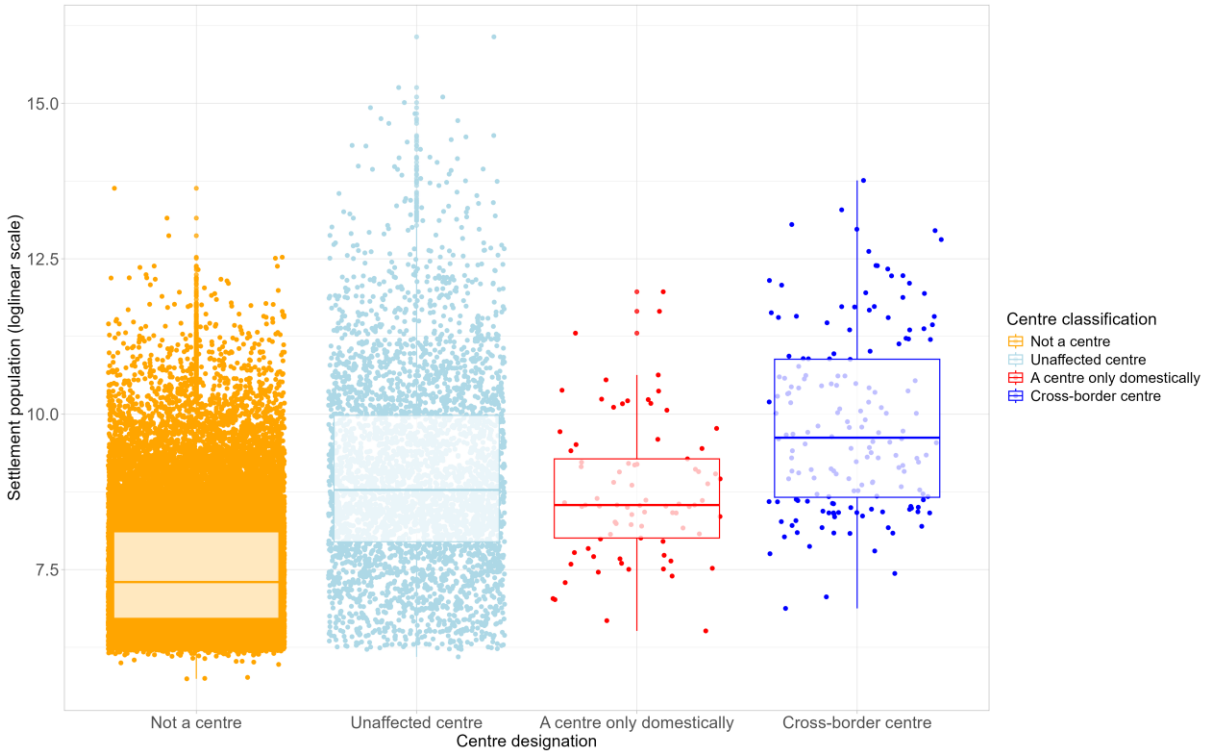

*Source: Author's elaboration.*

**Figure 25.** Settlement size by cross-border regional centre designation.




*Source: Author's elaboration.*

**Figure 26.** Settlement size by cross-border national centre designation.




*Source: Author's elaboration.*

## 4.3.2. Cross-border functional rural areas

The local centres described previously have been used to create FRAs. To this end, local unaffected and cross-border centres (i.e. the biggest in a 15-minute drive) were used to create catchment areas, with geographies only restricted in non-remote EU territories that are not within FUA boundaries, as provisionally provided by Eurostat in June 2025. Subsequently, these catchment areas were combined to create functional areas with a target population of 25 000, with a minimum of 30 minutes and maximum of 60 minutes of driving between 'floating' area centres.

This process yielded 2 750 FRAs. We linked each FRA to a Member State or EFTA country by establishing which state contained the area's geographical centre. We subsequently identified how much of a FRA's surface and population was contained within the country we identified as the central country. This allowed us to perform a rough analysis of the cross-border character of FRAs (**Table 3**). This analysis indicated that the vast majority of FRAs were within national borders. For instance, only 12.5 % of all FRAs created had more than 1 % of their surface area in other countries, and only 2.8 % of all FRAs had more than 25 % in other countries.

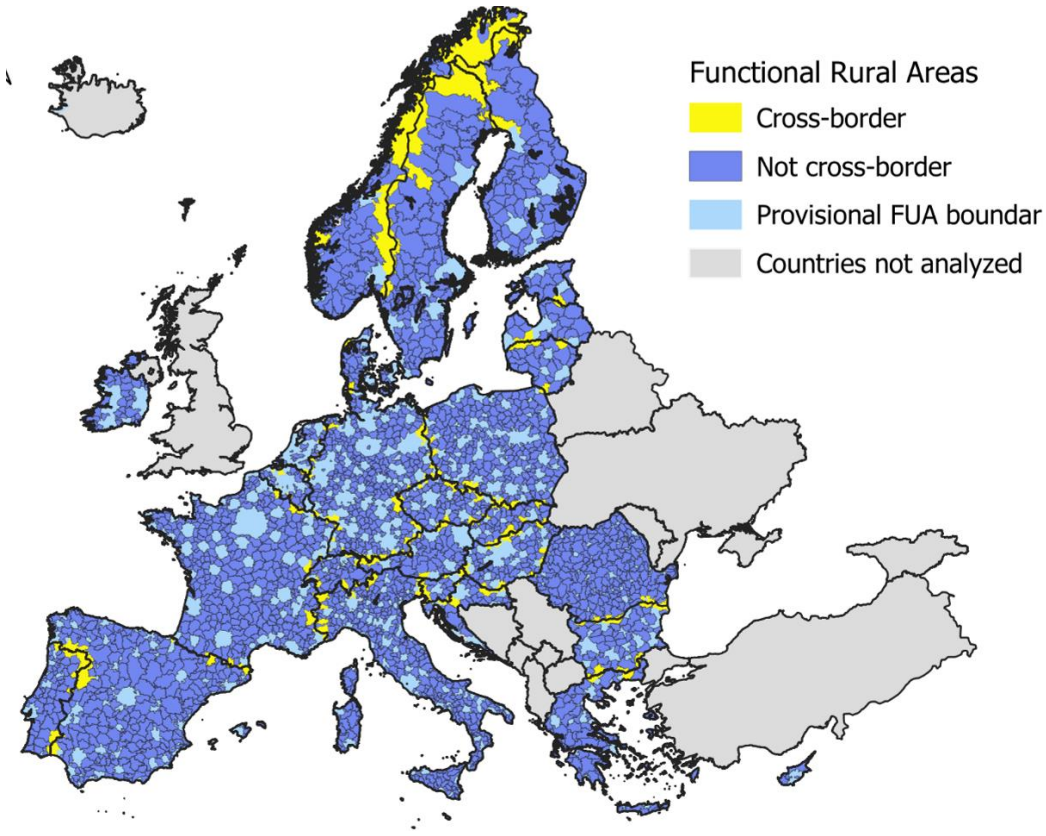
**Table 3.** Cross-border characteristics of FRAs.

| | Number of FRAs (by domestic surface) | Number of FRAs (by domestic population) |
|---|---|---|
| All FRAs (no criterion) | 2 750 | 2 750 |
| < 99 % domestic | 343 (12.5 %) | 269 (9.8 %) |
| < 95 % domestic | 221 (8.0 %) | 166 (6.0 %) |
| < 85 % domestic | 139 (5.1 %) | 88 (3.2 %) |
| < 75 % domestic | 76 (2.8 %) | 62 (2.2 %) |
| < 50 % domestic | 18 (0.6 %) | 25 (0.9 %) |

*Source: Author's elaboration.*

Practically, this means that only a small portion of EU action spaces would change considerably if national borders were completely removed as barriers in daily lives. The cross-border FRAs that provide these action spaces (in one specification from almost endless possibilities) are mapped in Figure 27. In many Member States and EFTA countries, functional integration may allow for better cross-border markets in rural areas. This is the case, for instance, on the Portugal–Spain border; in the north-east of France; at Germany's borders with Austria, Czechia and Poland; and in the border areas between Bulgaria, Hungary, Romania and Slovakia. The north of Scandinavia is also noteworthy, with many functional areas potentially crossing the borders between Finland, Norway and Sweden.

**Figure 27.** Cross-border, FRAs and FUAs in Member States and EFTA countries (current results).




*NB:* All FRAs with at least 10 % of their surface area in other countries are considered cross-border FRAs.
*Source: Author's elaboration.*

### 4.3.3. Key takeaways and next steps

- An experimental analysis of FRAs across the EU's internal borders shows that the 12.5 % of these areas in border regions have more than 1 % of their surface area in a neighbouring Member State or EFTA country. For only 2.8 % of FRAs, this proportion exceeds 25 %, indicating that the majority of rural action spaces remain nationally bounded.
- The existence of cross-border FRAs highlights targeted opportunities for rural market integration, improved service provision and agglomeration benefits, especially along the Portuguese–Spanish, French-German, German-Polish and Nordic cross-border areas.
- The lack of cross-border commuter data regarding rural areas is the main limitation. In addition, infrastructural upgrades such as new cross-border bridges could substantially reshape these results. As a next step, the analysis should be extended to incorporate cross-border FUAs, providing a more comprehensive view of both urban and rural functional integration across EU borders.

## 4.4. Access to healthcare services – a closer look at the EU's internal border areas

**Mert Kompil**

Accessibility is one of the key instruments for assessing EU-wide regional and transport policies, such as the EU cohesion policy (Kompil et al., 2016; Rosik et al., 2015) and the Trans-European Transport Network (Gutiérrez et al., 2011). Providing better and fair accessibility to economic and social opportunities and services in cities and regions is a fundamental component of easing territorial disparities in the EU. Establishing sufficient and affordable access to high-quality services is one of the main goals of EU territorial cohesion and social policy. Therefore, successful territorial and transport policies need to ensure efficient and effective social and economic interactions through the necessary infrastructure. Accessibility analyses inform us about locational advantages or disadvantages of a region relative to others and help us identify adequate/inadequate parts of a transport system. Because of this, accessibility has been widely promoted as one of the most relevant criteria in territorial policy evaluations.

In Europe, there is a growing challenge in terms of providing services in regions and localities that are sparsely populated, scattered and difficult to access (see, for instance, Kompil et al., 2022). Poor access to services reduces quality of life in those areas and worsens economic disparities with urban areas. The importance of this issue is also highlighted in the strategic policy documents of the Commission covering the cohesion policy (European Commission, 2022c), a long-term vision for the EU's rural areas (European Commission, 2021b) and the sustainable and smart mobility strategy (European Commission, 2020).

### 4.4.1. Studying service accessibility in cross-border regions

In terms of social and economic activities, the most attractive places are spatially located at the centre of countries or regions; these include most of the European capitals, like Paris, Rome, Madrid, Brussels and Prague. In general, these places offer the most access to opportunities in

their countries. Cross-border regions usually lack this high level of service provision and social and economic attractiveness, and hence have a lower level of accessibility in terms of available opportunities. Being at the border of a country and, more importantly, facing (potential) restrictions in nearby areas of a neighbouring country plays a significant role in this undesirable situation.

A time series analysis (Jacobs-Crisioni et al., 2017) of municipal population, accessibility and infrastructure in cross-border regions of Western Europe indicates that transport infrastructure supply is not significantly lagging in border areas. However, accessibility only to domestic destinations, and not foreign destinations, has a positive impact on municipal population growth. This means that borders are limiting population growth through a persistent reduction in access to available opportunities; and even if this is not due to the insufficient infrastructure supply, other factors, such as institutional, cultural or linguistic factors, play an important role in creating barriers at borders. Because of this, it is fundamental to support studies that reinforce social and economic interactions between cross-border regions and reconnect sides of the border. An EU-wide service provision and accessibility analysis, at this point, would be very useful in helping us identify whether border regions are lagging behind their domestic and foreign counterparts. The analysis in this section focuses on access to healthcare services and aims to outline the main challenges that cross-border areas may be facing.

### 4.4.2. Data and methodology

To explore spatial access to healthcare services, we needed three main inputs: (a) facility locations, (b) a gridded population distribution and (c) a detailed view of the road network, to measure road distances and driving times separating facilities from their users. All three inputs have recently been produced and/or updated, as indicated below.

Healthcare services in Europe (Eurostat, 2023) were investigated as follows.

- The main healthcare services were considered to be 'hospitals' by Member States (usually ministries of health). There are more than 11 000 hospitals in the dataset – one hospital for every 38 000 people on average.
- Definitions vary slightly from country to country. Some countries also provide information on emergency services and numbers of hospital beds, etc.
- EU, EFTA and some non-EU countries are included. In the current exercise, only Member States are studied.

The distribution of the European population in 2021 (Eurostat, 2025b):

- is based on 1 $km^2$ grids covering the territory of the EU plus Liechtenstein, Norway and Switzerland;
- was slightly adjusted to match with regional and national population totals, using more recent population data from Ardeco.

The streets and routing dataset from TomTom (2023):

- provides a detailed transport network with proper road and driving restrictions, traffic conditions and speed profiles, etc.;
- covers EU, EFTA and neighbouring countries.

We calculated average road distance and driving times to healthcare services at 1 $km^2$ grid level and aggregated them by cross-border area EU-wide. We used 25 km-wide border areas for the 27 Member States. Finally, our main indicator became average driving time per person to the nearest healthcare service (hospital), calculated for 72 EU-to-EU border areas.

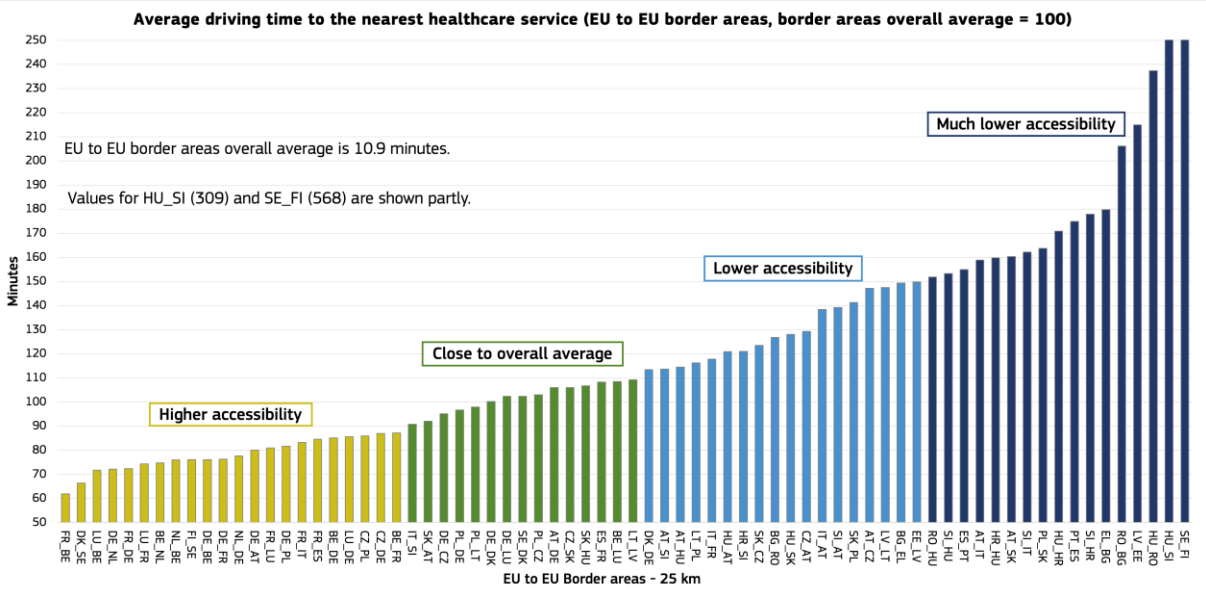
### 4.4.3. Results

In Europe, service provision and accessibility differ between urban and rural areas. In general, accessibility is higher for lower-order services (e.g. primary schools, retailers) and lower for higher-order services (e.g. hospitals, cinemas). The gap between urban and rural areas increases through lower order services to higher order services. Healthcare services or hospitals are among those higher-order services where the urban–rural difference is quite large.

According to our EU-wide analysis with a recently updated dataset, average driving time to a healthcare service or hospital is 5 minutes in cities, 10 minutes in towns and 17 minutes in rural areas. Overall, EU-wide average driving time is 10.5 minutes. Cross-border areas have a slightly higher average driving time, at 10.9 minutes (4 % more).

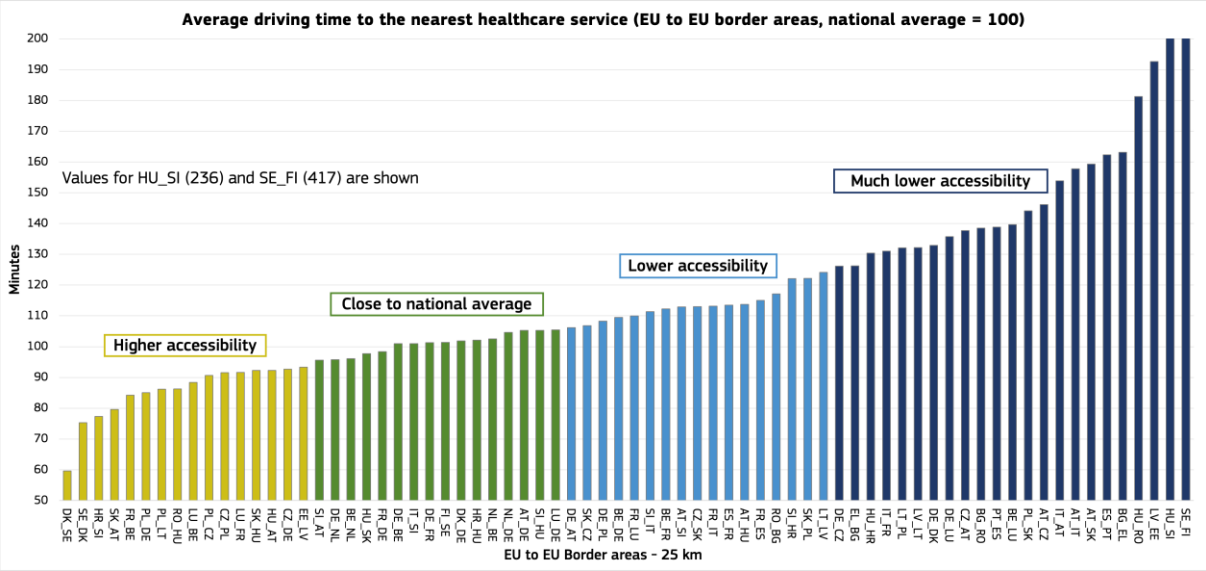
Average driving time to the nearest hospital for each border area is shown in **Figure 28**. Each direction of travel is given separately; for example, Belgium–France and France–Belgium are both given. For simplicity and better comparability, the overall average for EU border regions is set at 100. According to the data, border regions like France–Belgium, Denmark–Sweden, Luxembourg–Belgium, Germany–Netherlands, France–Germany and Luxembourg–France have higher accessibility levels (lower average driving time to reach a hospital). Border regions with much lower accessibility levels include Sweden–Finland, Hungary–Slovenia, Hungary–Romania, Latvia–Estonia, Romania–Bulgaria and Greece–Bulgaria. **Figure 29** shows accessibility levels, this time compared with national averages. It shows that the Denmark–Sweden, Sweden–Denmark, Croatia–Slovenia, Slovakia–Austria, France–Belgium and Poland–Germany border regions have higher accessibility levels than the national averages. Border regions with much lower accessibility levels than their countries as a whole include Sweden–Finland, Hungary–Slovenia, Latvia–Estonia, Hungary–Romania, Bulgaria–Greece and Spain–Portugal. The distribution of accessibility levels is also shown in **Figure 30**, which gives the same information spatially.

**Figure 28.** Average driving time to the nearest healthcare service in the EU's border areas.



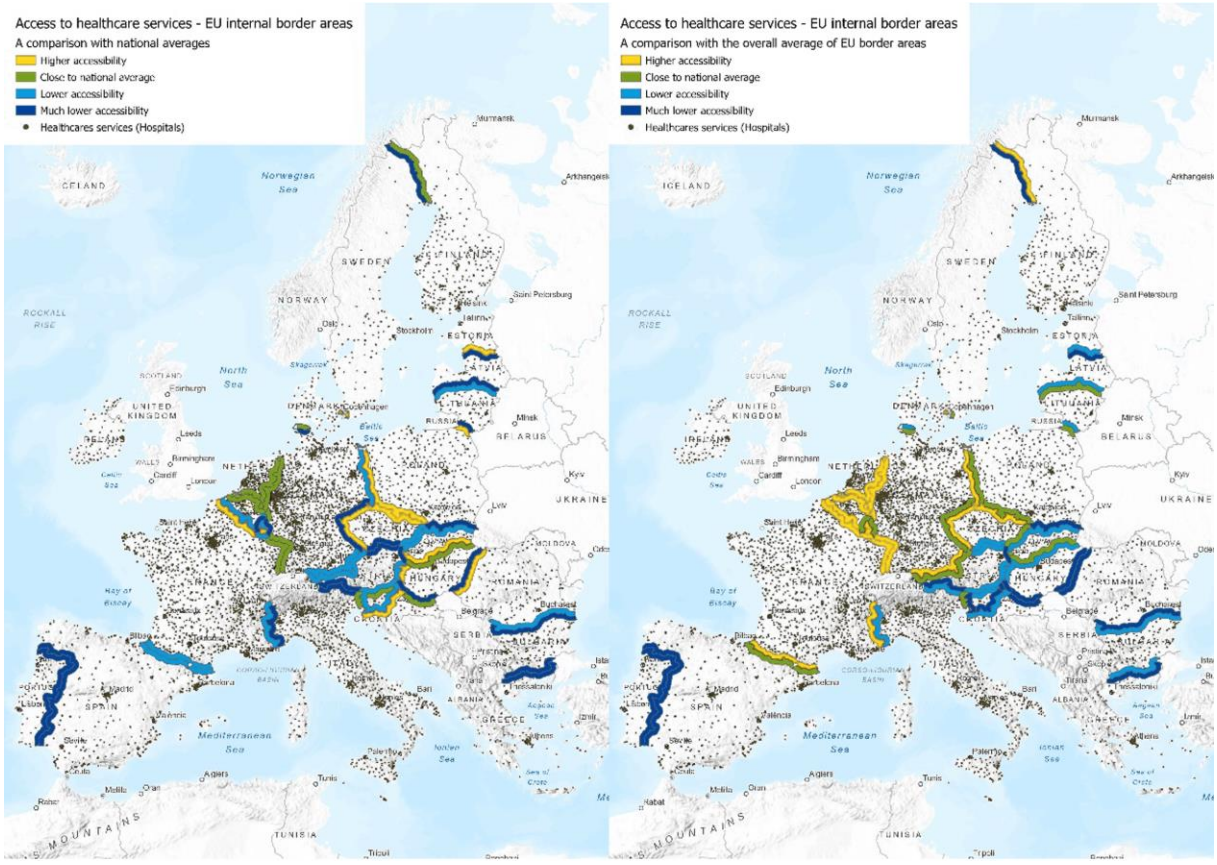

*NB:* The overall average of border areas is taken to be 100.
*Source: Author's elaboration.*

**Figure 29.** Average driving time to the nearest healthcare service in the EU's border areas.




*NB:* The national averages are taken to be 100.
*Source: Author's elaboration.*

**Figure 30.** Access to healthcare services in the EU's internal border areas compared with the national (A) and EU border area (B) averages.

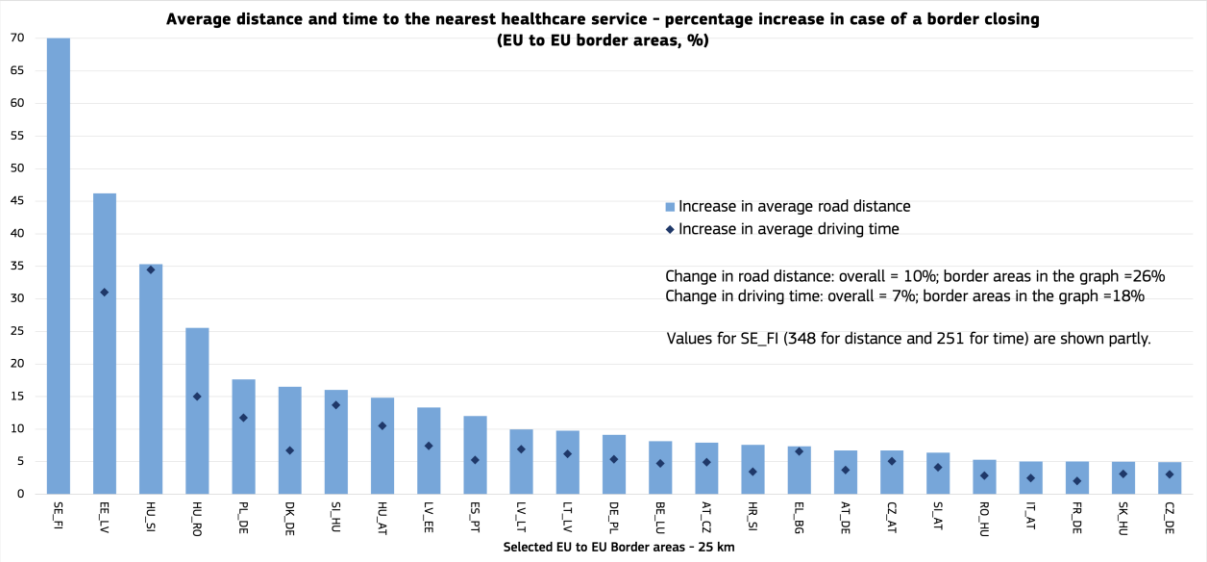



*Source: Author's elaboration.*

In another type of analysis, we tested a 'what if' scenario for border areas. **Figure 31** shows the increase (% change) in average road distance and average driving time to the nearest healthcare service in the event of a border closing.

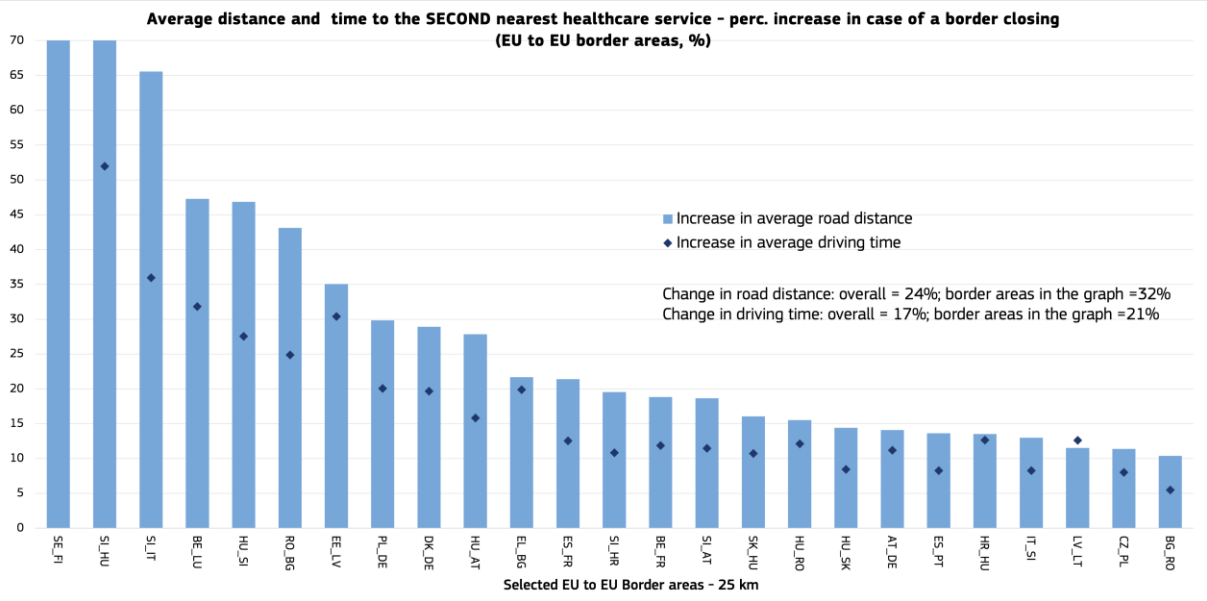
According to this, the Sweden–Finland, Estonia–Latvia, Hungary–Slovenia, Hungary–Romania, Poland–Germany and Denmark–Germany border areas are among those seeing the highest increase in average distance and driving time. When borders are closed (for any reason), overall average distance by road and driving time to the nearest hospital increases by 10 % and 7 %, respectively, in border areas. As shown in **Figure 32**, this increase becomes more dramatic when average distance and driving time to the second-nearest healthcare service is calculated – an increase of 24 % for average distance and 17 % for average driving time. In this exercise on healthcare service accessibility, the figures once more underline the importance of policies that support cross-border cooperation and territorial integration.

**Figure 31.** Increase in average distance and time to the nearest healthcare service in the event of a border closing (EU-to-EU border areas, %).




*Source: Author's elaboration.*

**Figure 32.** Increase in average distance and time to the second-nearest healthcare service in the event of a border closing (EU-to-EU border areas, %).




*Source: Author's elaboration.*

## 4.4.4. Key takeaways and next steps

- Access to healthcare services is a major issue for residents of EU border areas, making the identification of functional healthcare regions a priority for policymakers. Data-driven methods that combine hospitals' location, high-resolution population grids and detailed road network datasets provide a robust, measurable way to estimate average road distance and driving time to the nearest healthcare facility.

- The EU-wide analysis shows that people living in border areas (in a 25 km buffer zone from the border) are slightly less well served, with an average of 10.9 minutes compared with non-border regions. A border closure scenario would increase the average distance by 10 % and driving time by 7 % to the nearest hospital, and by 24 % and 17 %, respectively, to the second-nearest facility, underscoring the fragility of cross-border healthcare accessibility.
- Further improvement could enhance the analysis, for example, by including all healthcare services in EU border regions; however, a shared definition and differing coverage are challenges. In addition, considering hospital register data on cross-border patient mobility would allow the results to be contrasted and refined.

## 4.5. Gravity models to assess potential interactions between border regions

**Andrius Kučas**

Why does regional connectivity matter? Regional development depends not just on physical proximity, but also on functional integration – how people, services and economies interact across space. As European regions grow increasingly interdependent, understanding these invisible connections becomes essential for effective spatial planning and policy design. Traditional administrative maps show borders; our approach goes further by showing how strong or weak the real-world links between regions are.

Quantifying the invisible ties is crucial because borders shape daily life, but not always visibly. A gravity-based model allows us to measure the invisible ties – how people, services and ideas flow across space. It helps change policy from reactive to proactive, by identifying opportunities for integration long before issues arise. This method turns abstract ideas like regional cooperation into measurable potential and real indicators. It is a tool for planners, policymakers and researchers alike, because it is easy to understand and powerful when applied. In an EU striving for unity, the question is not just where the borders lie but how strong the ties across them really are.

This section applies a gravity model approach to assess interaction potential at the LAU level across three cross-border areas, exploring how population size, geographical distance and administrative structure influence regional cohesion in three border regions:

- Lithuania–Latvia–Estonia;
- Bulgaria–Romania;
- Sweden–Finland.

### 4.5.1. Model concept, enhancement and implementation

#### The model concept

Gravity models have to be made simple. We use a well-known spatial interaction tool: the gravity model derived from Newtonian physics (Rowe et al., 2024). In our context, it estimates the potential for movement, cooperation or service sharing between two LAUs based on the following equation:

$$G_{ij} = \frac{P_i * P_j}{d_{ij}^2}$$

where:

- $P_i$ and $P_j$ are the populations of LAUs *i* and *j*;
- $d_{ij}$ is the distance between their centroids.

This base equation provides a raw interaction score, a proxy for how connected two areas are likely to be.

#### The model enhancement

Cross-border relationships are not just shaped by geography – they are influenced by policies, culture and infrastructure. For instance, to capture this phenomena, we can introduce a cross-border permeability coefficient:

$$G_{ij} = C_{ij} \frac{P_i * P_j}{d_{ij}^2}$$

where, for example:

- $C_{ij}$ of 1 indicates fully open borders;
- a $C_{ij}$ of 0 represents a closed or impermeable border.

Values between 0 and 1 may reflect partial openness (e.g. good transport but low cultural ties).

This enhancement allows policymakers to simulate how changes in policy, infrastructure or cooperation may affect regional connectivity.

#### The model implementation

Implementing the model requires the following steps.

1. **Identification of neighbours.** Using spatial analysis, we determine which LAUs are direct neighbours – both within and across borders.
2. **Gravity calculation.** We compute gravity-based interaction values for each pair of neighbouring LAUs.
3. **Post-processing:**
   - sum the values to get total interaction strength for each LAU;
   - normalise scores between 0 and 1 to ensure comparability;
   - visualise the results by shading LAU regions based on interaction strength.

This creates a heatmap of functional integration, highlighting regions of strong and weak connectivity.

### 4.5.2. Case studies

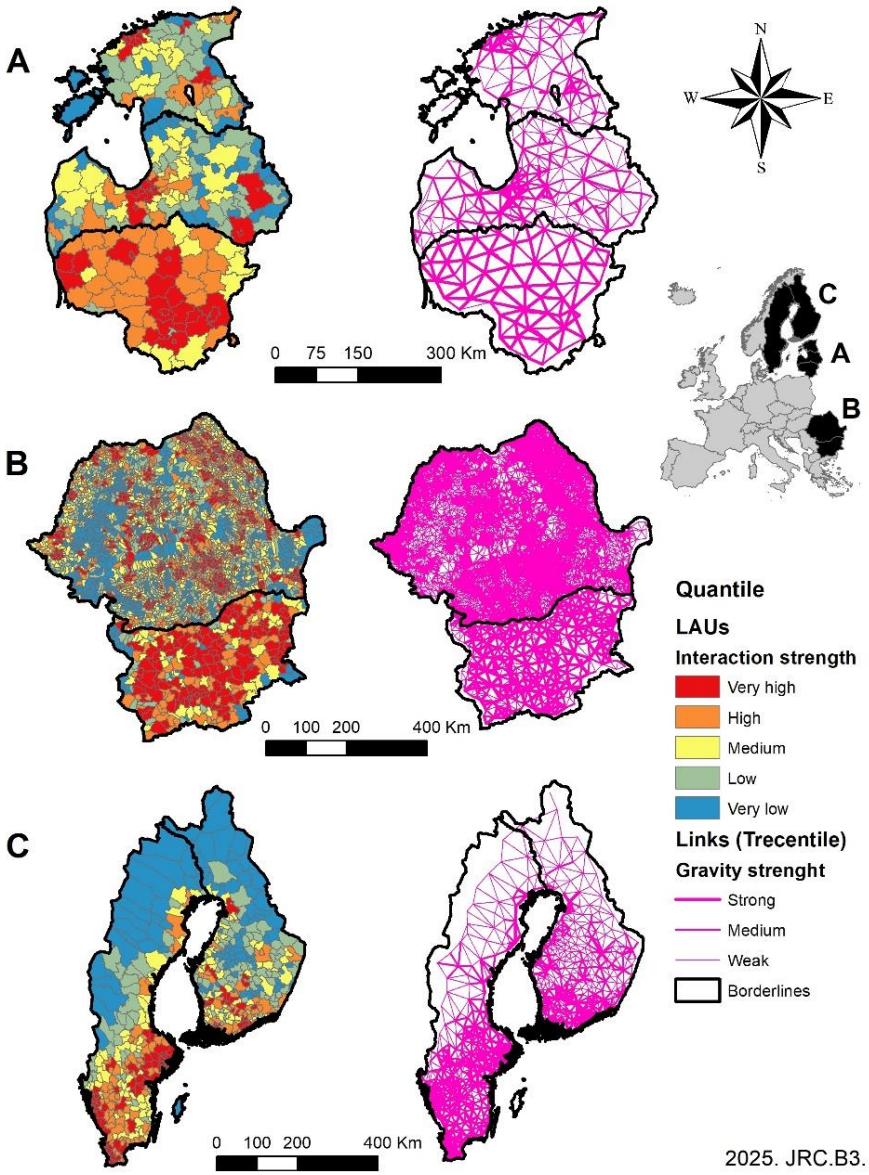
Three areas were selected as case studies. Population data were collected at the LAU level, and gravity model tests were conducted. The results are presented in **Table 4** and spatially in **Figure 33**.

**Table 4.** Population integrity patterns of case study areas (see **Figure 33**).

| Regions | Observations | Effect | Policy insight |
|---|---|---|---|
| A. Lithuania–Latvia–Estonia | Highly fragmented LAU systems (many small units) in Estonia and Latvia, with moderate fragmentation in Lithuania. | Lower cohesion, with more localised interactions in Estonia and Latvia and less localised interactions in the Lithuania–Latvia border region. | Integration efforts need to overcome both administrative fragmentation and border barriers. Investment in shared services and cultural programmes could improve cohesion. |
| B. Bulgaria–Romania | High fragmentation in Romania, but moderate fragmentation in Bulgaria. Physical barriers like the Danube reduce permeability. | Even when populations and distances are favourable, lack of infrastructure (e.g. bridges) reduces actual connectivity. | Infrastructure investment – for example in bridges and transport corridors – could significantly increase $C_{ij}$ values, enhancing regional integration. |
| C. Sweden–Finland | Larger LAUs in the north of both countries, with more cohesive spatial patterns in the south. Countries have strong cultural and institutional ties. | Higher normalised gravity and similar gravity values on the borderline, with smoother integration across borders. | A shared cultural and political history enhances cross-border potential. Local cooperation platforms (e.g. Sami region governance) offer models for other regions. |

*Source: Author's elaboration.*

**Figure 33.** Gravity model results for the three case study areas.




*Source: Author's elaboration.*

### 4.5.3. Key takeaways and next steps

Administrative fragmentation weakens interaction strength; coordinating LAUs can improve cross-border integration, and distance alone does not ensure connectivity when borders act as impermeable filters.

Borders operate as filters rather than binary open/closed barriers. Understanding and enhancing permeability through transport links, cultural ties and legal frameworks, and investing in infrastructure such as bridges and public transport, can convert physical links into functional connections.

Policymakers can use gravity model metrics to identify under-connected areas for regional development action, prioritise EU funding where latent interaction is high but permeability is low and monitor integration over time while tailoring border policies to combine administrative cooperation, infrastructure upgrades and cultural programmes.

# 5. Data interoperability challenges for cross-border regions

**Davide Auteri, Carmelo Attardo and Andrius Kučas**

In the EU, border regions act as living laboratories of integration. They reflect, in their complexity, the balance between diversity and unity that defines the EU project. Yet this balance is not merely political or cultural; it is also digital. The capacity of institutions, platforms and data systems to communicate, exchange and make use of information across borders determines whether cross-border cooperation can be evidence-based, efficient and future-oriented. In this context, the interoperability of data is not only a technical requirement – it is also a fundamental enabler of territorial cohesion and of the data-driven governance envisaged by the European Commission.

Interoperability, as defined by the European interoperability framework ([14]), international standards such as ISO/TC 211 ([15]) and the Infrastructure for Spatial Information in the European Community Directive ([16]), refers to the ability of computer systems or software to exchange and make meaningful use of information (INSPIRE, 2008; Tóth et al., 2012). In cross-border contexts, this seemingly simple principle becomes a multidimensional challenge. Each Member State produces, structures and governs data within its own administrative, linguistic and legal framework. When data must flow across borders for initiatives such as the data hub for EU border regions ([17]), inconsistencies in content, structure and metadata accumulate. The task of harmonising them – without losing semantic accuracy, spatial precision or legal meaning – demands a shared digital 'grammar' for Europe's borders.

The data hub for EU border regions, developed jointly by DG Regional and Urban Policy and the JRC, represents an ambitious step towards such a 'grammar'. Its objective is to collect harmonised geospatial data and socioeconomic indicators describing interactions across forty internal land borders. By integrating datasets from NSIs, regional administrations, EU agencies and research institutions, the hub aims to transform fragmented information into a coherent framework for comparative analysis. However, the process of transforming raw data into interoperable indicators is arduous. Differences in georeferencing systems, the coding of administrative units (NUTS, LAU), file formats and update frequencies require continuous conversion, conformance testing and validation. Every conversion, however, risks a loss of accuracy, whether through rounding errors, the generalisation of geometries or the simplification of attribute structures. Thus, one of the first interoperability challenges is epistemic: how can we translate data without diluting the knowledge embedded in their original form?

Metadata play a decisive role in mitigating this risk. Without rich, standardised metadata, even correctly formatted datasets can be misinterpreted or misaligned. Metadata not only describe the content and structure of data; they also capture the conditions of their production – their temporal validity (ISO/TC 211, 2002), methodology (ISO/TC 211, 2014), quality constraints (ISO/TC 211,

([14]) https://ec.europa.eu/isa2/eif_en
([15]) http://iso.org/committee/54904.html
([16]) https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32007L0002
([17]) https://territorial.ec.europa.eu/across?lng=en&ctx=ACROSS

2022) and lineage. In a multilingual and multi-jurisdictional environment, metadata also act as the semantic glue that binds together otherwise incompatible datasets.

In the age of AI and automated analytics, interoperability challenges have acquired new dimensions. Machine learning models are ingesting vast volumes of structured and unstructured data to detect cross-border patterns. However, the performance of AI models depends on the consistency and comparability of the input data. Ensuring that data pipelines respect common ontologies and standards has therefore become a technical imperative. Moreover, in the context of the General Data Protection Regulation and the Data Governance Act ([18]), cross-border data sharing must comply with stringent privacy rules, particularly when datasets involve personal or location-based information (e.g. mobile data).

The proliferation of unconventional data sources further complicates the picture. Traditional statistical data – censuses, labour records and administrative registries – are now complemented by non-traditional sources such as mobile phone traces, transport sensor networks, social media and web-scraped content. As this report underlines, these new data streams can illuminate aspects of cross-border mobility that conventional sources overlook. Yet their integration into official data infrastructures raises methodological and legal challenges. Web scraping, for instance, can provide real-time insights into cross-border job postings, housing markets or public services, but the variability of website structures, the volatility of online content and intellectual property restrictions demand careful harmonisation. AI-assisted web scraping may automatically extract structured information but, without interoperability at the semantic level, the meaning of that information remains fragmented. Harmonising and testing these sorts of unconventional data require not only technical standardisation but also conceptual alignment (Baker et al., 2007; ISO/TC 211, 2000; Lopez-Pellicer et al., 2014; Tóth et al., 2018) and an explicit ontology (Hess et al., 2006) that defines what constitutes, for instance, a 'cross-border event,' a 'functional cross-border area', or a 'commuting flow' across different datasets.

Data harmonisation processes in the data hub for EU border regions exemplify the complexity of achieving interoperability in practice. Datasets are available in diverse formats, requiring various types of conversion or aggregation to present their information in harmonised and comparable spatial units such as NUTS 3 border regions or buffer zones based on a distance from the border (e.g. 25 km). The design and maintenance of harmonised data have to be well planned for the data to be explicit and replicable. Designing these harmonisation processes have a cost, but designing them in terms of open standards and services ensures the replicability of these processes, the maintenance of source data by their producers and the provision of services and connectors that are able to be federated with others.

However, technical harmonisation alone cannot solve the problem. Institutional interoperability – aligned mandates, workflows and access rights – is equally necessary. The Border Focal Point Network ([19]) and programmes launched under the Interreg initiative ([20]) exemplify how cross-administrative dialogue can support the alignment of data. The creation of shared data governance frameworks, including common data quality protocols and joint metadata repositories, allows for more resilient cooperation. Ultimately, interoperability is not achieved through technology alone but through trust among data providers – a trust built on transparency, reciprocity and shared benefits.

([18]) https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32022R0868

([19]) https://futurium.ec.europa.eu/en/border-focal-point-network

([20]) https://interreg.eu/programmes

Another crucial challenge lies in maintaining interoperability over time. Datasets evolve, administrative codes are revised and standards are updated. Temporal interoperability – the ability to compare data across versions of a dataset – requires careful versioning and documentation. In Ardeco ([21]) and the territorial data platforms ([22]), the continuous processing of updated datasets necessitates validation mechanisms that flag inconsistencies in spatial boundaries, attribute names or units of measurement. Machine-readable feature-level metadata linked to persistent identifiers can support this process. Interoperability, therefore, is not a static achievement but a dynamic practice – an ongoing negotiation between data stability and change.

Establishing pan-European validation services and open-source transformation tools can reduce discrepancies and democratise access to data. The goal is to create an ecosystem where accuracy is preserved not by avoiding transformation but by making it transparent, traceable and reversible (Tóth et al., 2016).

From the broader perspective of EU cohesion policy ([23]), interoperable data systems underpin evidence-based policymaking and accountability. However, achieving this vision requires continued investment in data literacy, metadata governance and the collaborative development of ontologies and standards. Interoperability requires collaboration between geographers and computer scientists, between policymakers and data engineers, and between local actors and European institutions. Only through such multidimensional cooperation can the potential of the data hub for EU border regions be fully realised.

## Key takeaways

- The challenges in creating data interoperability for cross-border regions are not mere technicalities – they are the scaffolding for building EU integration in the digital age. As new data sources proliferate and AI transforms analytical practices, maintaining coherence, accuracy and trust across borders becomes ever more vital.
- A clear separation between observed data and their derivatives is crucial to avoid losing clarity and direction in the expanding sea of algorithmic outputs. Focusing on verifiable observed values anchors analyses in reality and safeguards meaning in the age of AI.
- The capacity to exchange and make use of information faithfully, securely and meaningfully is what enables border regions to function as truly shared living spaces. In the intertwined landscapes of Europe, interoperability is the invisible infrastructure that keeps cooperation alive.

([21]) https://territorial.ec.europa.eu/ardeco?lng=en
([22]) https://territorial.ec.europa.eu/?lng=en&ctx=udp
([23]) https://ec.europa.eu/regional_policy/policy/what/investment-policy_en

# 6. Conclusions

**Matteo Berzi and Benedikt Herrmann**

The evidence gathered in this report confirms that high-quality, fine-grained data on cross-border movements are a prerequisite for designing more effective policies in EU border regions. Flow data are therefore an essential foundation for understanding and conceiving of border regions as living spaces in which multiple interactions occur and distinct functions can be mapped.

Traditional administrative statistics – such as demographic registers, business databases and socioeconomic indicators – were created for domestic analyses and consequently lack the spatial and temporal resolution required to capture functional area dynamics, as the French case demonstrates. Nevertheless, a number of under-exploited resources have been identified; the cross-border data collection project, for example, shows how a targeted effort to uncover cross-commuter information hidden in public registers can unlock valuable evidence. Translating this potential into usable knowledge calls for dedicated funding and coordinated efforts to clean, harmonise and publish data at the regional and local cross-border levels. The proactive stance of countries such as Germany illustrates how national commitment can set a benchmark for others, encouraging the systematic monitoring of inbound and outbound flows within a legally defined and methodologically consistent framework. GTFS data represent a valuable source of transport-focused information. When GTFS feeds are available on both sides of a border, they enable the construction of time-based accessibility maps and origin–destination matrices that capture the connectivity of public transport across national boundaries. By linking GTFS schedules with road networks and points of interest, analysts can model the multimodal accessibility of jobs, schools, hospitals or administrative centres and quantify the share of the population who can reach these services within given travel time thresholds. Although the quality and harmonisation of data remain challenges – feeds differ in coverage, update frequency and level of detail – the open-standard nature of the GTFS makes it a uniquely comparable source for cross-border transport analysis.

All these sources can be further enriched and complemented by surveys. Surveys constitute a complementary pillar for these data: by asking individuals directly, they reveal the motivations behind cross-border commuting – whether it is for work, study, shopping or leisure – and can map precise routes, border-crossing points and the frequency of travel. This level of detail, unattainable from aggregated registers, enables policymakers to tailor interventions to the specific motivations and obstacles that shape daily mobility. Moreover, the adaptability of questionnaire design allows researchers to introduce new questions at short notice, for example to investigate perceived border-related difficulties, thereby enriching the evidence base with timely, context-specific insights. The challenges associated with conventional sources – limited data availability, uneven geographical coverage, divergent definitions and reference periods across Member States, and legal constraints on data sharing – can be mitigated by turning to innovative, non-traditional methodologies that capture previously hidden cross-border flows with greater accuracy and granularity in key policy domains such as the labour market, demographic change and public service accessibility.

MNO records provide near-complete coverage of population movements at a spatial resolution finer than 100 $m^2$ and a temporal resolution of minutes, revealing daily commuting, shopping and leisure trips that are invisible to traditional registers. Geolocated social media traces, when processed through KDE, generate high-frequency density maps that differentiate weekday work-related travel

from weekend leisure flows. Finally, web-scraped short-term rental listings offer a strategic view of the structural and institutional dimensions of cross-border flows by mapping tourism-related housing capacity across border municipalities. All three sources have specific limitations – notably in relation to spatial and temporal precision, acquisition and processing costs and, for MNO data, privacy-related restrictions – which must be carefully considered when constructing robust indicators.

Nonetheless, complementing conventional statistics with these novel data streams allows for the collection of multidimensional, high-resolution evidence to better understand the multifaceted geographies of functional cross-border regions. From a policymaking perspective, combining traditional administrative statistics with novel, non-traditional data streams allows for a clearer assessment of regional functionalities and the identification of hidden cross-border geographies. The EU-wide Crossgov study shows how a multidimensional approach can delineate functional border regions by integrating a broad set of indicators. Targeted gravity-based models further refine these estimates at a granular level: by using population size and the distance between centres, cross-border FRAs can be defined, while the availability of commuting-zone data enables the mapping of cross-border FUAs. Adding hospital accessibility analyses – based on road network data, population distributions and the hospitals' locations – can guide the siting of healthcare facilities and improve cross-border service access. The precision of all these estimates can be enhanced by incorporating a cross-border permeability coefficient that captures policy-related factors such as cultural ties, governance arrangements, linguistic barriers, infrastructure investments and overall border openness, making the gravity model more realistic and useful for targeted regional policies.

The pathway to mapping cross-border flows with the required granularity, systematic coverage and accuracy remains long, and it calls for a continued broadening of both quantitative and qualitative data streams so that the 'living space' concept can be examined in greater depth. High-resolution remote sensing products, such as night-time light imagery, can be processed into detailed maps of economic intensity, allowing analysts to track how commercial activity expands, contracts or shifts over time on either side of a border. Complementary traffic-monitoring technologies (e.g. systematic vehicle counts at secondary-road border-crossing points) would provide near-real-time indicators of local functional connectivity, revealing peak-hour bottlenecks and seasonal or event-driven fluctuations that are invisible in counts taken only on major roads. A recent pilot in the Lake Constance cross-border region demonstrates how micro-level traffic data can expose the everyday mobility patterns of residents who otherwise travel on routes that bypass the border entirely.

Beyond pure flow metrics, a fuller picture of border regions requires the integration of the institutional dimension of cross-border flows. Formal cooperation arrangements documented in EU-wide programmes and actions (e.g. keep.eu, the B-solutions initiative or the resilient borders project) should be systematically coded and merged with movement data to show how regulatory, funding and governance networks reinforce or impede spatial interactions. Equally important are informal links – local business alliances, cultural associations and civil-society initiatives – which can be captured through the network analysis of partnership registers or targeted stakeholder surveys. Additionally, qualitative analysis can enrich quantitative flow maps by adding semantic insights. The text mining of policy documents, local news outlets and social media feeds can uncover the narratives that shape cross-border identities and a sense of belonging, enabling researchers to test whether perceived borders correspond to observed mobility patterns.

Finally, GeoAI offers a powerful toolbox for synthesising these heterogeneous datasets. Deep learning models for spatial and temporal interpolation, multimodal data fusion pipelines and graph neural network representations of cross-border networks can reconcile differing spatial resolutions,

fill data gaps and generate predictive scenarios. Such scenarios can inform policy decisions on where to invest in cross-border transport infrastructure, how to target Cohesion Fund allocations and which regulatory adjustments would most effectively enhance integration.

Although this report focuses mainly on the EU's internal border regions, the methodological and data availability challenges it highlights apply worldwide. BIG_Lab treats the 'dyad' – the shared territorial line between neighbouring countries – as its unit of analysis, offering a single, standardised perspective that enables the comparison of global borders. Integrating this approach with European regional methodologies is analytically and methodologically demanding and requires further investigation. As a first step, the data hub for EU border regions provides aggregated information at the borderline level for specific datasets. Expanding data collection and harmonisation beyond the EU should involve international organisations such as the Organisation for Economic Co-operation and Development (and the wealth of data contained in its Local Data Portal), data providers including United Nations agencies and the World Customs Organization, and research networks like the Association for Borderlands Studies.

In conclusion, delivering accurate, reliable and integrated data on cross-border flows remains a major research challenge, yet these data are strategic assets for evidence-based decision-making in EU border regions. The persistent gap between academic research and EU policymaking on cross-border cooperation must be narrowed. Although both spheres share the common goal of improving citizens' lives, they operate with divergent approaches, terminologies and dissemination channels. Consequently, their bridging should be promoted through the joint production of grey literature, shared participation in forums and the development of common data infrastructures, which could help turn numerous unanswered policy questions into actionable knowledge. The ACROSS project has been created as a framework for bridging this gap and bringing academia and policy agendas closer together. By consolidating the datasets of the DG Regional and Urban Policy inventory into a single, openly accessible data hub for EU border regions, the project provides a comparable set of high-quality, granular and georeferenced indicators and visualisations that can be readily used by policymakers, public authorities and researchers. The platform not only supplies data to support cross-border analysis but also offers a space that can be continuously enriched with new information on existing and potential cross-border interactions, thereby fostering evidence-based cooperation and more integrated development in EU and EFTA border regions.

In this spirit, DG Regional and Urban Policy and the JRC are jointly promoting a network of local and regional cross-border observatories, with the aim of connecting these observatories to each other and to other EU-wide initiatives. This network enhances data harmonisation, supports systematic monitoring and facilitates the production and collection of on-the-ground data. Together with the recommendations discussed in this *Science for Policy* report, these steps are essential for seeing border regions as living laboratories of EU integration and turning borders from obstacles into opportunities.

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## Relevant EU legislation

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# List of abbreviations and definitions

| Abbreviations | Definitions |
|---|---|
| #ACCESS | Promotion of legal accessibility across the Slovak–Hungarian border |
| ACROSS | Data and analysis for cross-border regions |
| Ardeco | Annual Regional Database of the European Commission |
| BIG_Dyads | Borders in Globalization |
| BIG_Lab | Borders in Globalization Research Laboratory |
| CESCI | Central European Service for Cross-border Initiatives |
| Crossgov | Governance mechanisms for cross-border functional areas |
| EFTA | European Free Trade Association |
| EGTC | European Grouping of Territorial Cooperation |
| ESPON | European Observation Network for Territorial Development and Cohesion |
| Eurostat | Statistical office of the European Union |
| FL | Federated learning |
| FRA | Functional rural area |
| FUA | Functional urban area |
| GDP | Gross domestic product |
| Geo-R2LLM | Knowledgeable and multimodal geographic large language models grounded with reasoning and retrieval |
| GeoAI | Geospatial artificial intelligence |
| GIS | Geographical information system |
| GTFS | General transit feed specification |
| INSEE | French National Institute of Statistics and Economic Studies – Institut National de la Statistique et des Études Économiques |
| Interreg | European Union initiative that funds cross-border, transnational, or interregional cooperation projects between countries and regions |
| JRC | Joint Research Centre |
| KDE | Kernel density estimation |
| LAU | Local administrative unit |
| MNO | Mobile network operator |
| MOT | Mission Opérationnelle Transfrontalière |
| NSI | National statistical institute |
| NUTS | Nomenclature of territorial units for statistics |
| r5r | An R package for rapid realistic routing on multimodal transport networks |

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