Energizing EU Regions: Smart Grids at the Crossroads of Technological Relatedness and Smart Specialization

Smart grid (SG) is a critical infrastructure in our transition towards more sustainable development. It promises to integrate renewable energy, information, and communication technologies with the existing electrical grid. This integration aims to deliver electricity more efficiently and reliably (Refaat *et al.*, 2021), with low losses and elevated levels of quality, security, and safety (ERGEG, 2009). Therefore, it plays a key role in the process of twin transition (Sifat *et al.*, 2023) and incorporates significant aspects of the circular economy (Mofatteh *et al.*, 2023; Musti, 2020). By enabling and facilitating the co-production and sharing of energy, the smart grid is fundamental to the backbone of energy communities and smart cities (Barone *et al.*, 2023). Finally, given its position at the crossroads of many key enabling and existing technologies, the smart grid may emerge and has been already indicated as a significant domain of smart specialization for many EU regions. It helps foster smart specialization strategies that aim to promote the integration of resources, energy efficiency, create energy-efficient technologies, and optimize resource allocation in specific areas (Polido *et al.*, 2019).

The inception of smart grid has brought about a revolutionary transformation in power systems globally and has become prevalent in the European policy domain since its establishment. Concurrently, the energy sector has undergone significant changes, including the adoption of clean energy, digitalization, and the rise of artificial intelligence (AI) (Kang *et al.*, 2023; IqtiyaniIlham *et al.*, 2017). To attain the Fit for 55 and REPowerEU targets related to renewables and energy efficiency, an estimated €584 billion in electricity infrastructure investments is required from 2020 to 2030, with a particular focus on the distribution grid. Also, the Digitalisation of Energy Action Plan, adopted in October 2022, aims at effectively promoting investments in smart grids[1].

The objective of this paper is to investigate the drivers supporting the diversification of regional know-how at the EU level in SG technologies, as a potential niche of smart specialization. To this end, existing literature investigates the relationship between smart specialization and green innovation (Montesor & Quatraro, 2020). In line with the consolidated literature, Montesor & Quatraro (2020) demonstrate that relatedness to pre-existing knowledge makes green-tech specialization more probable. However, they also reveal that relatedness to non-green knowledge plays a greater role in supporting diversification into green-tech.

[1] https://energy.ec.europa.eu/topics/markets-and-consumers/smart-grids-and-meters_en

Smart grid technologies represent a unique form of green innovation as they often require the recombination of knowledge from three domains: digital, green, and non-green. The unique nature of these technologies has already been noted by Bachtrögler-Unger et al. (2023) in their report on technological capabilities and twin transition in EU regions. The term "twin transition" refers to technologies that recombine knowledge from the green and digital domains (Bianchini *et al.*, 2022) and for this specific dynamic, special capabilities are required (van Eechoud & Ganzaroli, 2023). Collaboration, both within and outside regions, is expected to play a crucial role, as the required knowledge is often distributed across multiple inventors, companies, and EU regions (Bachtrögler-Unger *et al.,* 2023). Furthermore, Cova et al. (2023), while confirming that environmental technologies rely more on collaboration than non-environmental ones, also highlight that the national scale is critical in supporting the development of this technology. In this regard, we suggest that the growth of new technologies might be determined by the extent of technological knowledge space and collaborations (Samara *et al*., 2023).

However, there is no specific literature on the development of SG technologies in regions, neither considering both the regional internal technological portfolio and the linkages. Some studies (Boschma *et al.,* 2014) have analyzed what lies behind technological developments in digital technologies, evidencing mixed results on the importance of technological path-dependence in a region vis-à-vis with cross-regional collaborations (Zeng *et al*., 2019). Few of them analyze the growth of new technologies in cities (Boschma *et al*., 2014) underlining the importance of firms' physical proximity to generate new technologies (Rigby, 2015). Moreover, as stated in economic geography literature, an intra-regional lens (Neffke *et al*., 2011) and an extra-regional lens (Kogler *et al.,* 2023) should be further investigated. Some studies found a complementary effect stating that in the presence of strong capabilities, the presence of external linkages will enhance the regional capabilities in developing new technologies (Balland & Boschma, 2021). On the other hand, they are thought to have a substitution effect on the region, compensating for the lack of internal capabilities and minimizing the knowledge gap in the field (De Noni *et al.,* 2018; Kogler *et al.,* 2023).

Thus, in this paper, we focus on smart grid as form of twin technology, and we look at the role of technological relatedness and collaboration in supporting the diversification of EU regions on SG technologies. Through taking an exploratory approach, we intend to analyze whether the regional development of SG technologies relies on the extent to which region's existing technological portfolio that are related to SG technologies, intra-region collaborations and the potential collaborations with other regions that are already considered "SG specialized regions". The reasons why we consider both the intra- and extra-regional scale together are twofold. First, we want to analyze whether external collaborations influence the internal capability of the region to develop SG technologies.

Second, whether the already present and internal knowledge plays a role in the development of SG technologies first, and in establishing external collaborations. By examining these drivers, the research aims to provide insights into effective strategies for fostering technological leadership in the evolving landscape of smart grid innovations. Secondly, we contribute to the analysis of the role of SG technologies as a bridge between digital transformation (smartness) and sustainability, forming an essential conjunction ring for achieving a twin transition.

To achieve our objective, we conduct a patent-based empirical analysis of NUTS-2 regions in the all EU-28 countries, Iceland, Norway, UK, and Switzerland. Patent data were extracted from OECD-REGPAT database (August 2023). To extract SG patents, we implemented the Y04S CPC class (Angelucci *et al.,* 2018). Y04S patents are regionalized at the NUTS-2 level according to the inventor's address. Furthermore, Eurostat database is used to obtain relevant socio-economic data. The final dataset encompasses 238 NUTS-2 European regions that produce Y04S patents from 1978 to 2019.

To assess whether a region has developed smart specialization in SG technologies, we use RTA (Relative Technological Advantage). Consequently, a region is considered to have developed a smart specialization in SG when, at time t, it has an RTA in the Y04S category greater than 1, and at $t-1$ (the previous time period), this value was lower than 1. Technological relatedness density has been calculated according to Balland et al. (2019). Finally, to assess the intensity of collaboration between regions, we use data about co-patenting. Last, following previous studies (Balland *et al.,* 2019; Balland & Boschma, 2021), we also include gross domestic product (GDP) per capita, the level of population, technological size and technological stock as our control variables.

We expect that relatedness density has a positive effect on the development of SG technologies within regions. Also, regions lacking relevant technological portfolios are expected to develop faster if they are less connected to intra-regional networks, but more connected to cross-border regions specialized in SG technologies. Moreover, we expect this finding also holds for the regions possessed with abundant relevant portfolio, so regions can still access and leverage knowledge from extra-regional connections. To conclude, our paper aims to understand how the technological portfolio, intra- and extra-regional connections influence the growth of SG technologies in regions. We contribute to the literature on the twin transition of digital technology by investigating the characteristics of Y04S patents at the European level. To our best our knowledge this is much underdeveloped in the relevant studies. Also, we intend to provide empirical evidence to address the mixed findings in the effects of intra- and extra-regional connections on technological innovation.

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