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Original article

Does social capital foster renewable energy cooperatives?

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Abstract

In recent decades, renewable energy cooperatives have substantially increased their share of renewable energy production. The operation of these cooperatives requires collective action, potentially supported by local social capital. We investigate whether municipal-level bonding and bridging social capital explain the differences in the prevalence of renewable energy cooperatives across Dutch municipalities. We measure social capital directly from social network structures within and between municipalities, thus overcoming limitations of using proxies. Our empirical results reveal that bonding rather than bridging social capital supports renewable energy cooperatives, shedding new light on the role these types of social capital play in regional development.

Keywords: bonding social capital; bridging social capital; community initiatives; technology adoption; social networks.

JEL classifications: F15, J61, N94, R12.

1. Introduction

Innovation geographers attribute a central role to firms in regional development (Feldman and Kogler 2010; Carlino and Kerr 2015). However, addressing today's societal challenges not only involves innovation by firms, but also the adoption of innovations by users (Truffer and Coenen 2012; Coenen, Hansen, and Rekers 2015; Köhler et al. 2019). Nevertheless, the role of users has received little attention in the study of the geography of innovation (Grabher, Ibert, and Flohr 2008; Dewald and Truffer 2012; Losacker et al. 2023).

We analyze the geography of renewable energy (RE) cooperatives as a prominent example of user involvement in local market formation. Community-based energy generation, particularly RE cooperatives, plays a pivotal role in the transition toward low-carbon energy systems (Seyfang, Park, and Smith 2013; Van der Schoor and Scholtens 2015; Wierling et al. 2018). Previous studies have examined the physical and institutional factors fostering the emergence and development of RE cooperatives, but have paid little attention to local social structures (Oteman, Wiering, and Helderman 2014; Bauwens, Gotchev, and Holstenkamp 2016; Mignon and Rüdinger 2016; Punt et al. 2022; Lode et al. 2022a). As RE cooperatives usually have a strong embedding in local user communities (Hufen and Koppenjan 2015; Süsser, Döring, and Ratter 2017; Wyse and Hoicka 2019), social networks are likely to play a crucial role in explaining the geography of RE cooperatives.

Previous studies have argued that social innovations, such as RE cooperatives, benefit from strong social networks within local communities (Evers and Ewert 2015). For example, research has

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highlighted the importance of "social cohesion" for community energy projects, but such studies refer to the concept of social cohesion without unpacking this notion theoretically and empirically (Bomberg and McEwen 2012; Haggett et al. 2013; Boon and Dieperink 2014; Mundaca, Bush, and Schwer 2018). Instead, we start from the theory of social capital in local development and investigate specifically whether social capital fosters RE cooperatives at the municipality level, while distinguishing between bonding and bridging social capital. Thus, we contribute to the literature on economic geography that investigates the effects of bonding and bridging social capital on regional economic growth, entrepreneurship, innovation and diversification (for a recent review, see Muringani, Fitjar, and Rodríquez-Pose 2021).

Our contributions are threefold. Theoretically, we argue that bonding social capital, which is generally considered detrimental to radical innovation (Coleman 1988; De Vaan, Frenken, and Boschma 2019), is expected to support RE adoption by user cooperatives. While the importance of social capital at the community level for the founding and operation of RE cooperatives has been emphasized previously (Walker et al. 2010; Brummer 2018), to the best of our knowledge, no study has investigated whether regional differences in social capital can explain the regional differences in the prevalence of RE cooperatives.

Methodologically, using detailed social media data (Norbutas and Corten 2018), we can measure bonding and bridging social capital at the level of citizens' social networks within and across municipalities, consistent with the social network perspective on social capital (Chetty et al. 2022a, 2022b). In doing so, we overcome the known limitations of typical social capital proxies (charity donations, voter turnout, and blood donations) and more so demonstrate that in our context these proxies have little explanatory power (Putnam 2001; Van Deth 2003; Guiso, Sapienza, and Zingales 2004; Staber 2007; Andini and Andini 2019). Empirically, we contribute to the understanding of social capital by examining its effect on RE cooperatives as central regional agents in sustainability transitions (Truffer, Murphy, and Raven 2015). By studying cooperatives as drivers of change, we go beyond the firm focus often encountered in the geography of innovation literature (Grabher, Ibert, and Flohr 2008).

The remainder of this paper is organized as follows. The next section provides background information on RE cooperatives in the Netherlands. Section 3 describes the role of social capital in fostering RE cooperatives. Section 4 presents the data and methods, and Section 5 presents the empirical results. Finally, we end with the conclusions of our study and further discussion in light of social capital research in economic geography.

2. Renewable energy cooperatives

Renewable Energy (RE) cooperatives are characterized by collective ownership by individual members. Member orientation aims to improve individual members' situation as well as a broader focus on a variety of activities along the energy industry value chain (e.g., generation, distribution, trading, and services). Joining an RE cooperative allows members to share the costs and risks associated with adopting renewable energy technologies, most often wind turbines and solar panels. The cooperative structure further ensures democratic voting, in which each cooperative member has one vote (Tarhan 2015; Yildiz et al. 2015; Klagge and Meister 2018).

Cooperative organizing in the energy sector has a long tradition dating back to the late nineteenth century in countries such as Germany and Denmark. In early cooperatives, local members pursued mutual goals to improve living conditions by establishing electric networks and production, especially in rural areas where such infrastructure was mostly absent (Mori 2014; Klagge and Meister 2018). After World War II, the centralization of national energy sectors led to a decline in the number of energy cooperatives (Holstenkamp 2015). However, since the last decade of the 20th century, the liberalization of retail energy markets and the introduction of public policies supporting the deployment of renewable energy sources have led to the revival of energy cooperatives, especially in Europe and the USA, with a specific focus on renewable energy (Rossetto, Verde, and Bauwens 2022).

Although the Netherlands might not have such a long tradition in energy cooperatives compared to countries such as Germany or Denmark (Oteman, Kooij, and Wiering 2017), in more recent times the field has grown from about 20 active RE cooperatives in 2010 to over 600 RE cooperatives in 2022 (Schwencke 2017, 2022). The drivers behind this growth are mostly sustainability considerations, financial motives, and general dissatisfaction with the current state of the energy market (Van der

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Schoor and Scholtens 2015; Oteman, Kooij, and Wiering 2017). Public policy also stimulated the founding of RE cooperatives by the introduction, in 2014, of a postal code area arrangement ('postcoderoos' in Dutch), which provided a tax rebate on cooperative members' energy bills. The tax rebate was conditional upon the requirement that the members lived within the same or directly adjacent postcode area where the production assets owned and operated by their cooperative were located (Butenko 2016).

Most studies examining the factors fostering the deployment of RE cooperatives have been qualitative in nature (Oteman, Wiering, and Helderman 2014; Bauwens, Gotchev, and Holstenkamp 2016; Mignon and Rüdinger 2016), while those of a quantitative nature have mostly focused on factors at the national or regional level (Punt et al. 2022; Lode, Coosemans, and Ramirez Camargo 2022b; Liu and Guenther 2024). These studies have mostly focused on regulatory and institutional settings and cultural elements, such as environmental or anti-nuclear movements (Beveridge and Kern 2013), to explain the emergence of RE cooperatives. However, because previous studies have also emphasized that the deployment of a cooperative is heavily driven by individuals' ideological motives (Schneiberg, King, and Smith 2008; Boone and Özcan 2014), we expect factors at a more localized level, specifically the municipal level, to play an essential role. Therefore, we examine the municipal level in our empirical study.

3. Social capital

In sociology, social capital is conceptualized as resources made available by social relations (Kadushin 2012), and is commonly associated with various benefits, with one of the most emphasized being economic prosperity (Granovetter 1973; Coleman 1988; Burt 2001; Norbutas and Corten 2018). Dense social networks among economic agents support the circulation of information reducing transaction costs as well as voluntary contributions to community projects and services. Thus, social capital helps individuals and organizations can trade more efficiently and cooperate more effectively.

3.1 Social capital and regional development

Following the seminal works of Putnam, Leonardi, and Nanetti (1993) and Putnam (2000), social capital has also been understood as a regional-level phenomenon that increases trust within a region, resulting in benefits for regional economic development. Evidence for this thesis has been found in a number of studies in the USA and Europe (Beugelsdijk and Van Schaik 2005; Akcomak and ter Weel 2009; Dicner and Uslaner 2010; Muringani, Fitjar, and Rodríquez-Pose 2021).

However, the same dense social networks that promote trust and facilitate the enforcement of norms may also constrain other types of activities. In particular, as Coleman (1988, S105) noted, "effective norms in an area can reduce innovativeness in an area, not only deviant actions that harm others but also deviant actions that can benefit everyone." That is, dense networks within a region may be high, but this does not imply that the goods traded and the information exchanged are valuable or contribute to a greater good. Some even argue that, as high network density creates demands for conformity in ideas and values, it may hamper regional innovation as new and deviant ideas and behaviors are penalized (Westlund and Bolton 2003; De Vaan, Frenken, and Boschma 2019).

A more elaborate network theory of social capital, innovation, and regional development starts from the idea that dense networks may hamper radical innovation and new business models, while favoring incremental innovation and traditional business models (De Vaan, Frenken, and Boschma 2019; Chronopoulos, Sobiech, and Wilson 2021). Thus, regions with dense networks may suffer from "conformity bias," which makes them more likely to promote incremental improvements in established technologies rather than innovate or adopt radically new ones. Following this theory, network density may be beneficial in increasing economic prosperity in the short run by rendering established industries more productive but may be detrimental to regional development in the long run, as more radical innovations will not develop or diffuse, hampering structural change.

However, the case of renewable energy diffusion, and infrastructure building more generally, is rather different from economic geographers' typical focus on entrepreneurship and innovation. Indeed, the development of such a shared infrastructure echoes the dilemma of collective action, as highlighted by Putnam, Leonardi, and Nanetti (1993). This development involves a *collective* process of technology adoption and management that require levels of "social trust" and generalized reciprocity

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within regional communities. Following this, such collective action is more likely to occur where social exchange networks are denser (Putnam, Leonardi, and Nanetti 1993). Thus, to understand the diffusion of renewable energy technologies, social capital theory needs to be extended to cover collective technology adoption as an instance of collective action by regional residents.

The actors involved in renewable energy technology diffusion, particularly wind and solar energy technologies, are not limited to regional governments or utilities procuring such technologies. In addition to such actors, citizens engage in collective adoption through the shared ownership of renewable energy technologies, often within cooperatives. As a social structure facilitating economic action and knowledge spillovers, one can expect that dense social networks support the founding and operation of RE cooperatives (Caferra et al. 2023). For cooperatives to emerge, some level of network density can be seen as a necessary condition, as it requires a group of potential members to provide organizational structures and resources through their social networks to start a cooperative organization (Bauwens and Defourny 2017). The role of social networks is underscored by a recent empirical study by Goedkoop, Dijkstra, and Flache (2022), who found that willingness to participate in energy cooperatives is positively related to community members' ties with the initiators of these initiatives. In addition, research on members has found that the presence of close social ties with other members of the cooperative in one's network is an essential determinant of the level of financial investment (Bauwens 2019). Thus, dense social networks can increase the affinity between individuals, which can provide a motive for trust and other cooperative behaviors (Schmid 2000). In the case of energy cooperatives, this means that a low density could result in ineffective cooperative governance (e.g., free-riding and inefficient decision-making), as trust between cooperative members is low (Nilsson and Svendsen 2011). This leads to the following hypothesis:

H1: The denser a region's social network, the higher the number of renewable energy cooperatives in the region.

3.2 Bonding versus bridging social capital

Previous research has underscored the importance of various types of social capital when evaluating regional differences in economic development (Sabatini 2008; Chetty et al. 2022a). The social capital literature commonly distinguishes between bonding and bridging social capital. These notions address the specific structure of social networks, rather than merely their density, which is important as it has previously been asserted that different social network structures play a role under different circumstances (Adger 2003; Storper 2013; Morone, Caferra, and Lopolito 2024). Bonding social capital is associated with ties within a defined social group (e.g., ethnic, local, or interest groups) in which increasing number of ties lead to highly clustered networks. This type of social capital is based on ties of friendship and kinship, providing emotional support and a sense of belonging to tight social networks. In contrast, bridging social capital is more outward-looking and is derived from ties across more disparate social groups (Adger 2003; Kadushin 2012; Storper 2013). From a geographical perspective, bonding social capital is commonly understood as being held among people of the same local community, whereas bridging social capital is understood extend beyond local boundaries and tie people from the local community to people outside (Larsen et al. 2004; Callois and Aubert 2007; Sørensen 2012, 2016).

Different authors have argued that there are stark regional or local variations in the stocks of both bonding and bridging social capital (Lorenzen 2007; Sabatini 2008; Malecki 2012). While prior studies have argued that economic development is mostly fostered by a balanced dynamic between bonds and bridges (see Storper 2013), the geography of innovation literature has emphasized that the two types of social capital exert very different effects on regional innovative processes (Beugelsdijk and Smulders 2003; Knudsen and Rousseau 2007; Cortinovis et al. 2017; Norbutas and Corten 2018). Bridging social capital is expected to support innovation and entrepreneurship, because it helps information percolate between different communities, and brings together different, non-redundant ideas (Granovetter 1973), which may, in turn, lead to new innovations and ventures. Bonding social capital supports social norms that penalize deviant innovative behavior. Thus, the effects of bonding social capital have been hypothesized to be the reverse of those of bridging social capital; bonding relations are seen as harmful to a community's potential to adopt new ideas or combine different forms of knowledge, hampering regional economic growth (Eagle, Macy, and Claxton 2010; Norbutas and Corten 2018).

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However, theoretical predictions of the effects of bonding and bridging social capital on innovation and adoption by firms may not apply to residents' collective technology adoption. As stressed before, the process of building regional energy infrastructure, particularly renewable energy technologies, can be considered a collective action problem, as individuals benefit from sharing ownership and the management of such infrastructure. Furthermore, RE cooperatives' innovation is not primarily about technological novelty, but about providing a new collective institutional configuration for local technology management, a typical example of "transformative social innovation" (Avelino et al. 2019; Punt et al. 2022).

Hence, for the adoption of renewable energy technologies by citizen collectives organized in cooperatives, one can expect communities to benefit from both bonding and bridging social capital. Bonding social capital provides the trust that helps individuals invest time and resources in establishing and running a cooperative, and lowers the risk of free-riding and conflicts in decision-making. In contrast, bridging social capital helps source relevant knowledge and information from communities elsewhere, providing models and templates for establishing and governing a new cooperative. Moreover, bridging ties between regions facilitate the spillover of rationales and motivations underlying the founding of cooperatives across regions.

Hence, we derive the following two hypotheses:

H2a: The higher a region's bonding social capital, the higher the number of renewable energy cooperatives in the region.

H2b: The higher a region's bridging social capital, the higher the number of renewable energy cooperatives in the region.

4. Data and methods

4.1 Dependent variable

The data for this study were taken from "Lokale Energie Monitor," a database of RE cooperatives in the Netherlands (Hier Opgewekt 2020). From this database, we obtained data for 623 Dutch RE cooperatives registered between 1986 and 2020 which were operational during the time of data collection. The data included the name of the cooperative, its founding date and its location (municipality). This database distinguishes between *local energy cooperatives* and *production cooperatives*. Production cooperatives focus solely on energy generation, whereas local energy cooperatives pursue additional social or environmental goals.

Figure 1 and 2 depict the number of RE cooperatives per municipality and the same number per capita, respectively. In terms of absolute number of cooperatives, the capital city of Amsterdam in the western part of the country, stands out (see Fig. 1). This is hardly surprising since Amsterdam is the municipality with the largest population. Furthermore, cooperatives are concentrated in the northern provinces of Friesland and Groningen. This resonates with an earlier study emphasizing strong regional identities, the well-established cooperative culture, and the long history of local energy and environmental activism in these provinces (Warbroek 2019). Looking at the number of cooperatives per capita, we observe that they are overrepresented mainly in the northern and eastern areas of the country. Interestingly, these areas tend to be rural and dominated by agricultural production.

4.2 Independent variables

Measuring regional social capital is not an easy task, because the concept's definition stems from the function it provides for communities (Adler and Kwon 2002). This has prompted many researchers to try to measure social capital by looking at the outcomes of social capital such as charity donations, voter turnout, blood donations and membership in associations (Putnam 2001; Van Deth 2003; Guiso, Sapienza, and Zingales 2004; Malecki 2012). The idea behind measuring donations, turnout and memberships is that such variables would reflect the varying levels of civic engagement that result from varying levels of social capital. However, studies using indirect measures of social capital as independent variables ultimately try to predict the regional presence of one outcome of social capital with another, while at the same time both these outcomes may be contaminated by factors other than just social capital (Guiso Sapienza, and Zingales 2011). Or, as Putnam (2000:117) puts it, such outcomes are "diagnostic signs" of social capital, but not social capital itself.

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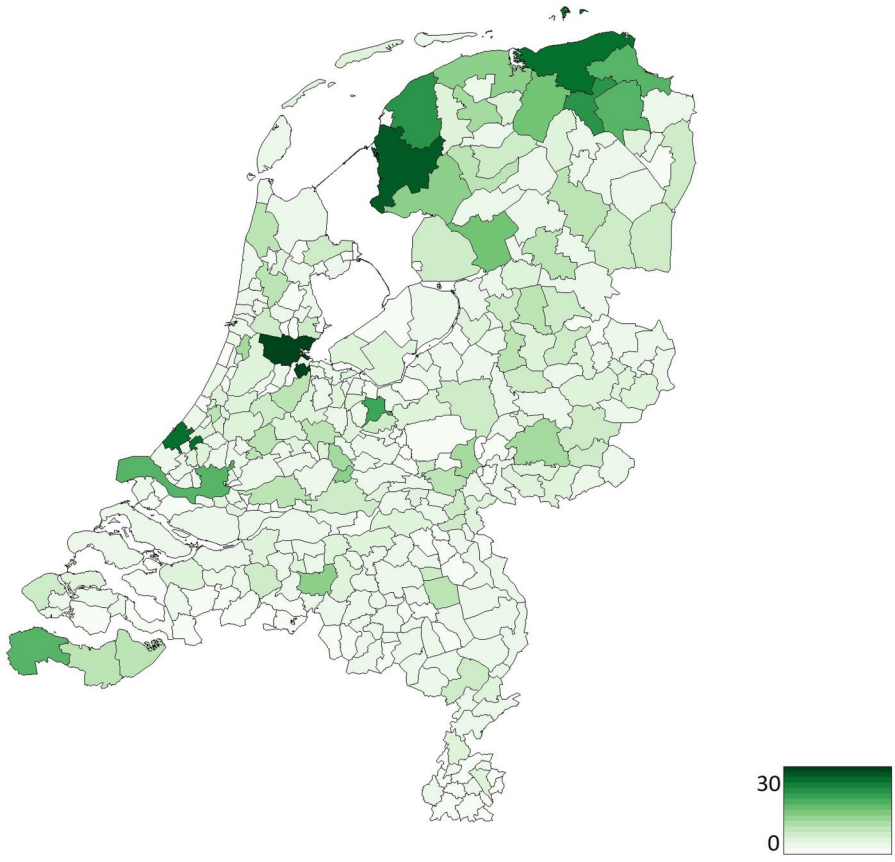

Figure 1. Number of RE cooperatives in the Netherlands (municipality level).

In much of the literature on social capital, variation in social network structure has been viewed as causing variation in outcomes of social capital (Coleman 1988, Lin 2001). In particular, the denser social networks are, the more resources become available through social relations held by community members. However, for a long time, measuring social networks at the scale of communities was not feasible (cf Putnam 2000). More recently, leveraging data from social networking platforms has been proposed as a way to overcome these measurement challenges. For example, Chetty et al. (2022a, 2022b) use Facebook network data to provide a more direct measure of social network structures, yielding a comprehensive picture of geographic variations in social capital (also see Norbutas and Corten 2018).

To capture network density and the two forms of social capital, we use an existing data set first analyzed by Corten (2012) and later aggregated to the municipal level by Norbutas and Corten (2018). This data set is based on data from Hyves.nl, a (now defunct) online social network service that allowed users to create an online profile and befriend other members, similar to Facebook. For some years, Hyves was the leading online social network in the Netherlands (comScore 2011) until it was outcompeted by Facebook. The data consists of an anonymized snapshot of the entire network in July 2010, when over 10 million users in the Netherlands were registered (out of 16.5 million inhabitants at the time), in which individual profiles are the nodes and "Friend" relations between members are the ties. Filtering by age (18–65), residence (only in the Netherlands), and activity (at least one friend) resulted in a subset of 441 municipality networks based on 3.2 million users and 123 million undirected friendship ties between them. For more detailed information on how this database was constructed, we refer to Corten (2012) and Norbutas and Corten (2018). Using the place of residence as reported by individual users, we can use measure general social capital, bonding social capital, and bridging social capital at the municipal level.

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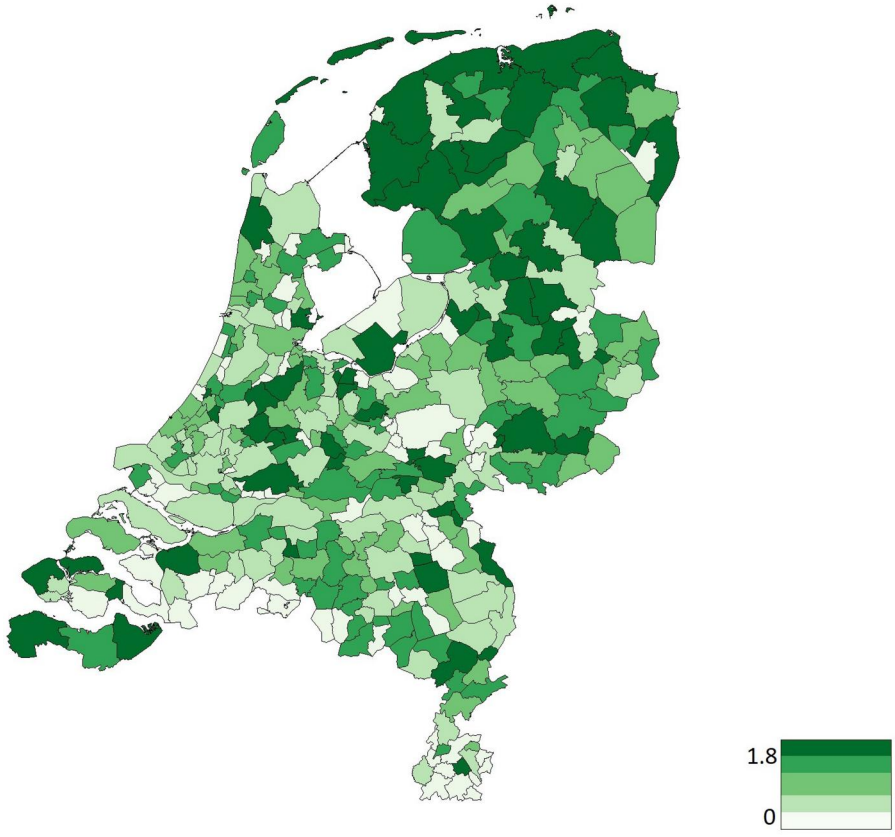

Figure 2. Number of RE cooperatives per 1000 inhabitants in the Netherlands (municipality level).

To test Hypothesis 1, we use the *network density* measure. Network density refers to the extent to which residents in a municipality are connected within social networks. Density is calculated by dividing the number of ties between Hyves members in the same municipality by the maximum number of possible ties that Hyves users could have in a municipality. The scores for this measure range from 0 to 1, with 0 indicating no connectivity and 1 indicating a fully connected municipality.

To test Hypotheses 2a and 2b, we distinguish between bonding and bridging capital. Bonding social capital is associated with tight subcommunities, also known as cliques. In network analysis, such communities can be detected as modules within the network, with each module having a high density of ties among members within a module, while the ties between modules are sparse. To calculate modularity, we follow Norbutas and Corten (2018) in employing the Louvain algorithm (Blondel et al. 2008), a method widely used to detect community structures in larger networks. This measure detects smaller subcommunities that are densely connected in a larger network and ranges from 0 to 1, with a low value indicating that the network is a single connected community and a high value indicating that the network is highly fragmented into subcommunities. Thus, this measure captures bonding network ties in terms of smaller, tightly connected subgroups within a municipality, regardless of how tightly the municipality is connected.

Bridging social capital refers to the extent to which residents of a municipality are connected to those in other municipalities through network ties. Such ties act as bridges between municipalities, through which spillovers occur. Following Norbutas and Corten (2018), *network diversity* is calculated at the level of individual i as

$$D_i = \frac{\sum_a^A p_{ia} \log(p_{ia})}{\log(A)}$$

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where p_{ia} is the proportion of individual i's network ties with individuals living in municipality a of total A municipalities. This measure ranges from 0 to 1, with 0 indicating that all ties are with individuals in the same municipality and 1 indicating that all ties are equally spread across municipalities. A municipality's network diversity was then computed as the average of the network diversity scores of individuals living in the municipality.

While we base our social capital variables on social network data, previous research has employed different indicators of social capital, as reviewed by Westlund and Adam (2010). To compare the results of our social capital variables with those of well-known proxies of social capital used in previous research, we tested the robustness of our approach. To this end, we used other indicators of social capital at the municipal level, as in Odding and ter Weel (2022). First, as an indicator of altruism, they measured the average charitable donations per household in 2017 at the municipality level. As a second indicator, to capture solidarity, they measured turnout in municipal elections by taking the percentage of eligible voters who voted in the 2014 and 2018 municipal elections. Finally, they measured the average number of blood donors per 100 inhabitants between 2010 and 2016 to capture reciprocity.

Figure 3 depicts the maps for all social capital variables. The correlations between the variables (Table 1) are sufficiently low to warrant their simultaneous inclusion in the regression models.

4.3 Control variables

We include several control variables. First, we control for municipalities' population and land area as provided by Statistics Netherlands (CBS) (CBS 2020). We consider these important controls, as higher population numbers mean that more people could become members of a cooperative, and a larger land area implies that more land is available to install renewable energy technology. We also control for the average level of education and income at the municipal level as provided by Environmental Data Compendium (CLO) (CLO 2021). As RE cooperatives are often founded by members with political or ideological motives, we also explicitly control for votes in municipal elections going to one of the three largest green parties in the Netherlands (Democraten 66, GroenLinks and Partij voor de Dieren). These data were obtained from Kiesraad (Kiesraad 2022). Finally, to control for possible spillovers from more populated neighboring municipalities, we control for the population of neighboring municipalities by taking the sum of the number of residents in adjacent municipalities.

4.4 Final dataset

The RE cooperatives database is from 2020, while the social network data taken from Norbutas and Corten (2012), the three proxies of social capital taken from Odding and ter Weel (2022), and the variable for education taken from CLO (2021) were collected in earlier years. Because Dutch municipalities occasionally merge, all these variables were adjusted to municipality borders in January 2021. We did so by taking the population-weighted average of the merged municipalities, thus recalculating the data for the updated municipality division. Data on four municipalities have thus been merged with adjacent municipalities in the period between 2009 and 2021, and were therefore abolished from the dataset. Finally, the municipalities of Rozendaal and Schiermonnikoog were excluded from the analysis because no social capital data were available. In total, 350 municipalities were included in the analysis.

4.5 Models

We estimated negative binomial regression models to model the differences in the number of RE cooperatives between municipalities, because the dependent variable is constructed as count data or nonnegative integers and the data were overdispersed, as is clear from the descriptive statistics in Table 2 (also see Fig. 1). Table 1 reports the correlations between the variables. Education was removed from our main analysis, because its inclusion caused multicollinearity in our models, and is only inserted as a robustness check.[1]

We tested for spatial autocorrelation using a Global Moran's I to determine whether the presence of RE cooperatives in the Netherlands is spatially clustered. After row-standardizing our spatial weights, this test returned a Moran's I of 0.187 ($P = 2.5e\text{-}09$). Although this is only a weak autocorrelation, such

[1] The variable *education* had a VIF higher than 5, which can be considered as problematic (Stine 1995). Furthermore, the variable correlates strongly with the variable for green voting and also changes direction when the latter variable is added to our model. Finally, the coefficient for this variable strongly increased when the social capital indicators were included.

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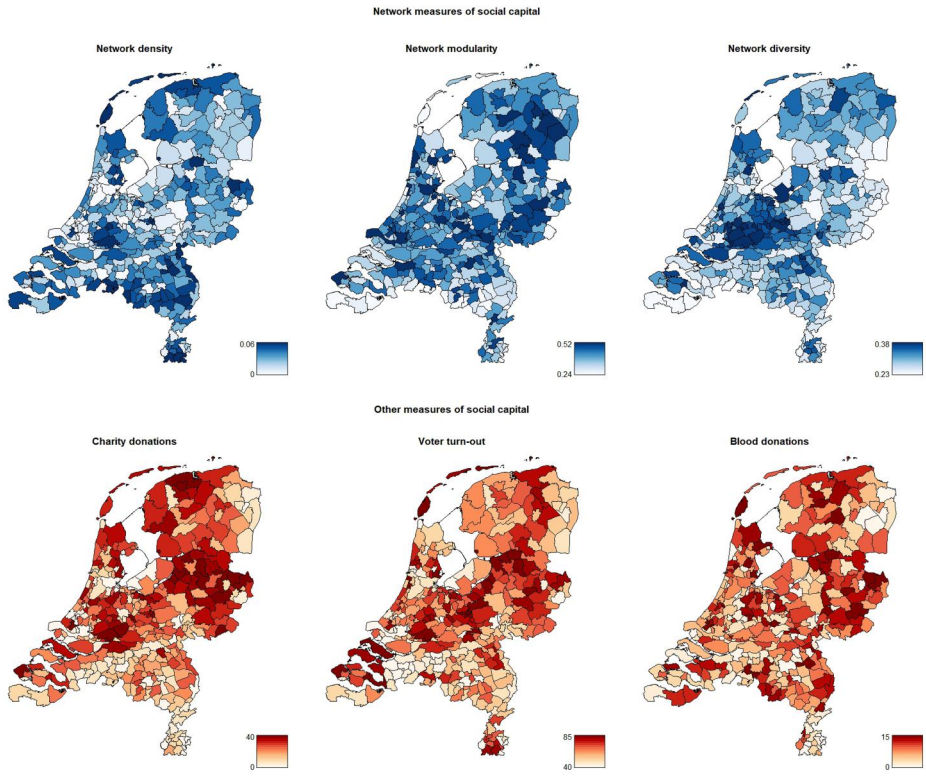

Figure 3. Social capital measurements per municipality.

spatial dependence might be good to consider when estimating our models. Hence, a province dummy was included in our final model to control for unobserved differences between provinces.

Previous studies have highlighted the intricate causal relationships inherent in research employing social capital as covariate, particularly concerning issues of endogeneity and reverse causality (Mouw 2006; Li 2013). This was also highlighted by Putnam, Leonardi, and Nanetti (1993) who discussed the mutual reinforcement of social trust and reciprocity on one hand and civic engagement (as observed in RE cooperatives), on the other. Given the nature of our study, we acknowledge the possibility of reverse causation. However, social capital in regional contexts is generally considered a relatively stable asset built up over an extended period (Putnam, Leonardi, and Nanetti 1993; Uslaner 2008; Algan and Cahuc 2010; Weiss et al. 2019), also specifically in the context of Dutch municipalities (Odding and ter Weel 2022). Moreover, since our social capital measures are snapshots from 2010 and only 18 out of 623 cooperatives were founded before that time, we anticipate limited issues with reverse causation. Finally, we conduct a time-to-event analysis, explicitly studying how long it takes for the very first energy cooperative to be founded in each municipality, to check the robustness of the results from our main analysis. Such an analysis mitigates the risk of the founding additional RE cooperatives to be influenced by the build-up of social capital through earlier RE cooperatives.

5. Results

Table 3 reports the results of our negative binomial regression. Model 1 only contains the control variables, including the province dummy. Population and Land area have positive and significant effects, indicating that RE cooperatives are more likely to be founded in larger municipalities, in terms of both number of residents and land area covered. Income and neighboring population do not have a significant effect. Finally, green votes display a significant positive effect, indicating that municipalities in which green parties receive more votes are more likely to host more RE cooperatives. All control

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Table 1. Correlation matrix

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
(1)	RE cooperatives	1												
(2)	Population (1,000)	0.65	1											
(3)	Neighbouring population (1,000)	0.09	0.21	1										
(4)	Land Area	0.41	0.13	−0.1	1									
(5)	Education	0.15	0.28	0.33	−0.28	1								
(6)	Income	−0.07	−0.01	0.33	−0.31	0.65	1							
(7)	Green votes	0.31	0.42	0.7	−0.12	0.7	0.42	1						
(8)	Network density	−0.15	−0.34	−0.24	0.11	−0.09	−0.24	−0.3	1					
(9)	Network modularity	0.21	0.21	0.23	0.04	0.31	0.17	0.27	−0.42	1				
(10)	Network diversity	−0.07	−0.22	0.1	−0.15	0.26	0.3	0.19	0.15	0.2	1			
(11)	Charity donations	−0.05	−0.31	−0.08	0.14	−0.19	−0.05	−0.41	0.32	0.03	0.04	1		
(12)	Voter turn−out	−0.04	−0.28	−0.05	0.08	0.08	0.14	−0.21	0.41	0.04	0.23	0.68	1	
(13)	Blood donations	0.05	−0.04	0	0.04	0.03	−0.03	0.01	0.12	0.02	−0.02	0.28	0.26	1

Table 2. Descriptive statistics and data sources

	N	Mean	SD	Min.	Max.	Sources
RE cooperatives	350	1.78	2.59	0.00	30.00	Hier Opgewekt (2020)
Population (1,000)	350	49.92	73.70	1.19	873.34	CBS (2020)
Neighbouring population (1,000)	350	317.73	253.99	0.00	1522.28	CBS (2020)
Land area	350	118.03	129.03	7.84	907.87	CBS (2020)
Education	350	0.29	0.07	0.00	0.57	CLO (2021)
Income	350	26.16	3.18	20.00	44.10	CBS (2021)
Green votes	350	0.21	0.07	0.01	0.48	Kiesraad (2022)
Network density	350	0.01	0.01	0.00	0.06	Norbutas and Corten (2018)
Network modularity (bonding social capital)	350	0.44	0.05	0.26	0.58	Norbutas and Corten (2018)
Network diversity (bridging social capital)	350	0.31	0.03	0.17	0.37	Norbutas and Corten (2018)
Charity donations	350	6.95	3.40	0.55	36.86	Odding and ter Weel (2022)
Voter turn−out	350	57.46	6.31	43.45	80.11	Odding and ter Weel (2022)
Blood donations	350	4.45	2.21	0.55	14.24	Odding and ter Weel (2022)

variables that have a significant effect have the expected sign and remain robust over the four regression models.

In Model 2 we include the measures of network density and social capital as our main independent variables. The coefficients of our control variables are stable and hardly display any difference in significance or direction compared with Model 1. This model reports a very strong positive and significant coefficient for network density meaning municipalities with more densely connected networks seem to host more RE cooperatives. This implies that the general level of network connectivity within a municipality exerts a positive effect on the number of RE cooperatives in a municipality.

Network modularity also has a significant positive effect, implying that RE cooperatives are more likely to be found in municipalities that contain higher bonding social capital. Considering the range of these two variables (0–0.06 for network density and 0.26–0.58 for network modularity), it is unsurprising that network density has a considerably larger effect than network modularity. To enable a comparison, Table 4 reports the standardized regression coefficients for the different models.[2] Model 2 in this table shows that when coefficients are standardized, network modularity has a stronger effect (0.07) compared to the network density (0.03).

[2] We obtained standardized coefficients by applying the 'standardize_parameters' function (using the re-fit method) from the R package *effectsize* (Ben-Shachar, Lüdecke, and Makowski 2020).

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Table 3. Negative binomial regression models on the founding of RECs

Dependent variable: Number of RE cooperatives in a municipality				
	Model 1	**Model 2**	**Model 3**	**Model 4**
Population (log)	0.442***	0.541***	0.508***	0.574***
	(0.075)	(0.092)	(0.080)	(0.094)
Neighbouring population (log)	0.041	0.072	0.025	0.053
	(0.039)	(0.044)	(0.039)	(0.046)
Land area	0.002***	0.002***	0.002***	0.003***
	(0.0003)	(0.0003)	(0.0003)	(0.0003)
Income	0.022	0.021	0.024	0.028
	(0.021)	(0.020)	(0.022)	(0.022)
Green votes	3.346***	2.964***	3.957***	3.470***
	(0.856)	(0.885)	(0.927)	(0.977)
Network density		41.011**		38.105**
		(13.183)		(13.485)
Network modularity (bonding social capital)		2.750*		2.437*
		(1.130)		(1.142)
Network diversity (bridging social capital)		−1.554		−1.166
		(2.450)		(2.219)
Charity donations			0.059*	0.048
			(0.020)	(0.021)
Voter turn−out			−0.010	−0.016
			(0.012)	(0.012)
Blood donations			0.027	0.023
			(0.024)	(0.024)
Intercept	−6.214***	−8.516***	−6.746***	−8.293***
	(0.929)	(1.514)	(1.160)	(1.558)
Max. VIF	1.58	2.10	1.89	2.14
Observations	350	350	350	350
Log Likelihood	−512.79	−506.41	−508.58	−503.86
Akaike Inf. Crit.	1,061.6	1,054.8	1,059.2	1,055.7
Province dummy	YES	YES	YES	YES

Note:
* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. Standard errors in parentheses.

Finally, network diversity, as a measure of bridging social capital, has no significant effect on the number of RE cooperatives. This means that municipalities in which individuals have more ties with other municipalities do not necessarily also host more RE cooperatives.[3]

In Model 3, we replace our measures of social capital with the well-known proxies of social capital: charity donations, voter turn-out, and blood donations. Of these three indicators, only charity donations has a significant positive effect, meaning that municipalities with higher average charity donations also host more RE cooperatives.

In Model 4, we run the full model and find that the results for network density and modularity are robust in sign and significance, while the coefficients are slightly lower than those in Model 2. However, the effect of charity donations becomes insignificant in Model 4. We also tested for spatial autocorrelation between the residuals in Model 4 using a Global Moran's I test. After row-standardizing our spatial weights, this test returned a very low, and insignificant, Moran's I of 0.0256 ($P = 0.91$). We can conclude from the full model that the general level of social capital and bonding social capital exert a positive effect on the number of RE cooperatives, while no effects can be found for the other measures of social capital.

Overall, our results confirm Hypotheses 1 (*the higher a region's social capital, the higher the number of renewable energy cooperatives in the region*) and 2a (*the higher a region's bonding social capital, the higher the number of renewable energy cooperatives in the region*). However, we do not find any evidence for

[3] We also run the same model replacing network diversity with node locality, as an alternative measure for bridging ties which takes into account the geographical distance between municipalities (see Norbutas and Corten (2018). The effect for node locality is also insignificant, meaning that the geographical distance of municipalities' individuals' network ties do not affect the number of RE cooperatives in the municipality.

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Table 4. Standardized coefficients for negative binomial regression models

	Model 1	Model 2	Model 3	Model 4
Population (log)	0.96***	0.92***	1.06***	1.03***
Neighbouring population (log)	0.24	0.18	0.20	0.15
Land area	0.23***	0.23***	0.22***	0.22***
Income	0.07	0.06	0.08	0.08
Green votes	0.17***	0.15***	0.22***	0.20***
Network density		0.02**		0.03**
Network modularity (bonding social capital)		0.10*		0.07*
Network diversity (bridging social capital)		−0.01		−0.02
Charity donations			0.24*	0.23
Voter turn−out			−0.13	−0.13
Blood donations			0.05	0.05
Intercept	−0.45***	−0.36***	−0.45***	−0.39***

Note:
* $P < .05$; ** $P < .01$; *** $P < .001$.

Hypothesis 2b regarding the effect of bridging social capital (*the higher a region's bridging social capital, the higher the number of renewable energy cooperatives in the region*).

5.1 Robustness check

We check the robustness of our findings by running an additional time-to-event analysis, using a Cox regression model to explore the time to the first founding of a RE cooperative per municipality. This additional analysis serves two primary purposes. First, it introduces a temporal dimension to our investigation, enabling a more nuanced understanding of municipalities' receptiveness to RE cooperatives as social innovation. This includes identifying the municipalities that took pioneering steps and those that exhibited a more cautious approach. From an innovation standpoint, one could anticipate that municipalities with more bridging ties may play a more significant role, as setting up the first cooperative in a municipality may benefit more from knowledge spillovers from other municipalities compared to any other cooperative founded hereafter. Second, as outlined in the Methods section, the time-to-event analysis mitigates the risk of endogeneity associated with social capital already established by other RE cooperatives, as it focuses on the founding of the first cooperative per municipality only.

Table 5 presents the results of the time-to-event analysis.[4] When compared with our main analysis in Table 3, we find minimal differences. Notably, the effects of density and bonding social capital remain consistent in both magnitude and direction, retaining their statistical significance. The coefficient of bridging social capital, while now exhibiting a positive coefficient compared to Table 3, remains statistically insignificant, contrary to our expectations regarding its role in approaching RE cooperatives as a social innovation for municipalities. Thus, our robustness check suggests that endogeneity may not have played a significant role in our main analysis as the results for our hypotheses remain stable. From a substantive point of view, we can conclude that even when narrowing our focus to the founding of the very first RE cooperative in a municipality, bridging ties appear to have no notable impact.

Another robustness check involved substituting the variable "green votes" with the variable "education" in our analysis. Despite the strong correlation between the two variables and the presence of multicollinearity signals in the variable "education," we consider it an important explanatory dimension that warrants control. As presented in Appendix Table A.1, our results remain robust even after this replacement. Notably, the only discernible change occurs in the traditional measures for social capital, where "charity donations" loses its significance in comparison to Table 3.

[4] Considering coefficient inflation problems with dummy variables for fixed effects when running Cox PH models (Allison 2002, 2009), we do not include the province dummy in our model but rather use standard-errors clustered by province. Furthermore, considering the small range of our social capital measures and that we are reporting hazard ratios here, we standardize these covariates before running the Cox PH model. Network density, Network modularity and Network diversity were all standardized so that their maximum value is 1. Similarly, the variable Green votes is added as measure in percentage points (rather than a fraction).

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Table 5. Cox PH regression models on the founding of the first REC

	Model R1	Model R2	Model R3	Model R4
Population (log)	1.723***	2.133***	1.908 ***	2.265***
	(0.103)	(0.093)	(0.112)	(0.112)
Neighbouring population (log)	0.900	0.889*	0.889*	0.876*
	(0.062)	(0.049)	(0.050)	(0.050)
Land area	1.001	1.001*	1.001*	1.001
	(0.001)	(0.001)	(0.001)	(0.0005)
Income	1.026	1.021	1.017	1.017
	(0.014)	(0.015)	(0.014)	(0.016)
Green votes (percentage points)	1.046***	1.039***	1.060***	1.051***
	(0.013)	(0.012)	(0.012)	(0.012)
Network density		16.303**		10.859*
		(1.078)		(0.904)
Network modularity (bonding social capital)		9.075**		6.321*
		(0.865)		(0.867)
Network diversity (bridging social capital)		3.939		4.415
		(0.796)		(0.906)
Charity donations			1.060**	1.068**
			(0.031)	(0.030)
Voter turn–out			1.006	0.993
			(0.020)	(0.019)
Blood donations			1.003	1.008
			(0.023)	(0.023)
n	5,564	5,564	5,564	5,564
Events	280	280	280	280
Log Likelihood	−1429.57	−1422.53	−1423.17	−1417.95
Akaike Inf. Crit.	2869.14	2861.06	2862.34	2857.90

Note:
* $P < .05$; ** $P < .01$; *** $P < .001$. Standard errors in parentheses are robust standard errors clustered by province. Reported effects are hazard ratios (exponent of the coefficient). Intervals are on yearly basis.

6. Discussion and conclusion

Our study analyzed the importance of social capital for the emergence of renewable energy (RE) cooperatives at the municipal level in the Netherlands. We adopted a social network approach to social capital grounded in social capital theory. Using social network data within and across Dutch municipalities, we analyzed the effect of different network structures, associated with general, bonding and bridging social capital, on the presence of RE cooperatives. We expected all three types of social capital to benefit cooperatives, but for different reasons. For cooperatives to emerge, some general level of social capital can be seen as a necessary condition, as it requires a group of potential members to provide the organizational structures and resources through their social networks to start a cooperative organization. Bonding social capital, more specifically, promotes trust that helps run a cooperative by lowering the risks of free-riding and conflict-making, while bridging social capital helps source relevant knowledge and information from communities outside a municipality.

Using a comprehensive database of all known RE cooperatives in Dutch municipalities, we found that general social capital and bonding social capital foster RE cooperatives while no such effect was found for bridging social capital. This suggests that dense local network structures, both at the municipality level (general social capital) and within subcommunities in a municipality (bonding social capital), support the establishment of RE cooperatives.

In our analysis, we also include typical proxies of social capital used in previous studies, including charity donations, voter turnout, and blood donations. Such proxies measure the expected outcomes of social capital rather than social capital directly. Contrary to our network-based measures of social capital, the three proxies for social capital show little effect on RE cooperatives, in line with Chetty et al. (2022a) who argued that the use of data from social networking platforms can help overcome the traditional measurement challenges associated with social capital. Network-based measures can be preferred methodologically, as they are derived from an explicit representation of the social network structures within and across municipalities, as well as empirically, as network-based measures provide more robust empirical relationships than alternative proxies of social capital.

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One limitation of our study is that we measure the number of RE cooperatives per municipality rather than the total number of members of RE cooperatives or total RE production by cooperatives, for which data were not available. Hence, we abstract from differences in size between cooperatives. However, to the extent that the size of cooperatives scales with municipality populations, such differences could be controlled for by the population variable in our analysis.

This study contributes to the literature on the geography of innovation and regional development. It challenges previous studies, which tend to argue that bonding social capital hampers regional economic development, because it is harmful to a community's potential to adopt new ideas or combine different forms of knowledge (Beugelsdijk and Smulders 2003; Cortinovis et al. 2017; Eagle, Macy, and Claxton 2010; Knudsen and Rousseau 2007; Norbutas and Corten 2018) or to engage in deviant social practices (De Vaan, Frenken, and Boschma 2019). When comparing the effects of bonding and bridging social capital, we found evidence of a positive effect of bonding social capital on the presence of RE cooperatives, while such an effect was absent for bridging social capital. This is particularly striking compared to Norbutas and Corten (2018), who found clear effects of bridging social capital on economic prosperity using the same network data. Thus, our study thus sheds new light on the role of bonding social capital.

Our results can be interpreted as stemming from the different nature of entrepreneurship involved in the founding and operation of a cooperative compared with the founding and operation of a new form. Entrepreneurial activity involved in the founding of RE cooperatives can be regarded as a form of "collective entrepreneurship" (Cook and Plunkett 2006; Bauwens, Vaskelainen, and Frenken 2022). Rather than technological novelty, the innovation brought about by RE cooperatives is best described as "transformative social innovation," which provides a new institutional configuration for collective technology management at the local level (Avelino et al. 2019, Punt et al. 2022). Such social innovation, leading to local diversification in energy supply, benefits from localized bonding social capital, to the extent that these activities are rooted in communal interests.

Building on our study, we advocate for further developing the theory of social capital in the field of economic geography in two ways. First, notwithstanding the theoretical arguments and empirical evidence concerning the enhancing effects of social capital on the *generation* of innovation, we call for social capital scholars to extend their work to cover the *adoption* of innovation. Second, we call for more detailed studies on the particular collective action problems faced in local contexts and the variety of solutions being developed and adopted across regional contexts. Zooming in on the specific solutions emerging in different local contexts, and embedded in multi-level institutional structures, would help understand better how local conditions lead to different outcomes of collective action.

A focus on entrepreneurial activities and innovation adoption rooted in communal interests may be especially critical when considering technology users in local and regional policymaking. The traditional focus on leveraging the technological capabilities of local firms in stimulating regional development might conceal potential regional development from technology users and collective action (Dewald and Truffer 2011; cf Tanner 2014). Our study suggests that users and communities can play an essential role in regional development, particularly in sustainability transitions where the adoption of innovation and practices is central (Truffer and Coenen 2012). Through collective action that builds on local social relationships, users deploy technologies for energy generation that might otherwise be imported from other regions.

A follow-up question in the study of social capital and cooperatives is the role of social capital in the collective action of cooperatives themselves vis-à-vis businesses, governments, and the wider public. Just as residents face collective action problems in running a cooperative, cooperatives face collective action problems to exchange knowledge and create joint assets among themselves, and collectively lobby for better regulations often in umbrella organizations (Bauwens, Vaskelainen, and Frenken 2022). At the meta-organizational (national) level, bridging rather than bonding social capital may foster effective cooperation, as meta-organizations connect members embedded in different cooperatives, carefully balancing national and local interests.

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Appendix

Table A.1

Dependent variable: Number of RE cooperatives in a municipality

	Model R5	Model R6	Model R7	Model R8
Population (log)	0.574***	0.690***	0.623***	0.701***
	(0.070)	(0.088)	(0.082)	(0.093)
Neighbouring population (log)	0.002	0.026	−0.012	0.014
	(0.037)	(0.043)	(0.039)	(0.044)
Land area	0.002***	0.001***	0.002***	0.001***
	(0.0003)	(0.0003)	(0.0003)	(0.0003)
Income	0.031	0.034	0.037	0.041
	(0.024)	(0.023)	(0.025)	(0.024)
Education	1.528	0.903	1.613	1.192
	(0.924)	(0.930)	(1.029)	(1.042)
Network density		40.481**		41.720**
		(13.367)		(14.110)
Network modularity (bonding social capital)		3.214**		3.127**
		(1.107)		(2.407)
Network diversity (bridging social capital)		−0.023		0.542
		(2.416)		(2.477)
Charity donations			0.033	0.025
			(0.024)	(0.025)
Voter turn−out			−0.009	−0.018
			(0.013)	(0.013)
Blood donations			0.038	0.036
			(0.024)	(0.024)
Intercept	−7.317***	−10.401***	−7.728***	−10.100***
	(1.029)	(1.646)	(1.372)	(1.645)
Max. VIF	3.28	3.82	3.75	4.34
Observations	350	350	350	350
Log Likelihood	−518.657	−511.335	−516.1294	−509.307
Akaike Inf. Crit.	1073.3	1064.7	1074.3	1066.6
Province dummy	Yes	Yes	Yes	Yes

Note:
* $P < .05$; ** $P < .01$; *** $P < .001$. Standard errors in parentheses.

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