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Survey

The emergence of a global innovation system – A case study from the urban water sector

Jonas Heiberg [a,b,*], Bernhard Truffer [a,b]

[a] Swiss Federal Institute of Aquatic Science and Technology (Eawag), Überlandstrasse 133, CH-8600 Dübendorf, Switzerland
[b] Copernicus Institute of Sustainable Development, Utrecht University, Princetonlaan 8a, 3584 CB Utrecht, the Netherlands

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ABSTRACT

Innovation studies is increasingly acknowledging the multi-scalar nature of the systemic contexts, in which innovations are being developed and deployed. This paper builds on and further develops a recently proposed framework for studying global innovation systems (GIS). It aims at explaining the emergence of a GIS by outlining the specific local resource-related conditions that lead to the creation of structural couplings, i.e. actors, networks and institutions that allow for multi-scalar resource flows. Deploying a qualitative case study, the paper investigates the interrelated developments of eight demonstration sites of innovative wastewater treatment technology in North-Western Europe. It shows how resource-related deficits lead actors to draw on resources generated outside of their local context. The paper contributes to the literature on the Geography of Transitions by highlighting the importance of resource complementarities among different local contexts, as well as the crucial role of trans-local systemic intermediaries in shaping an emergent GIS.

1. Introduction

The globalization of innovation activities is one of the well-established facts in innovation studies of the past decades (Archibugi et al., 1999, Carlsson et al., 2002, Carlsson, 2006). Especially in the quest for tackling grand societal challenges, like climate change, urbanization, inequality and migration, harnessing resources from trans-local networks will be important for innovation success (Coenen et al., 2012, Truffer and Coenen, 2012). Accordingly, innovation- and transition studies have increasingly recognized that socio-technical transformation processes are not limited by the boundaries of specific countries, but often span across places and even scales (Carlsson and Stankiewicz, 1991, Oinas and Malecki, 2002, Coenen et al., 2012, Dewald and Fromhold-Eisebith, 2015, Gosens et al., 2015, Sengers and Raven, 2015, Fuenfschilling and Binz, 2018). The dominant approach in transition studies to understand emerging clean tech industries – the framework of technological innovation system (TIS), however, had a strong but mostly implicit focus on national system boundaries (Bergek et al., 2008a), which got increasingly problematized in recent years (Bergek et al. 2015; Coenen et al. 2012). Scholars started to reformulate the framework to embrace multi-scalar or even global structures in socio-technical innovation dynamics (Binz et al., 2014, Wieczorek et al., 2015, Sengers and Raven, 2015, Binz and Truffer, 2017). Binz and Truffer (2017) argued that in order to conceptualize multi-scalar or even "global" innovation systems (GIS) two assumptions had to be introduced. First, systemic synergies in the build-up of resources could emerge from the interaction of actors, their cooperation in networks or institutions, which constitute partial, urban, regional or nationally delimited subsystems. Second, for an overall (global or

* Corresponding author.
E-mail address: jonas.heiberg@eawag.ch (J. Heiberg).

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multi-scalar) innovation system to function properly, these place-bound resource formation processes have to be "structurally coupled", i.e. specific actors, networks or institutions (Binz & Truffer, 2017, p. 1285) have to enable the access to these resources across subsystems (henceforth related to as "structural couplings"). Innovation processes within or across such subsystems are assumed to contribute to the generation of four key resources, according to Binz and Truffer (2017): knowledge, legitimacy, market structures and financial capital.

While research in economic geography has a long tradition in explaining how spatial or other proximities matter in the diffusion of different types of knowledge for innovation processes (Bathelt et al., 2004, Martin and Moodysson, 2013, Boschma, 2005), scholars are only starting to understand the underpinnings of trans-local couplings in the co-creation and diffusion of market structures, capital and legitimacy (e.g. Binz et al., 2014, Chaminade and Plechero, 2015, Yeung and Coe, 2015, Binz et al., 2016b, Heiberg et al., 2020, Gong, 2020). Some scholars have elaborated how GIS may differ along the value chain of a specific innovation (Rohe, 2020, Hipp and Binz, 2020, Malhotra et al., 2019). Others identified how multi-scalar development trajectories differ between sectors (Binz et al., 2020). The mechanisms behind the emergence of new multi-scalar GIS structures have, however, not yet been addressed. What are the conditions that drive innovating actors to build long-distance networks and learn from experiences in other places? And how can systemic synergies be generated in trans-local networks? These are the leading questions which the present paper aims at answering.

We assume that actors can contribute to building up resources for innovation success like new knowledge, early market structures, financial capital or legitimacy, for example through R&D, networking, investments, or institutional work (Hekkert et al., 2007, Musiolik and Markard, 2011, Binz et al., 2016b). Their spatial contexts may be conducive to these activities by providing portfolios of resources, by hosting pre-existing local networks, infrastructures, funding opportunities, or related knowledge. However, a lack of resources or the inability to build them up locally may represent barriers for the further development and maturation of the innovation. In the extant literature, these barriers are typically conceptualized as system failures (Woolthuis et al., 2005, Weber and Rohracher, 2012, De Oliveira et al., 2020), which have to be proactively addressed by joint activities in the innovation system. For instance, innovators in a region with plentiful related industries, a differentiated labor market and matching universities will more easily be able to build up knowledge stocks that are critical for innovation success (Jaffe et al., 1993, Audretsch and Feldman, 1996). Other regions may host a population, with a high awareness for environmental challenges and a higher willingness to support and adopt new, seemingly more sustainable technologies and products (Jeannerat and Kebir, 2016, Binz et al., 2016b). Hence, actors in this latter region may be more easily able to mobilize legitimacy and engage in early market formation, even if the related knowledge base is not well established. Depending on the stage of maturity of an emerging innovation system and its spatial context, specific "motors" of innovation may be at work, leading to different local resource constellations (Suurs and Hekkert, 2012, Suurs and Hekkert, 2009). Therefore, in many emerging systems, we may witness only a partial establishment of an innovation system, generating specific resources, while being confronted with barriers for further progress. When unable to mobilize these resources locally, actors may start to look for accessing them from elsewhere perhaps following specific forms of proximities, such as similar formal or informal institutional set-ups (Boschma, 2005, Content and Frenken, 2016, Carvalho and Vale, 2018, Heiberg and Truffer, 2021).

Based on these considerations, we conceptualize how resources get mobilized in spatially distant subsystems and ultimately give rise to a multi-scalar, global innovation system. In explaining these developments, we identify resource stocks and barriers in specific sites where innovation happens. To overcome the limitations, the local actors may try to establish structural couplings with initiatives in other places hosting potentially complementary resource portfolios. Another signal for a GIS to take shape is when structural couplings are managed by systemic intermediaries i.e. organizations or individuals who facilitate and moderate the interactions among otherwise unrelated actors (van Welie et al., 2020). Intermediaries might help coordinate trans-local activities and resource flows among previously unconnected spatial contexts. With this, the GIS perspective opens up for a wider set of spatial development trajectories compared to the linear pathway often implicitly assumed in TIS studies, in which a TIS starts to form in one particular place, where it matures by mobilizing all relevant resources locally, before the innovation gradually diffuses to other places. Potentially, development pathways may as well start in global networks and then diffuse to different regions, or early mover regions may lose leadership along the way, while other regions catch up.

Empirically, we explore an emerging translocally connected set of demonstration sites, in the field of onsite blackwater treatment and vacuum sewerage in North-western Europe over the past decade. Initiatives with alternative, often decentralized, water treatment technologies have emerged in many cities across the world as a means to counter impacts from climate change on urban water management like flooding and droughts (Larsen et al., 2016). Mostly, these initiatives remain isolated as different cities, regions or countries try to find local solutions to such global problems. These specific places often lack critical resources to scale and mature solutions and, therefore, their contribution to overall transitions remains limited. In the case of blackwater treatment, we observe an increasing interconnection of experiments in different places and the emergence of trans-local system resources and structural couplings across North-Western Europe. We, therefore, hypothesize that the technological field of blackwater treatment has developed into a trans-local innovation system over time showing core processes that we would expect in the emergence of a GIS. We trace the evolution of this network of local experiments as well as the mechanisms behind local and trans-local resource mobilization processes over the past twenty years from the origins around individual research groups in Norway and Germany to a current wave of investment, technology deployment and translocal coordination across the Netherlands, Belgium and Sweden.

Methodologically, we base our case study on the analysis of transcripts of twenty expert interviews with individuals involved in blackwater development and deployment experiments across North-Western Europe, as well as drawing on supplementary documents (Yin, 1994). These data, allow for a detailed reconstruction of initial local resource endowments, degrees of partial subsystem maturity, and spatial scales of resource mobilization that can be linked to the emergence of multi-scalar innovation system.

The article is organized as follows. Section two introduces existing conceptualizations of innovation system resources and barriers, typical resource constellations during maturation phases of innovation system, and the role of intermediaries in facilitating resource mobilization, leading to GIS emergence. Section three introduces the empirical case around a blackwater treatment technology and elaborates the methods. Section four present the results along three phases of development before section five discusses the results in light of our conceptual approach. We conclude with conceptual lessons and future research avenues in terms of further conceptualizing general GIS dynamics.

2. Perspectives on Innovation system formation

To formulate a dynamic understanding of GIS emergence, we will elaborate how core system resources get built up through strategies of different actors depending on the specific development stage of their demonstration site and, potentially, its local systemic context. In a second step, we will extended this understanding in order to explain the establishment of structural couplings across spatial contexts.

2.1. Resources and barriers for innovation system formation

Innovation studies has established that success of innovations is often best explained by adopting a systemic perspective, especially when radical innovations or those that are supposed to respond to grand societal challenges are at stake (Edquist, 2005). Instead of solely depending on actor-internal capabilities, strategies and resources, innovation success often depends on the strategies of and interactions among a wide set of actors, such as companies, academic research, industry associations, government offices, and even users and NGOs. This perspective was most prominently spelled out by the well-established family of innovation systems frameworks, which gained strong resonance both in academic and in policy circles over the past three decades (Edquist, 2005, Sharif, 2006, Chaminade and Edquist, 2010, Weber and Truffer, 2017). In the context of sustainability transitions research, the approach of technological innovation systems (TIS) gained most prominence, by focusing on emergent industry dynamics in clean tech sectors such as photovoltaics, wind, biogas, organic food, electric cars or urban water (Carlsson and Stankiewicz, 1991, Bergek et al., 2008a, Negro et al., 2012). Scholars proposed that innovation systems could first of all be described by their structural characteristics, i.e. the different types of actors, their networks and the rules and regulations that they developed for their coordination (Jacobsson and Bergek, 2004, Carlsson and Jacobsson, 1997). A complementary description of the system was later proposed through identifying the core activities, processes or “functions” that these actors engaged in: knowledge creation, entrepreneurial experimentation, market formation, capital mobilization, guidance of the search and legitimation (Bergek et al., 2008a, Hekkert, 2007). The conceptual added value of looking at innovation success through a systemic lens is that it emphasizes the joint construction of key resources through cumulative causation or what authors have coined “virtuous circles” (Jacobsson and Bergek, 2004, Carlsson and Jacobsson, 1997). Despite having highlighted the relevance of these cumulative processes, innovation systems approaches have repeatedly been criticized of being primarily descriptive and lacking explanatory power (Weber and Truffer, 2017, De Oliveira et al., 2020).

To counter these limitations, Binz et al. (2016a) and Binz and Truffer (2017) proposed to interpret these seven functions as activities to build up four core resource stocks, which they identified as knowledge, financial capital, market structures and legitimacy. Knowledge is mostly related to expertise in technology, manufacturing, operation and maintenance, which are needed in the course of the development, diffusion, and deployment of new technologies. It can be differentiated in codified knowledge, which can be easily reproduced and mobilized through information and communication technologies, and tacit knowledge, which is spatially sticky and can only be learned through face-to-face interactions and on-site learning (Jensen et al., 2007). Knowledge is the one resource, which has gained most attention in innovation studies and much of economic geography (Hassink et al., 2019). For instance, in their seminal paper, Carlsson and Stankiewicz (1991, p.111) defined technological systems as the “knowledge and competence networks” of actors working in a specific field and under a specific institutional infrastructure. However, success of innovation will also strongly depend on how new products, technologies or services will interact with existing value concerns in society: Will options be perceived as providing added value to customers compared to existing product alternatives? How will these relate to pre-existing regulations and will they mobilize any sort of support or opposition by broader societal circles?

Binz and Truffer (2017), therefore, hypothesized another three resource stocks to be decisive for innovation success, and which denote value-related aspects of innovation: market structures, financial capital, and legitimacy. Market structures represent regularized exchange relations with users, which stabilize income flows for the innovating companies. However, especially in early phases of innovation, proper markets do not yet exist and have to be built up conjointly by different actors. Value chains will have to be established, market segments with users interested in this option have to be addressed, particular value propositions and corresponding business models have to be defined and implemented. Hence, actors pushing for radical innovations typically have to engage in building up markets structures from scratch (Dewald and Truffer, 2011, Dewald and Truffer, 2017, Boon and Edler, 2018, van der Loos et al., 2020). The same holds true for financial capital. Financial investment is crucial to provide the means to fund activities in the absence of income streams from established markets (Karltorp, 2016, Geddes and Schmidt, 2020). Early innovation activities, however, are associated with high uncertainties in terms of functionality, cost structures and actual consumer segments. Innovating actors, therefore, have to establish a specific resource stock consisting of a basic understanding of and trustful relationships with creditors like banks, venture capital firms, and other private investors. The same holds for political actors and public authorities prepared to support R&D, experimentation and demonstration projects (Hekkert, 2007, Binz et al., 2016b). Finally, legitimacy for an emerging technology needs to be actively created to raise positive expectations among different actors, and help align regulation in policy in favor of the novel technology (Aldrich and Fiol, 1994, Bergek et al., 2008b, Binz et al., 2016a). The balanced accumulation of such knowledge- and value-related resources is necessary for innovation system formation and, their absence will result in system weaknesses or blocking mechanisms, system failures or systemic barriers (Jacobsson and Bergek, 2004, Woolthuis et al., 2005, Bergek et al., 2008a, Wieczorek

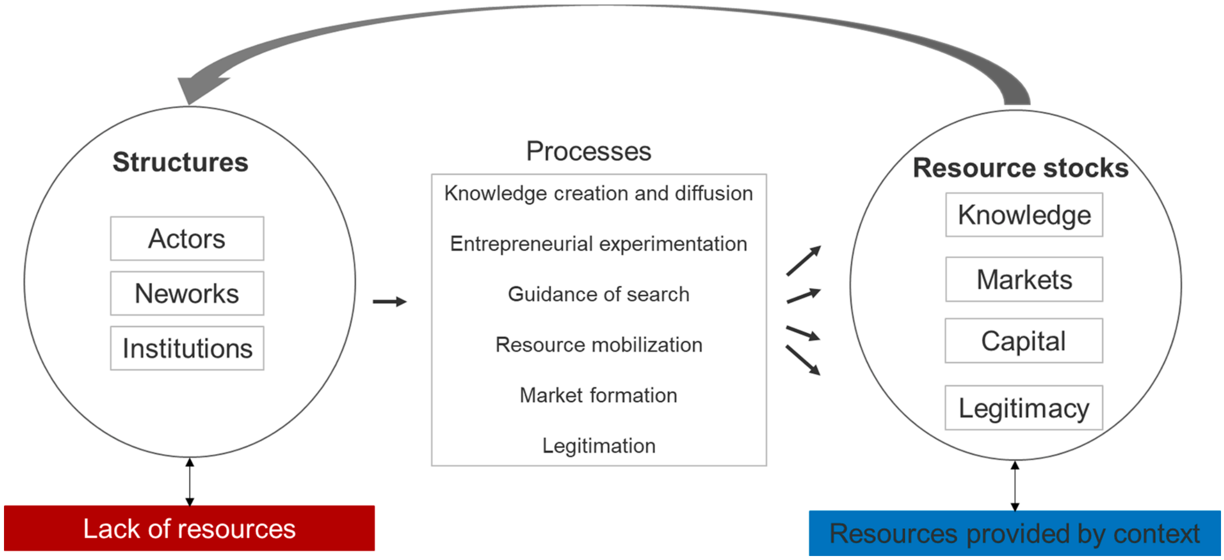

Fig. 1. Causal scheme of innovation system build up based on Hekkert (2007), Bergek et al. (2008a), Binz et al. (2016b), Musiolik et al. (2012) and Hekkert, 2012, De Oliveira et al., 2020).

The focus on resources enables to identify causal mechanisms connecting innovation system structures with innovation success through the intermediate concepts of key processes and resource stocks (see Fig. 1). The causal connection between the three dimensions can be summarized as follows: Actors typically first draw on their internally available resources (e.g. capabilities, capitals and networks) to manage their in-house innovation processes. Especially, for radical innovations or those that respond to grand challenges, however, many of the critical resources may not be in the ownership of individual organizations. Innovators, therefore, have to access or create them by teaming up with other actors. As an example, positive expectations about the prospects of a new technology or product are key to raise funds and build up markets. An individual company's activities on its own behalf will, however, quickly run the risk of being perceived as a mere marketing and lobbying. A more effective form of creating positive expectations will be achieved by engaging in processes of technology legitimation jointly with other actors (Aldrich and Fiol, 1994). Technology legitimacy is a resource, which needs the coordinated actions of different organizations and the proactive institutional work for influencing normative or cognitive institutions becomes a collective challenge (Yap and Truffer, 2019). Legitimacy is a systemic resource if it cannot be fully controlled by any actor alone, while all actors will ultimately profit from its existence (Binz et al., 2016a, Markard et al., 2016). The literature has converged on a list of core processes or functions through which actors co-produce systemic resources as the ones listed above (Bergek et al., 2008a, Hekkert, 2007). Causal mechanisms, therefore, connect structures (actors, networks and institutions) through their activities and strategies (processes or functions) to create the four systemic resources stocks, which are essential for innovation success and eventually feedback on structures. Lacking or insufficient resource stocks may incentivize the structure to drive resource formation, or else will lead to system failures or represent barriers, which hamper the further maturation and scaling of the respective product, technology or service (see Fig. 1 for a schematic representation). However, systemic resources may be enhanced through the presence of actors, networks or institutions in the regional or urban context that may indirectly provide resources from outside the system, e.g. through the presence of supportive, universities or cluster organizations working in related knowledge fields.

2.2. *Multi-scalar processes of resource mobilization*

The origins of relevant resources for innovation success are not restricted to those within companies or co-produced within an emerging innovation system. A third origin can be from different contexts in which an innovation system is embedded (see Fig. 1 bottom, blue box) (Bergek et al., 2015). Most obviously, actors will try to draw on resources that are available in their specific social or geographical context. Specific localities, such as regions may host particular knowledge stocks, which are critical for solving the technological innovation challenges, a fact that is well-established in evolutionary economic geography (Frenken and Boschma, 2007, Hidalgo et al., 2007, Kogler et al., 2013). Or, the region might be the home of special cultural communities or institutional setups, which facilitate the mobilization of resources for early test markets (Dawley, 2014, Content and Frenken, 2016, Carvalho and Vale, 2018).

However, local resource stocks might not be sufficient to support innovation system development. Actors may then try to import them from elsewhere (Coenen et al., 2012, Binz et al., 2014, Gosens et al., 2015, Wieczorek et al., 2015, Trippl et al., 2018, Heiberg et al., 2020, Gong, 2020). Binz and Truffer (2017), therefore, proposed to study innovation systems as multi-scalar constructs, so-called global innovation systems (GIS) to account both for spatially contextual resources as well as interconnections that span across regions, countries or even the global scale. Depending on the technological and value-related characteristics of an industry or sector, different

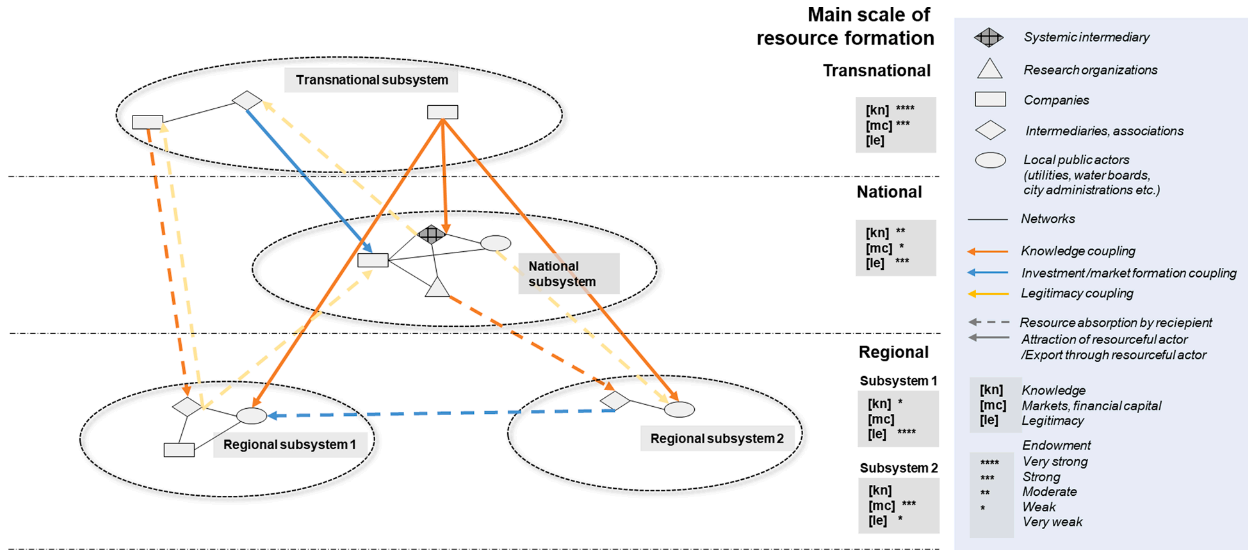

Fig. 2. GIS structure with different resource stocks in subsystems at different spatial scales. Own figure based on Binz and Truffer (2017).

geographical layouts of GISs are likely to emerge. For instance, footloose innovation systems, like solar photovoltaics, which draw strongly on codified knowledge are likely to see their manufacturing activities quickly moving to low-cost regions and establish globalized knowledge networks, markets, capital, and legitimacy, whereas in spatially sticky systems, like wind energy, locally-bound resources will lead to a GIS where certain manufacturing regions will maintain strong positions in the global industry (Binz and Truffer, 2017).

The GIS framework posits that, in addition to the usual structures, processes and resource stocks of an innovation system, we have to differentiate (spatially defined) sub-systems in which particular resources will be developed and become accessible. In order for the innovation to develop and mature, it is important that these different subsystems get interconnected through so-called structural couplings, i.e. actors, networks and institutions (Bergek et al., 2015), which span over different spatial scales and which enable the flow of specific resources among the relevant regions. At the actor level, a multinational firm or NGO might represent a structural coupling by actively liaising between system formation processes in different countries or regions. Regular international trade fares or conferences might represent opportunities to connect actors from different regions through networking. And institutions may also function as structural couplings, when global industry standards or professional cultures enable the flow of resources among different places (Binz and Truffer, 2017, Fuenfschilling and Binz, 2018). A fully functional GIS, will, in general, consist of several localized initiatives engaging with resource formation, and a set of structural couplings to complement the overall resource stocks necessary for the development and maturation of this innovation.

Fig. 2 exemplifies a specific constellation of resource stocks captured in subsystems at the regional, national and transnational scale. We depict subsystems with their prevailing resource stock constellation (grey blocks in the middle of Fig. 2). A low score on any of the three resource stocks suggests that actors would have to engage in corresponding activities to correct for this deficiency. For simplicity, and since we are interested in GIS emergence, we have grouped capital investment and market formation in one category. Especially in early innovation system formation these two will be strongly connected since early markets need to be subsidized financially by public or private actors. In our generic example, region #1 shows weak knowledge, almost no market structures, but high levels of legitimacy for the emerging innovation. To further promote the innovation in region #1, actors' might try to import these resources from elsewhere, like accessing expertise from the transnational level in Fig. 2.

Previous research in evolutionary economic geography showed that transnational transfer and regional embedding of knowledge and legitimacy might operate through the *attraction* of specific individuals to a specific region or country, or through the *absorption* of resources by actors with the relevant capabilities (Binz et al., 2014, Trippl et al., 2018, Heiberg et al., 2020). The other way round, resources might also be consciously *exported* elsewhere, e.g. through foreign direct investments or knowledge embodied in tradeable goods. Thus, we would expect multi-scalar resource mobilization to be instantiated by actors, networks and institutions that span across spatial subsystems with *complementary* resource stocks. However, these complementarities may not be sufficient. Actors still have to identify their existing resource constellation, find out about potentially complementary resource stocks elsewhere, and finally establish the structural couplings necessary to tap into these resource stocks (Wieczorek et al., 2015). In this light, coordination and reflexivity become crucial dimensions of GIS emergence.

When one can meaningfully speak of a GIS and what differentiates it from mere trans-local linkages among individual actors, might then crucially depend on the ability of the system to self-coordinate and maintain its activities at the trans-local scale. In this context, a central aspect may be the establishment of 'systemic intermediaries' (van Lente et al., 2003, Klerkx and Leeuwis, 2009). Systemic intermediaries are by definition actors addressing systemic barriers and connecting the "different components of international, national, sectoral and/or regional innovation systems" (Klerkx and Leeuwis, 2009, p.850). Indeed, van Welie et al. (2020) found in the

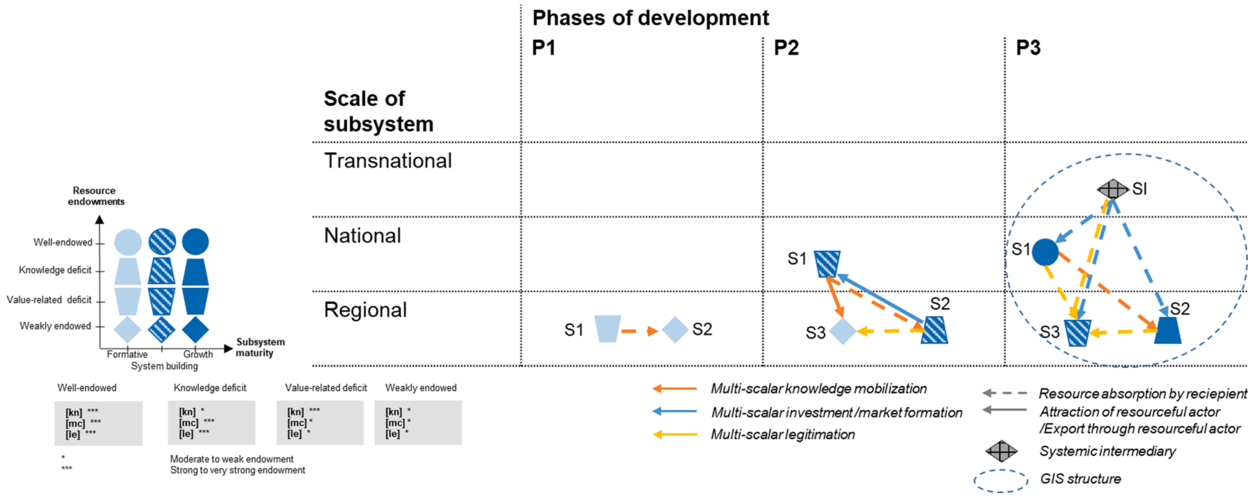

Fig. 3. Multi-scalar resource mobilization and intermediation during different phases in the emergence of a hypothetical GIS . Own figure.

context of a GIS around sustainable sanitation solutions in the Global South that systemic intermediaries might be a crucial element for facilitating the development of networks for the mobilization of knowledge and legitimacy for subsystems during their formative phase, and for the guidance of search and resource mobilization within and across subsystems during their growth phase. While not a sufficient condition for successful innovation system build-up, we, therefore, argue along the lines of van Lente et al. (2003, p.30) that "the efforts of systemic intermediaries in encompassing systemic innovations are (…) probably necessary". These intermediaries may originate from or be embedded in any subsystem context at any specific spatial scale. In Fig. 2, the exemplary systemic intermediary is a national industry association that also coordinates activities among subsystems. In other cases, systemic intermediaries might equally originate from the global scale, like the global membership based association for sustainable sanitation innovations in the global south identified by van Welie et al. (2020), or from the regional-scale like, for example, grassroots network hubs that coordinate a network of localized transition town movements (Feola and Nunes, 2014).

Hence, we can assume that along with resource complementarities and the necessary capabilities for multi-scalar resource mobilization, an indicator of the emergence of a GIS is the presence of one or more systemic intermediaries that coordinate innovation activities and facilitate the creation of structural couplings among several individual subsystems. At the same, time we consider intermediaries to be an indicator for spatial subsystems at higher spatial scale. Hence we will in the following only speak of a national subsystem in the presence of a national-scale systemic intermediary. Departing from these static, structural features of GIS, we will now formulate a framework, which captures the dynamic interplay of the different causal mechanisms in a multi-scalar context and which may ultimately give rise to a fully-fledged GIS.

2.3. *Mechanisms of global innovation system emergence*

TIS scholars established early on that innovation systems are likely to develop through different stages of maturity. Especially for emerging industries different phases of development can be distinguished (Bergek et al., 2008a). To develop a more explanatory framework of innovation system emergence, Suurs and Hekkert (2009, 2012) proposed to analyze how the profiles of salient functions – so-called motors of innovation – shifted over the course of system maturation phases. During the *formative phase,* knowledge-related activities as well as legitimation and the creation of positive expectations by promoting actors matter very strongly. Although initial financial resources need to be mobilized, market formation is still largely absent. In the subsequent *system building phase*, market formation needs to be tackled more proactively, e.g. by active strategies of the state, community based organizations or by pioneering companies themselves, and legitimation and knowledge creation remain equally important. While funding and the provision of human capital is crucial throughout system development, these processes are mostly driven by the legitimation activities of proponents to secure research and innovation grants, while later, financial resources are increasingly available as a result of market formation and demand articulation. In the latest *growth phase*, legitimation is less important, since market formation, the mobilization of financial resources and the knowledge creation have been institutionalized. We take from these elaborations that different constellations of activities may prevail in different phases of system development. In our interpretation, these processes relate to the buildup of specific resources, which are in critical demand at each development stage.

Fig. 3 combines these insights in a joint framework. On the Y-axis it differentiates between subsystems at different spatial scales: regional, national and transnational. They X-axis (P1-3) represent phases in the development of the overall GIS, independent from the maturity of its individual subsystems. The symbol shadings, in turn, differentiate the maturity of a subsystem in formative, system building and growth phase. Eventually, the symbol shapes differentiate four different combinations in the presence or absence of specific resource stocks at the level of individual subsystems. In the exemplary illustration in Fig. 3, two regional subsystems (S1 and S2) coexist in their formative phase. S1 is more advanced in terms of local knowledge endowments, so S2 can absorb knowledge from it. During the second phase, S1 and S2 enter the system building phase, during which market structures and capital investment become much more important. S1 is still specialized on producing local knowledge and has been able to draw on networks at the national scale. Investment can now be attracted form the regional subsystem S2, which has specialized on value-related resources. A third, rather weakly-endowed subsystem is entering the field in a different region, benefitting from the anchoring of knowledge and legitimacy crucial during its formative phase. In the third phase, S1 and S2 institutionalize their exchange and mature further, as a transnational donor organization (SI) with a strong interest in the focal technology enters the field, providing continued funding for all subsystems and coordinating resource exchanges at the trans-national scale. As such, SI fulfills the role of a systemic intermediary coordinating the system building processes at a higher spatial level. The interconnected set of innovation activities across larger distances may now be characterized as a newly formed GIS, represented by the dotted circle around the whole system.

To answer our focal research questions, when and why multi-scalar resource mobilization processes do emerge, it is, therefore, instrumental to study resource endowments that emerge in different spatial contexts, resource complementarities among these contexts, as well as the coordination of multi-scalar resource exchanges among them, over time. In the following, we will outline our methods and introduce the particular empirical context through which we will reconstruct the emergence of a GIS for the district-scale blackwater treatment technology in Northwestern Europe.

3. Empirical cases and methodology

Empirically, we study a set of international innovation processes around blackwater treatment and vacuum toilets in North-Western Europe over the past 20 years. Vacuum toilets represent a mature technology already widely adopted in cruise ships and trains. Blackwater treatment technologies in turn have so far rarely been applied to on-site wastewater treatment in urban contexts. This novel combination of blackwater treatment with vacuum toilets has evolved as one of several source-separating alternatives to conventional centralized wastewaster treatment. It might help alleviate environmental and economic impacts from the provision of urban water management services in the future (Larsen et al., 2016) as it allows to treat the blackwater on-site. The less diluted water is treated by an anaerobic reactor. Often it is combined with a separate treatment unit for greywater from the kitchen, washing machines and showers, where heat and energy may be captured at the source. Also different methods to recover resources like nitrogen and phosphorus from the wastewater may be added to this configuration, as well as the production of biogas. Early research experiments around this configuration took place during the late 1990s at Wageningen University, in the Netherlands, at TUHH, in Hamburg, Germany, and at the Norwegian University of Life Sciences NMBU in Olso (Larsen et al., 2013). Since then, a couple of demonstration and deployment cases have been set up in Northwestern Europe showing some typical innovation system dynamics in and across different localities. The focal sites and organizations were selected based on prior desk research and through references from earlier research campaigns (de Mul, 2020) . Interviewees were selected in order to be able to reconstruct resource mobilization processes contributing to the realization of demonstration projects situated in different geographical contexts.

The first author conducted twenty interviews were organizations involved in eight major demonstration sites for blackwater treatment in five North-Western European countries. We asked the interviewees about the goals that were associated with each individual project site, which kind of resources were mobilized, and which context-specific resources and barriers shaped the development of their demonstration projects. The interviews were transcribed and coded with help of the qualitative content analysis software Nvivo12. A coding scheme was abductively developed differentiating codes for local resource drivers and local barriers related to three core resource mobilization realms of the GIS framework: knowledge, market structures & financial capital, and legitimacy. As conceptually expected for early innovation system formation, we also here chose to combine market structures and financial capital since market structures usually exclusively involved investments associated with the stimulation for demand around niche markets.

For each demonstration project, we generated a resource profile based on the presence of resources and associated barriers, counting any resource or barrier detected as 1. Resources were identified, if interviewees explicitly mentioned the availability of a resource or the capability to produce it in the local context during the planning and implementation of their respective projects. Barriers were identified through references to specific problems that related to a lack of knowledge, markets and capital, or legitimacy. Subsequently, an index ranging from 1 for a strongly resource stock to -1 for a weakly developed stock or the presence of strong barriers respectively was calculated subtracting the share of barriers present from the share of resources present in each of the three resource realms (for details on the index calculation see App. 1). This way, we derived a basic index score for each project site regarding resource availability/scarcity during the planning and implementation phase of each project. The purpose of the index is to structure the qualitative data from the interviews in such a way that demonstration sites and their surrounding subsystems can be compared regarding available and lacking resources stocks. Importantly, the time during which planning and implementation was executed varied strongly across the cases. Therefore, for each project site the starting year of planning and implementation was captured to orient the project sites in a timeline. Only capturing resource stocks at the planning and implementation stage of each project, of course, inhibits our ability trace resource developments within project sites over time. However, due to the graduated introduction of novel project sites, this procedure still allowed to explore major differences in resource stocks and barriers across sites, and accordingly, the major lines of resource complementarities among them. Maturation dynamics within sites could be captured through the introduction of novel sites within the same region or country, and/or through the emergence of intermediaries in a subsystem.

Additionally, any evidence of multi-scalar resource mobilization was coded in the transcripts according to its resource realm and type, as absorption or attraction/export. The results of individual resource profiles and multi-scalar mobilization processes were mapped over three periods of time, differentiating between the starting years of the individual demonstration projects. The phases were chosen to differentiate the early mover projects and dynamics (1990s and 2000s) from the more recent ones (2010s), and from

Table 1
Local resource score. Resource present minus barrier score for each resource category. Symmetric local resource scores from very strong to very weak.

	Decision year	knowledge	market & financial capital	legitimacy
Oslo	App. 1998	0.17	-1.00	-0.25
Wageningen	App. 1998	0.00	0.00	0.00
Sneek	2003	0.33	-0.33	0.50
Hamburg	2008	0.00	0.17	-0.50
Helsingborg	2012	0.00	0.50	-0.50
Ghent	2014	0.33	0.67	0.25
Stockholm	2018	-0.17	0.00	-0.13
Visby	2020	-0.17	-0.33	0.63

the developments, which are unfolding during the interview campaign (2020s). Each projects' resource score, as well as the individual case narratives emerging from the interviews were drawn upon in order to explain the differentiated patterns of multi-scalar resource mobilization observed.

4. Results

The results will be presented by first introducing the individual demonstration sites, and discussing the subsystem resource stock indicators. Second, we will elaborate the resource complementarities, and the evolution of multi-scalar resource mobilization processes among the sites and their respective subsystems, as well as the presence of potential systemic intermediaries during different phases of GIS structure development. Third, we will link these evidences back to the proposed conceptualization to discuss how and why subsystems have co-evolved into a larger GIS structure.

The first sites, in which actors had implemented blackwater systems are Oslo in Norway and Wageningen in the Netherlands. The efforts of these two sites date back to the end of the late 1990s. Later, in the 2000s, Sneek in the Netherlands and Hamburg in Germany became demonstration sites. In the 2010s Helsingborg (Sweden) and Ghent (Belgium) developed major demonstration sites. Visby and Stockholm in Sweden, eventually entered the planning stage of demonstration projects more recently, for implementation in the 2020s.

The share of resources present and barriers within each of the three resource realms in each major demonstration site during their respective planning and implementation phases can be obtained from App. 2(c). Table 1 shows the final the resource index scores for all project sites. As can be seen from Table 1 demonstration sites had different starting dates and local resource stocks. The two last projects, Stockholm and Visby, are still in the planning process, while all other projects have at least finalized parts of their demonstration sites that are in operation now. In terms of resources, Sneek and Ghent had a stronger knowledge stock than all other localities, while Ghent and Helsingborg stood out in terms of stronger early markets and financial capital. In terms of legitimacy related conditions, Visby, Ghent and Sneek had slightly better conditions than the other localities. Additionally, project contexts lack resources to varying degrees. While most localities have only moderate knowledge stocks, Oslo, Sneek and Visby were especially lacking early market structures and capital investments. Legitimacy problems were most prevalent in Oslo, Hamburg and Helsingborg. With this general description of the local context conditions of different demonstration sites at time of their initialization and implementation, we can now turn to the specific multi-scalar resource mobilization processes that have emerged around them over time. Further, we will draw on the qualitative information from the interviews to elaborate mechanisms linking local resource stocks to the emergence of multi-scalar resource mobilization, i.e. a GIS structure. We will elaborate on the emergence of the GIS following the three phases, which will be labeled 'inception phase', 'coordination phase', and 'expansion phase'.

4.1. Inception phase: late 1990s to 2000s

The inception phase was characterized by the initial engagement by Wageningen University of the blackwater configuration during the second half of the 1990s, marked by the publication of a series of seminal papers like Lettinga et al. (1997). Researchers had already developed a treatment technology for blackwater but needed a more concentrated waste stream than usually received from toilets. To this end, they were looking for practical experiences with low-flush, or ideally, vacuum toilets. In the late 1990s, they visited Lübeck Flintenbreite in Germany, where researchers of Technical University Hamburg-Harburg (TUHH) had implemented vacuum sewerage in a small ecovillage already in the 1990s (In10). Exchanges with TUHH helped generate confidence that a combination of the Dutch UASB reactor and vacuum toilets could actually become a useful technology in the Netherlands. Technological knowledge was thus absorbed from the Lübeck experiences, as well as legitimacy. Another conducive factor was that the Dutch national institute for applied water research (STOWA) was looking for ways to make the Dutch Water sector more resilient against shocks. STOWA helped the researchers connect to individual water boards (mostly in Friesland), as well as regional municipalities and water professionals. In this way, STOWA clearly fulfilled the function of a systemic intermediary in the Dutch national context. Eventually, this led to the implementation of the first larger demonstration site covering 24 homes in ***Sneek***, starting from around 2003 (In10 & In14).

Parallel to these developments in the Netherlands, researchers at the Norwegian University of Life Sciences, NMBU, started developing knowledge around blackwater treatment with vacuum sewerage, collaborating with the Norwegian vacuum toilet producer Jets that is mostly producing for the maritime sector (In16). The technology was applied in a demonstration project in a dormitory in ***Oslo***. All of these developments were rather isolated, research-driven activities, reflecting a very formative phase of system

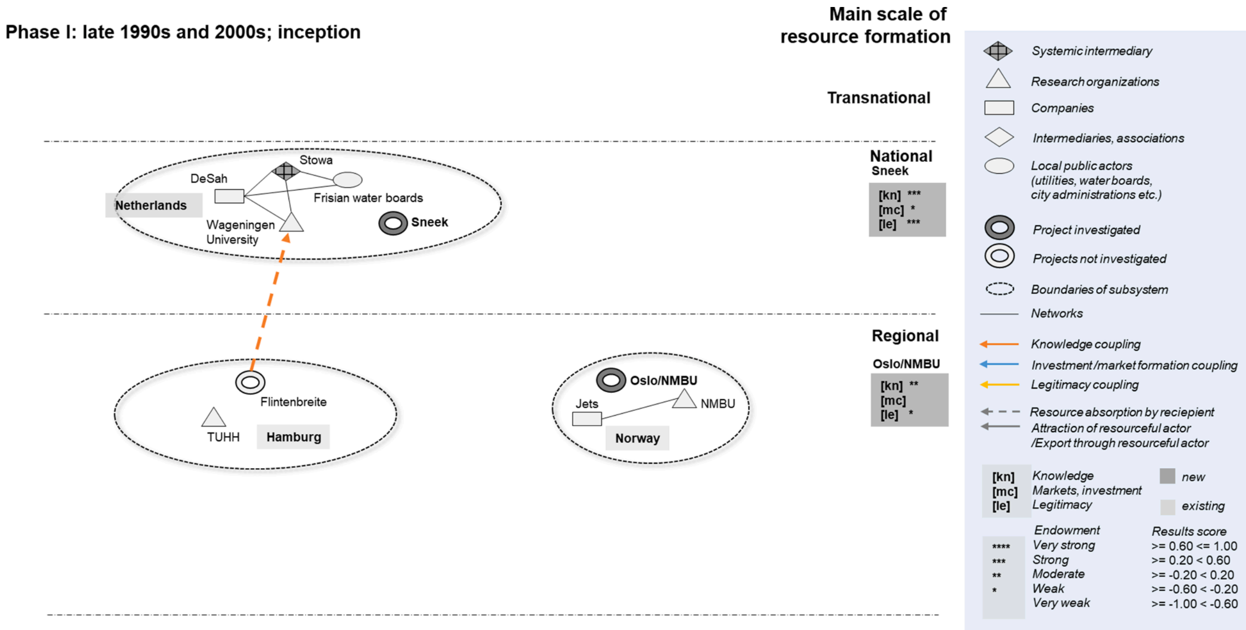

Fig. 4. Inception phase of GIS structure emergence. Own drawing.

development. During this phase, a trans-local structural couplings were established through site visits of Dutch engineers in Hamburg, which provided knowledge and potentially legitimacy, contributing to the Dutch subsystem's formative phase (Fig. 4).

4.2. Coordination phase: 2010s-2020

Beginning around the turn of the 2010s, several new projects emerged in different countries building on variegated sets of local resources. In the Netherlands, ***Sneek***'s succeful application of the technology secured local legitimacy for continued experimentation. A spin-off firm, Desah, as well as an engineering consultancy, LeAF BV, were created by members of Wageningen University to commercialize and further develop and diffuse the technology, allowing for more demonstration projects in Venlo and Kerkrade. Thus, legitimation and knowledge creation were developed locally during this phase. However, market formation and access to financial resources were rather scarce and fluctuating. Major influx of financial support during this phase came through the support by funding schemes of the European Commission, like through the participation of Dutch actors in a Horizon2020-funded project called Run4life from 2017 onwards (In10, 11). Without these external funding sources, the Dutch innovation system might not have been sustained during this period (In11). On the vacuum toilet end of the technology, however, knowledge was channeled to the Netherlands through a collaboration with the Dutch branch of Jets. Thus, while legitimation was generated local, knowledge for specific components, and funding were mobilized from outside of the Dutch national subsystem mainly through Jets and the EU.

In ***Hamburg***, the local water utility decided to implement the technology in an urban neighborhood already as early as 2008 (Augustin et al., 2013, In17). Being sole supplier of water and wastewater services in the city, they actively engaged in market formation themselves. Knowledge and capabilities were built by an internal innovation team, which drew inspiration from TUHH's previous research projects at Flintenbreite and a Fraunhofer project, DEUS21 that had been running near Stuttgart between 2003 and 2010. They also collaborated with various German research institutes and universities (In17). Major barriers were related to local environmental legislation and legitimacy, which needed a lot of local institutional work by the utility and which resulted in compromises around the specific technological variants chosen (In17, In15). Resources were mobilized from abroad to address some of these shortcomings. A major factor was also the funding via the EU's Life+ program (In17), which helped to legitimize the technology locally and provided important funding to execute research and development in-house at the utility. Both big international vacuum producers, Roediger, from Germany, and Jets, from Norway, were contracted for parts of the piping and vacuum installations, however it was Roediger, who was chosen as the main supplier due to their progress made with vacuum noise reduction (In17). External knowledge was further absorbed from Sneek but also made available for interested parties from other sites due to the public character of the utility (In17). Thus, in Hamburg, multi-scalar resource mobilization took place through the absorption or attraction of capital and legitimacy from the EU-level, and of knowledge from multinational vacuum toilet producers and exchange with other sites. These helped address shortcomings in terms of knowledge and legitimation.

In ***Helsingborg,*** the decision to go for the technology dated back to 2013 (In15). A waterfront district was subsequently developed, partly using the blackwater treatment & vacuum technology. Niche market formation was actively stimulated, and resources were made available by the city itself to apply for additional external funding at the scale of Sweden. Especially, the city provided a clear vision and guidance for the project to be realized. At the same time, and similar to Hamburg, the implementation faced a number of

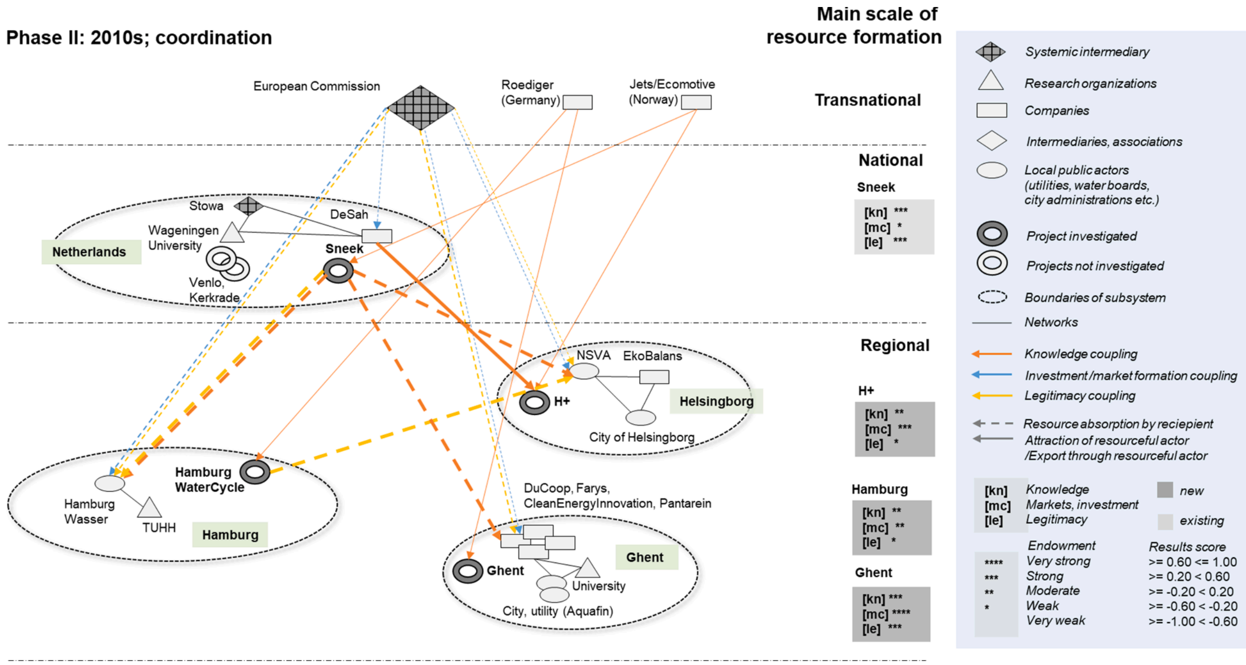

Fig. 5. Coordination phase of GIS structure emergence. Own drawing.

institutional hurdles in the beginning, related to national water legislation, and getting environmental permits for the production of potable water and pelletized fertilizer (In9, In12, In15)(Lennartsson et al., 2019). Also technological knowledge was missing in the beginning. An important template for how to deal with institutional and organizational issues was found in Hamburg, which was visited by the municipality and the utility during the early phase of the project (In15). The mobilization of institutional resources from outside the subsystem was further intensified through the participation in the EU's Run4life project from 2017 onwards. While Hamburg was instrumental as a source of legitimacy, technological knowledge was mostly absorbed from Sneek, which also led to the contracting of Dutch technology provider Desah for the Helsingborg plant (In15). Thus, in Helsingborg structural couplings were very instrumental in providing knowledge and legitimacy, while market formation and funding were mostly mobilized regionally or nationally (Fig. 5).

Building on progress made in Sneek, Hamburg and Helsingborg, another project started in the Belgian city of ***Ghent*** around 2014 (In18). The city of Ghent had a strong interest to lower the environmental footprint of newly built districts, and already in 2011, an investment fund (Clean Energy Projects) and three real estate companies were chosen to develop the Nieuwe Docken area in the greater Ghent area, as a lighthouse sustainable district. Together with more investors, including the municipalities drinking water utility Farys, these companies formed a cooperative company called DeCoop in 2014 that explored different technological alternatives in the realms of energy and water, especially absorbing technological knowledge and inspiration from study visits to Sneek (In18). Also the municipalities' solid waste company, the Flemish Environmental Agency that grants environmental permits, and the local University were involved in the development of DeCoop from early on (Ampe et al., 2021). This way, the project not only secured funding but also generated an enabling environment for the implementation of the blackwater technology. The treatment plant was finally built by a local firm specialized in on-site industrial treatment (Pantarein). However, on the knowledge side, additional inputs were attracted through the contractual involvement of transnational vacuum producer Roediger. This was despite early inspirations for the vacuum technology of Jets, who had co-developed the installations at Sneek, and who DuCoop was collaborating with in the Run4Life project (In18). A study visit to Hamburg as part of the EU-project, led to the contracting of Roediger, whose technology was more convincing and suitable to DuCoop's engineers (In18). Thus, in Ghent, it was mostly technological knowledge that was mobilized from outside the subsystem. While these knowledge spillovers were also key to the participation in the EU-project, market formation, funding and legitimacy were strongly developed locally.

As is evident from these case descriptions, the EU Commission became a central systemic intermediary through the funding provided by the Life+ and H2020 funding schemes, which members from different sites selectively drew upon for the purpose of absorbing legitimacy, capital or technological knowledge, as well as to build and maintain networks among the different sites. Especially, the Run4Life project (2017-2021), which had a dedicated project manager, formalized this coordinating role. We, therefore, identify the emergence of GIS, albeit on that is still rather weakly coordinated.

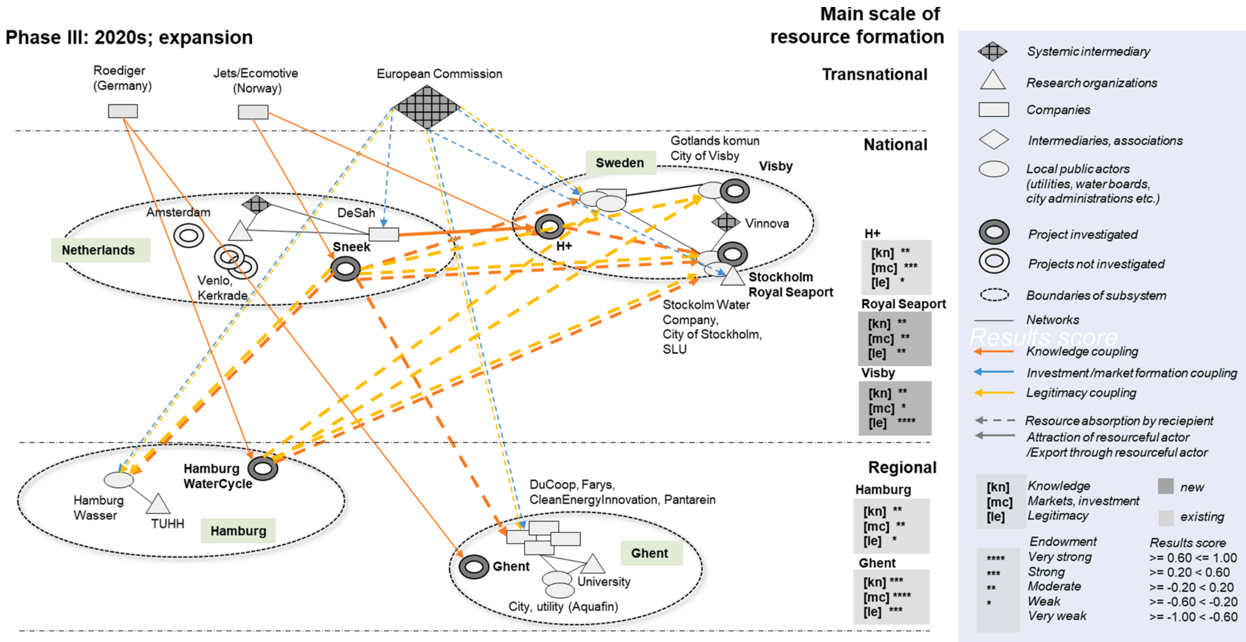

Fig. 6. Multi-scalar growth phase of GIS structure emergence. Own drawing.

4.3. *Multi-scalar expansion phase: 2020- looking forward*

In the very recent years, most of the emergent GIS structure remained stable but a new expansion dynamic is evolving in Sweden. Two additional cities have decided to develop districts with the blackwater technology: Stockholm and Visby on Gotland. While these encompass varying starting conditions and resource portfolios, this suggests the formation of new Swedish national subsystem in the blackwater treatment field. At the "global level" of the emerging GIS, the Run4Life project coordinated many activities in the late 2010s. However, it ended in 2021. During the more recent years, there have been attempts to re-activate EU-level funding and outreach by actors from Sweden. For example, actors on Gotland are exploring options for continued funding for their blackwater treatment demonstration site at the EU-level (In19).

In ***Stockholm***, the idea to implement the technology was already vivid since the early 2010s, when it was included in the development plan for the Royal Seaport area (In9) (Lennartsson et al., 2019). In the following ten years, the project got, however, stuck due to internal budget allocation procedures at the city level and lack of legitimacy among crucial stakeholders in the utility (In9). The utility only changed course and started to explore and develop the novel technology in 2018, after changes in core staff of the utility, when the city started collaborating with the cities of Helsingborg and Visby in a national research project (MACRO) on on-site wastewater treatment funded and coordinated by the Swedish innovation agency, Vinnova, and when there was a political shift in the city parliament towards greener parties. Thus, Vinnova now assumed the role of a national systemic intermediary in bringing together all three major Swedish projects. Both knowledge and legitimacy were then absorbed in field visits to Hamburg and Sneek, where the technological configurations were found to be convincing (In9). It was only after the water engineers of the utility had talked to their peers in Hamburg and Sneek that they were fully convinced to further drive the development of the demonstration site. So, again, resources from outside the systems were instrumental in this formative phase of the Stockholm Royal Seaport case.

In ***Visby***, on Gotland, a much smaller city than Stockholm, the story still unfolded in a very similar vein. Here it is the public authorities, the municipality and the region that have pushed for the implementation of a blackwater system in a newly developed real estate project. Legitimacy, too, was imported from Helsingborg, and to lesser extent from hearing stories about Hamburg and Sneek. By now an investment decision was made to develop the site and implement the technology. It was planned that the local utility would develop the technology but absorb knowledge from the other experimental sites in Northwestern Europe. As other actors before, the driving regional authority was hoping to draw on funding and legitimacy as well as access to networks from the EU level (In19).

To summarize, the emergence of demonstration projects in Sweden, is characterized by connections of projects at the national scale (e.g. through the MACRO project) on one hand, and through the mobilization of, in particular, knowledge, and to some extent legitimacy, from abroad on the other hand (Fig. 6).

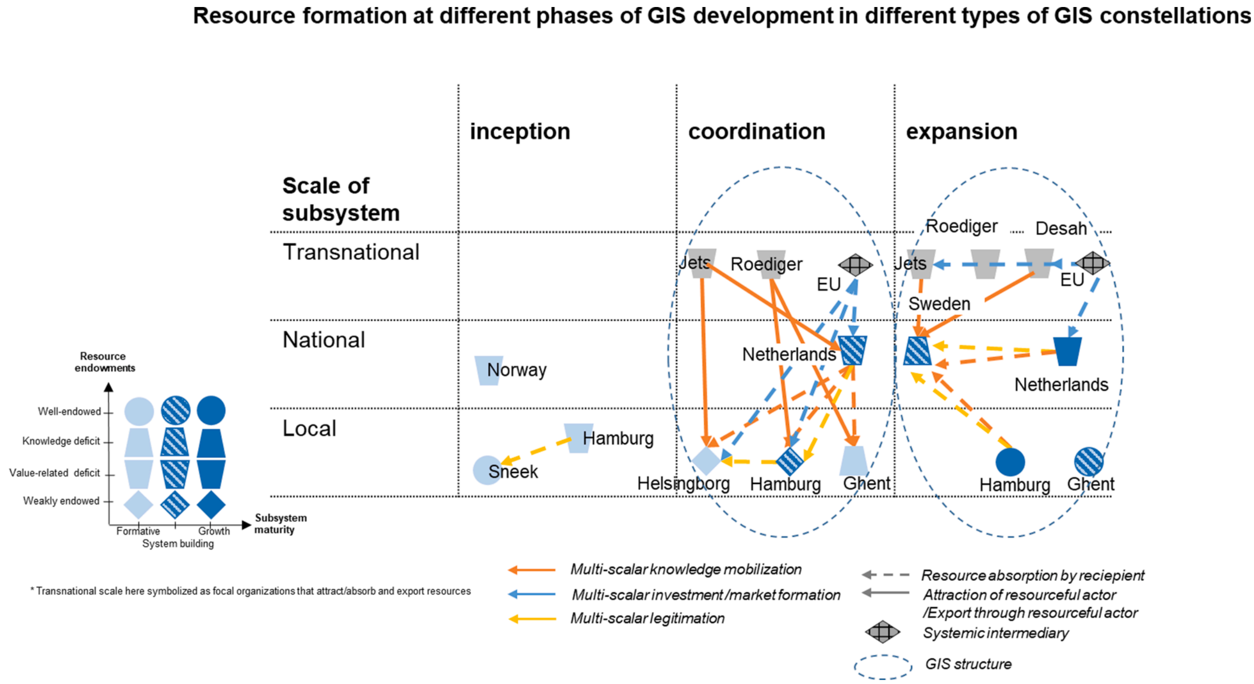

Fig. 7. Multi-scalar resource mobilization through phases of GIS emergence.

5. Discussion

Reflecting on the patterns observed in the empirical cases, we have been witnessing maturation processes in various subsystems at regional and national-scales, in which crucial resources were drawn from non-local sources. Furthermore, we observed the emergence of systemic intermediaries at the level of the Netherlands and Sweden, enabling the formation of national TISs, but also the increasing role of the joint management of trans-local activities through the EU. Hence, we claim that an actual GIS has emerged and that the system is starting to operate as an integrated set of innovation activities.

Fig. 7 summarizes how subsystems have evolved in terms of their spatial scale and multi-scalar resource mobilization over the different phases of GIS formation. As can be seen from this stylized representation of the observed dynamics, the inception phase was characterized by individual subsystems, all in their formative phase, showing loose connections among them. In the coordination phase, trans-local resource flows intensify and the EU enters the scene as a provider of resources offering new structural couplings. The Dutch subsystem, coordinated by the systemic intermediary STOWA, has been a first mover in terms of local innovation activities, became a core source of technological knowledge, for a newly emerging formative subsystems in Ghent, and in Helsingborg. Since Hamburg and the Netherlands entered their local system building phase during the 2010s, they required additional financial investments, which they sourced from the transnational scale through the European Commission's Life+ and H2020 programs. The two multinationals Jets and Roediger, both already established firms in the vacuum toilet industry, became key transnational technology providers for the different subsystems during the coordination phase. Eventually, in the expansion phase, the knowledge dimension was more firmly established, allowing the Dutch subsystem to move into a growth phase, with Dutch technology experts exporting their knowledge to various other subsystems, and legitimizing deployments both locally and abroad. The newly emerging Swedish subsystem, built around the national innovation agency Vinnova and the national-scale MACRO project, entered its system building phase well embedded into the established GIS structure, absorbing initial legitimacy, but more importantly, most of the technological knowledge from abroad. Hence, systemic intermediaries emerged as coordinating actors at the national scale but only after the EU entered the scene and incentivized transnational coordination a GIS structure developed and stabilized. However, it remains to be seen for how long this will be the case, and who will take the lead in coordinating trans-local resource mobilization in the future. The fact that Swedish actors are now actively reaching out to absorb knowledge, legitimacy and funding from abroad might indicate that the GIS structure will indeed prevail also in this decade. However, even if it does not, the structural couplings of the 2010s have been instrumental to help create various regional and national subsystems, which at least remain loosely coordinated.

In the medium-term future, one might expect other regional or national subsystems to follow the example of Sweden and enter the field by providing legitimacy, market structures and funding primarily internally, and absorbing or attracting the knowledge and capabilities from abroad. The Dutch subsystem became the leading knowledge producer around the treatment technology, and value-related activities started to take place in different subsystems at different scales (EU, Sweden, other urban, regional subsystems around the world). However, a core question will be whether and how the EU will continue to assume its role as systemic intermediary, or who will take this place in the future.

What do these elaborations imply for our initial question, when and why a GIS emerges? First of all, multi-scalar resource mobilization can be conceptualized as a local response to resource barriers or lack of internal resources. This implies, that GIS might emerge out of one local subsystem, which successfully mobilizes knowledge and value-related resources locally, or several subsystems, which are complementary in mobilizing different types of resources. As such, we might see subsystems entering an existing GIS although they lack key local innovation resources (like Ghent), or value-related resources (Netherlands), or both (Hamburg, Helsingborg). In fact, a spatially linear diffusion trajectory might be rather unlikely for a GIS since it would require a single subsystem to host the relevant knowledge and value-related resources to gain a first-mover advantage, as well one or several powerful systemic intermediaries to oversee the diffusion. Instead, other trajectories might be imagined as our case study suggests. For example, two subsystems with complementary resources might engage in resource flows out of a mutual interest, coordinated through an intermediary organization originating from within one of the subsystems. However, it might also be that an external intermediary, not belonging to any subsystem, enables the creation of structural couplings among subsystems. Arguably, in our case, we witness a combination of the latter two, rather than a simple diffusion story. At first, exchanges among the Dutch and the Hamburg subsystem were self-coordinated and mutual. Later the EU acted as an external, transnational intermediary that facilitated couplings among various subsystems. In the future, trans-local exchanges might be coordinated by a strong national or regional intermediary, for example from the emerging Swedish subsystem. Other subsystems, like Oslo, have disappeared, or might only be further developed at the regional scale, like in Germany, where potentials for a German subsystem have not been harnessed beyond the Hamburg region.

6. Conclusion

The goal of this paper was to elaborate when and why the mobilization of non-local resources occurs in different spatial subsystems that enter a field with different resource stocks at different points in time, and to explore how this leads to the emergence of an integrated GIS among them.

While previous research has hinted at the importance of sectoral differences (Binz and Truffer, 2017), of different value chain segments (Rohe, 2020, Hipp and Binz, 2020), and of local absorptive capacities (Binz and Anadon, 2018) in shaping the scalar dynamics of emerging GIS structures, our contribution adds to these perspectives a temporal dimension. It shows that especially in newly emerging fields, resource complementarities among different subsystems with different degrees of maturity might be crucial in providing the breeding ground for a GIS. Importantly, however, the emergence of a stable GIS structure may be dependent on the presence of trans-local systemic intermediaries.

Our case generated relevant insights in this respect. It suggests, that subsystems may develop and diffuse complementary resources in order to enter a novel technological field. Additionally, mobilizing resources absent in the local context from non-local sources may help subsystems move from formative to growth phases. Eventually, first mover advantages might be available to localities that enter a technological field early, be it as a first mover or in coordination with others. In our case, the early pioneering sites in the Netherlands and Hamburg became important sources of knowledge and legitimacy, for late-mover subsystems in Sweden or in Ghent. The Norwegian case, additionally, shows how the specialization in a specific knowledge field may create business opportunities abroad, even if there is no local subsystem emerging.

These findings have several implications for future research in innovation and transitions studies. They point to the ability of local actors to absorb or attract resources from other contexts and to actively embed the subsystem into more transnational GIS structures (Crevoisier and Jeannerat, 2009, Binz et al., 2016b, Binz and Anadon, 2018, Heiberg et al., 2020). The article illustrates how a GIS may develop by mobilizing resources locally and by compensating for local resource deficiencies through complementarities among subsystems established at different spatial scales and at different stages of maturity. At the same time, local capabilities and trans-local resource complementarities alone are not sufficient for the emergence of a GIS structure. Systemic intermediaries prove to be crucial without which multi-scalar resource flows may not be developed or maintained (Musiolik et al., 2018, van Welie et al., 2020).

Additional insights may be important from a policy perspective. The fact that actors from different regional demonstration sites in Sweden selectively drew on resources from other Western-European contexts, depending on their specific starting conditions, illustrates that a pure national promotion policy for the Swedish innovation system would likely have failed (Coenen, 2015, Heiberg and Truffer, 2021). Our work shows that innovation and industrial policy should also facilitate of vertical and horizontal resource mobilization, as well as the creation of transnational systemic intermediaries for overcoming such failures (Binz and Anadon, 2018, Binz and Truffer, 2021). Thus, future research could further explore implications for policymaking since policy usually seeks to address systemic and transformational failures within a specific national or regional spatial jurisdiction (Weber and Rohracher, 2012). In our specific case, instead, the directionality and coordination imposed by the EU level was a distinct facilitator for an at least temporary GIS structure.

Conceptually, the present article has bridged research on the geography of transitions (Coenen et al., 2012) and innovation system dynamics (Hekkert, 2007, Suurs and Hekkert, 2009) by both taking into account the temporal dimension of innovation system formation, as well as the spatial relations into which it is embedded. So far, this research could only provide some first indications on how and when resources are being mobilized from outside the local subsystem, and on the emergence of a GIS. Future research should further test these findings, for example by exploring the different local resource portfolios, the presence of systemic intermediaries, and other place-dependent factors that may lead to the multi-scalar mobilization of resources, and the emergence of a GIS. Also a more differentiated analysis of the different resource portfolios may inform a differentiated view on multi-scalar structural couplings as recent research on different knowledge bases suggests (Tsouri et al., 2021).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The authors are employed at the leading Swiss research institute within the field of modular water technologies, Eawag. However, the way the data have been gathered and analyzed does in our view not create any financial or otherwise benefits to our employer or to us as authors. We maintain to have respected all conditions of objectivity and impartiality when conducting the research

Acknowledgments

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App. 1. Interviews

Type	Focus/ Project	Organisation	Code	Date
Research	Source separation (Europe)	Research institute	In1	23.07.2019
Private	Bern (CH)	Engineering consultancy	In2	30.07.2019
Private	Stockholm (SE)	Technology company	In3	08.08.2019
Research	Source separation (Europe)	Research institute	In4	21.08.2019
Research	Source separation (Europe)	Research institute	In5	19.09.2019
Research	**Sneek**, Amsterdam (NL)	Research institute	**In6**	30.09.2019
Research	DEUS21 (DE)	Research institute	In7	11.11.2019
Research	DEUS21 (DE)	Research institute	In8	06.12.2019
Research	**Helsingborg, Stockholm** (SE)	Research institute	**In9**	27.10.2020
Research	**Sneek** (NL)	Research institute	**In10**	04.11.2020
Private	**Sneek** (NL)	Technology company	**In11**	05.11.2020
Public	**Helsingborg** (SE)	Utility	**In12**	06.11.2020
Public	**Stockholm** (SE)	Municipality	**In13**	09.11.2020
Public	**Sneek,** Amsterdam (NL)	Intermediary	**In14**	13.11.2020
Public	Malmö, **Helsingborg** (SE)	Utility	**In15**	17.11.2020
Private	**Oslo** (NO)	Technology company	**In16**	19.11.2020
Public	**Hamburg** (DE)	Utility	**In17**	01.12.2020
Private	**Ghent** (BE)	Consultant	**In18**	03.12.2020
Public	**Visby** (SE)	Municipality	**In19**	07.12.2020
Private	Bern (CH)	Engineering consultancy	In20	10.12.2020

App. 2. Resource index calculation

For each site, local resource availability was captured through the presence of drivers or barriers within the three resource realms: knowledge, markets and financial capital, and legitimacy. The concrete categories for drivers and barriers within each realm were generated from the interview material inductively and only subsequently categorized in to the larger resource realms. Results can be obtained from App. 2a and 2b, where a value of 1 indicates the presence of a driver or barrier and 0 indicates the absence of a driver or barrier.

The calculation of the subsequent resource score within these realms followed the following logic: For example, eight legitimacy-related drivers were detected throughout the whole dataset and four barriers. A demonstration project, for which three out of eight legitimacy drivers were present (0.375) and three out of four legitimacy barriers (0.750) would receive an index score of (0.375) - (0.750) = (-0.375), indicating a prevalence of barriers within this realm. The index, which can take values between -1 and 1, was subsequently classified into five equally distributed classes ranging from very strong resource stocks to very weak resource stocks. The results of this index calculation can be obtained from App. 2c

App. 2a
Local drivers identified in different project sites and grouped in resource realms. 1 = driver highlighted in interviews, 0 = driver not highlighted in interviews.

	Economics	Ownership transferred to users	Comfort (acceptance)	Directionality	Fit-and-conform narrative	Flexible interpretation of laws	Local actor networks	Mentality	Political shift	Urine-diversion delegitimized	Experience with onsite systems	Industrial diversification	Maintenance
Ghent	1	1	0	1	1	1	1	0	0	0	0	0	1
Hamburg - Hamburg Water Cycle	1	0	1	1	0	0	0	0	0	0	0	0	0
Helsingborg - H+	1	0	0	1	0	1	1	0	0	1	0	0	0
Oslo - Hareid - Jets	0	0	1	0	0	0	0	0	0	1	1	1	0
Sneek	0	0	1	1	0	0	1	1	0	0	0	0	1
Stockholm - Royal Seaport	0	0	0	1	0	0	0	0	1	1	1	0	0
Visby	0	0	1	1	1	0	1	0	1	0	0	0	1
Wageningen Uni	0	0	0	0	1	0	1	0	0	0	0	0	0
	Markets and financial capital	Legitimacy							Knowledge				

App. 2b
Local barriers identified in different project sites and grouped in resource realms. 1 = barrier highlighted in interviews, 0 = barrier not highlighted in interviews.

	Immature technology	Lack of local experimentation	Economics	Lack of competition	Lack of demand for nutrient recovery	Lack of directionality	Lack of guidance by utility	Mentality - professional logics - lock-in	Regulation and standards
Ghent	0	0	0	0	1	0	0	0	1
Hamburg - Hamburg Water Cycle	0	0	0	0	1	1	0	1	1
Helsingborg - H+	0	0	0	0	0	1	1	1	1
Oslo - Hareid - Jets	1	0	1	1	1	0	1	1	0
Sneek	0	0	1	0	0	0	0	0	0
Stockholm - Royal Seaport	0	1	0	0	0	1	0	1	0
Visby	0	1	1	0	0	0	0	0	0
Wageningen Uni	0	0	0	0	0	0	0	1	0
	Knowledge		Markets & financial capital			Legitimacy			

App. 2c
Local resource and barrier scores. Share of overall resources/barriers present within each resource realm.

	knowledge & capabiity	Market structures & capital	Legitimacy & institutional	Knowledge & capability barriers	Market structures and capital barriers	Legitimacy & institutional barriers
Oslo	0.67	0.00	0.25	0.50	1.00	0.50
Wageningen	0.00	0.00	0.25	0.00	0.00	0.25
Sneek	0.33	0.00	0.50	0.00	0.33	0.00
Hamburg	0.00	0.50	0.25	0.00	0.33	0.75
Helsingborg	0.00	0.50	0.50	0.00	0.00	1.00
Ghent	0.33	1.00	0.50	0.00	0.33	0.25
Stockholm	0.33	0.00	0.38	0.50	0.00	0.50
Visby	0.33	0.00	0.63	0.50	0.33	0.00

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