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Cities in Sustainability Innovation and Transition

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Transitions towards higher levels of sustainability have been subject of many investigations, both theoretically and empirically. While the focus has been on the scale of national innovation systems and technology systems, the quality of space (place) with regard to regions and cities has received scarce attention or no attention at all, thereby overlooking spatial specificities that may enhance or block pathways towards transition. This paper deals with sustainability innovators among young high-tech companies, as spin-offs from universities. They mainly deal with sustainable energy, sustainable transport, and healthcare. It explores whether the character of the city of location and of networks of these companies make a difference in growth and potential contribution to transitions.

The paper starts with a conceptual reflection on what the role of cities as seedbeds including nodes of networks may be according to various spatial-theoretical perspectives. The paper proceeds with an exploratory analysis of growth among innovators (spin-offs) in two different cities in Europe, in a core metropolitan area and a rather peripheral region, and with an analysis of the network types and city characteristics involved. We use a sample of 60 companies in a comparative analysis and regression modeling in the first part and retrospective descriptive analysis of five case studies in the second part of the paper. It appears that companies dealing with sustainability innovations grow quicker and benefit stronger from diversity in networks in a metropolitan city compared to a peripherally located city. At the same time there is a trend of adaptation of location, like building a multi-site company and connecting with partners locally and globally. Aside from spatial influences there is the role of the national innovation system, particularly public policy in favor of particular sustainability inventions and enhancing niche development. If favorable national policies are abandoned, university spin-offs as vulnerable companies, tend to broaden their focus and diversify in products and markets in order to survive, thereby reducing the chance of contributing to pathways to sustainability. The paper concludes with implications and research needs.

Keywords: responsible innovation, urban seedbed, university spin-off firms, firm growth

1. Responsible Innovation

The small literature on responsible innovation to date indicates that this approach to sustainability innovation is relatively new. Responsible innovation can be described as follows: 'Responsible research and innovation is a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view to the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products' (von Schomberg, 2012). This definition is not only end-result oriented, namely, on type of application of new products, processes etc., but also clearly process oriented, putting an emphasis on the interaction between science and society (see, van den Hoven et al., 2012; Owen et al., 2012). Using a normative perspective, new and concrete ideas should be turned into products and services that create jobs and prosperity, but at the same time accommodate moral and public values. This development enables to avoid innovations that turn out to be contested, to attend fields concerning societal needs that have been unattended to date, and to continue successful innovations based on societal needs that have already been recognized, like green technologies (van den Hoven et al., 2013).

To gear the innovation process to societal (sustainability) needs or to see sustainability as a driver of innovation is not new, and questions on the desirability of particular new technologies 'among the public' have been raised earlier (Hall and Vredenburg, 2003; Leydesdorff and Etzkowitz, 2003; Roome and Winn, 1993) but the emphasis today is much stronger than in previous times, particularly in many high-level policy and strategy EU documents. We mention the EU Innovation 2020 strategy to create smart growth and the Horizon 2020 program that defines Societal Challenges as one of the main priorities (EC 2011).

Major improvements in sustainability cannot be achieved with technology only, rather, technological innovations need to be coupled with changes in infrastructure and transformation of related institutions: also named socio-technical transitions (Geels, 2004; Farla et al., 2012). For example, to exploit wind energy in a decentralized way by local communities, one needs new types of companies, like cooperates and 'new nuts', and a massive use of electric vehicles needs to be accompanied by a dense public infrastructure of battery charging equipment. Thus both aspects, technical and non-technical, have to be understood in their co-determination over time.

Remarkably, in research on socio-technical transitions towards higher sustainability of society, the quality of space (place) has received scarce attention or no attention at all. Rather, the focus has been on the national innovation system (e.g. Coenen et al., 2012; Truffer and Coenen, 2012) thereby overlooking local/regional specificities that could enhance or block developments towards transitions. However, spatially oriented studies are quickly increasing in number today (e.g., Bulkeley et al., 2010; Quitzau et al., 2012; Klitkou and Coenen, 2013), as it can be reasoned that specific qualities of regions and cities make a difference, in general in innovation potential and also specifically in potentials for responsible innovation. For example, transformative forms of urban planning as niche management, localized assets in the form of research facilities at universities, like a wind tunnel or nuclear reactor for research, network potentials with other regions (Quitzau et al., 2012) and proximity to testing grounds like windy shores or empty land in sunny areas.

Some cities or regions may be more creative than others in raising novel ideas (inventions) in responsible innovation, may be better 'incubators' in nurturing them on the way to market, eventually in co-creation with local firms, and may be better nodes in networks. There is an urgent need to understand which places hold privileged positions in transition networks and substantially contribute to the transition process in particular regions (Hodson and Marvin, 2010). In a network theory approach, this requires a better understanding of how localized assets (technology, actors, resources) and institutions are strategically coupled with needs/interests of trans-local actors, in multi-scalar networks. A better insight is also needed about the impact of scale and scope effects on transitions due to city size (critical mass), while using approaches based on agglomeration theory. Broadly speaking, a diverse economic structure of cities seems more advantageous for innovation (Jacobs, 1969; Glaeser, 1992) compared to specialized cities, but does this also hold for responsible innovation? A similar question can be raised for the positive influence of highly localized concentrations of creativity and capabilities in cities, tolerance and power of creative pressure groups, potentially enabling local/regional niche protection and empowering (Florida, 2002; Coenen et al., 2012; Smith and Raven, 2012).

The role of complementarities between cities and between specialized clusters, and how transition networks make use of them, eventually as compensation, is also virtually unknown but deserves attention. Also, it is important to better understand, by using an evolutionary approach, what a selection environment is and how regions may act as such an environment for sustainable technologies (van den Bergh et al., 2006; Boschma and Martin, 2010; Brachert et al., 2013).

The lens through which this paper focuses on these issues, particularly the networks between cities facing different localized assets, is that of university spin-off companies dealing with responsible innovation. University spin-offs are seen as a major channel of knowledge transfer (interaction) between universities and the economy and society (Shane, 2004), eventually acting as a 'trigger' and enabling a 'jump' in transition development. However, most university spin-offs are facing a shortage in resources, particularly knowledge of the market, marketing skills, management capability and financial capital (van Geenhuizen and Soetanto, 2009). More importantly, if responsible innovation or sustainability is a major *driver* of innovation among them, a higher level of complexity tends to emerge in their learning networks (Hall and Vredenburg, 2003; Sweet et al., 2003), this because these networks include a wider diversity of partners, like public authorities, pressure groups, and customer groups aside from the conventional ones, calling for additional skills and (managerial) competences, while it may be questioned whether young spin-offs are able to cope with this complexity given their short in many resources.

To our knowledge there are no studies to date that have addressed responsible innovation among university spin-off companies in relation to the city of location. As earlier indicated, the perspective of responsible innovation is relatively new. Given the exploratory stage of research, the paper contributes to the literature by connecting responsible innovation among a selected category of high-technology start-ups, university spin-offs, to cities of origin of the invention and cities acting as incubators, and to networks of actors of different kind in other cities.

We draw on a sample of 59 companies and three case studies involved in responsible innovation in answering the following questions: (1) To what extent does urban location matter in growth of young spin-offs, and (2) What are the characteristics of the cities and networks that influence growth and potential moves towards transition?

2. Involvement in Responsible Innovation

We make use of a given dataset from two universities, Delft University of Technology (Delft, the Netherlands) and Norwegian University of Science and Technology (NTNU) (Trondheim, Norway). No differences were assumed in national innovation systems between the two countries, as they share a somewhat risk-avoiding entrepreneurship culture, show similar scores on the main Innovation Scoreboard indicators, and have a relatively small domestic market (Ye et al., 2013). There is one exception to this, namely, Norway has a supportive national policy towards wind energy, the Netherlands has not or not anymore, but this country - through its research program on high-tech automotive - has been supportive in the development of electric vehicles.

The population of spin-offs satisfied important conditions: survived to 2006 at an age not older than 10 years. With an overall response rate of 70 per cent (105 spin-offs), in 2006, data were collected using a semi-structured questionnaire in face-to-face interviews with the principal manager, focusing on company characteristics, particularly product/service and profiles of the external networks in terms of type of partners and level of openness. In 2011, in an update, information was collected on status of the company, size (employment and turnover) and changes in product/services. In addition, three companies served as an in-depth case study (2012) to explore the type of cities and the networks involved.

Translating the concept of responsible innovation into measurable indicators of business activity and interactive processes does not go without difficulty. First, the conceptualization of ‘ethical acceptability’, ‘unattended social fields’ and ‘contested innovations’ in a business context, is still somewhat weak. This means that we had to adopt a pragmatic approach in selecting those companies that are engaged in product/services that satisfy broad criterions of sustainability, safety, and health, while overlooking others, for example, the ones that avoid to be engaged in contested technology but are not involved in sustainability, etc. Secondly, and particularly true for this study, we can only partially grasp the process characteristics, like those serving (early) detection of disadvantages of new technology in consultation with main societal stakeholders, and avoiding of contested technology. The process characteristics we measure through the social networks, could cover them, but we guess that in the social networks in 2006/7, there were no clear ideas about responsible innovation in an interactive societal context. However, at the time, there were clear ideas about improving environmental sustainability, safety and healthcare. These observations indicate that the current study deals with a somewhat limited approach to responsible innovation.

We distinguish between a full and a partial involvement in responsible innovation. The first means that all activity of the company is focused on a responsible innovation product/service, the last that part of the activity can be labeled as such. In addition, we picture the area of application of the product, process, advice, etc. (Table 1). A small majority of the sampled companies (56 per cent) is engaged in responsible innovation in 2010, either full or partially; a good 40 per cent of the companies in the original sample are not dealing with a responsible innovation product/service at all. A full involvement mostly refers to the medical sector and sustainable energy, each at 19 per cent of all involved companies (59), there are also companies partially involved in sustainable energy (at a level of 10 per cent).

Sustainable mobility (including vehicle technology) is third in full involvement at 12 per cent of all involved companies. Waste treatment/recycling is fourth regarding full involvement at 10 per cent. In more detail, the medical sector includes design of instruments for minimal invasive surgery, ergonomic furniture, and practical help in daily care of elderly, as well as new medicines. Sustainable energy, as a category, includes new types of solar cells, improved batteries for storage, improved windmills (rotor blades and body), improved turbines, but also energy saving in use of refrigerators and cooling systems.

Table 1 Responsible innovators' products/services in the sample

Application area	Full involvement Abs.	%	Partial involvement Abs.	%
Medical care and cure	11	18.6	0	-
Sustainable energy [a)]	11	18.6	6	10.2
Sustainable mobility, vehicle technology	7	11.9	7	11.9
Efficient industrial processes	1	1.7	5	8.5
Efficient waste treatment (recycling)	6	10.2	0	-
Sustainable buildings and safety	4	6.8	1	1.7
Totals (N = 59 spin-offs)	40		19	

a) including energy efficiency

3. Firm Growth in Contrasting cities

3.1 Delft and Trondheim city regions

Our analysis is limited to two contrasting cities. We address the question to what extent growth trends among responsible innovators differ between the two cities of Delft (the Netherlands) and Trondheim (Norway). Theories on agglomeration economies posit that the potentials for innovation are better in economies in large metropolitan areas compared to small cities, for example, due to a stronger presence of professionals in the labour market, knowledge spill-overs, launching customers and a better connection in world city traffic.

Delft University of Technology (TU Delft) is in Delft, a medium-sized city with 96,800 inhabitants (2010) in the Randstad metropolitan area in the western part of the Netherlands. Unlike many other metropolitan areas, the Randstad does not consist of one large core city, instead, it is composed of several relatively large cities that are connected to each other, i.e. it is a polycentric urban system. The area includes four large cities, i.e. Amsterdam, Rotterdam, The Hague, and Utrecht. Two of these cities are in the province of South-Holland at approximately 10 km distance of Delft: The Hague, with a population of 488,600 in 2010 (municipal level), home of the national government and many international organizations on justice and safety, and Rotterdam (605,500 inhabitants in 2010), a world centre of seaport activity, (petro)chemical industry, and logistics and trading. The city of Delft is in-between these larger cities. Other large cities in the Randstad, i.e. Amsterdam and Utrecht, each with their own universities are approximately at 50 km distance from Delft.

Norwegian University of Science and Technology (NTNU) is in the city of Trondheim in the middle of Norway, with a population of 170,900 inhabitants in 2010 (municipal level). Trondheim is a single city at a large distance from large cities, for example, the distance from Trondheim to Oslo and Bergen is approximately 400 km and to Stockholm (Sweden) approximately 600 km. Entrepreneurs in Trondheim have to spend a much longer travel time to get to other large cities than their counterparts in Delft even if air transport is used. Also, due to a smaller number of inhabitants and firms, local launching customers tend to be relatively scarce in Trondheim. Although Trondheim (unlike Delft) is located in a non-metropolitan area, it has an important function in the national city-system. Besides being the third largest city in

Norway after Oslo and Bergen, Trondheim is the knowledge capital of Norway with many government research institutes, like SINTEF.

Trondheim is the center of Trøndelag region. This region covers a wide area of more than 40.000 km^2 and has a population of slightly more than 420,000 inhabitants (2010). By contrast, the province of South Holland hosts 3,5 million inhabitants (Table 2), clearly indicating a difference in 'mass'. A difference in 'mass' is also evidenced by the size of the economy. South-Holland's economy, in terms of gross domestic product, is almost seven times larger than the one of Trøndelag. However, per capita, gross domestic product is almost the same.

Table 2. Size indicators of the population and economy in South-Holland and Trøndelag

	South-Holland (NL)	Trøndelag (No)
Population (2010)	3,506.0 (x 1000)	422.1 (x 1000)
Regional gross domestic product (RGP) (2010)	124,2 million Euro	18,8 million Euro
RGP (PPS) per capita (2010)	32,000 Euro	30,200 Euro

Source: Eurostat

3.2 Differences in firm growth

As for employment, spin-offs involved in responsible innovation in Delft grow quicker than their counterparts in Trondheim. Average annual growth (in full time equivalent, fte) tends to be stronger in Delft at a rate of 1.8 compared to 0.6 in Trondheim, a difference that is significant at p=0.05 level (Table 3). Different from employment growth, turnover growth in the current study is measured in classes as a rank variable, in order to prevent non-response. The broad pattern of employment growth is also true for growth in turnover, Delft has a stronger presence of higher growth classes, witness 86 per cent versus 70 per cent in Trondheim (Table 4). In line with our expectations, these results indicate stronger potentials for developing responsible innovations in large metropolitan areas in core areas compared to isolated cities at a distance from the economic core.

Table 3 Employment growth (average annual, full time equivalent)

	Total sample	Delft	Trondheim
Mean (SD)	1.2 (2.28)	1.8 (2.90)	0.6 (1.24)
Number of spin-offs	59	29	30
t-test		2.05**	

** p<0.05

Table 4 Turnover growth

Turnover	Delft	%	Trondheim	%
No turnover	1	3.5	3	10.0
< 100,000	3	10.3	6	20.0
100,000<<300,000	5	17.2	4	13.3
>500,000	20	69.0	17	56.7
Total	29	100	30	100

Pearson Chi^2=2.34, p=0.51

3.3 *Factors influencing growth*

As a next step, we explore a growth model on the company level in which various networking variables are included. Responsible innovators are typically in need for external resources, for example, if the innovation is radical and infrastructures and institutions need to be transformed, and localized assets need to be accessed in and outside the place of location. However, at the same time, young spin-off companies are faced with limited experience in networking and limited management capacity to fully benefit from open networks.

We measure openness by using two dimensions, i.e. openness capacity and openness diversity (Ye et al., 2012). Openness *capacity*, as the 'size' of the external knowledge pool, is measured as a two-dimensional variable composed of breadth and depth (Laursen and Salter, 2006) (see Annex A). Breadth, number of different types of knowledge acquired, and depth, tie strength between the company and its partners, constitute the knowledge pool that is actually accessed. The mathematical modelling is unique in the sense that it assigns weights to the strength variables, using entropy-weight method, this measures the effective amount of information of the data and better reflects reality. Further, openness *diversity* describes the heterogeneity of partners' social background, including spatial orientation (local versus regional). A distinction is made between partners from large companies and from small ones, government representatives at high level, university professors, lead customers, family and friends, etc.

Table 5 Descriptive statistics

Variables	
Number of spin-off firms	59
Dependent variable	
Employment growth: annual job growth since firm foundation to 2010	Avg.: 1.16; Sd.: 2.28; min-max: -0.40-10.92
Independent variables	
Openness Capacity: continuous variable indicating size of the external knowledge pool, constructed using 'breadth' and 'depth'	Avg.: 4.81; Sd.: 2.62; min-max: 1.08-11.99
Openness Diversity: continuous variable indicating diversity of the external knowledge pool, including socio-economic heterogeneity of partners and spatial orientation	Avg.: 0.35; Sd.: 0.17; min-max: 0-0.88
Urban location: location of the firm: Trondheim (0) and Delft (1)	(0): 30; (1): 29
Firm age: continuous variable as years since firm foundation to 2010	Avg.: 8.76; Sd.: 3.09; min-max: 4-14
Size at start: continuous variable as number of full time equivalent when the firm was founded	Avg.: 2.03; Sd.: 1.06; min-max: 1-5
Growth ambition: variable in three categories, (a) large firm with international orientation; (b) small firm with international orientation; (c) small firm with local orientation	(a): 36%; (b): 50.5%; (c): 13.5%

As controls we use a set of four variables, namely, alongside urban location, growth ambition of managers, indicating whether they really intend to grow and push their innovation to a large (international) market thereby bringing a transition closer; age of the company, indicating increasing potentials for growth at later ages from accumulated learning in dealing with risks and overcoming the 'liability of newness', and size of the company at start. We follow a stepwise approach in first inserting the control variables, followed by the network variables separately and the full model. We also explore moderating effects, namely of location with network characteristics. Descriptive statistics of all the variables can be found in Table 5.

The power of the first model (Model 1) only including the control variables, reaches a level of 0.27 (R^2) with the coefficients of urban location and growth ambition as significant ones, indicating a positive influence of located in Delft and a positive influence of the ambition to grow. Including only the network variables gives a clearly weaker model power of 0.16 with the coefficient of openness diversity as the only significant one. However, the full model (Model 3), including both the control variables and the network variables, reaches a model power of 0.38. Model 3 also encompasses the positive and significant moderating effect of location with openness diversity.

We may conclude so far that networking with various partners makes sense in terms of diversity, a stronger diversity in network partners tends to enhance growth. This particularly holds if the spin-offs are in Delft, indicating that large metropolitan areas provide not only a better location for growth of responsible innovation but also a better place for benefits from networking, particularly with respect to diversity.

Table 6 A simplified model of employment growth (OLS) a)

	Model 1 β (s.e.)	Model 2 β (s.e.)	Model 3 β (s.e.)
Control variables			
Urban location	0.69 (0.28)**		0.78 (0.27)***
Growth ambition	0.52 (0.14)***		0.44 (0.14)***
Firm age	-1.10 (3.03)		1.64 (3.04)
Size at start	-0.01 (0.13)		0.05 (0.13)
Network variables			
Openness Capacity (pool)		-0.02 (0.15)	-0.03 (0.14)
Openness Diversity (partners)		0.52 (0.17)***	0.41 (0.16)**
Openness Diversity x Urban location		2.73 (1.82)	3.48 (1.73)**
N	59	59	59
F	5.07***	3.52**	4.45***
R^2	0.27	0.16	0.38
Root MSE	1.04	1.11	0.99

* p<0.1; ** p<0.05; *** p<0.01

a) We applied the usual checks (Annex B), including endogeneity test, and log-transformed the dependent variable.

4 Case Studies on Networks and Cities

We make use of three case studies to explore characteristics of the networks and cities involved. The case studies represent wind energy in the Netherlands and Norway, and battery technology for electric vehicles in the Netherlands. The three case studies also represent clear differences in employment growth, with smallest growth for the case study on wind energy in the Netherlands and largest growth for the case study on electric vehicle battery technology in the Netherlands.

We focus the analysis on the city/cities of location and their local assets and the type (functionality) of the networks with the cities that are involved. Concerning the networks, a distinction is made between various functionalities, for example, providing financial capital (venture capital), collaboration with related firms as co-developer, customer, or suppliers, launching customer, pilot, etc., this enables us to identify differences between diverse and rich networks and one-sided networks, and the changes in these patterns. In addition, the analysis enables to identify different spatial scales (scalarity) of the networks.

Company A has benefitted from two main localized assets in Delft: the wind tunnel facility at Delft University of Technology allowing improvement in modeling airflow dynamics and a remarkably strong push towards entrepreneurship at the Faculty of Aerospace at the same university (Table 7). The company started in Delft but moved to Breda in a province that provides location subsidy and 'soft' venture capital. Due to lack (reduction) of protective measures for wind energy technology by the Dutch government, the company moved from shaping wind turbine blades (boundary layer suction) and applications in the car industry to building construction and food process industry causing a large but one-sided network of customers of a similar type, namely with customers. This company seems less able to contribute to transformations in wind energy, as well as optimal shaping of vehicles reducing fuel use, this due to the more recent spread of attention over different applications in different industry sectors. We may conclude that the networks have become 'poor' in terms of many different customers, lacking financial investors, suppliers, pilot projects, etc. in the core technology and application. In addition, the networks tend to shrink from multi-scalar to mono-scalar.

In contrast, Company B in elaborating a gearless drivetrain and a solution for better stabilization of the wind turbine body, has maintained focus on the application over time supported by government investment and venture capital in various rounds, and supported by two test customers in Norway. At the same time, it extended presence both in the largest wind turbine cluster in Europe (Greater Aarhus area, Denmark) and in China. The networks are clearly more diverse compared to case study A in terms of number of functions connected to the core technology. This case illustrates that shortages in the own location can be compensated by presence in highly relevant clusters. The city of the creative ideas and seedbed has become part of a multi-scalar network.

While initially Company C was involved in charging technology of batteries in a broad range of consumer electronics, it developed a focus on battery technology for electric vehicles around 2009. It subsequently attracted venture capital (including international venture capital from the sector) and received national and EU support through research programs on electric vehicles, in order to elaborate its path breaking charging technology. This technology shortens the charging time of vehicle batteries substantially, namely from hours to a half hour, without damaging the battery. The company opened a second location in the Netherlands, in Eindhoven at the High-Tech campus, as a 'place to be' but also as a place providing easy access to the automotive and mechatronics cluster in the region. This site made the company also eligible for investment of 'soft' regional venture capital.

Table 7 Location and networks in three case studies

	Assets in cities of location and functionality of networks
Company A (2005) Air Flow Dynamics Technology (initially car aerodynamics and rotor blades)	**Local urban assets**
Location -Delft (NL) followed by Breda (NL)	- Delft (TU): *source of creative ideas* (but later on in co-development with customers abroad) - Delft (TU): *wind tunnel facility and strong entrepreneurship building* (Faculty of Aerospace at TU Delft). -Breda is in North-Brabant (Province) providing *location subsidy and 'soft' venture capital*
	Functionality of networks
Early Network - Focus: Modena (It), Ingolstadt (Germany) and Utrecht (NL) *Currently: shift to one-sided pattern with many cities (in NL)* *From multi-scalar towards mono-scalar*	-Car industry as *customer/co-developer* and rail industry as *customer/co-developer* -Additional industries, e.g. food process industry and construction *(customers/ co-developers)*
Company B (2006) Wind Turbine Technology	**Local urban assets**
Location -Trondheim (No) -2nd site in Silkeborg (Denmark) -Test site in Valsnes (No) -Representation: Hongkong (China)	-Trondheim (NTNU) and Bath (UK): *source of creative ideas* -Trondheim (NTNU): *wind tunnel facility* -Silkeborg: access to *wind turbine cluster* in Aarhus -Valsnes: *space for testing* (land/seashores) -Hongkong: access to Chinese *suppliers and customers*
	Functionality of networks
Network –Focus: Trondheim, Stavanger, Oslo and Aarhus cluster *Diverse pattern (functionalities) and increasingly multi-scalar*	-Venture funds (partly government, oil company, environmental funds): *financial capital* -Governmental organization and oil company as *co-developers and (test) customer (pilots)*
Company C (2005) Battery Charge Technology	**Local urban assets**
Location -Delft (NL) and later on 2nd site in Eindhoven (NL)	-Delft (TU) as one of the *sources of creative ideas in early networks with customers (micro-electronics)* -Eindhoven seen as *'the place to be', access to mechatronics/ automotive cluster*; Province of North-Brabant provides *location subsidy and 'soft' venture capital*
	Functionality of networks
Later networks (since 2009) -Amsterdam, Vancouver (Canada), Taipei (Taiwan), Den Bosch (NL) -Rotterdam, Leeuwarden (NL), Zurich (CH) *Highly diverse pattern (functionalities) and multi-scalar*	-*Venture capital*, from the sector (international) and from the region -*Pilots* of public charging stations in various cities, mainly Rotterdam and Leeuwarden *(a protective niche)*, also supported by energy (electricity) companies and *a launching customer*

Already in the early networks various companies in the value chain were present and the network today turns out to be highly diverse - aside from financers and co-developers/customers also local governments involved in creating a protective niche. Remarkably, the main niche network is in another region, namely the north of the Netherlands where the Province of Friesland intends to play a role in bringing sustainable energy solutions to market, this particularly holds for the city of Leeuwarden, where a pilot was performed in laying out public charging stations across the city. In addition, venture capital came from a company from the sector based in Vancouver, Canada (a cluster of manufacturers of environmental friendly energy devices), a development that has clearly enhanced the international reputation of the spin-off. The network can be qualified as highly diverse and multi-scalar. Most recently, however, the company joined a multinational company in Zurich, Switzerland, with Benelux headquarters in Rotterdam, because it was not able to gain sufficient strength to continue competition and access mass markets abroad on its own. This multinational has adopted a strategy of acceleration of the adoption of electric vehicles through rolling out advanced charging stations.

Overall, we may expect company A not to contribute to a sustainability transition, mainly due a shift to other applications (customers). There has also been a change from multi-scalar (incl. international) to more mono-scalar networks, and the current networks seem relatively one-sided. With regard to company B, we may expect a contribution to transition in the near future. There has been a consistent focus on a single product and market. Shortages in the city of location (Trondheim) could be compensated by accessing other regions through a multi-scalar location and network. Company C is already contributing to a transition, namely large scale use of electric vehicles. The company shifted to a focus on a single product-market, developed a multi-site location and established highly diverse, multi-scalar, networks. In particular, the venture capital from 'overseas' marked the gaining of a global reputation of the company as an important technology player.

The above results make us conclude so far that the chance of market introduction and steps towards transition are largest if the companies maintain a tight product-market focus, and if necessary because of short in localized assets, adapt their location in order to be present in major clusters and markets (multi-sited), and connect with partners - locally and globally - covering different essential functions; the last development reflects a positive influence of openness *diversity* on growth as indicated among the sample of companies in the previous section. However, we also realize the pressure of missing national policies in supporting responsible or sustainable innovation, urging young and vulnerable spin-off firms, in their need to survive, to look for alternative applications which will divert them from the road to transitions.

5 Concluding Remarks

This paper is one of the first attempts that connects the cities and networks of high-technology start-up companies involved in responsible innovation with growth and steps towards sustainability transitions. A database of 59 university spin-off companies was used, representing responsible innovation in medical care/cure, sustainable energy, sustainable mobility, waste treatment, safety, etc. The results of modeling of growth of these companies revealed a trend that responsible innovators benefit from (mass in) a location in a metropolitan area and from openness in networks, the latter mainly through diversity in partners; this in contrast with a city in an isolated, peripheral region. In addition, the results drew on an analysis of three case studies of which the preliminary results can be summarized as follows. Cities offer different localized assets that support creativity and nurturing conditions whereas networks may provide access to complementary localized assets (e.g. financial incentives) and cluster advantages outside the city of location. A higher level of diversity in the networks (more different functions) tends to be important, and this also holds for multi-scalarity, for example, in co-development with customers and venture capital.

With regard to localized assets in the city of location, the preliminary conclusion is that these are important at the start but most probably not sufficient in next stages, because both in large metropolitan areas and in isolated cities not all relevant conditions are present in one city and therefore need to be supplemented through networks with other cities (regionally and globally). This seems the more true for isolated cities, from which networks need to be built to clusters elsewhere. One major other factor ought to be mentioned. To enable growth and steps towards transition, the national innovation system needs to be favorable to a certain level, because if not, spin-offs - as highly vulnerable companies in a struggle to survive - tend to diversify and move away from their core technology and/or specific application.

Despite the interesting results, this study is faced with some limitations. As previously indicated, the first lies in the somewhat *limited* approach to responsible innovation following from the currently still limited conceptualization of responsible innovation and from the nature of the database used, providing data on social networks in 2006/7, years in which responsible innovation was not a common concept and approach. Thus, the major challenge is to elaborate responsible innovation conceptually and, in empirical research, to picture and characterize recent processes and interaction with societal actors along steps towards transitions, as a more comprehensive empirical approach. This would also enable to connect company development to strategic niche development and transitional/evolutionary perspectives which are involved in bringing about societal and technical change (Schot and Geels 2007; Smith and Raven, 2012). A second limitation resides in the research design, in which only two, contrasting, cities were involved. To increase evidence, a larger number of core metropolitan and isolated cities needs to be involved in next step of the research. The third limitation originates from the countries where the sample of university spin-off companies was drawn, i.e. the Netherlands and Norway. The results tend to be generalizable given a similar context under the EU framework and similarity with regional economies based on knowledge in the maritime cluster and energy clusters (sustainable energy, energy efficiency, safety), like in Sweden, Denmark and parts of the northern UK (e.g. Scotland). However, this is a small part of the EU, and the interpretation of responsible innovation may be culturally defined, calling for a study of context-dependency across the EU countries.

In addition and more importantly, ways need to be found to increase involvement of university spin-offs in responsible innovation. This category of high-tech start-ups is important as a channel for bringing university knowledge to market/society, particularly in responsible innovation, yet their short in resources puts limits on the number of network partners with which they can interact and how they interact. A main future step is thus to identify best practices among university spin-offs in the recent past in being selective in choosing those open innovation partners, e.g. large customers (co-creation), international venture capitalists, governmental or non-governmental organizations, which provide on their turn access to a complex and diverse network (platform), necessary for bringing responsible innovations to market and contribute to transitions. The use of social network analysis tools (Hermans et al., 2013) may be helpful in characterizing the networks of a larger sample of spin-off companies covering a larger number of cities.

Annex A

The value of *openness capacity* was calculated as:

$$Cap = \sum_{i=1}^{n}(B_i \times D_i) \quad (1)$$

where *n* is the number of types of external knowledge, like market, technology, etc. The breadth B_i is the counted number of partners within a type of knowledge. There are B_i partners within the knowledge content *i*, each has a "depth" as d_j $(j = 1 \ldots N)$, which is a composite variable derived from frequency of interaction (*r*), duration of relationship (*u*), and entrepreneurs' assessment of closeness of the relationship (*c*, *M*-rank categorical variable) calculated as:

$$\begin{cases} r_j = r \times l \\ u_j = \ln(u+1) \\ c_j = \frac{c}{M} \end{cases} \quad (2)$$

where r_j, u_j and c_j are the frequency of interaction, duration of relationship and entrepreneurs' assessment of closeness of the relationship for the partner *j*. $r \times l$ can be seen as "frequency-distance product", which intends to eliminate the distance as a contamination of freqency of interaction. These variables will be further normalized (for each variable, min: 0; max: 1). Next, a weighting method is used derived from thermodynamic theories. Entropy is a measure of the degree of disorder, uncertainty, or randomness of a probabilistic system, while information entropy can also measure the effective amount of information of the data. If there are m criterions and n objects which need to be evaluated, the entropy of the *i*th criterion is defined as *Hi*:

$$H_i = -k \sum_{j=1}^{n} f_{ij} \ln(f_{ij}) \quad (i = 1, 2, \ldots, m) \quad (3)$$

where $f_{ij} = \frac{r_{ij}}{\sum_{j=1}^{n} r_{ij}}$, and $k = \frac{1}{\ln(n)}$. And we assume that when $f_{ij} = 0$, $f_{ij}\ln(f_{ij}) = 0$.

Basically, the larger the entropy *Hi*, the less information it is possible to provide. For instance, if most of the partners are judged as very close to the entrepreneurs, the assessment of closeness (r) would not be an efficient indicator for the tie strength, since it cannot provide enough information or distinction to differentiate various strengths of tie. Therefore, the entropy weight of the *i*th criterion can be calculated by:

$$w_i = (1 - H_i)/(m - \sum_{i=1}^{m} H_i) \quad (4)$$

The entropy weights for the three indicators of tie strength can now be calculated, as $w_u = 0.30, w_r = 0.38, w_c = 0.32$. And the formula for the tie strength is as follows:

$$D_j = w_u u_j^* + w_r r_j^* + w_c c_j^* \quad (5)$$

where for D_j, a higher value indicates a relatively tighter relationship, thus a greater "depth" (min: 0; max: 1).

Openness diversity describes the heterogeneity of partners' socio-economic background, including spatial orientation. The knowledge partner diversity is calculated as:

$$Der = (1 + \frac{EI}{2}) \times Hs \quad (6)$$

where $Hs = 1 - \sum_{k=1}^{8}(\frac{a_k}{N})^2$, and (7)

where a_k is the number of partners with a different social background,
$k = 1$ (*large or medium business*), 2 (*government*), 3 (*university*), 4 (*small business*), 5 (*family/friends*), 6 (*venture capitalists*), 7 (*lead customers*), 8 (*others*).

N is the total number of partners a firm interacts with, with a higher value indicating a higher level of social background difference (min: 0; max: 1). Further, *EI* is calculated as

$$EI = \frac{E_p - I_p}{E_p + I_p} \quad (8)$$

where E_p is the number of external, non-local, partners, reached within one hour car driving, and I_p is the number of local partners ($E_p + I_p = N$). A high value indicates a relatively strong external orientation (min: -1; max: 1).

Annex B

Linear regression diagnostics (n=59)

Diagnostic	*Description*	*Employment growth models*		
Model		1	2	2
Detecting unusual and influential data	Residuals, leverage, Cook's D and DFBETA, etc.	Checked	Checked	Checked
Test for normality of residuals	Inter-quartile range (iqr) test and Shapiro-Wilk test	iqr: no outlier Shapiro-Wilk test: z: -0.497 p-value: 0.69	iqr: no outlier Shapiro-Wilk test: z: 0.493 p-value: 0.31	iqr: no outlier Shapiro-Wilk test: z: 1.011 p-value: 0.16
Test for heteroscedasticity of residual	(1) white's test (2) Breusch-Pagan test	(1) Chi^2: 29.34 p-value: 0.04 (2) Chi^2: 0.39 p-value: 0.53	(1) Chi^2: 5.95 p-value: 0.92 (2)Chi^2: 0.03 p-value: 0.86	(1) Chi^2: 47.00 p-value: 0.18 (2) Chi^2: 0.15 p-value: 0.70
Test for multicollinearity	Variance inflation factor	Mean VIF: 1.03	Mean VIF: 1.16	Mean VIF: 1.20
Test for model specification error	ovtest	F: 0.47 p-value: 0.70	F: 0.63 p-value: 0.60	F: 0.14 p-value: 0.94

Endogeneity Test

The performance of a firm in employment growth may also affect the extent of openness, particularly the variable that is significant in the model. Therefore we treat *Openness Diversity* as endogenous. From our previous study (Ye et al., 2013), we include two additional variables, namely, *Pre-start experience breadth* and *Prospector strategy*, which are correlated with *Openness Diversity* but not employment growth. Single-equation instrumental-variables regression is used with 2SLS estimator, with the result that the endogeneity test shows that the variable is not endogenous:

H0: variables are exogenous
Durbin (score) Chi^2 (1) = 0.0969 (p = 0.7556)
Wu-Hausman F(1, 50) = 0.0822 (p = 0.7754)

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