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## **Open innovation as a driver for new organisations: a qualitative analysis of green-tech start-ups**

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**Abstract:** Start-ups, to which two-thirds of radical sustainable innovations are credited, have been identified as the driving force of the green-tech industry. Linking green-tech start-ups with open innovation, this study used semi-structured expert interviews to identify key partners for open innovation, providing insights into core opportunities and risks emerging in the innovation process. The results showed that green-tech start-ups rely on both inbound and outbound innovation. The study identified key open innovation network partners, namely academic institutes, support platforms/other start-ups, incumbent firms, and customers. Although opportunities and risks appear to be partner-specific, they can be related to three distinct levels of impact: firm development, technology development, and technology commercialisation. Synergetic partnerships, such as R&D collaborations with universities and incumbent firms, create opportunities at all three levels. Risks affect particularly the level of technology and of firm development. This paper contributes to the literature through key findings addressing five propositions.

**Keywords:** green entrepreneurship; green tech companies; green start-ups; social entrepreneurship; sustainable innovation; open innovation; innovation process; openness; external partnerships; open innovation partners; green technology; new organisations; experts interviews; qualitative research; Germany.

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## 1 Introduction

Researchers have highlighted the leading role of *start-ups* in the development of *sustainable* product and service *innovations* (cf. Bergset and Fichter, 2015; Dixon and Clifford, 2007; Schaltegger and Wagner, 2011; York and Venkataraman, 2010). Start-up firms are able to challenge incumbent firms by disrupting “existing conventional production methods, products, market structures and consumption patterns, and replace them with *superior environmental and social products and services*” [Schaltegger and Wagner, (2011), p.223]. Although incumbent firms also strive to develop environmentally superior innovations, research highlights that start-ups are key market actors in developing and introducing *sustainable innovations* into the market (Bergset and Fichter, 2015; Fichter and Weiss, 2013). By creating new sustainable product and service niches and alternative technologies, start-ups can initiate impulses for radical change (Belz, 2013; Cohen and Winn, 2007; Dean and McMullen, 2007) and – if successful – their innovations can have a real and sustainable impact on complex societal or environmental problems (Schiederig et al., 2012). This accentuates that start-ups, which promote environmentally sound innovations, so-called *green innovations* (Schiederig et al., 2012), should be a major research subject given their substantial social impact.

Recent findings on the economic importance of innovative social business ideas warrant more research in the field of social entrepreneurship (Halberstadt and Kraus, 2016). Yet, knowledge of green start-ups (Demirel et al., 2019) and the innovation processes that they adopt is limited. Environmental innovation research is still in its early phase, particularly in the innovation management field (Andersen, 2008). One of the factors, which has been described as crucial to the overall success of innovation in start-ups, is *openness*. Only recently, researchers have explored the role of openness in the success of new venture creation, highlighting that openness to external knowledge sources positively affects the survival of new firms (de Jong and Marsili, 2006; Eftekhari and Bogers, 2015; Nambisan and Baron, 2013). Furthermore, literature has indicated that innovation in smaller firms has by nature an external focus because start-ups face various resource constraints (Baum et al., 2000; Edwards et al., 2005). In this sense, it appears that openness also plays a crucial role in the context of green-tech start-ups and their innovation process.

Although openness might affect the overall success of the new venture, a limited number of studies has provided a more detailed view of the involved actors and the opportunities and risks of openness that emerge when green-tech start-ups pursue an open process of green technology innovation. The purpose of this study was to address this gap and to examine in more detail the role of openness in green-tech start-ups and their innovation process. To this end, this study addressed the following two research questions:

- RQ1 Who are the key open innovation partners of green-tech start-ups?
- RQ2 Which opportunities and risks emerge when green-tech start-ups pursue an open process of green technology innovation?

To analyse the research questions addressed, the study built on the concept of *open innovation* (OI). A qualitative approach was used to collect in-depth data on ten green-tech start-ups. The present study adopted one of the empirical settings proposed

by Bogers et al. (2017) and based the analysis on founder networks and knowledge domains in high tech settings. The research focused on start-ups at the intersection of green start-ups (Bergset and Fichter, 2015) and tech start-ups (Beckman et al., 2012) that develop and commercialise green-tech innovations. Herein, the paper refers to them as *green-tech start-ups* (GTSUs). Green or sustainable entrepreneurship, which focuses on value creation for the environment and society rather than on profit (Kirkwood and Walton, 2010), is embedded at the intersection of the research streams on *social* entrepreneurship and entrepreneurship (Schlange, 2009).

Thus far, research has discussed the concept of *open innovation* (OI) by focusing on the context of large incumbent firms (Dahlander and Gann, 2010; Gassmann et al., 2010). The key concepts of OI focused on small and medium-sized enterprises (SMEs) and have not been well explored (Lopes and de Carvalho, 2018). Only recently, authors have turned towards SMEs and found that SMEs and incumbent firms engage in different types of OI practices (cf. Bianchi et al., 2010; Brunswicker and Vanhaverbeke, 2015; Lee et al., 2010; Parida et al., 2012; Spithoven et al., 2013; van de Vrande et al., 2009). The authors stress that the lessons learned from OI in large firms are automatically transferable neither to the context of smaller firms nor to the context of social and sustainable businesses. A separate stream of OI research should be developed for smaller firms (Spithoven et al., 2013; West et al., 2014; West and Bogers, 2017). Although start-up firms have been excluded in the literature on OI (West and Bogers, 2017), scholars have called for more research on how start-ups use OI (Bogers et al., 2017; Chesbrough and Bogers, 2014; van de Vrande et al., 2009).

In the context of green start-ups, Demirel et al. (2019) detected a crucial gap in research, stating, “where improvement is urgently needed is better embedding and enlarging the reach of green entrepreneurship by following recent trends in existing areas of research” [Demirel et al., (2019), p.767], e.g., exploration of open innovation opportunities for green start-ups (Demirel et al., 2019). Accordingly, the present study contributes to the literature by bridging together entrepreneurship and OI to equip green entrepreneurship literature with a theoretical framework adopted from OI. Thus, it aimed to narrow the research gap on the advantages of openness to GTSUs.

## 2 Theoretical background

### 2.1 *Green-tech start-ups*

Start-ups have been identified as key drivers of sustainable development and radical change (Cohen and Winn, 2007), as they are able to solve market failure and environmental problems (Dean and McMullen, 2007; Hall et al., 2010) by creating new sustainable product and service niches and alternative technologies (see, e.g., Schaltegger et al., 2016 for research on business models for sustainability). Furthermore, they are initially more likely to engage in sustainable entrepreneurship compared to market incumbents because they are less likely to be caught in a specific technical mindset and more likely to try out innovative approaches (Hockerts and Wüstenhagen, 2010).

Start-ups can generally be referred to as SMEs that are in their early phase of development and challenge budget and resource constraints (Lounsbury and Glynn, 2001). The present study defined GTSUs at the intersection of three interlinked concepts: *green start-ups* (Bergset and Fichter, 2015), *green-tech innovation* (Klewitz and Hansen,

2014; Petruzzelli et al., 2011; Schiederig et al., 2012), and the *green-tech industry* (BMUB, 2014). Recently, authors have introduced the label green start-up as a generic term that comprises different types of start-ups that contribute to the goals of a greener economy (Bergset and Fichter, 2015). In this sense, green start-ups focus not only on economic value creation, but also on *social* and *environmental value creation* (Bergset and Fichter, 2015), which reflects an understanding of green start-ups by referring to the framework for *social entrepreneurship* (Schaltegger and Wagner, 2011). In theory and practice, technologies that reduce environmental degradation by using fewer resources and producing less pollution have received the label *green-tech innovation* (Petruzzelli et al., 2011). This term is also known as eco-innovation, green innovation or clean-technology (Boehnke and Wüstenhagen, 2007; Klewitz and Hansen, 2014; Schiederig et al., 2012). Green-tech innovations are closely related to the industry that promotes them: the *green-tech industry*. The German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety proposed to define the green-tech industry in terms of its *six lead markets*, namely ‘environmentally friendly power generation, storage and distribution’, ‘energy efficiency’, ‘material efficiency’, ‘sustainable mobility’, ‘waste management and recycling’, and ‘sustainable water management’ [BMUB, (2014), p.34].

Hence, this study refers to GTSUs as sustainability mission-driven start-ups that follow the primary goal of meeting societal and environmental problems and having a real impact on those problems.

## 2.2 *The concept of open innovation and start-ups*

OI has become an essential practice for firms, encouraging them not to rely on knowledge consistent within the company, but to obtain crucial knowledge outside the firm’s boundaries both for creating and commercialising innovations (Bogers and West, 2012). OI research builds on the idea that the boundary between the firm and its surrounding environment is permeable, which enables knowledge to move easily between the two areas (Chesbrough, 2003a, 2003b). The most recent definition by Chesbrough and Bogers (2014, p.24) highlights that OI can be determined through two central dimensions: the inflow of knowledge, which literature refers to as *inbound OI*, and the outflow of knowledge, which has been labelled as *outbound OI*. Stakeholders of firms, such as suppliers, competitors, customers and universities are valuable sources of knowledge for innovation (Brunswick and Vanhaverbeke, 2015; Dahlander and Gann, 2010; Enkel et al., 2009). Organisations that integrate the knowledge of external sources are able to enrich their own knowledge base and thus increase their innovation potential (Laursen and Salter, 2006). Inbound OI practices describing external knowledge sourcing are, among others, in-licensing, acquisitions and R&D contracts (Bianchi et al., 2010). Firms focusing on outbound processes are able to transfer their internal technologies and knowledge to external organisations for commercial exploitation (Chesbrough and Crowther, 2006). The focus of exploitation is therefore shifted outside a firm’s boundaries. A firm is no longer restricted to the markets it serves directly.

Prior literature has indicated that innovation in smaller firms has by nature an external focus because start-ups face various resource constraints (Baum et al., 2000; Edwards et al., 2005). Apart from limited financial resources, they also lack intangible resources, such as technological expertise (Baum et al., 2000). Moreover, start-ups can suffer from their evolving organisational structures and a lack of strategic alliances (Freeman and

Engel, 2007). Researchers have recently started exploring the relationship between openness and success of new venture creation. Eftekhari and Bogers (2015) pointed out that by opening up to external partners, start-ups are able to compensate for their resource constraints. This, in turn, positively affects overall firm survival.

### 2.3 Open innovation and green-tech innovation

Looking at prior literature on green-tech innovation, scholars have only recently begun to investigate the role of collaboration in the context of green technology (Petruzzelli et al., 2011). Findings have shown that collaboration and knowledge exchange with external actors play a crucial role in the successful development of green-tech innovations. In fact, the development of green technologies depends on collaboration with external actors to a greater extent than the development of conventional innovations (ibid). De Marchi (2012) pointed out that environmentally innovative firms cooperate with external partners to a higher extent compared to other innovative firms. Especially, cooperation with suppliers and universities is even more relevant for the development of green technologies than it is for conventional innovations (ibid). The findings suggest a substitution effect between cooperative activities and internal R&D in firms that promote green-tech innovations. Halila and Rundquist (2011) found that innovators of green technologies use collaboration and networks to solve technological problems whereas conventional innovators collaborate with financing and marketing for assistance. Triguero et al. (2013) demonstrated that collaborative networks with research institutes, agencies and universities might be crucial drivers of green technology.

The concept of OI has not been transferred to the context of GTSUs, although the existing literature has indicated that openness to key OI network partners (such as research institutes) may play a crucial role in this type of start-up as and the development of green technologies.

### 2.4 Green-tech start-ups and the role of openness

#### 2.4.1 Open innovation opportunities and risks

Table 1 presents the analytical framework and a brief overview of the literature. The following paragraph highlights crucial opportunities and risks of inbound and outbound OI practices presented in OI literature with the main focus of start-ups.

To categorise the opportunities and risks, the study used the distinction of inbound and outbound innovation as a starting point. Following Dahlander and Gann (2010), this research further divided inbound and outbound innovation to *pecuniary* versus *non-pecuniary* interactions, resulting in four different categories. *Non-pecuniary* practices of the *inbound innovation* refer to the ‘sourcing’ of external knowledge. The logic of exchange is described by the indirect benefits of openness, as no direct financial rewards are involved (Dahlander and Gann, 2010). *Pecuniary inbound innovation* practices refer to the ‘acquiring’ of external knowledge. The focus of this type of openness lies on buying knowledge that is needed for the innovation process (Dahlander and Gann, 2010). *Non-pecuniary* practices of *outbound innovation* focus on ‘revealing’ internal resources to external actors without receiving immediate financial rewards (Henkel, 2006; Nuvolari, 2004). Whereas *pecuniary outbound innovation* is defined as the ‘selling’ of

products or knowledge (out-licensing), as outside partners may be better equipped to commercialise inventions (Dahlander and Gann, 2010).

**Table 1** Literature overview of opportunities and risks of OI by inbound and outbound OI

	<i>Opportunities</i>	<i>Risks</i>
	<i>Non-pecuniary and pecuniary</i>	<i>Non-pecuniary and pecuniary</i>
Inbound open innovation	<ul style="list-style-type: none"> <li>• Inbound practices with heterogeneous partners increase innovation performance (Laursen and Salter, 2006; Brunswicker and Vanhaverbeke, 2015)</li> </ul> <p style="text-align: center;"><i>Non-pecuniary</i></p> <ul style="list-style-type: none"> <li>• Access to a wide network of knowledge and ideas (Laursen and Salter, 2005)</li> <li>• Knowledge gaps can be rapidly filled without the need of control measures (van de Vrande et al., 2009)</li> <li>• Less internal R&amp;D efforts (Chesbrough, 2006)</li> </ul> <p style="text-align: center;"><i>Pecuniary</i></p> <ul style="list-style-type: none"> <li>• Spill-over technologies of external partners can be purposively acquired without the need to build network (Chesbrough, 2006)</li> <li>• Leveraging complementarities with OI partners (Dyer and Singh, 1998)</li> </ul>	<ul style="list-style-type: none"> <li>• Absorptive and connective capacities are needed in order to make sense out of acquired knowledge (Cohen and Levinthal, 1990; Lichtenthaler, 2011)</li> <li>• Risk of over-searching (Laursen and Salter, 2006)</li> <li>• Long-term dependency on external knowledge sources (Laursen and Salter, 2006)</li> <li>• Knowledge sources can become obsolete (Christensen et al., 2005)</li> <li>• Control and management of external knowledge sourcing requires resources (Laursen and Salter, 2006)</li> </ul>
	<i>Non-pecuniary</i>	<i>Non-pecuniary</i>
Outbound open innovation	<ul style="list-style-type: none"> <li>• New ideas emerge (Henkel, 2006; West and Gallagher, 2006)</li> <li>• Gaining legitimacy from external environment (Nuvolari, 2004)</li> <li>• Mutual support: firms can build upon each other's work (Nuvolari, 2004)</li> </ul> <p style="text-align: center;"><i>Pecuniary</i></p> <ul style="list-style-type: none"> <li>• Technologies that would have been ignored internally can be commercialised through another firm ('spill-over technologies') (Chesbrough, 2003a)</li> <li>• By selling or out-licensing innovations, companies can benefit more from their R&amp;D investments; access to new markets (Chesbrough, 2003a)</li> <li>• Win-win: Outside partners are better equipped to commercialise inventions to the mutual interests of both organisations (Chesbrough and Rosenbloom, 2002)</li> </ul>	<ul style="list-style-type: none"> <li>• Difficulty to capture direct benefits of knowledge revealing (Chesbrough, 2003a)</li> <li>• Internal resources can leak to competitors (Laursen and Salter, 2005)</li> </ul> <p style="text-align: center;"><i>Pecuniary</i></p> <ul style="list-style-type: none"> <li>• Protection of IP requires resources (Bianchi et al., 2010)</li> <li>• Over-commitment to own technologies and research limits the benefits of outbound open innovation (Lichtenthaler and Ernst, 2007)</li> </ul>

### 2.4.2 Inbound innovation opportunities

*Non-pecuniary* knowledge and technology sourcing require less internal efforts and expenditures when innovating (Chesbrough, 2006). Regarding the context of SMEs, the creation of informal networks allows to rapidly fulfil specific knowledge needs without spending money on developing the respective know-how internally. Inbound innovation provides access to a wide array of knowledge and ideas (Laursen and Salter, 2005). Such networks can furthermore evolve into formal collaborations, such as R&D alliances (van de Vrande et al., 2009). *Pecuniary* practices imply benefits as well. One central advantage is that valuable resources, such as spill-over technologies, can be purposively gained without the need to build networks beforehand (Chesbrough, 2006). Additionally, pecuniary openness leverages complementarities with partners (Dyer and Singh, 1998). Overall, prior research has highlighted that inbound practices with heterogeneous partners can drive an increase in innovation performance (Brunswick and Vanhaverbeke, 2015; Laursen and Salter, 2006).

### 2.4.3 Inbound innovation risks

External knowledge sourcing requires accurate management to serve as a driver of innovation. Otherwise, the risk of over-searching the external environment can negatively affect innovation performance (Laursen and Salter, 2006). Furthermore, the sourcing firm must be able to recombine internal and external ideas by building up absorptive and connective capacities (Cohen and Levinthal, 1990). However, since smaller firms lack absorptive and connective capacities to a greater extent compared to larger firms (Spithoven et al., 2013), it can be assumed that start-ups too potentially face a constraint to build up capacities that may help them sense, assimilate and integrate external knowledge.

When engaging in inbound practices, the risk that firms become immoderately dependent on external knowledge sources increases (Laursen and Salter, 2006). Considering the lack of resources that new firms face, the risk that start-ups become too dependent on network partners offering diverse complementary resources increases. Likewise, the need for external knowledge might change over time as technologies mature so that certain knowledge sources become obsolete (Christensen et al., 2005). Thus, the risk is that start-ups might stick to the same knowledge sources for too long, even though they may no longer be valuable.

### 2.4.4 Outbound innovation opportunities

The *non-pecuniary* mechanism of outbound OI, which refers to the non-remunerated revelation of internal knowledge, allows firms to build on each other's work and technologies (Nuvolari, 2004), encouraging the emergence of entirely new ideas and innovations (Henkel, 2006). Non-pecuniary practices are especially valuable in projects where individuals collectively develop innovative solutions without enforcing intellectual property (IP) rights (West and Gallagher, 2006), e.g., free and open source projects.

Regarding *pecuniary* mechanisms, researchers have emphasised the opportunity of technology spill-overs (Chesbrough, 2003a). By selling or out-licensing internal innovations, companies can benefit more from their internal R&D investments as they also enter new markets (ibid.). In this sense, a win-win situation is created: if the external

partner is better equipped to commercialise internal knowledge and technologies, it is in the mutual interest of both the selling and the acquiring organisation to bring the respective product or technology to market (Chesbrough and Rosenbloom, 2002). Prior research has highlighted that pecuniary outbound practices are especially beneficial for smaller firms. This is due to the fact that smaller firms often lack resources and capacities in terms of marketing, manufacturing and distribution (van de Vrande et al., 2009). Therefore, the use of pecuniary outbound activities can help them commercialise their technologies successfully (Lee et al., 2010).

#### 2.4.5 Outbound innovation risks

Although the outbound mode of OI implies many opportunities, various risks are also involved. Focussing on the risks of *non-pecuniary* outbound practices, it can be difficult to capture and measure the direct benefits of knowledge acquisition. In fact, the benefits cannot be measured directly. Non-monetary practices tend to create long term benefits (Chesbrough, 2003a). These practices include a high degree of uncertainty regarding actual benefits to the knowledge-providing organisation. Furthermore, internal knowledge can leak to competitors when being revealed to external partners. If resources are being made available for others to exploit, it becomes more difficult to manage their protection (Laursen and Salter, 2005).

Considering *pecuniary* disadvantages, the protection of IP and the concept of ownership might inhibit the chances of collaboration, as the over-commitment to own products and technologies make it difficult to sell and out-licence (Lichtenthaler and Ernst, 2007). Previous research has found that SMEs struggle particularly with the management of technology pricing and IP strategies (Bianchi et al., 2010), which may also pose a risk for start-ups due to their resource constraints.

### 3 Methodology

#### 3.1 Research design and sample

The study applied a qualitative research approach. The data was collected in spring 2016 using *semi-structured expert interviews* with representatives of German GTSUs. Germany plays a pioneering role in the lead markets of the green-tech industry (Fichter and Weiss, 2013). Thus, German GTSUs constitute an appropriate starting point for building theory of GTSUs and OI. The interviews followed an interview guide developed according to insights drawn from the literature review and the analytical framework.

The GTSUs of the sample are active in different lead markets of the green-tech industry (as defined by BMUB, 2014) and promote different types of green-tech innovations. While fitting the criteria of the study's definition of the term 'GTSUs', the selected start-ups also vary from one another. Such a heterogeneous sample selection allows a diversified and wider picture of the research area and prevents investigating only one homogenous characteristic. Interviews focused on GTSUs founded within the last six years (cf., Lambertz and Schulte, 2013: the process of start-up development can last up to six years) that have less than twenty employees, apart from two exceptions, one with a greater number of employees [I7] and another one where the GTSU had not been founded prior to the interview [I1]. Hence, these cases turned out to be significant interview



partners with additional insights and expertise. These cases were included in the study as well. All interviews were conducted with the founder and CEO or managing director in the German language, the native language of the interviewees. Out of a total number of fifty German GTSUs that were contacted by mail, ten GTSUs took part in the study. Interviews were transcribed using the software MAXQDA, which was also used to analyse the collected data. For confidentiality reasons, the data has been anonymised. Table 2 briefly describes the start-ups with regard to the selection criteria.

**Table 2** Sample

<i>Green-tech start-up ID</i>	<i>Start-up age in years</i>	<i>No. employees</i>	<i>Green technological function</i>	<i>Lead markets green-tech industry</i>	<i>Interview details (duration, position interview partner)</i>
I1	< 1	< 5	Energy efficient transportation and storage of pharmaceuticals	Material and energy efficiency	45:29 min, CEO and founder
I2	[>2-4]	[5-10]	Vertical farming	Material and energy efficiency	33:43 min, CEO and co-founder
I3	[1-2]	[5-10]	Renewable energy production	Environmentally friendly power generation, storage and distribution	36:18 min, CEO and founder
I4	[>2-4]	< 5	Decentralized hydro-energy production	Environmentally friendly power generation, storage and distribution	15:24 min, Managing director and co-founder
I5	[>4-6]	[> 10-20]	Renewable energy storage	Environmentally friendly power generation, storage and distribution	40:04 min, Vice President Business development
I6	[>2-4]	[5-10]	Inner-city e-mobility	Sustainable mobility	26:38 min, CEO and co-founder
I7	[>4-6]	> 20	Inner-city e-mobility	Sustainable mobility	38:16 min, Director Sales and Business Development
I8	[>2-4]	[> 10-20]	Wastewater treatment and reuse	Sustainable water management	26:27 min, CEO and Founder
I9	[1-2]	[5-10]	Waste recycling	Waste management and recycling	36:56 min, Managing Director and Co-Founder
I10	[1-2]	[> 10-20]	Hardware and software for energy efficiency	Energy efficiency	30:21 min, CEO and Founder

### 3.2 Data analysis

A qualitative content analysis based on the Gioia method (Gioia et al., 2013) was conducted. To develop the first order concepts and second order themes, the data analysis proceeded in two major stages: *first cycle* and *second cycle coding* (Appendixes 1 and 2). The collected interviews were read and re-read several times to determine the initial open coding. Codes were used to group text segments according to thematic issues. While first cycle codes were initially assigned to the data chunks, the second cycle codes pointed out patterns and thereby summarised the first cycle codes (Miles et al., 2014). The use of pattern codes, as a method of second cycle coding, turned out to be suitable for translating the individual in- and outflows of knowledge into overall inbound and outbound practices. Moreover, it forwarded the identification of the respective network partners of GTSUs and enabled the researchers to classify the emerging partner specific opportunities and risks into overarching categories (see Appendix 3). External validity was addressed through the selection of the cases (e.g., by including cases of the different lead markets of the green-tech industry). Furthermore, as no research has discussed the opportunities and risks of OI in the context of GTSUs, the use of qualitative methods represents an adequate way to gather first insights into the topic. Construct validity was addressed via semi-structured expert interviews with representatives of the GTSUs. The study explicitly shows the links between certain observations and specific results (established by the coding). Both the establishment of protocols for each interview and the use of different sources of information [information from Ecosummit (2016) interviews and observations] ensured the reliability of the research. Notes were taken during each interview and the case reflections were written down immediately afterwards to minimise the biases associated with data collection.

## 4 Findings

### 4.1 Open innovation network of green-tech start-ups

Referring to the first research question, ‘Who are the key open innovation partners of green-tech start-ups?’, the different network partners could be divided into *four contextual groups*. Although within sample differences were observed, the data demonstrated specific core partner organisations that are commonly approached during the development and commercialisation of green-tech innovations. First, *universities* were identified as core network partners of GTSUs. Nearly all cases opened up to universities, six out of ten to a greater extent compared to the rest (cf. I4: 13; I5: 7; I6: 57; I1: 14). In this context, interviewees also gave insight into the role of business incubation programmes offered by universities. Particularly GTSUs offering products and services that have not yet reached marketability approached such university incubation programmes (I8: 5; I9: 14; I1: 69). Apart from universities, other research institutes were also viewed as a network partner of GTSUs (I10: 57; I3: 27). Second, the data highlighted that *support platform* (including accelerator programmes and conferences, and competitions) played an important role in the network of the sample (eight out of ten, e.g., I2: 15; I8, 53; I4: 27). In the context of these platforms, experts often referred to the crucial role of opening up to *other start-ups* (cf. I8: 53; I9: 28; I10: 15; I1: 93; I3: 33). Third, *incumbent firms* represented another crucial network partner type. Some GTSUs

had closer ties with incumbent firms (cf. I8: 39; I9: 12; I5: 13; I6: 19) compared to others (I1: 89; I3: 19). Interaction between GTSUs and incumbent firms could range from close ties, such as R&D partnerships, to rather loose ties in case of supplier and investor relationships. Fourth, the data revealed that *customers* constitute an important group in the OI network of GTSUs. Since the start-ups in the study served both B2B and B2C markets, customers could be private persons (cf. I2: 31; I4: 37; I9: 72; I1: 23) or other firms (I8: 11; I9: 12; I5: 15; I7: 16).

## 4.2 Opportunities and risks of knowledge in- and outflows of green-tech start-ups

Referring to the second research question, ‘Which opportunities and risks emerge when green-tech start-ups pursue an open process of green technology innovation?’, opportunities and risks appeared to be partner-specific. First this paper presents the opportunities and risks for *each* of the four OI partners separately before offering a more holistic interpretation of the results.

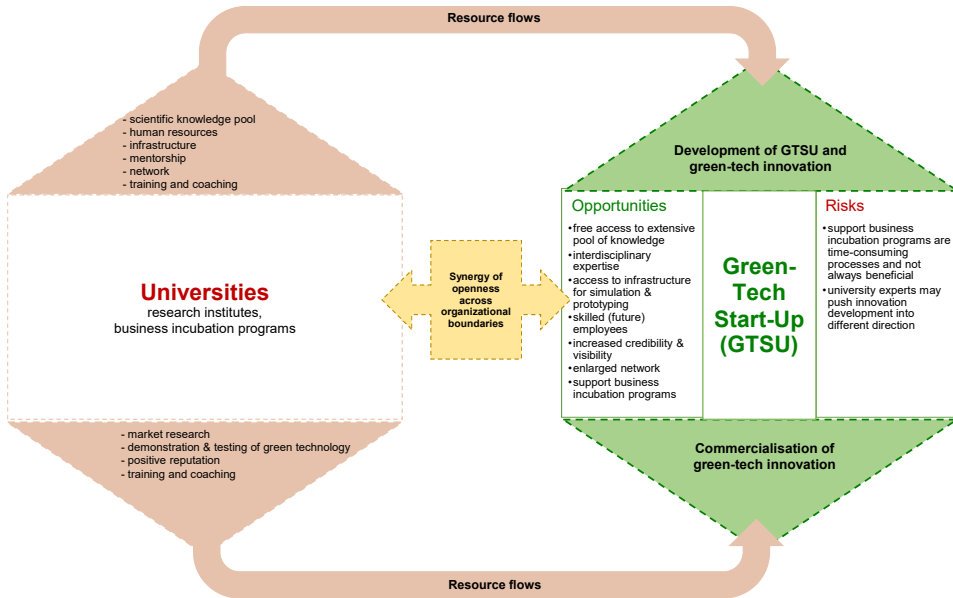
### 4.2.1 Universities and research institutes

Figure 1 illustrates the opportunities and risks in the context of openness towards academic institutions. Regarding the *development of green-tech innovations*, collaboration with universities offers numerous opportunities. Universities provide access to an extensive pool of knowledge from various disciplines that is needed to develop the respective green technology (I3: 7). Data highlighted that a start-up by itself could not provide all required scientific expertise (I3: 7). GTSUs sourced knowledge from universities to cope with technological complexities (I3: 7). While GTSUs themselves composed the overall business idea and the technological basics, universities filled in specific knowledge and expertise gaps (I2: 4). Universities supported the creation of mentorships between scientists and founders of GTSUs (I9: 18-20; I3: 27-35). Such mentorships could emerge out of doctoral supervision (I3: 27), university events (I3: 35) or participation in a university’s business incubation programme (I9: 18). Especially the expertise and knowledge of mentors positively influenced the overall development of GTSUs (I3: 41). When GTSUs opened up to universities and research institutes, they could acquire knowledge and expertise free of charge in most cases.

“[...] the openness of the universities, [...] they provided us with access to students and interested people. Well, if you are an incumbent firm, you have to [...] pay a few thousand euros in order to receive support. And we, actually, found very, very open support [...] that was also free of charge.” (I3: 41)

By providing GTSUs with the required scientific expertise and knowledge (I8 39; I7: 33), universities also provided access to highly skilled and motivated staff, in most cases students, who could later turn into employees (I10: 57; I3: 43; I7: 33-35). Furthermore, they provided access to crucial infrastructure for development processes, which GTSUs could not have afforded otherwise (I7: 33). The business incubation programmes that were offered by universities served as platforms for networking and offered various free services (I8: 5; I9: 14-18; I1: 69). In this sense, they provided the GTSUs with overall knowledge and support (I8: 5).

**Figure 1** Opportunities and risks of openness towards academic institutions (see online version for colours)



Apart from the opportunities pertaining to the *development phase*, universities furthermore served as a knowledge source for the *commercialisation phase*. They provided the GTSUs with market knowledge gathered through market research, and they served as platforms for the demonstration and testing of the respective technology (I6: 57). They further increased the overall public credibility and visibility of the GTSUs and the respective innovation, as they shared their positive image with the GTSUs (I10: 57).

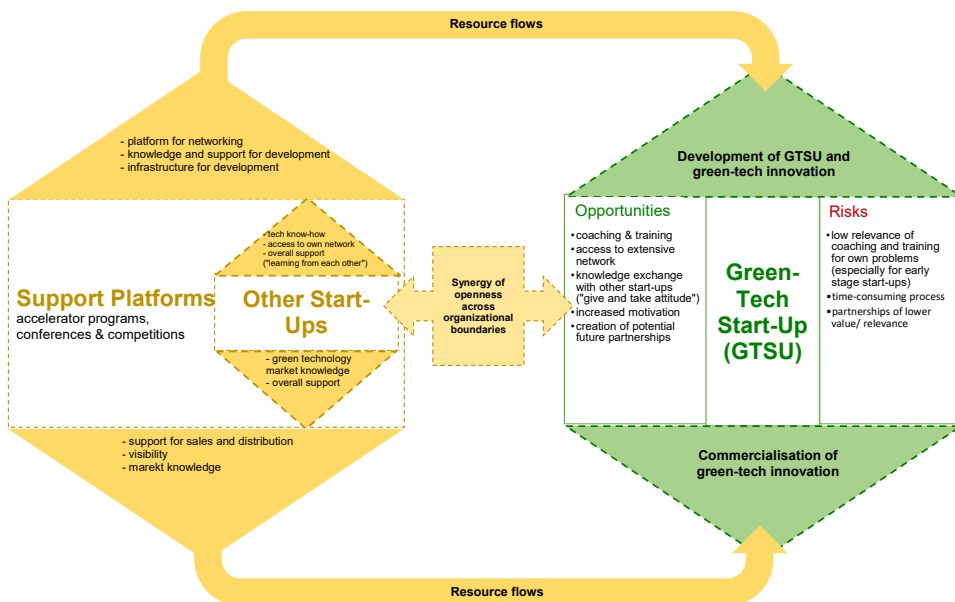
However, when GTSUs opened up to universities, not only opportunities, but also *risks* emerged. The data shows that the participation in university business incubation programmes could involve certain risks. It seems that these programmes were not always advantageous to the GTSUs because they did not forward the overall firm development and did not fit to the technological challenges of the start-up (I1: 65). The training and coaching services offered by university incubation programmes did not always fit the stage and the needs of the start-up, as they often provided standardised knowledge (I1: 31, 67). GTSUs risked committing themselves to time-consuming processes that were not beneficial in the long term. Constituting a further risk, the knowledge complexity of green technologies could be challenging for collaboration partners. The representatives of universities were not always able to think across disciplines. This could push the development of technology in a specific (wrong) way (I3: 47).

“If you have people that only focus on one scientific core area and are not able to think in an interdisciplinary way, it is possible that the development is shaped into a certain direction, and this can lead to problems [...] if the other possibilities are overlooked.” (I3: 47)

#### 4.2.2 Support platforms and other start-ups

Figure 2 presents an overview of the aggregated data. Accelerator programmes played a central role in the overall start-up success and *firm development* (I3: 41). They functioned as platforms providing access to a knowledge network and infrastructure, and they offered consultancy services and coaching (I8: 53; I1: 19; I9: 58). Accelerator programmes gave GTSUs access to a highly cooperative network, providing them with technological expertise and market knowledge. Furthermore, the creation of supplier and customer relationships with other firms was encouraged (I9: 32). The accelerator's network facilitated the establishment of contacts with potential future partner firms. Moreover, incumbent firms that were part of the accelerator's network gave access to their own network (I9: 34). This highlights the high degree of openness and collegiality of accelerator programmes, which was reported in the interviews. Conferences and competitions also played an important role for GTSUs in serving as support platforms that facilitated networking and created room for potential partnerships to emerge (I9: 12; I1: 93).

**Figure 2** Opportunities and risks of openness towards support platforms and other start-ups (see online version for colours)



Data highlighted particularly the creation of close ties with other start-ups. Given the fact that other start-ups had to cope with similar issues and problems as the GTSUs, knowledge exchange was based on a *give-and-take mentality* (I2: 6; I8: 53; I9: 28; I3: 37; I1: 31). Although start-ups support each other in terms of technical aspects (I2: 6), the focus of the knowledge exchange seems to be on aspects regarding the overall firm development as well as the company structure, sales and distribution and financial issues (I8: 17; I10: 15; I3: 37). Especially the knowledge exchange with other start-ups, also those that served other markets, offered outstanding mutual benefits and facilitated reciprocal motivation (I10: 15; I1: 31). Furthermore, GTSUs collaborated with other start-ups that were at the same time their competitors.

“However, in principle, we both realize that we address [...] the same customer with a similar product [...]. Of course, there are some overlaps, but we complement each other significantly more than if we were competitors. [...] They [the other start-ups] share their knowledge with us, and we do it the same way vice versa.” (I1: 27, 29)

“Well, everything concerning pharmaceuticals and new licence types and other things we share with each other. Likewise, all the competitions and networks [...]. Well, it is a very vibrant exchange.” (I1: 31)

Besides the benefits emerging in the context of support programmes and other start-ups, potential *risks* seemed to be involved as well. One risk was that such programmes only had minor relevance to the GTSUs in the long run. The participation in support platforms often involved time-consuming processes, which required start-ups to invest a large amount of time and resources without reaping any benefits of it (I3: 33). Not all support programmes fulfilled the promises that they had initially given to the participating start-ups (I6: 55).

#### 4.2.3 Incumbent firms

Figure 3 illustrates further opportunities and risks identified in the context of incumbent firms. Formal partnerships with incumbent firms, for example through R&D collaborations and sparring partnerships, revealed the greatest amount of opportunities (I9: 12; I6: 19; I7: 16). These partnerships were in particular able to promote the *technological development* and furthermore saved the start-up a large amount of money (I2: 12). Especially larger incumbent firms provided a wide array of tangible and intangible resources to the GTSUs. Incumbent firms could offer access to technical knowledge and expertise that was crucial for the development of the respective green-tech innovations (I8: 43; I9: 32; I6: 37). Moreover, incumbent firms gave access to their own networking ties with other organisations (I9: 32, 34). Depending on the target markets of the GTSUs, the partner firms could be settled in distinct industries (I9: 12; I6: 41; I7: 55) or serve similar or even the same markets (I6: 19; I5: 65; I3: 17, 19). In this context, GTSUs even opened up to potential competitors in order to build up partnerships (I10: 49). Depending on the type of partnership, external expertise and know-how were offered free of charge (I2: 7-12; I5: 17; I6: 23-25; I7: 45) or for an agreed payment (I9: 26). In this sense, partnerships could also include a mixed form of monetary and non-monetary practices (I2: 8):

“We share the overall development expenditures with [X]. [...] they bear the development costs of 100% and we have to bear the expenses for the certification of the LED module.” (I2: 8)

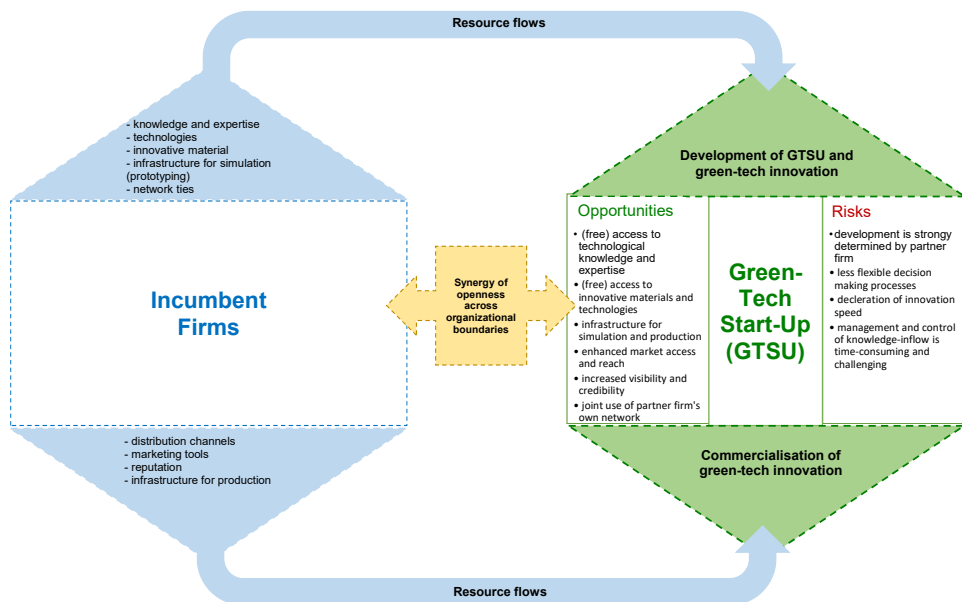
Incumbent firms gave free access to their proprietary, innovative resources, such as specific material or specific know-how, on design aspects and development processes (I6: 19) and, furthermore, constituted a valuable source to GTSUs in terms of production methods and access to infrastructure for production (I6: 19). In addition, they provided access to infrastructure that was required for simulation and prototyping processes.

“We also simulate things together, the programmes behind all the plastics that nobody else can provide. This means that we can simulate the entire vehicle beforehand, which is normally not possible. And this is great of course!” (I6: 23)

GTSUs normally did not only focus on a single partner firm, but also opened up to different firms to fill in the respective knowledge gaps and resource needs that occurred over time (I6: 43–45; I3: 13). Opening up to incumbent firms create various opportunities concerning not only the *development of green technology*, but also the *commercialisation phase*. Partnerships with large incumbent firms were able to increase the overall visibility and credibility of GTSUs in public (I7: 61). In some cases, partnerships with incumbent firms also included access to specific marketing tools (I6: 33) that could facilitate a wide market reach and access to international markets (I6: 25–27; 37). In cases in which patenting was rather embraced, GTSUs pursued out-licencing their products to incumbents in the long run to reach other markets.

“Well, licencing of course! There are definitely markets for which our technology is relevant. These are not the same markets that we want to serve. [...] In this case, we would use licences.” (I1: 47)

**Figure 3** Opportunities and risks of openness towards incumbent firms (see online version for colours)



The data also offers insights into potential *risks*. Since incumbent firms, which collaborate with GTSUs, are likewise driven by strategic interests, there is a risk that the benefits of the incumbent firm outweigh the opportunities of the GTSUs. In some cases, the data indicates that the overall development process of the green-technology is strongly determined and shaped by incumbent partner firms (I9: 12; I7: 16). Moreover, the flexibility and agility, which characterise the organisational structure of start-ups, were in some cases limited, as GTSUs had to adapt to the processing speed of incumbent firms (I2: 21; I5: 25, I7: 53). Thus, the overall process speed could decelerate. In addition, the management of knowledge inflows seemed to be overwhelming in some cases. Controlling and managing different partnerships and the respective knowledge exchange were time-consuming and challenging and required managerial resources (I3: 49, 51–53).

“[...] it has to do a lot with building up relations and with building up trust. And it takes quite a while until you know with whom you have to talk, how you have to talk with the people. Are you a trustworthy partner, do they believe that you are able to implement all the things? It is connected to all those aspects.” (I6: 29)

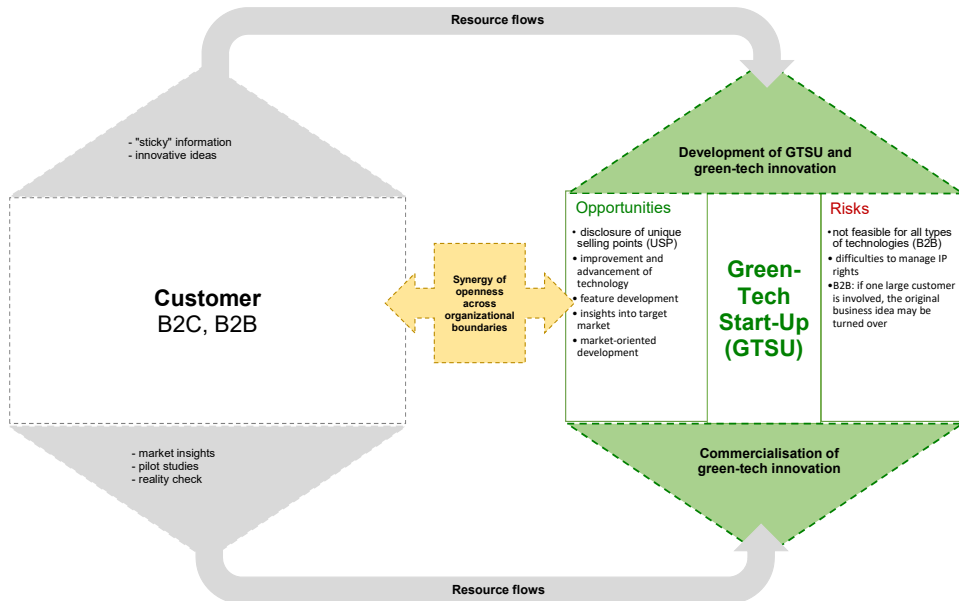
4.2.4 Customers

Figure 4 summarises the overall opportunities and risks that emerged when GTSUs opened up to customers, both end customers and business customers, during the innovation process. The integration of customer knowledge, e.g., through product feedback, was pointed out as highly important for the *development of green-tech innovations* (I2: 9; I10: 11), as it could optimise the respective usability (I2: 10). In order to make products and services marketable, customers were encouraged to test the respective green technology over a certain period (I2: 31). Moreover, customer involvement in the context of B2B relationships promoted the development of additional features of the green-tech innovation (I10: 9). Overall, the integration of customer knowledge could advance the course of the technological development (I9: 72–74; I4: 37-39), as they provide GTSUs with relevant knowledge and ideas (I1: 23).

“Yes, that is highly important! For example, there exists an aspect, which we have never been aware of before. [...] We have conducted focus group interviews with two of our future customers [...]. As a result, it came up, that not only [X], but also [Y] represents a critical factor [...] and we would have never considered this aspect on our own account [...].” (I1: 23)

In both B2B and B2C markets, customers of GTSUs provided crucial knowledge free of charge to the GTSUs that led to the advancement of technology. Furthermore, customers could disclose unique selling points (Ne: 25). GTSUs that opened up to business customers were able to acquire knowledge that promoted both the technical development and the *overall commercialisation* (I10: 8; I8: 11).

Figure 4 Opportunities and risks of openness towards customers (see online version for colours)





However, the data indicated that GTSUs struggled to find the right IP strategy for involving customers in the innovation process, which prevented the overall collaboration with customers (I6: 39). GTSUs customers were not always able to provide the specified insights. Since green-tech innovations often require entirely new and innovative solutions, it can be difficult to gather customer knowledge that fits and promotes a complex technology (I3: 11). GTSUs that had B2B marketing relationships had difficulties integrating customer knowledge into the development process.

“What I would wish for is, so to say, to be more connected with the customer group, to acquire more customer feedback. I think in the B2B area, it is even harder than in the B2C area to be closer to the customer and to integrate their knowledge in the development process. I would say that in any case, it is challenging to develop the product [...] in close collaboration with the customer, so to say.” (I10: 53)

The data also showed that customers who represented the most important commercial partners of the GTSUs were able to change the original business idea, turning the course of development into another direction than originally pursued (I7: 6, I7: 16).

## 5 Discussion

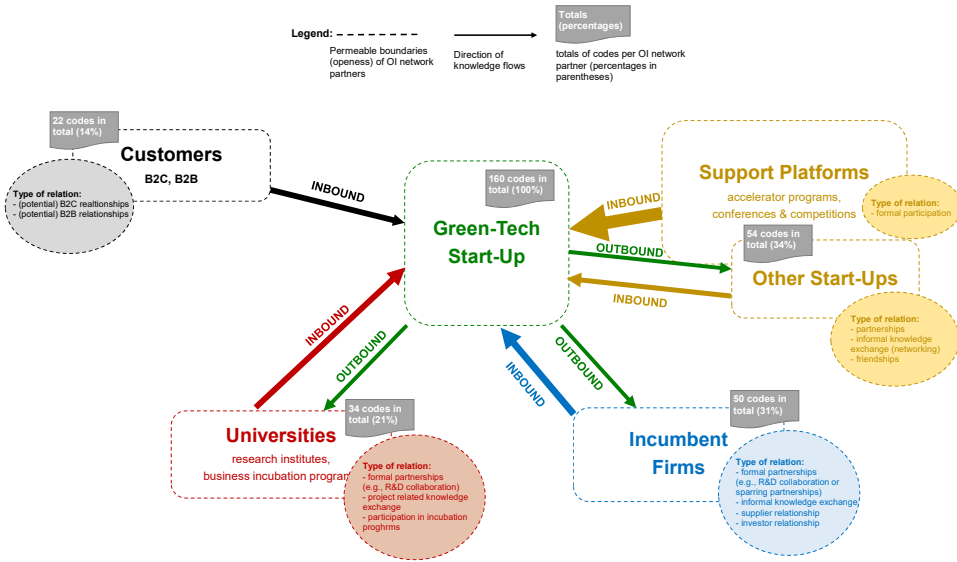
### 5.1 Open innovation network partners and the role they play

The study identified four core OI network partners of GTSUs, showing that different partners present different opportunities and risks. Moreover, the importance of each partner and their relationships turned out to be unequal. Figure 5 summarises the in- and outflows of knowledge between GTSUs and the network partners and their forms of relationships that emerged from the interviews. Indicated by the aggregated codes in total and supported by the qualitative analysis, the paper discusses the importance of different roles of OI partners in GTSUs opening.

The different *forms of relationships* range from formal partnerships and collaborations to informal relationships and friendships. With three out of four network partners – academic institutes, other start-ups, and incumbent firms – GTSUs seem to use both inbound and outbound practices. GTSUs not only source knowledge from these groups, but also share internal knowledge with them. Thus, depending on the type of network partner and respective relationships, the knowledge flows are reciprocal. This shows that GTSUs focus not only either on inbound or outbound practices, but also on both processes simultaneously. However, the outbound and coupled practices of GTSUs do not necessarily involve only commercialisation activities, as described by Chesbrough and Bogers (2014), but rather the overall reciprocal exchange of knowledge and expertise with the respective network partner by way of *non-pecuniary practices*. Although both inbound and outbound practices appear to be pursued, the findings highlight that GTSUs focus on purposive inflows of knowledge. As indicated by the arrow thickness in Figure 5, more knowledge, ideas and technologies flow in GTSUs than out. This is in line with prior research, which has emphasised the overall resource constraints of start-ups and the important role of partnerships and alliances in overcoming these constraints (cf. Baum et al., 2000; Meyskens and Carsrud, 2013). Moreover, the results are consistent with the findings of prior literature, which has investigated OI in the context of SMEs (Bianchi et al., 2010; Parida et al., 2012). Since SMEs also favour inbound practices over

outbound practices (ibid.), further similarities between OI practices of SMEs and those of start-ups may exist.

**Figure 5** OI network partners of GTSUs: importance of partner, knowledge in-and outflows (see online version for colours)



Note: The arrows provide information about the direction, kind of relation (in- or out-bound) and strength of the dependencies (the latter indicated by the arrow thickness) between the OI partners and the GTSUs. The totals (and percentages) of codes per OI network partner indicate the importance of the network partners compared with each other.

The findings demonstrated that GTSUs and SMEs approach similar network partners for OI practices (cf. Brunswicker and Vanhaverbeke, 2015). Although all four partners turned out to be crucial, it appears that openness towards one group, namely *support platforms/other start-ups*, is unique and most important in the start-up context (54 codes in total, Figure 5). This follows the findings of Eftekhari and Bogers (2015) who emphasised that participation in incubator programmes enables start-ups to network, obtain new ideas and exchange experiences, which in turn positively affects the overall survival and success of start-ups. The findings confirmed that start-up OI partners and OI network partners of established firms are not the same and have different effects on the innovation process. This is in line with Brunswicker and Vanhaverbeke (2015) who found that not all knowledge sources are of equal importance and relevance for SMEs. In contrast, Su et al. (2009) found that only partnerships with universities and research institutes have a significant effect on either product or process innovativeness in incumbent biotechnology firms. Universities and research institutes appear to be important for GTSUs, but in comparison with support platforms and other start-ups, they rank third (34 codes) after incumbent firms (50 codes) but before customers (22 codes). This finding might have arisen from the different use of OI partners in different start-up stages, as the interviewees revealed. Early-stage start-ups seem to exchange more knowledge with other start-ups (cf. I9; I1), whereas start-ups in later stages focus more on close ties with incumbent firms and universities (cf. I6; I3; I7). Especially in later stages,

incumbent firms can offer access to complementary innovation resources as well as operational complementary assets with regard to manufacturing and marketing (Baum et al., 2000). If they are approached on the basis of a supplier relationship, they can also provide technical expertise and short-term solutions that are able to add commercial value (Chesbrough and Prencipe, 2008).

## 5.2 Opportunities and risks of knowledge in- and outflows at different levels of impact

By zooming out of the micro perspective towards a macro view of the findings, the study can conclude that the core inbound and outbound benefits and disadvantages can be structured into *three different levels of impact* with regard to the start-up, more specifically the innovation stage (as shown in Table 3). The study summarised the key inbound and outbound opportunities and risks that emerge when GTSUs open up and related them to the core OI partners and the *three levels of impact* at which they occur. First, the results found key opportunities and risks at the level of *firm development – a process which can last up to six years for SMEs* (Lambertz and Schulte, 2013). Second, interviews indicated crucial core benefits and disadvantages that occur at the level of *technology development*. Third, interviews revealed opportunities and risks, which are crucial particularly at the *level of commercialisation*.

At the first level, *firm development*, the findings showed that openness may enlarge the network of GTSUs from which knowledge can be sourced. Moreover, by opening up to universities, GTSUs could receive guidance through mentorships with, e.g., professors and academics. Likewise, openness towards support platforms appears to positively affect the overall firm development, particularly with regard to early-stage start-ups. They get access to infrastructure for firm development and are offered various coaching and training services. In this context, openness towards other start-ups also benefits GTSUs, as it increases the level of motivation and supports the overall firm development based on the *give-and-take* attitude between start-ups. *Risks of openness*, which can be related to the level of firm development, include decreased organisational flexibility and agility as well as an overall deceleration of decision processes. These risks may particularly emerge when GTSUs open up to large, incumbent firms. Moreover, the overall management and control of knowledge in- and outflows can also be overwhelming and challenging for GTSUs. Openness towards support platforms and universities indicates a downside as it is related to time-consuming processes, which are not always beneficial to the firm's overall development.

Opportunities and risks at the level of the *technological development* revealed that a central *opportunity of openness* is an interdisciplinary pool of knowledge, which academic institutions and incumbent firms offer free of charge based on the type of partnership. These network partners provide infrastructure for simulation and prototyping, which can accelerate the overall development process of green technologies. Furthermore, opening up to incumbent firms can give GTSUs access to various tangible resources, such as innovative material or technological components. Regarding the openness towards customers, GTSUs are able to disclose unique selling points and get access to new ideas, which may promote the development of new technological features. The *risks of openness* at the level of technological development are related particularly to close partnerships with universities and incumbent firms, as they may push the

development of the technology in a different direction. The partner organisation can set up binding rules that determine the entire course of development.

Considering the level of *technology commercialisation*, most *opportunities* are related to close partnerships with incumbent firms. Those partnerships can give GTSUs access to marketing tools, distribution channels and infrastructure for production. Moreover, by opening up to incumbent firms as well as academic institutes, the public visibility and credibility of GTSUs can be increased. Openness allows GTSUs to acquire crucial market knowledge from various network partners, which can advance the overall commercialisation process. In addition, commercialisation processes can also be supported by involving customers. The findings demonstrated that customers are able to optimise the respective technology, pushing it towards market maturity. The only *risk* that was identified concerning the level of commercialisation is related to openness towards other start-ups. Since they face the same limitations with respect to market access and market reach, other start-up firms might not represent suitable partners for commercialisation processes.

Overall, the result indicated not only that OI partners are of different importance and relevance, but also that the sourcing strategies might depend on the different stages of the innovation process. In the first stage, support platforms are most prominent, whereas in the second and third stages, the technology development and commercialisation stages, incumbent firms played a key role as OI partners. The results are consistent with Brunswicker and Vanhaverbeke' (2015) findings, which indicated that SMEs engage in different sourcing strategies. The study found a similar result in the context of GTSU's OI practices.

Furthermore, in terms of the differences between inbound and outbound innovation, inbound advantages are most relevant in the first two stages. At the third level, i.e., the level of technology commercialisation, outbound knowledge flows provide the most crucial opportunities along with the sourcing strategy in which incumbent firms present a key OI partner in this stage of technology innovation.

Moreover, in the context of outbound innovation strategies, the results showed that the respective *IP strategy* affects the way in which GTSUs open up to different partners. Though the results demonstrated that both GTSUs with and without protective measures open up to external actors, the ones with patenting show some peculiarities in that they approach direct and indirect competitors in order to forward the development and commercialisation of the own technology (cf. I1; I3). Moreover, GTSUs with patents on their technology aim to out-license their technologies to incumbent firms (cf. I2; I1). This indicates that the protection of IP does not prevent GTSUs from engaging in OI practices with external actors but allows them to find better ways to commercialise their technologies (cf. I2; I8; I3). This finding is in line with Chesbrough's (2003a) idea to use IP rights to profit from the external world. In this sense, the protection of green technologies does not limit but rather enables GTSUs to open up, particularly with regard to outbound practices, such as out-licensing.

**Table 3** Overall OI opportunities and risks of GTSUs – the three levels of impact

Open innovation network partners						
	UR = universities and research institutes	SP = support platforms	OS = other start-ups	IF = incumbent firms	C = customers	
<b>OPPORTUNITIES</b>						
<i>Level 1: Firm development</i>						
Inbound innovation	x					
Guidance (mentorship)				x		
Access to larger network	x	x				
Partnership building		x				
Overall support: coaching and training		x				
Infrastructure (first start-up steps)		x				
Reciprocal motivation and support			x			
<i>Level 2: Development of green-tech innovation</i>						
Inbound innovation	x					
Free access to interdisciplinary pool of knowledge				x		
Infrastructure for simulation and prototyping	x					
Technical know-how and expertise				x		
(Free) access to resources (e.g., material)				x		
'Sticky' knowledge (disclosure of USPs)					x	
Access to new ideas (feature development)					x	
<i>Level 3: Commercialisation of green-tech innovation</i>						
Outbound innovation						
Optimisation and advancement of green-tech innovation						x
Increased public awareness and credibility (positive reputation)	x					
Access to market knowledge				x		
Access to marketing tools	x					
Access to distribution channel				x		
Infrastructure for production						x

**Table 3** Overall OI opportunities and risks of GTSUs – the three levels of impact (continued)

		Open innovation network partners				
		UR = universities and research institutes	SP = support platforms	OS = other start-ups	IF = incumbent firms	C = customers
<i>RISKS</i>						
<i>Level 1: Firm development</i>						
Inbound innovation	Decreased organisational flexibility and agility				x	
	Deceleration of decision processes/ too many partnerships				x	
Overall	Difficulties to manage and control knowledge in- and outflows				x	
	Time-consuming processes that are not always beneficial	x				
<i>Level 2: Development of green-tech innovation</i>						
Inbound innovation	Development is pushed into wrong direction	x				
	Development is determined by rules of the OI partner					x
<i>Level 3: Commercialisation of green-tech innovation</i>						
Outbound innovation	OI partner has to cope with similar limitations in terms of market access and reach			x		

## 6 Conclusions

On these grounds, and by revisiting the analytical framework and the benefits and disadvantages of OI in the context of GTSUs discussed in the literature review, the paper concludes by highlighting the main findings supporting the study's five propositions. Being one of the first studies that interlink GTSUs and OI, this study demonstrated that both inbound and outbound practices are used. The results showed that most opportunities that emerge when GTSUs open up within the innovation process can be related to the context of non-pecuniary inbound practices. In most cases, these opportunities emerge to cope with an overall lack of resources start-ups generally face (Lounsbury and Glynn, 2001). In particular, non-pecuniary inbound practices that are based on synergetic partnerships with incumbent firms, academic institutions and other start-ups appear to be beneficial because they are able to close specific knowledge and resource gaps of GTSUs without capital expenditures or expensive control measures. This leads to the following proposition:

Proposition 1 Non-pecuniary inbound practices of GTSUs advance the overall innovation process.

Furthermore, the study found that GTSUs open up to diverse heterogeneous OI partners during the development and the commercialisation of green-tech innovations. These partners were divided into *four* contextual groups of open innovation network partners:

- 1 universities and research institutes
- 2 support platforms and other start-ups
- 3 incumbent firms
- 4 customers.

The findings highlight that the opportunities and risks of knowledge in- and outflows of GTSUs are in most cases partner-specific. Hence, the study developed the following proposition:

Proposition 2 Opportunities and risks of open innovation of GTSUs depend on the different knowledge sources.

Prior studies of OI have emphasised the importance of analysing the benefits and risks emerging from open innovation (Lichtenthaler, 2011; Schuster and Brem, 2015; Su et al., 2009). However, no literature provides an overview that completely covers this topic. By conducting an overview of both the core opportunities and risks in open innovation literature within an analytical framework and presenting qualitative data to identify the core opportunities and risks in the context of OI and GTSUs, the study addressed this gap in research. The research included both inbound and outbound OI processes. Although the analysed cases used different combinations of inbound and outbound practices, the study found thematic patterns in the data that shed light on the key opportunities and risks, which emerge when GTSUs open up to the four identified groups of network partners. These opportunities and risks can be structured into *three* different *levels of impact* depending on the firm's development and the technology innovation stage:

- 1 the level of firm development
- 2 the level of technology development
- 3 the level of technology commercialisation.

In particular, synergetic partnerships, such as R&D collaborations with universities and incumbent firms, created opportunities at all three levels. Risks of OI affect particularly the level of technology and firm development. This leads to the following propositions:

**Proposition 3** GTSUs chose different sourcing strategies and knowledge sources depending on the firm's development and technology innovation stage.

Although GTSUs focus on inbound practices, the findings also showed that opportunities and risks can emerge regarding the purposive outflows of knowledge. The findings revealed that GTSUs that followed a protective IP strategy pursued the use of pecuniary outbound practices, meaning the selling of products or knowledge (out-licensing). Although not all technologies were yet market-ready at the point of data collection, the GTSUs already proceeded or aimed to out-license the technologies to other firms that were better equipped to successfully commercialise them. In this sense, outbound practices seem to enable GTSUs to get better access to the target market. Moreover, by out-licensing their technologies, GTSUs can furthermore reach new markets. Although the findings do not offer insights into whether non-pecuniary practices are less beneficial compared to pecuniary ones, they lead to the following proposition:

**Proposition 4** Pecuniary outbound (out-licensing) practices allow GTSUs to both increase their market access and reach new markets.

Regarding GTSUs that do not follow a protective outbound strategy, partnerships with incumbent firms and academic institutes seem to better commercialise green technologies. In this context, various opportunities can emerge. Incumbent firms are able to provide GTSUs with production infrastructure, marketing tools and distribution channels. Enjoying the backing of an incumbent firm or a prestigious academic institution furthermore enhances the overall public visibility and credibility. In addition, different network partners can be approached to gather market knowledge that can promote commercialisation processes.

Opportunities, particularly in the context of non-pecuniary outbound practices, can emerge for GTSUs that feature a software component in their technology. By sharing data with other network partners and giving free access to certain components of software – such as 'selective revealing' (Henkel, 2006), GTSUs can contribute to communities from which they can also source knowledge and ideas (cf. I10). The findings support a cooperative *give-and-take* approach between GTSUs and certain network partners. This is in line with the 'sharing paradigm' (McLaren and Agyeman, 2015), which considers sharing in society without expectation of economic gain (Muñoz and Cohen, 2017). The sharing paradigm refers to non-economic objectives of sharing activities (such as sharing data with other networks). For example, GTSUs having partnerships with universities and other firms offer access to their own knowledge and expertise and receive the same in return. In this sense, outbound practices of GTSUs are thus incentivised by profiting from mutual support rather than by gaining further profits or by commercialising the respective knowledge or technology. In particular, the interaction between GTSUs and other start-ups seems to be based on this mutual support with regard to organisational, technical and



commercial aspects. In some cases, GTSUs even shared their knowledge base with potential competitors, as they faced the same problems and challenges (cf. I1; I3). Considering these results, it appears that the use of non-pecuniary outbound practices does not represent a risk to GTSUs. Such practices are rather based on cooperative relationships among network partners providing knowledge. This leads to the last proposition:

Proposition 5 GTSUs benefit from non-pecuniary outbound practices if they are based on a cooperative ‘give-and-take’ approach with the involved network partners.

### 6.1 Limitations and further research directions

The results of this study have to be considered in light of methodological and content-related *limitations*. This study used a qualitative research design involving semi-structured interviews with experts from ten German GTSUs. Although a qualitative approach was appropriate for gaining insights into new fields of research, it also had some limitations. First, the study focused on German GTSUs. Future research should expand the scope of the sample by including GTSUs from different national contexts. This would increase the generalisability of the findings because the national context is important when studying OI (Garriga et al., 2013). Second, future research should analyse start-ups in other fields of specialisation (Bogers et al., 2017) to verify whether start-ups in different sectors face similar opportunities and risks. Third, this research, as one of the first to investigate OI from the point of view of start-ups, focused on opportunities and risks of both inbound and outbound practices as well as the respective partners involved in these practices. Future research could try to reduce the focus of interest by concentrating specifically on either in- or outbound practices, such as open-source projects or out-licensing. Fourth, the examination of OI in the context of GTSUs revealed that different knowledge sources come along with different opportunities and risks. Furthermore, the results lead to the assumption that sourcing strategies vary with different innovation stages. This poses a question of *why* and *when* GTSUs prefer certain OI practices to others, for example, inbound to outbound or non-pecuniary to pecuniary. *Future research* might find the answers. Finally, this study was only the first step to contribute to the qualitative research on OI in the GTSUs context and to open up the field for future research.

### 6.2 Practical implications

This study has *practical implications* relevant to both GTSUs and start-up firms of other industries. The findings of this research highlight particularly the positive synergies that emerge when GTSUs open up to their surrounding environment. Therefore, the results are also relevant to the network partners of GTSUs. Based on the findings, start-ups should acknowledge that OI cannot be implemented using a *one-fits-all approach*. Instead, it is recommended that GTSUs create an individual mix of inbound and outbound practices, which is in line with their respective needs. The findings of this study show that start-ups can use different types of relationships with heterogeneous network

partners in order to forward the *development and commercialisation of green-tech innovations*. Such relationships can range from loose and informal networking ties to close and formal partnerships, such as R&D collaborations. Although all types of relationships can forward innovation processes of start-ups, the overall firm development, as well as the technological development and commercialisation, benefit most from close partnerships with incumbent firms and universities. To build such partnerships, accelerator programmes and start-up competitions represent valuable platforms to connect with others and exchange knowledge and ideas on an informal basis. In this sense, other start-up firms represent useful knowledge sources that can be approached to advance innovation processes without the need to raise time and money or build formal partnerships.

Since every inbound practice of start-ups represents at the same time an outbound practice of the respective partner, the findings are of importance to potential network partners of start-ups. Especially incumbent firms and universities, which aim to advance green-tech innovations, should be aware of the benefits of supporting start-up firms. While larger organisations possess resources, expertise and market access, start-ups provide innovative ideas and organisational agility. In this sense, the combination of these two sides can be a promising driver of the development and commercialisation of environmentally sound technologies.

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## Appendix 1

### First cycle coding method

<i>First cycle coding method</i>	<i>Definition</i>	<i>Example</i>	<i>Description</i>
Descriptive coding	<i>Descriptive coding</i> summarizes data in a short phrase or word, which represents the basic topic of the respective passage (Miles et al., 2014).	< <i>Expertise and know-how</i> > < <i>Increased credibility</i> > > < <i>Enhanced visibility and public awareness</i> > > cf., second cycle code: <i>incumbent firms/ opportunities (INBOUND) and opportunities (OUTBOUND)</i>	In the original data source, the interviewer stresses various opportunities that emerge as part of a development cooperation with BASF. The company does not only provide expertise & know-how to the green-tech start-up, but also increases public credibility and visibility by providing access to own marketing channels.
Holistic coding	Instead of line-by-line coding, the <i>holistic coding</i> method uses a single code in order to capture the sense of a larger chunk of data and its overall contents (Miles et al., 2014). This method can be applied as a pre-stage to the detailed coding process.	< <i>Platform for partnership building</i> > cf., second cycle code: <i>accelerator programmes and competitions/ opportunities (OVERALL)</i>	In the original data source, the interview partner highlights in a large chunk of data that informal partnerships were formed with other start-ups, which likewise participated in the respective accelerator programme. Thus, accelerators can function as a platform that facilitates partnership building with other knowledge carriers.
Provisional coding	<i>Provisional coding</i> begins with a provisional list of codes. Later on, the preliminary codes are revised, modified, deleted or expanded to include new codes, as suggested by Miles et al. (2014).	< <i>intellectual properties</i> > ↓ < <i>CONTRA protective strategy (IP)</i> > < <i>PRO protective strategy (IP)</i> > cf., second cycle code: <i>start-up background information/role of IP</i>	In the very beginning of the coding process, the passages that contained information about intellectual properties and the respective strategies of the green-tech start-ups were provisionally coded with the first cycle code “intellectual properties”. At a later point in time, this code was split up into two different first cycle codes that made a clearer distinction between the different degrees of protectiveness ( <i>CONTRA</i> and <i>PRO</i> ).
In vivo coding	<i>In vivo coding</i> generates codes by using words or short phrases from the expert’s own language. Therefore, it is especially appropriate for phrases that reoccur within one interview as they point to patterns in the setting (Miles et al., 2014).	< <i>free of charge</i> > cf., second cycle code: <i>universities and research institutes/ opportunities (INBOUND)</i>	In the original text passage, the interview partner refers to a crucial opportunity that has been created as part of a collaboration with a university. It is emphasized that the services and knowledge provided by the university to the green-tech start-up are free of charge.

## Appendix 2

### *Second cycle coding method*

<i>Second cycle coding method</i>	<i>Examples</i>	<i>Corresponding first cycle codes (examples)</i>	<i>Description</i>
Pattern codes	Universities and research institutes opportunities (INBOUND)	<ul style="list-style-type: none"> <li>• Access to interdisciplinary knowledge</li> <li>• Skilled employees</li> <li>• Enlarged network</li> </ul>	<p>The use of pattern allowed the coders to combine the individual first cycle codes into one overarching meta-code. As demonstrated by the examples, the titles of the pattern codes were chosen to subsume the opportunities and risks that emerged when green-tech start-ups opened up to different network partners. Moreover, the pattern codes point to the direction of the involved knowledge flows (INBOUND/OUTBOUND). In cases where opportunities and risks emerged at a firm level, the respective pattern code was marked accordingly with the addition '(OVERALL)'.</p>
	Incumbent firms opportunities (OUTBOUND)	<ul style="list-style-type: none"> <li>• Access to new markets</li> <li>• Increased scope of distribution</li> <li>• Production infrastructure</li> <li>• Increased credibility</li> </ul>	
	Customers opportunities (INBOUND)	<ul style="list-style-type: none"> <li>• Joint feature development</li> <li>• Disclosure unique selling points</li> </ul>	
	Incumbent firms risks (OVERALL)	<ul style="list-style-type: none"> <li>• Limited flexibility/dependency</li> <li>• Partnerships do not fit</li> <li>• High costs</li> </ul>	

## Appendix 3

### *Coding system: list of first and second cycle codes*

<i>Aggregates/key OI network partners</i>	<i>Second cycle</i>	<i>First cycle</i>
Universities and research institutes	Opportunities (INBOUND)	Free of charge Access to interdisciplinary knowledge Access to infrastructure (prototyping) Skilled employees Support from knowledge experts and mentors Support business incubation programs enlarged network
	Opportunities (OUTBOUND)	Increased credibility and visibility Market knowledge
	Risks (OVERALL)	Missing commitment Support programs



*Coding system: list of first and second cycle codes (continued)*

<i>Aggregates/key OI network partners</i>	<i>Second cycle</i>	<i>First cycle</i>		
Accelerator programs and competitions	Opportunities (OVERALL)	Platform for partnership building Access to capital Coaching and trainings Increased visibility Support from knowledge experts and mentors Overall guidance Increased motivation		
	Risks (OVERALL)	Time-consuming processes (uncertainty of outcomes) No partnership 'fit' Low relevance (long-term)		
Other start-ups	Opportunities (INBOUND)	Joint projects Reciprocal support Learning from each other		
	Opportunities (OUTBOUND)	Support commercialisation		
	Risks (INBOUND and OUTBOUND)	Unprofessional structures Cannot provide access to markets		
Incumbent firms	Opportunities (INBOUND)	Access to relevant components (resources) Technical know-how Infrastructure for prototyping Access to international network Expertise and know-how Free of charge		
		Opportunities (OUTBOUND)	Increased scope of distribution Marketing tools Production infrastructure Enhanced visibility and public awareness Increased credibility Access to new markets Access to market insights Non-pecuniary outflows Possibilities for future out-licensing	
			Risks (OVERALL)	Barriers outbound Difficulties to agree on IP rights Partner sets up rules Partnerships do not fit Deceleration (too many partnerships) Limited flexibility/dependency High costs

*Coding system: list of first and second cycle codes (continued)*

<i>Aggregates/key OI network partners</i>	<i>Second cycle</i>	<i>First cycle</i>
Customer (B2B and B2C)	Opportunities (INBOUND)	Joint feature development Disclosure of unique selling point (USP) Crucial knowledge for development (needs of customer)
	Risks (OVERALL)	IP management difficulties Determination of development Difficulties to involve B2B customer Difficulties to involve B2C customer