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Technology transfer and cooperation for low carbon energy technology: Analysing 30 years of scholarship and proposing a research agenda

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ABSTRACT

While North-South technology transfer and cooperation (NSTT) for low carbon energy technology has been implemented for decades, South-South technology transfer and cooperation (SSTT) and South-North technology transfer and cooperation (SNTT) have only recently emerged. Consequently, the body of literature on NSTT is mature, while the body on SSTT and SNTT is still in its infancy. This paper provides a meta-synthesis of the scholarly writings on NSTT, SSTT and SNTT from the past 30 years. We specifically discuss core drivers and inhibitors of technology transfer and cooperation, outcomes as well as outcome determinants. We find policies and practices for low carbon development to be the main driver, both pushed by governments and international aid programs, as well as by firms that are interested in expanding overseas. Inhibitors include a non-existent market in the host countries and the abundance of cheap fossil fuel resources that price out renewables. The literature is divided on whether intellectual property rights are inhibitors or drivers of technology transfer to the Global South. Outcomes of technology transfer and cooperation are mixed with approximately one-third of instances reported as successful technology transfer and another one-third reported as failures. Core key success factors were identified as suitable government policies as well as adequate capacities in the recipient country. This analysis is then followed by an introduction of the papers of the special issue 'South-South Technology Transfer and Cooperation for Low Carbon Energy Technologies'. Finally, a research agenda for future work on NSTT, SSTT and SNTT is proposed.

1. Introduction

Global energy consumption is growing at a rapid pace. It may increase from about 13,650 Million tonnes of oil equivalent (Mtoe) in 2015 by nearly 30% to about 17,750 Mtoe in 2040 (EIA, 2017; IEA, 2017). Countries in developing Asia account for more than half of this increase due to their strong economic growth (EIA, 2017). Fossil fuels, especially natural gas and oil, are and will continue to be the primary energy sources to power these economies (IEE, 2016). This development will create carbon lock-in, i. e. make countries dependent on fossil-fuel based energy systems (Unruh, 2000). After all, assets such as natural gas plants or coal-fired power plants “cannot be […] understood as a set of discrete technological artefacts, but have to be seen as complex systems of technologies embedded in a powerful conditioning social context of public and private institutions” (Unruh, 2000, p. 818) that create “a self-reinforcing positive feedback [for a chosen] technological solution” (Unruh, 2000, p. 823). These fossil-fuel based energy systems will then further accelerate climate change, “the single greatest challenge of mankind” (UNEP, 2016, p. 3), with energy consumption contributing up to 80% of relevant greenhouse gas emissions (GHGs) (Akpan and Akpan, 2011).

How to escape carbon lock-in is thus a pressing question for policymakers around the world (Unruh, 2002). Technology transfer and cooperation for low carbon energy technology such as solar PVs, wind energy and hydropower has emerged as one possible response to it (Nakayama and Tanaka, 2011; Urban et al., 2015a). We define low carbon technology transfer and cooperation throughout this paper per the Intergovernmental Panel for Climate Change (IPCC) definition as a “broad set of processes covering the flows of know-how, experience and equipment for mitigating […] climate change […] The broad and inclusive term’transfer’ encompasses diffusion of technologies and technology cooperation across and within countries. It comprises the process of learning to understand, utilise and replicate the technology, including the capacity to choose it and adapt it to local conditions and integrate it with indigenous technologies” (Hedger McKenzie et al., 2000, p. 109).

Although much discussed both by practitioners and scholars, no comprehensive synthesis has been undertaken yet on the academic

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work on technology transfer and cooperation for low carbon energy technologies, as far as we are aware. The only literature synthesis we identified on technology transfer and cooperation, Enos and Yun (1997), does not specifically mention low carbon energy technologies. The aim of this paper is to provide a synthesis of the scholarly literature on technology transfer and cooperation for low carbon energy technologies. We specifically focus on solar PV, wind and hydropower as the three main sources of low carbon energy that are technologically mature and widely commercialised (Urban, 2018; Urban et al., 2015a). The three specific research questions addressed in this paper are:

- What are the main drivers and inhibitors of technology transfer and cooperation for low carbon energy technology (solar PV, wind, hydropower)?
- What have been the outcomes of this technology transfer and cooperation?
- What are outcome determinants?

To answer these research questions, we have analysed 30 years of scholarship on this topic, contained in 104 peer-reviewed articles. Via this literature review, we introduce the special issue 'South-South Technology Transfer and Cooperation for Low Carbon Energy Technologies' which was edited by the two authors of this paper. We hope that this work proves to be instructive for scholars keen to advance the research on this topic as well as policy-makers and firms engaged with technology transfer and cooperation for low carbon energy technology.

The remainder of this paper is structured as follows. First, we provide background information regarding technology transfer and cooperation. We then outline the methods adopted to gather and analyse our sample of literature. Results of our analysis are presented and discussed in Section 4. Meanwhile, Section 5 outlines the contributions of our special issue 'South-South Technology Transfer and Cooperation for Low Carbon Energy Technologies'. The last section of this paper summarizes our argument and proposes potential lines for future research.

2. Background

The technology transfer and cooperation definition we outlined in Section 1 of this paper is not uncontested since it does not contain any notion of novelty. Xie et al., (2013, p. 472) define technology transfer and cooperation as "the use of equipment and/or knowledge not previously available in the host country", i. e. a movement of technology from country A to country B only counts as technology transfer and cooperation if the technology is novel to country B. We did not adopt this definition since most (if not all) scholarly writings that have been published under the heading 'technology transfer and cooperation' would need to be excluded from our review then with the case studies examined usually analysing a technology that was already in place (at least to some degree) in the host country before the technology transfer and cooperation took place. While scholars may not agree on whether technology transfer and cooperation entails an element of novelty or not, most conceptualize the term as containing two *dimensions,* as also evident from the definition of Xie et al., (2013, p. 472). These are *hardware* and *software*[1]*;* this distinction was introduced by Bell (1990), acknowledged by the IPCC in 2000 (Hedger McKenzie et al., 2000), and further refined by Bell (2009), Ockwell et al. (2010) and Ockwell and Mallett (2012, 2013). Hardware refers to the technology that is needed to create the relevant physical assets. It thus comprises the capital goods and equipment as well as services such as engineering services. Meanwhile, *software* refers to the skills needed upon the completion of the relevant physical asset. It can be further distinguished between *know-how* and *know-why*. Know-how are the skills enabling the operation and maintenance of the physical asset. Meanwhile, know-why is the ability to understand the principles of how the physical facility at question works. These know-why skills are thus essential for the replication as well as innovation of the asset, as also discussed by Kirchherr and Matthews (2018, p. 548).

Technology transfer and cooperation which usually occurs via the private sector, e.g. argued by IPCC (2000), Kulkarni (2003), Schneider et al. (2008) and Lewis (2011), is distinguished in three *types* for this work: North-South technology transfer and cooperation (NSTT), South-South technology transfer and cooperation (SSTT) and South-North technology transfer and cooperation (SNTT) (Lema et al., 2015; Winstead, 2014). NSTT is technology transfer and cooperation from developed to developing countries, SSTT from developing to developing countries and SNTT from developing to developed countries (Urban, 2018). Admittedly, developing countries consist "of a diverse set of countries from emerging economies to low-income countries" (Lema et al., 2015, p. 185); we define those countries as developing countries that are denoted by the World Bank as low income (LI), lower middle income (LMI) or upper middle income (UMI), while developed countries are those denoted as high income (HI) (Lema et al., 2015; Winstead, 2014; World Bank, 2017). Urban (2018) argues that most of the literature on low carbon energy technology transfer and cooperation is on NSTT, yet the rise of emerging economies like China and India and their increasing innovation capacity is challenging this dominant technology transfer and cooperation paradigm. We investigate which type of technology transfer and cooperation is examined most frequently in the scholarly literature in Section 4.1.

The literature often examines drivers as well as inhibitors of technology transfer and cooperation which enable or impede it in the first place. Both drivers and inhibitors are further distinguishable in push and pull factors with push factors originating in the site of origin and pull factors originating in the site of use (cf. Erickson and Chapman, 1995 or Rai et al., 2014). For instance, Erickson and Chapman (1995, p. 1130) write that "renewable energy technology transfer [and cooperation would be] a supply push rather than a demand pull". We further present and discuss the various drivers respectively inhibitors of technology transfer and cooperation (distinguished in push and pull factors) in Section 4.2 of this paper.

A successful technology transfer and cooperation is one that does not only provide hardware to a recipient country, but that also enables it to operate, maintain, replicate and innovate this technology. Meanwhile, the technology transfer and cooperation outcome is judged to be 'mixed' if the recipient has received the technology and is able to operate and maintain it, but unable to replicate and innovate it.[2] Technology transfer and cooperation has failed if only hardware was provided (Ockwell and Mallett, 2012; Pueyo et al., 2011). Several scholars, e.g. Ockwell et al. (2010), Unruh and Carrillo-Hermosilla (2006) and Urmee and Harries (2009), have claimed that most technology transfer and cooperation endeavours have failed. We present our results on this in Section 4.3; this section then also outlines the key determinants of technology transfer and cooperation outcomes, according to the scholarly literature.

3. Methods

We built a database of relevant literature on technology transfer and cooperation for low carbon energy technologies, in specific solar PV, wind and hydropower, via numerous Scopus searches. A variety of keywords were used, e. g. 'technology transfer', 'technology transfer

[1] Lema and Lema (2012, p. 39) note that the using 'technology transfer' in combination with 'software' is misleading since "capabilities [which are meant by 'software'] are built and acquired rather than transferred". Hence, we use the term 'technology transfer and cooperation' which includes knowledge cooperation through staff exchange and training, joint R&D, joint ventures, licensing and mergers and acquisitions (M&A) etc.

[2] For an illustrative case study about the mixed results of SSTT in the hydropower sector, see Urban et al. (2015a, 2015b).

and cooperation', 'technology dissemination' and 'technological leapfrogging' in combination with 'renewable energy', 'low carbon energy', 'clean energy', 'solar', 'solar PV', 'wind energy', 'dams', 'hydropower' and so on. We chose the year 1987 as the starting date for our searches due to the Brundtland Report 'Our Common Future' of the World Commission on Environment and Development WCED (1987) which introduced the concept of sustainable development and arguably contributed significantly to launching the search for a sustainable energy future (Naudé, 2011; Sauvé et al., 2016). We thus review 30 years of scholarly writing in this paper. We considered peer-reviewed journal articles, books, book chapters[3] and conference proceedings[4] for our database. All literature considered was published in English.

Overall, our searches yielded 1320 results. We first removed duplicate results from this initial database. We then read the abstract of the remaining results to assess an article's relevance for our database. We excluded any pieces from the initial sample that did not focus on solar PV, wind energy or hydropower, given the topical focus of this special issue. Furthermore, we excluded pieces that focused on North-North technology transfer and cooperation only such as Bento and Fontes (2015). This choice was again grounded in the topical focus of this special issue. A scholarly expert on technology transfer and cooperation double-checked and complemented our database created via this process. The final database contains 104 articles. This list of articles is available upon request. This database size was deemed sufficient based upon the review of comparable papers. For instance, Baydar et al. (2017) reviewed 71 articles on freight villages; De Boeck et al. (2015) reviewed 65 articles on energy efficiency in residential buildings; meanwhile, Fischer et al. (2017) only reviewed 7 studies in their literature review on mindfulness and sustainable consumption. We do not claim that our database is exhaustive regarding the relevant literature, but we are confident that it is fairly representative regarding this literature, given the systematic approach adopted.

We undertook a content analysis (Hsieh and Shannon, 2005) for all 104 articles in our database. The coding framework for this was created in an iterative process ('emergent coding' (Haney, 1998)) with initial codes based on the existing knowledge of the authors regarding the topic and these codes then refined while reading and re-reading the articles in the sample. For instance, initial codes for the coding category 'Success factors' included the code 'Supportive government policy', whereas the code 'Demonstration plants' was only added upon coding an initial batch of articles. All coding was undertaken in Excel, mirroring Kirchherr et al., (2016, 2017a, 2017b, 2017c), with articles coded as '1' for a dimension if that dimension was found to be present in the article at question and '0' if it was found to be absent. Eventual core coding categories adopted pertain to the dimensions of technology transfer and cooperation examined, the chosen unit-of-analysis, the type of technology transfer and cooperation, drivers, inhibitors, outcomes and outcome determinants. We note that many articles only examined certain categories of our coding framework and we thus also only coded these articles in these categories. Overall, we undertook a conservative coding approach. Hence, we only coded an article in a coding category if it featured this category (reasonably) explicit in the text. Some of our results may thus be underreporting.

All articles were read, re-read and eventually coded by two scholars. Inter-coder reliability (Sanders and Cuneo, 2010; Swert, 2012) was high with overall results not differing more than 10% between the scholars. Hence, we report the average coding results in Section 4. At the same time, we acknowledge, also written by Kirchherr et al. (2017a), (2017b), (2017c), that any quantification of written text simplifies and thus distorts it, whereas, on the other hand, this quantification also enables a succinct synthesis across a large corpus of text.

Limitations are that some papers will not show up in the analysis for the following reasons: first, if their titles or key words are not easily recognisable as being related to technology transfer and cooperation; second if the publications do not appear in major peer-reviewed journals that can be found on Science Direct, Google Scholar or Web of Science. This research does therefore not claim to be complete or exhaustive. Also, this is work in progress as more research is being conducted in this area.

4. Technology transfer and cooperation for low carbon energy technology: a review of the literature

This section first provides an overview regarding our database. We then discuss drivers and inhibitors that enable or impede technology transfer and cooperation in the first place before outlining outcomes and outcome determinants of undertaken technology transfer and cooperation endeavours. We present results in the text from the perspective of the full sample unless there are marked differences between the three technologies examined, solar PV, wind and hydropower, and/or marked differences from a temporal perspective. We adopted the year 2000 as a cut-off year for our temporal analysis, i. e. we compare coding results from articles published 2000 or earlier with those published after 2000, since the year 2000 is considered as "a cornerstone" (Lema and Lema, 2012, p. 24) in the technology transfer and cooperation debate because the IPCC featured the term 'technology transfer and cooperation' prominently in its 2000 report and thus provided much momentum for it (IPCC, 2000; Kirchherr and Matthews, 2018, p. 548).

4.1. Overview

Scholarly literature on technology transfer and cooperation is relatively nascent (Fig. 1). The oldest article in our sample is Cromwell (1992) examining technology transfer and cooperation for small-scale hydropower development in Nepal. We note, though, that some of the literature from the late 1980s and 1990s may not be digitized yet and was thus not identified by the authors of this paper. We were surprised to observe a decline in relevant publications when comparing the periods '1998 – 2002' to '2003 – 2007' since we expected that the publication of the IPCC (2000) on technology transfer and cooperation would have fuelled scholarly work on the topic. Yet Fig. 1 suggests that the practitioner and scholarly discourse on technology transfer and cooperation may have been somewhat disconnected at least in the early 2000s. Meanwhile, the marked increase of scholarly publications in the period '2008 – 2012' (as compared to '2003 – 2007') may be explained by the implementation of the Clean Development Mechanism (CDM) (commencing in 2005) as one of the Flexible Mechanisms in the Kyoto Protocol (IPCC, 2007); the CDM proved to be a vehicle for technology transfer and cooperation (Burniaux et al., 2009). We note that 19 of the 104 articles in our dataset discuss technology transfer and cooperation in the context of the CDM – 16 of these have been published after 2007. The 2009 United Nations Climate Change Conference in Copenhagen, Denmark, likely boosted further scholarly interest in technology transfer and cooperation for low carbon energy technology (Tawney and Weischer, 2010; Urban, 2018; Urban et al., 2015b).

Publications on technology transfer and cooperation for low carbon energy technology were identified in 53 different journals with only 6 journals accounting for more than 50% of the examined publications though. Most articles (19 articles) on technology transfer and cooperation have been published in this very journal, *Energy Policy,* followed by *Renewable and Sustainable Energy Reviews* and *Renewable Energy* (both 9 articles), *Climate Policy* (7 articles), *Global Environmental Change* (5 articles) and *Energy for Sustainable Development* (4 articles). The most cited article in our sample, according to Scopus, is also an *Energy Policy* article, Lewis and Wiser (2007), with 238 citations (article focus: wind industry development in 12 countries), followed by

[3] We acknowledge that we were unable to access some of the identified books and book chapters.

[4] These different items are referred to as 'articles' from now on to enhance readability.

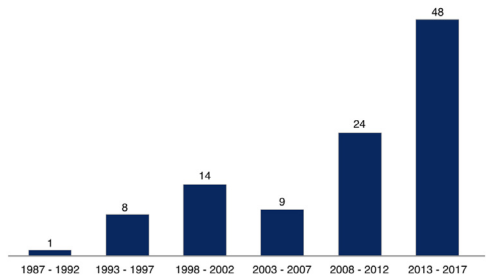

Fig. 1. Articles published on technology transfer and cooperation for low carbon energy technologies (solar PV, wind, hydropower).

Table 1
Overview of literature corpus.

Mentioning of (in relevant articles) … (%)		
Renewable energy technology	Wind	64
	Solar PV	63
	Hydro	27
Type of technology transfer	North-south	92
	South-south	11
	South-north	8
Regional focus	Asia	56
	Africa	21
	The Americas	18
	Europe	11
	Global	12
Unit of Analysis	Firms	57
	Donors	25
	Research	15
	Government	27
	NGOs	15

Note: Full sample = All 104 articles.

Dechezleprêtre et al. (2008) with 121 citations (article focus: CDM drivers in the context of technology transfer and cooperation) and Lewis (2007) with 95 citations (article focus: wind industry development in China/India).

General information on the sample can be found in Table 1. 64% of the analysed articles examine technology transfer and cooperation for wind, 63% for solar PV, while only 27% of the articles in our sample study hydropower.[5] This indicates a research gap regarding technology transfer and cooperation in the hydropower industry. Meanwhile, we also find a regional bias in the literature examined. 56% of our articles consider Asia, 21% Africa, 18% the Americas and 11% Europe.[6] The focus on Asia, in turn, is driven by many studies specifically studying China and India with 42% of all studies considering China and 28% considering India. We note that this regional bias can limit the external validity of the corpus of literature with Lema and Lema (2012, p. 40) writing, for instance, that "policies that work for China and India may be very different for countries with other needs". The main originating country for technology transfer and cooperation is Germany (66% of articles), followed by Denmark (42%) and the Netherlands (31%).

We also examined the unit-of-analysis in our sample. Several authors have claimed that the main unit-of-analysis is the private sector, as outlined earlier, with Lewis (2011, p. 301) writing, for instance, that "technology transfers are occurring between private companies […] with little government interference". These claims are largely corroborated by our coding. Indeed, the private sector is the unit-of-analysis in 57% of the relevant articles examined, followed by the government (27%) and multilateral and bilateral donors (25%) with Tarik-ul-Islam and Ferdousi (2007, p. 424) writing, for instance, that "there have been a number of [technology transfer and cooperation] initiatives taken in Bangladesh, mostly on donor's support". NGOs and academic institutions are both featured as a unit-of-analysis in 15% of the relevant articles.

Regarding types of technology transfer and cooperation, the literature has argued for decades for the need to go beyond NSTT with Sabolo (1983, p. 593) writing, for instance, that "[SSTTs] offer undoubted advantages since the technologies exported are better adapted to the needs of the developing countries", while Brewer (2008, p. 524) writes that "technology transfers from South-to-North and South-to-South need to be recognized as significant components of […] technology transfer". Meanwhile, Urban (2018) suggests that technology transfer and cooperation beyond NSTT remains understudied, as outlined earlier. This is corroborated by our work with 92% of relevant articles focusing on NSTT, compared to 11% for SSTT and 8% for SNTT. The analysed papers on SSTT reveal the following trends: There is still a small minority of papers on technology transfer and cooperation, as well as on technological capabilities, that are focussing on interactions between countries in the Global South. Most of the papers that exist are focused on Asia, for example by Urban (2018), Siciliano et al. (2016), Urban et al. (2015a, 2015b), and on Africa, for example by Shen and Power (2017), Power et al. (2016) and Baker and Shen (2017). Latin America and the Middle East are under-represented in this area. The papers focus on hydropower, wind and solar energy; while there is a shortage of papers on bioenergy and other less commercially available low carbon technologies. Many of the papers focus particularly on China, but also India and Brazil, as a source of technological innovation for other countries in the Global South. Brazil is particularly strongly involved in SSTT with countries that have historic and linguistic ties to Brazil, such as in Mozambique (Power et al., 2016), whereas engagement with China is particularly strong in Southeast Asia (e.g. Urban et al., 2015a), which can be explained by close political, economic and geographic ties and also in Africa (e.g. Baker and Shen, 2017). In Africa, low carbon energy technology is only one small part of a large and varied trade, aid and investment portfolio that China operates. Literature of SNTT is even more rare, with Urban (2018) and Urban et al. (2015b) being one of the few exceptions. Our subsequent literature review on drivers and inhibitors as well as outcomes and outcome determinants of technology transfer and cooperation for low carbon energy technology is mostly about NSTT, due to the abundance of literature in comparison to the still under-studied SSTT and SNTT literature.

4.2. Drivers and Inhibitors

We continue with a discussion on drivers and inhibitors of technology transfer and cooperation for low carbon energy technology with our core results depicted in Table 2. The main push factor among drivers that appears in the literature, according to our coding, is the attempt by developed countries' governments and firms to foster low carbon development in a recipient country with this factor found in 60% of the relevant articles. This is partly driven by government policies and international aid programs that support investments in low carbon energy technology in countries in the Global South. In addition, it is driven by the investments of companies that see the business potential of countries in the Global South. Urban et al. (2015a, 2015b) note that governments in the Global South, such as in China, are equally pushing for their low carbon energy firms to invest in other countries in the Global South to increase government tax revenues, create employments, generate economic growth, gain market access and expand

[5] We note that these figures do not add up to 100% since multiple articles focused on more than just one low carbon energy technology. This comment also holds for further data presented in this section. For instance, the sum of the figures presented on China and India as recipient countries of technology transfer and cooperation exceeds the figure presented for Asia as a recipient continent of technology transfer and cooperation since multiple studies focus on both China and India at the same time. These were then coded twice for the coding category 'Country' ('1′ for 'China' and '1′ for 'India'), but only once for the coding category 'Continent' ('1′ for 'Asia').

[6] 12% of articles adopt a global perspective. Hence, these works consider countries from at least three continents.

Table 2
Main drivers and inhibitors of technology transfer for low carbon energy technology (solar PV, wind, hydropower).

Mentioning of (in relevant articles) … (%)	**Drivers**							**Inhibitors**		
	Push			**Pull**				**Push**	**Pull**	
	Developed country-driven low carbon development (government and firm push)	Market expansion	Poverty reduction	Power shortage	Large domestic market	Low carbon development	Production costs	Weak intellectual property rights	Non-existence of domestic market	Low prices for fossil fuels
Total	60	37	22	54	30	25	25	58	31	29
Solar	68	32	23	56	31	19	21	67	17	33
Wind	59	44	10	41	35	31	31	53	44	26
Hydro	59	41	22	54	29	9	14	67	0	83
2000 and earlier	61	31	15	82	33	24	18	67	67	0
Post 2000	61	39	24	48	31	26	27	57	26	33

Note: Only coding results depicted if coding (total) ≥ 25% for at least one coder.

bilateral relations.

The second most frequent push factor among drivers is companies' strive for market expansion, featured in 37% of relevant articles, with Able-Thomas (1996, p. 1104) writing, for instance, that "firms [go abroad] when their domestic home market is saturated". The literature depicts market expansion as a core driver for all low carbon energy technologies examined. For example, the Chinese hydropower sector is reported to be nearly saturated with many rivers already dammed. Hence, significant growth for Chinese hydropower dam developers can only happen overseas (Kirchherr et al., 2017b; Urban et al., 2013).

Meanwhile, the most notable pull factor among drivers is reducing power shortages, featured in 54% of articles, with Gan (1998, p. 20) writing, for instance, that the "desire to solve the energy shortage problem [motivated a technology transfer and cooperation] experiment with new off-grid wind energy systems" in China and Kusekwa et al., (2007, p.429) writing that "international technical facilitation is needed [for] future rural electrification". We note that reducing power shortages appears as a pull factor in 82% of articles published in 2000 and earlier versus 48% of articles published after 2000. This may be explained by the general increase in global electrification rates (from 73% in 1990 to 85% in 2014) (World Bank, 2018). The second most mentioned pull factor among drivers is the large domestic market in the recipient country (30% of articles). For instance, Urban et al. (2015b, p.39) write that "recently it was important for India's leading firm Suzlon to acquire European firm REpower for access to [large] European markets". Meanwhile, production costs are mentioned by 25% of articles coded as a pull factor. For instance, Lema and Lema (2016, p. 233) find that the firm Solar expanded to Malaysia since it was "a skilled, low cost manufacturing hub".

Overall, drivers are discussed much more frequently in the literature (67% of articles) than inhibitors (23% of articles). We only identified one frequently mentioned push factor among inhibitors, i.e. weak intellectual property rights. While Komendantova and Patt (2014, p.1193) suggest that intellectual property rights (IPRs) only served as an inhibitor "until the second half of the 20th century [with] countries closely [guarding] their technology [then], seeing it as a source of military and economic power", 67% of relevant articles published 2000 or earlier and 57% published post 2000 still refer to it as an inhibitor. However, we also identified some literature that challenges whether limited intellectual property rights in recipient countries are inhibitors with Rai et al., (2014, p.60) writing, for instance, that "intellectual property issues do not represent a barrier to the diffusion of the relatively mature and low to medium cost low carbon technologies that are materially (at scale) most important for carbon dioxide emissions reduction in the short to medium term". Ockwell and Mallett (2013) argue that the issue of IPRs has to be viewed in a more differentiated way: weak IPRs may mean that developing countries can gain access more easily to climate-relevant technology and a pooling of publically-owned IPRs at free or low cost is commonly suggested as a way to promote access to climate-relevant technology in poor countries (Urban, 2013).

The two main additional pull factors among inhibitors that we identified are the non-existence of a domestic market in a potential recipient country and a weak investment climate (31% of articles) as well as low fossil fuel prices (29% of articles). For instance, Martinot (1999, p. 903 ff.) describes how multinational firms were reluctant to transfer wind turbine technology to Russia because they believed there would be limited potential for domestic market exposure. Meanwhile, Flamos and Begg (2010, p. 30) write that "currently available high-carbon or older technologies tend to be cheaper and more affordable for developing countries" which, in turn, impedes technology transfer and cooperation of low carbon energy technology to these countries in the first place.

4.3. Outcomes and outcome determinants

While several scholars have claimed that technology transfer for low carbon energy technologies has not been successful in most instances, as outlined in Section 2, this claim is only partially confirmed by our work, with approximately one-third of relevant articles examined coded as 'success', one-third as 'mixed' and one-third as 'failure' (Fig. 2). For instance, Phillips et al., (2013, p. 1594) write that the CDM "in India has produced a negligible number of projects that promote technology transfer if [it] is understood as a process of learning about technology". Technology transfer for hydropower is particularly unsuccessful, according to our coding, with 40% of examined instances resulting in failure. An explanation may be the common usage of build-operate-transfer (BOT) contracts in the hydropower industry (Ansar et al., 2014; Plummer Braeckman and Guthrie, 2015). Projects under BOT contracts are not only designed, financed and constructed by a dam developer, but then also operated by this developer (International Rivers, 2012), sometimes for several decades (Urban et al., 2015a). Hence, technology transfer is usually restricted to hardware transfer for these projects. An example of such a project is Cambodia's Kamchay Dam, as discussed by Urban et al. (2015a) and Hensengerth (2015). We further observe that technology transfer has become more successful ever since 2000 with 56% relevant articles coded as 'failure' and 24% as 'success' for '2000 or earlier', compared to 27% as 'failure' and 39% as 'success' for 'post 2000'.

The main key success factor for technology transfer and cooperation that was identified is supportive government policy, found in 50% of relevant articles (see e.g. Watson et al., 2015). Examples of government policies are tax relief programs, found in 31% of relevant articles as well as demonstration plants, found in 23% of relevant articles. Tax relief programs seem to have particularly fuelled technology transfer for wind, according to our coding, with these programs mentioned by

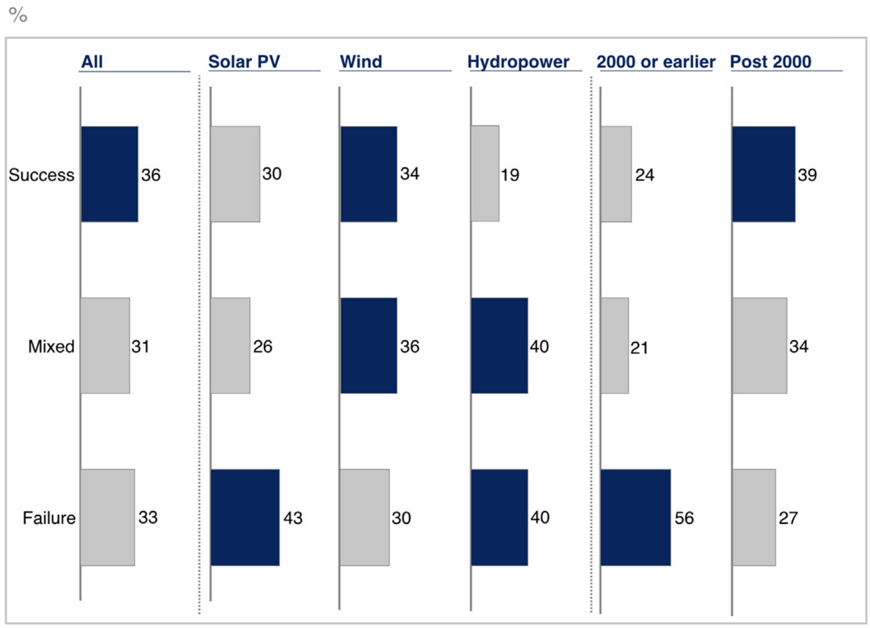

Fig. 2. Outcomes of Technology Transfer and Cooperation for Low Carbon Energy Technology.

Table 3
Key success and failure factors of technology transfer for low carbon energy technology (solar PV, wind, hydropower).

Mention-ing of (in relevant articles) … (%)	**Key success factors**							**Key failure factors**			
	Supportive govern-ment policy	*Tax relief*	*Demon-stration plants*	Availa-bility of finance	Capa-cities	Joint ven-tures	Li-cen-sing	Lacking supportive government policy	*Subsidy of fossil fuels*	Limited availability of finance	Lacking capacities
Total	50	31	23	35	45	38	26	58	24	40	46
Solar	44	16	20	33	49	29	14	53	24	51	63
Wind	59	38	21	40	40	49	36	65	22	39	46
Hydro	42	12	19	26	40	26	9	53	16	58	74
2000 and earlier	48	22	30	30	37	41	15	70	42	51	51
Post 2000	51	33	22	37	47	38	29	55	18	37	44

Note: Only coding results depicted if coding (total) ≥ 25% for at least one coder.

38% of relevant articles. For instance, Zhang et al., (2001, p. 37) write regarding wind energy development in China that "foreign investors in wind farms may enjoy two years of complete income tax exemption and another two years of reduced (by half) income tax starting from the year the enterprise is making a profit".

The second most frequently mentioned success factor are capacities, coded in 45% of the relevant articles, with de la Tour et al., (2011, p. 765) writing, for instance, that "Chinese PV companies have benefited strongly from the arrival of highly skilled executives, who brought capital, professional networks, and technology acquired in foreign companies or universities to China". Meanwhile, the third most common key success factor are joint ventures (38% of articles), usually depicted as a core channel of technology transfer in the literature (Lema and Lema, 2012; Schneider et al., 2008), followed by the availability of finance (35% of articles). Overall, our coding results regarding success factors largely resonate with Thorne (2008, p. 2837) who claimed that the three "building blocks for [successful technology transfer] are: 1. Dedicated finance (grant and debt); 2. affirming demonstrations; and 3. capacity", whereas our coding suggests to also add at least joint ventures to this list.

Fewer key failure factors than key success factors cut the 25% threshold chosen for Table 3 (four versus seven). The most common one is a lacking supportive government policy (58%), with the subsidy of fossil fuels mentioned as the core example (24% of articles). This subsidy of fossil fuels is found particularly frequently in articles published in 2000 or earlier (42% of articles). It thus possibly explains why the success rate post 2000 is higher than for the writings from 2000 or earlier, as outlined earlier. For instance, Lema and Lema (2016, p. 229) explain the initially unsuccessful technology transfer of solar PV to China by noting that "Chinese PV installations were quite slow [in the beginning] due to inadequate policies to close the gap to much cheaper coal fired power".

Lacking capacities appear as the second most frequent key failure factor, mentioned in 46% of articles. It is mentioned particularly frequently for hydropower 74% of articles) with Urban et al. (2015a) finding, for instance, "a low capacity to absorb and manage the [hydropower] technology and its impacts". The limited availability of finance is mentioned in 40% of relevant articles as a key failure factor for technology transfer. This key failure factor was suggested in 51% of writings published 2000 or earlier, compared to 37% published post 2000, thus suggesting that increasing availability of finance may also explain why the most recent technology transfer endeavours for low carbon energy technology appear to be more successful than the earlier ones.

5. Contributions of the special issue "south-south technology transfer and cooperation for low carbon energy technologies"[7]

Many argue, e. g. Urban (2018), Kirchherr and Matthews (2018),

[7] We note that not all articles referenced in this section are listed in the references yet since not all of them are accepted yet. This will be changed in the next iteration of this paper.

that we see a shift today away from the classical NSTT in the field of climate change and low carbon energy. Increasingly, emerging economies such as China, India, Brazil and South Africa play a role in technology transfer and cooperation to the global South. Yet, 92% of the articles we analysed focus on NSTT, while only a small minority focuses on SSTT and SNTT (11% respectively 8%). Hence, more research is needed in the field of SSTT. This section of the paper therefore introduces the special issue “South-South Technology Transfer and Cooperation for Low Carbon Energy Technologies”. This special issue explores the conceptual and theoretical implications particularly of SSTT and it also analyses various case studies of SSTT and SNTT in the field of low carbon energy technologies, drawing on evidence from hydropower dams, solar PV and wind energy. The special issue first introduces papers that explore conceptually novel ideas across a range of renewable energy technologies (Urban, 2008; Lema et al., 2018), followed by case studies from hydropower (Hensengerth, 2018; Kirchherr and Matthews, 2018; Chen and Landry, 2018), solar energy (Ulsrud et al., 2018) and wind energy (Nordensvard et al., 2018; Chen et al., 2018), as well as opportunities for SSTT as a result of new funding initiatives such as the New Development Bank (the so-called BRICS Bank) (Gu and Xue, 2018) and the Asian Infrastructure Investment Bank (AIIB).

Urban (2018) elaborates that, historically, technology transfer from the global North to China played a large role in renewable energy pathways in China, particularly for wind energy, partly also for solar energy. Yet, the rise of China and other emerging economies means a shift away from a reliance on technology transfer and production capabilities to strengthening indigenous innovation capabilities. Drawing on evidence from the hydropower, solar and wind energy industry in China, the paper introduces the concept of ‘geographies of technology transfer and cooperation’ and challenges the North-South technology transfer and cooperation paradigm for low carbon innovation and climate change mitigation. The empirical evidence shows that for low carbon innovation, the perception that China is lacking behind in innovation capabilities is partly outdated. Instead, there is an increase in indigenous innovation capabilities, resulting in SSTT as well as elements of ‘reverse’ SNTT.

Lema et al. (2018)’s paper asks how relevant SSTT is for low carbon development in Africa. It does so by focusing on the prospects for developing production and innovation capabilities arising from renewable electrification efforts. Countries in the global South, notably China, are increasingly important actors in Africa. Mention is often made of their financing of large scale energy infrastructure projects. However, Southern countries also provide an increasing avenue for renewable energy technologies such as solar home systems. One argument is that such technology transfer within the global South offers specific advantages over NSTT as such technology may be more likely to create opportunities for local capabilities building. Such discussions fall at the intersection of a number of literatures within innovation studies and development studies, combining ideas from across several academic fields of study that have rarely come together before. Since this is largely unexplored terrain, the paper seeks to provide conceptual framing based on insights from the literature.

The paper by Hensengerth (2018) has two aims: firstly, it adds to the small but emerging literature on SSTT by exploring the role of Chinese actors, using the Bui dam in Ghana as a case study. Secondly, it argues that technology transfer is not only a technical process, but it is inherently political as it includes crucial issues on decision-making regarding the type of technology that is transferred, who is granted access to the decision-making process, and who benefits from the new technology. In examining technology transfer from this perspective, the article draws on the sociology of technologies approach and the sustainable transitions literature arguing that technology transfer is a contested process that takes place within complex political, economic, social and cultural settings and actor networks. This determines the technology that is transferred, who benefits most from the transferred technology, and who is marginalized in the process.

Kirchherr and Matthews (2018) analyse technology transfer in the hydropower industry. Chinese dam developers allegedly dominate the global hydropower industry. Studies have been carried out on technology transfer in their projects in Africa and Asia. However, such work is lacking for Europe and Latin America. Their paper identifies the extent, drivers and inhibitors of technology transfer of Chinese dam developers’ in Europe and Latin America. The authors find relatively few Chinese projects and thus limited evidence for technology transfer both in Europe and Latin America. Transfers identified are frequently mutual with the Chinese player transferring technology to the host country and vice versa. This transfer is driven by business considerations in Europe (costs, capacities) and Latin America (costs, lacking access to finance), but also geopolitical ones (Europe: creation of a trading area; Latin America: access to (natural) resources). It is impeded by Chinese dam developers’ poor reputation regarding safeguards as well as (only in Latin America) protectionist policies and significant capacities of host country players.

Chen and Landry (2018) argue that China is an increasingly prominent actor in infrastructure development in the global South. Hydropower, as a renewable energy source, is a key area in which Chinese technological cooperation and finance can contribute to sustainable growth. However, many of China's overseas hydropower projects remain controversial due to their social and environmental impacts. This paper presents a comparative case study of a China Exim Bank financed project and a World Bank-led multilateral project - both located in Cameroon - to highlight the commonalities and differences between China as a rising power and traditional Northern donors in the field of hydropower development. It examines the financiers' influence on tendering, financing and implementation, as well as pathways of technology transfers undertaken. While both projects adhere to domestic regulations, the rigor of norm enforcement and the level of involvement from financiers differ considerably, with implications for the projects' construction, labour relations and potential for technology transfers. This study contributes to the understanding of the developing norms and practices surrounding environmental and social impact management and technology transfer in SSTT by engaging in a comparison of China, a rising power, and traditional donors such as the World Bank, who are re-emerging in the field of infrastructure development.

Ulsrud et al. (2018) present research on the transfer of sustainable energy innovation between countries of the global South from a socio-technical perspective. The analysis identifies factors important for how a deliberate transfer process may unfold. It is based on monitoring a case of South-South transfer of experiences with village-level solar power supply models from India to Kenya. This research shows that it is not so much stable technical solutions which travel between different spatial and cultural contexts, but that experiences with sustainable technologies in one country can provide important inspiration and knowledge for the development of new socio-technical designs based on local needs in a new socio-spatial context in a different country. Such learning processes can be especially effective between countries with similar problem situations, such as poverty and lacking access to electricity in rural areas. To achieve a successful transfer, strong emphasis must be put on mutual learning and exchange of knowledge, socio-technical experimentation, adaptation and social embedding. Innovative infrastructure in other geographical areas need to capture the micro-level interactions between people, technology and socio-cultural contexts, while also considering larger processes of systems innovation and emerging transitions.

Nordensvard et al. (2018) elaborate that some scholars have pointed to a rise of SSTT led by emerging economies such as China, India, Brazil and South Africa, while other scholars highlight that emerging economies still need to catch up with developed countries. Drawing on world system's theory, the paper argues that an adapted innovation framework of 'core - semi-periphery - periphery' could be an important analytical framework that may help us understand the end state of innovation catch-up. This may provide improved understanding of how an emerging economy can have sectors that could be defined as innovation core and therefore act as sources for technology transfer. The paper provides a case study from the wind energy industry, using citation network analysis and patent analysis to examine knowledge flows between wind firms and to identify and compare the position and role of each firm in the knowledge network. The paper argues that there is still, despite catching-up, a difference between innovation core countries such as the United States, Germany and Denmark and innovation semi-periphery countries such as China and India which will limit the opportunities of knowledge transfer within the wind energy industry.

Chen's (2018) paper provides a comparative analysis of two wind farm developments in Ethiopia, one as a case study of SSTT and one as a case study of NSTT. The paper compares HydroChina's involvement in Adama Wind Farm in Ethiopia with that of Vergnet, a French firm involved in the construction of Ashegoda Wind Farm. The impact of technology transfer and cooperation is evaluated along four dimensions: capital goods and equipment, direct skill transfer, indirect skill transfer, and knowledge and expertise. The rise of SSTT in Chinese-financed overseas renewable energy projects has rekindled the debate on motivations and impacts of China's engagements. Through interviews with key stakeholders and detailed analysis of the negotiation and construction processes, the paper finds that although HydroChina shared a higher level of knowledge and expertise during the construction phase, Vergnet formed stronger long-term skill transfer linkages with local university students and employed a larger share of local workers than HydroChina. The findings highlight the host government's capacity to facilitate successful technology transfer and cooperation. The paper concludes with a discussion of potential opportunities and challenges, and policy recommendations to facilitate successful technology transfer.

Gu and Xue (2018) argue that green transformations present a major challenge for Africa and the global community. The BRICS countries may explore new approaches to sustainable development, renewable energy and green economic growth in Africa. This article assesses how realistic this perspective is in practice. The study sets out the context of challenges posed by climate change, sustainable development and the 'greening' of economies, especially in the developing economies of Africa. This paper examines the BRICS approach to the development of renewable energy sources, China's role, and it also draws policy implications. It argues that, despite a robust declaratory intent, practical action has been slow to eventuate until recently when the New Development Bank, also known as the BRICS Bank, is providing an effective intervention mechanism for the BRICS. New BRICS initiatives suggest a more accelerated approach to renewable energy technological cooperation. The BRICS need to elaborate a specific strategy for renewable energy technology cooperation for both intra-BRICS and extra-BRICS development. Individual members, particularly China, have a significant capacity to help move this forward.

6. Potential lines for future research and conclusion

The need for climate change mitigation, adaptation and the search for cost-effective low carbon energy are pressing issues around the world. For several decades, countries in the global North played a key role in providing low carbon energy technology to poorer countries in the global South. Today, we see a shift away from the classical North-South technology transfer and cooperation (NSTT) paradigm. Increasingly, emerging economies such as China, India, Brazil and South Africa play a role in technology transfer and cooperation to the global South. This special issue explores the conceptual and theoretical and practical implications of this new development and it analyzes various case studies of South-South and South-North technology transfer and cooperation in the field of low carbon energy technologies, drawing for example on evidence from hydropower dams, wind energy and solar energy.

The stage for this special issue is set by the literature review on technology transfer and cooperation for low carbon energy technology that we present in this paper. Our review finds that most publications on technology transfer and cooperation for low carbon energy technologies are still focussing on NSTT, while only a very small percentage explores South-South technology transfer and cooperation (SSTT) or South-North technology transfer and cooperation (SNTT), despite the rapidly rising influence of emerging economies in the global South at economic, political, social and technological level.

To counter this imbalance, Urban (2018) suggests that future research should explore various geographies of technology transfer and cooperation and that there is a need to analyse the dynamics, characteristics and outcomes of SSTT and NSTT in more detail. Byrne et al. (2012) go even further than that suggesting that there is a need to look beyond technology transfer. Instead, they argue for exploring socio-technical transformations. This paper specifically finds that there is a large body of literature on technology transfer and cooperation for wind and solar energy technology, yet hydropower technology remains understudied. Another trend can be seen from our analysis, namely that the literature on low carbon technology transfer and cooperation mainly focuses on Asia and Africa, while other regions are less well analysed. Future research could therefore explore SSTT and SNTT in Latin America and the Middle East in more detail. Latin America is also a region that has abundant experience with hydropower and bioenergy, particularly Brazil, and is increasingly investing in African countries' infrastructure. Finally, the acknowledgement that rising powers in the global South such as China, India, Brazil and South Africa can play a significant role in technology transfer and cooperation in the global South and the global North and exploring these novel trends, dynamics and mechanisms may be able to help facilitate a global transition to a low carbon economy.

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