Catching-up meets sustainability: contemplating latecomer strategic trade-offs when facing emerging windows of opportunity in clean technologies[1]

Abstract

Scholars analyzing global environmental problems have repeatedly stressed that in order to curb the risks of major environmental disruptions on a global scale, industrial societies have to fundamentally change their systems of production and consumption. Such a sustainability transition is also in line with the industrial dynamics literature, which expects that a new green techno-economic paradigm is currently taking shape that may lead to a next big wave of potentially global prosperity generation induced by sustainability driven growth. While these challenges are increasingly endogenized in the policies of many old industrialized countries, newly emerging and developing countries are still to find out how to position themselves in sustainable industrial development paths. The present paper elaborates the various dimensions of tradeoffs that policy makers and industrial strategists have to confront under the condition of simultaneous industrial catch-up and sustainability transitions. We map out the main strategic alternatives and discuss in how far the green challenge starts to reshape some of the old tradeoffs and introduces new dimensions. We will illustrate this approach with the case of the recent Chinese rapid industrial growth in membrane bioreactor technology, a relatively path-breaking approach to deal with industrial growth and urban water management under the threat of global climate change at the same time. We show how an alternative management of the many tradeoff dimensions could have led to a potentially more sustainable trajectory in the long run for Chinese urban water management sector. Given the strong path dependencies that infrastructure sectors typically exhibit, national industrial development policies might come at the expense of better sustainable options far into the future. The proposed approach does not only enable the assessment of past strategic choices but may also inform policy makers in the design of catch-up policies at the wake of a new green era.

1.Introduction

Latecomers' aspiration to leapfrog global incumbents has driven several waves of industrializations in the past few decades, from Japan in electronics and automotive to South Korean conglomerates in memory chips and smartphones as well as Taiwan in integrated circuit designs and fabrications - to name a few (Mathews, 2002; 2006; Hobday, 1995; Kim, 1997; Lee and Lim, 2001.). Over the years a meaningful number of developing countries have aspired to follow the successful footsteps of countries like South Korea and Taiwan and tremendous national investments have been diffused into building indigenous manufacturing industries that require high technological capabilities, such as semiconductor, automotive and biotechnology. However, since one and a half decade ago when Taiwanese companies first caught up with and leapfrogged global incumbents in integrated circuits, other latecomers have not achieved comparable successes with their respective catch-up endeavors. Rather, a number of these developing countries are stuck in the so-called 'middle-income trap' and not having been able to move up to high-income status despite years of tremendous investments in those manufacturing industries.

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Latecomers at the current time juncture however face an unprecedented challenge due to increasing globalization. Not only the latecomers have to catch up with the world frontier in terms of technological capabilities, they are confronted with global pressure to transit to more sustainable paths while making rapid industrializations. This simultaneous challenge makes catching up and leapfrogging ever trickier as latecomers have to juggle between investing in either industrialization or sustainability. Fast developing countries like China are being finger-pointed by the outside world for the pollutions the country is causing while the nation is experiencing exponential growth in numerous manufacturing industries. Meanwhile, the idea of 'sustainability' still appears as a rather vague concept to other slower developing countries or middle-income trapped countries as to if it is just about subscribing to the current vision advocated by the advanced world to reduce the planet's carbon footprints and therefore complying to the existing global standards for cleaner solutions. More often than not, these developing countries find it more secured to continue channeling their national resources to building indigenous capabilities in conventional but technology-intensive manufacturing sectors in order to increase their national exports and GDP. Hence, positioning themselves as path-followers in global sustainability seems to be a safer bet.

A latecomer country that aspires to leapfrog global incumbents in terms of economic status and technologies might however think otherwise. These specific latecomers might instead target the global shift to sustainability as a specific window of opportunity to leap forward due to changes in societal cognitive beliefs, political agenda, market demands, industrial standards, etc. As already pointed out in Perez and Soete (1988), windows of opportunity for leapfrogging arise when there is a shift in techno-economic paradigm (TEP). Recent innovation studies identified that the world is at a critical juncture of 'the Fifth Great Surge of Development', a new industrial era that is simultaneously driven by Information and Communication Technology (ICT) revolutions and global sustainability transitions (Perez, 2013; 2016; Swilling, 2013). This signals that a latecomer country that seeks successful leapfrogging should contemplate a new positioning strategy of themselves in the emerging global cleantech sector.

Instead of merely making sustainability transitions, latecomers should perceive sustainability transition as 'the opportunity' as these emerging industries require new technological trajectories and industrial standards and hence every player is rather immature. It is crucial for latecomers to recognize this opportunity and quickly strategize themselves to be in a position to shape the next new dominant designs in these emerging industries in order to ensure such development steps are in favour of their internal capabilities and catch-up agenda. Such leapfrogging approach however entails drastic measures as it requires path-breaking or path-creating strategies within a short time frame. Often, drastic catch-up approaches instigate controversies from multiple levels of the society in the system. This process is ever more challenging when taking into account the concurrent drive for sustainability transitions especially when there are no existing rules and standards in place. In other words, these latecomers stand the chance to invest into the wrong infrastructures for its domestic scene while building on the wrong capabilities that might prohibit themselves from exporting their indigenous technologies and products. Different actors in the nation might perceive such economic development agenda differently and so latecomer countries are often caught in major national public discourse for their actions and options.

Recent studies have questioned whether deploying the new wave of industrial development requires the return of an active State to direct convergent and synergistic actions to ensure successful sustainability transitions. Economists have even called for a rethinking of capitalism and a revisit to policy making to deal with the new global challenges (Stern 2007; Jacobs and Mazzucato, 2016). Catch-up strategies targeted for industrial leapfrogging require particular system actors to play prominent roles in endogenizing the development trajectories of the new technologies. It is a process that requires endogenous actions in aligning collective visons and expectations among different system actors, as well as in directing and formulating policies and industrial standards that are congruent with the country's catch-up agenda.

This paper calls for a new lens when it comes to latecomer catch-up, of which the emerging cleantech sector should be perceived as the major windows of opportunity to achieve industrial leapfrogging in this era. The paper therefore provides an early analysis to the possible leeway of latecomers in breaking out of middle-income status by leapfrogging in global cleantech industries in this era. Our analysis takes into account the dilemma, controversies and disputes that these latecomers have to deal with. More importantly, catching up is no longer just about a 'technological' transition but a 'socio-technical' transition due to new elements associated with sustainability such as changes of societal lifestyles, valuations and the importance of legitimation. In so doing, it is imperative to understand latecomer catch-up processes by incorporating the scientific approaches used in sustainability transition studies. Catch-up studies might reach bottlenecks in terms of new strategies without taking into account the potentials of sustainability transitions. Meanwhile, global transitions to greener solutions also can no longer ignore the progress of latecomers that are aiming to achieve industrial leapfrogging.

Thus far, these two area of work developed largely in isolation. The catch-up studies have given very much focus to the latecomer countries' national innovation system (NIS) and their respective linkages to the world, often through the global value chain (GVC) framework (Jurowetzki, 2015; 2017). Meanwhile, there are also studies done using a rather management perspective to analyze latecomer leapfrogging strategies, especially in the case of South Korean Samsung - which has been studied quite exhaustively (Lee and Lim, 2001). Often, the cleantech sector is analyzed as technologies that latecomers should rather naturally learn in order to catch up with the world in innovations and manufacturing. On the other hand, sustainability transition studies mostly adopt the Technological Innovation System (TIS) framework, which is a framework mainly used to analyze the emergence of new industries. Instead of having spatial borders defining the object of analysis like the NIS, TIS analyzes the system as far as where the technological networks may lead. The TIS consists of actors, networks and institutions and is analyzed through seven key process functions. In particular, the function of Guidance of Search (GS) serves as a highly appropriate tool to analyze how latecomers can endogenously set in motion path-creating or path-breaking strategies in order to leapfrog while being confronted with the abovementioned challenges (Yap and Truffer, resubmitted). The function of GS is conceptualized as a process of exerting influences to the shape and pace of technological trajectories, involving changing the orientation of search processes in terms of technologies, applications, markets, business models, etc (Hekkert et al., 2007; Bergek et al., 2008). Although transition studies have in recent years placed increasing attention to the progress of developing countries in the cleantech sector, most of the studies have been merely applying the TIS approach in the context of developing countries, without putting the question of latecomer leapfrogging as the central objective of analyses that provides key implications to catching-up issues. However, rapid progress in the cleantech sector of particularly large developing countries like China makes it no longer wise to ignore the potentials of latecomers and so have prompted a few exceptions that explored the possibilities of successful latecomer catch-ups in these new technologies (Binz et al., 2012; Binz et al., 2016).

The objective of this study requires the case analysis to be a latecomer that is exactly going through the processes that have been described. In particular, focus is given to a fast-developing latecomer that in the recent years has showcased strong commitment in catching up in a particular cleantech industry and even demonstrated the potential of leapfrogging global multinational companies (MNCs) in the future. Such catch-up process is definitely a non-linear journey that involves multiple frictions from different system actors and of which policy makers are often confronted with dilemmas due to uncertainties associated with the concept of sustainability – something rather new in economic history. The case of China urban water management (UWM) sector is selected for this study given that China has since the last decade aggressively promoted the development of the country's UWM sector, which has led to exponential growth in terms of technological accumulations and manufacturing capabilities. More specifically, the selection environment of China UWM sector has been experiencing a fundamental shift in terms of its dominant technologies and industrial designs since the last decade, i.e. from an incumbent technology called the Conventional Active-Sludge (CAS) to an emerging new technology named Membrane Bio-Reactor (MBR). Different system actors have come into play within such a short time with strong endogenous GS roles while the industry's rapid growth has also instigated numerous controversies concerning the rightfulness of the country's policy making in terms of economic development, industrialization, and environmental protection or sustainability. The catch-up journey of China's UWM is currently seen as a remarkable case for being the so-called first leader among the latecomers to drive drastic movements for green growth - which makes it a rough and risky catch-up process but certainly a case that exemplifies the huge dilemma most developing countries are going under.

Our analysis draws on in-depth semi-structured interviews with 44 experts of Chinese UWM sector, with triangulation through content analysis of government and industrial reports, as well as secondary data. Section 2 below explains how catch-up studies and sustainability transition studies can usefully complement each other when dealing with latecomer strategic trade-offs in the green growth era and their respective role in global transitions towards sustainability. Section 3 describes the methodologies used in this study and set the background of analysis for the paper. Section 4 analyzes the rather turbulent process China encounters in its catch-up process in the UWM sector, which has been accompanied by public discourses, conflicts from different actors, system-level controversies and uncertainties. Section 5 however depicts the potential trajectories for other developing countries contemplating to catch up in the UWM sector. Section 6 concludes with implications to catch-up studies specifically dealing with latecomers that seek leapfrogging opportunity in the current global shift to sustainability. Meanwhile, it also explains the implications to transition studies in general about how developing countries might fit themselves into the current global windows of opportunity and their potential impact.

2. Latecomer strategic trade-offs in emerging clean technologies

The challenge of sustainable development adds fundamentally new dimensions of complexity in attempts to shaping industrial dynamics. It is not enough to identify factors for the successful development and diffusion of new technologies, products and lifestyles. Market success is not the sufficient condition for reaching a sustainable future. Rather industrial development should open up new economic opportunities, while respecting boundary conditions in terms of the social and environmental context. Furthermore, as past industrial development and the resulting globally available technologies have built up high global risks over the past decades, new products and technologies should rapidly start to replace the established ways of production and consumption. Industrial strategists and policy makers therefore have to embrace public policy concerns that go far beyond the conventional considerations of industrial policy. Without a deep understanding of the associated tradeoffs might lead to high costs either in terms of missed development opportunities or in terms of increased pressures on human living standards and the quality of the environment. In the following, we will therefore work out the major lines of tradeoffs that industrial policy in a catch-up context has to deal with. In a second step, we will elaborate how the new requirements of a green techno-economic paradigm (TEP) will add new tensions into the decision-making process, and how the conventional tradeoffs get reshaped by the new challenges. This will ultimately enable us to present a mapping of options, the assessment of tradeoffs and ultimately the design of more robust catch-up strategies.

2.1 Strategic choices in conventional catch-up context

There are a few fundamental trade-off concepts that have conventionally driven the development of catch-up studies. Most of these trade-off dimensions lie in the realm of industrial policy that latecomers pursue. Drawing these distinctions helps shed new light on research gaps that have rather been ignored thus far.

2.1.1 Domestic industrial development

Winner selection vs market competition A key dimension within the industrial policy realm is whether latecomers should pursue a winner selection approach or a market competition approach, or a combination of both. For instance, South Korean industrial leapfrogging experience was coined as a success story of pursuing the *chaebol* model which drives large indigenous conglomerates (Amsden, 1989; Kim, 1997; Lee and Lim, 2001). National resources were channeled to large conglomerates like Samsung and Hyundai in the beginning of the catch-up process. These conglomerates leapfrogged successfully in a variety of technologies, from shipbuilding to automotive, semiconductors, consumer electronics, etc. Each of these conglomerates essentially integrate all the value chain processes in each respective industry.

In general, it seems that drastic catch-up strategies often require the State to more or less select a few most potential firms as key winners to ensure resources are focused on them, although the scale and types of the firms involved as well as the policy strategies deployed might be different. Taiwan success story in the integrated circuit industry was depicted as having strong institutional support in the early catch-up stage (in late 1980s) of which resources were channeled to state-owned Industrial Technology Research Institute (ITRI) lab to incubate small firms who have then become two large MNCs running at the frontier of the semiconductor industry today, i.e. Taiwan Semiconductor Manufacturing Company (TSMC) and United Microelectronics Corporation (UMC) (Mathews and Cho, 2002; Mathews and Cho, 2007). In particular, TSMC had subsequently leapfrogged other frontier leaders such as Intel and Samsung in integrated circuit fabrications through a number of entrepreneurial strategies in its global industrial networks (Yap and Rasiah, 2017). Meanwhile, a typical middle-income trapped country like Malaysia had followed the footstep of Taiwan catch-up model and channeled tremendous investments to incubate an indigenous (state-owned) firm Silterra via the national R&D center MIMOS but did not manage to leapfrog to the frontier of technology (Rasiah, 2010).

More specifically, increasing industrial standards could induce more advanced firms to strive for more innovations but also eliminating less advanced firms who are not able to meet those standards. Meanwhile, shaping product standards in terms of sizes and measurements would give privileges to existing firms that are already producing in those forms and impose prohibitions to other firms who are otherwise not producing at those standards. However, creating formal product standards will direct all market players to produce similarly and therefore increases substitutability which also induces more competitions in the future in terms of cost reductions and quality. Policy makers of a latecomer country who seek to drive exponential growth of a new industry within a short time therefore have to plan these strategies carefully in order to time competitions in a desired manner and so mould the next new indigenous winners that could lead to successful industrial leapfrogging

Niche vs regime protection Industrializing a new technology indicates opportunities to new entrants but also challenges to the industrial incumbents or the regime actors. It is often impossible to create growth for small companies with new technologies without jeopardizing the roles of the incumbents. In other words, a leapfrogging strategy for a new technological development often require the process of driving out incumbents of the old product from the market. Policy makers are therefore often also confronted with the dilemma of whether to focus on just protecting particular niches on one hand or disfavoring the routine of regime actors on the other. Successful industrial emergence more often than not requires both strategies to be deployed concurrently.

National vs regional development When creating a new industry, policy makers also have to strategize between developing the industry in specific regions or not. A regional development approach will allow particular regions to thrive more in terms of development than the other regions. In contrast, policy makers may also let the industry grow on its own course to wherever business opportunities may arise for entrepreneurs, i.e. adopting a more nation-wide approach when creating an industry.

Related vs unrelated diversification There are different trajectories of how a new industrial path can be developed. The most obvious distinction is whether a region or country builds a new industry as a naturally branching-out process from its pre-existing knowledge base, i.e. related diversification, or based on broader-level systemic resources that is beyond or unrelated to its pre-existing knowledge base, i.e. unrelated diversification (Boschma et al., 2017).

Production vs innovation focused Another typical trade-off in the industrial policy realm is whether to build competitiveness by focusing on scaling up the production of a product or by focusing on the aspect of product innovations in order to arrive at the frontier of the technology (Awate et al., 2012). Developing countries seeking catch-up often focus on scaling up the production of a technology that is already more or less maturing in the global market in order to significantly drive down the costs. This seems to be a rational strategy for catching-up countries as they can assimilate capabilities by reverse-engineering globally ready technologies and so lower cost of production is often their competitive advantage. This strategy has been mostly adopted by middle-income countries like China, Malaysia and Thailand in conventional industries like semiconductor, consumer electronics and automobile. However, history shows that focusing on providing lower cost of production in conventional manufacturing industries is not sufficient to lead to knowledge intensive and high-income jobs in developing countries. In fact, the experience of South Korea, Taiwan and Singapore in semiconductor proved that prioritizing innovation aspects to arrive at the frontier of respective technologies was very crucial to these success stories of industrial leapfrogging (Kim, 1997; Lee and Lim, 2001; Mathews and Cho, 2002; 2007). Therefore, there has been strong national policy implications focusing on building tremendous knowledge base that is hopefully furthermore leads to related diversification opportunities or clustering effects.

2.1.2 Global industrial interdependencies

Creating new GVCs or positioning in existing GVCs The industrial policy realm also concerns how latecomer countries position themselves in terms of global industrial interdependencies (Pietrobelli and Rabelotti, 2005; 2009). This includes whether to formulate industrial policies that support indigenous firms in creating new GVCs or mainly inserting and positioning into existing GVCs. From earlier studies of East Asian success stories (Hobday, 1995) to the latest theories in catch-up studies (Lee and Malerba, 2017), leading scholars have argued that it is crucial for latecomers to move from being original equipment manufacturers (OEMs) to original design manufacturers (ODMs) and ultimately to original brand manufacturers (OBMs). The notion of choosing whether to build indigenous OBMs and OEMs has also very much been influenced by the concept of GVC governance (Gereffi et al., 2005) which argues that OBMs tend to be the leaders in GVCs and latecomers often live by the rules set by these industrial flagships MNCs. More specifically, OEMs are known as manufacturers producing without their own brand names but offering the MNCs lower costs of production. On the other extreme, OBMs are the ones that are leading or creating value chains, controlling the key intellectual properties and having their own brand names.

The Taiwanese government however pursued a rather technological specialization strategy to grow its high-end industries. Industrial policies were designed in favour to induce production fragmentation in the local industry with a cluster of synergistic upstream and downstream actors. Taiwan integrated circuit industry is therefore structurally fragmented, consisting firms that specialized in particular processes in the value chain (Mathews and Cho, 2002; Rasiah and Lin, 2005; Yap and Rasiah, 2017). These firms however compete with each other and intense competitions to gain MNC customers drove these firms to constantly innovate.

Strategic positioning in GVC also leads to the question of whether latecomers should start producing for their own domestic market or eye the foreign markets for national exports from the beginning. Pursuing an OEM strategy will have a latecomer inherit the inertia from the early catch-up stage by just remaining as manufacturers for global MNCs; this means that their productions are only tailored for the demands of one part of the overall GVC. Most developing countries are still more used to play the role of OEMs who produce without their own brand names. On the other hand, latecomers aiming to become an OBM might see domestic markets providing numerous opportunities for learning opportunities and scaling up production in order to lower cost of manufacturing.

FDI-leveraged vs indigenous innovation policy In particular, such positioning in GVC brings two major trade-offs to latecomer catch-up strategies. First, it is whether to pursue a *foreign direct investment - (FDI) leveraged policy or an indigenous innovation policy.* Latecomers often begin their catch-up process through technology transfer from more advanced MNCs, via partnerships, IP acquisitions, supplier-buyer relationships, etc. This is usually done by attracting these MNCs to set up a foothold in the latecomer country through industrial policies that incentivize FDI. Most successful cases have required strategic linkages to MNCs in the early stage of catch-up (Mathews, 2002; 2006). A successful example of latecomer sticking to the FDI-leveraged strategy is the case of Singapore (Wong, 1999), which has now become a central hub hosting numerous regional headquarters of global MNCs. While Singapore remains a rather unique case in this context, it is often important for the latecomers to carefully move out of their potential over-reliance on these MNCs at a later stage. Failure to do so might have the latecomer ended up remaining as manufacturers mainly offering lower costs of production to advanced MNCs. A typical example of latecomers' incessant pursuit of the FDI-leveraged strategy is Malaysia, which even hosted one of the first oversea relocations of MNC giants like Intel and Texas Instruments back in the early 1970s (Rasiah, 2010). However, due to lack of indigenous innovation capabilities and failure to leapfrog global incumbents, Malaysia remains as a manufacturing center practicing as OEMs and represents a typical middle-income trapped country.

A latecomer country that seeks indigenous innovation capabilities however has to decide to give up on the potentials of foreign MNCs could bring to the latecomer home country. Existing cases of South Korean and Taiwan companies have showcased that indigenous innovation policy is essential to a successful catch-up pathway. More specifically, the latter stage of local technological development is highly reliant on indigenous R&D (Amsden and Chu, 2003). Clearly, these successful economies have centered the notion of nationalism in their catch-up agenda – a traditional Friedrich Listian concept that perceive promotion and protection of nationally-owned firms are highly crucial to upgrade a country's technological capabilities (Szporluk, 1988). Pursuing an indigenous innovation path requires formulating an institutional environment that are mainly in favor for local indigenous firms but not the MNCs. Latecomers that pursue this strategy are determined to grow the indigenous small-and-medium-enterprises (SMEs) at the expense of the MNCs operating in their country.

2.2 Reformulating strategic trade-offs for alternative catch-up and leapfrogging pathways

Operating under the green TEP requires revisiting the conventional trade-off dimensions. At the most general level, policy makers have to now juggle between the realm of industrial policy and environmental policy. At the same time, the industrial policy realm requires a number of new understanding and reformulations which will be explained below. In addition, while the aspect of technological trajectories is rather embedded in the industrial policy realm for conventional industries, it becomes a different dimension in the context of a green TEP which could be proactively intervened or in contrast seconded given governmental strong tendency towards industrial policies.

2.2.1. Primary policy rationale

Industrial policy versus environmental policy Latecomers aiming to achieve industrial leapfrogging in the emerging cleantech sector are often confronted with the question of whether catching up should be driven by the realm of *industrial policy or environmental policy.* More specifically, policy makers are not sure whether the newly developed technology is already more sustainable than the existing infrastructures given that there is no industrial standards in place for the new technologies. Therefore, rapid industrialization of a clean-tech product might come at the expense of higher environmental sustainability. This leads to conflicts of whether policy makers should already formulate policies for the respective market formation. In other words, applying the new cleantech technology instead of conventional technology to infrastructure projects such as municipal wastewater treatment or energy supply might be at the expense of higher sustainability. However, to induce growth for the new technology, it is crucial to have a solid base for such technology to set foot on. Aggressive push for applying a new technology in the ground might nevertheless cause additional disadvantages as sellers, producers and operators have not accumulated sufficient experience, i.e. the new product itself might not have reached its optimal performance and might cause trade-offs in energy efficiency, reliability, etc.

2.2.2 Domestic industrial development

Winner selection vs market competition As discussed, to steer successful leapfrogging, latecomers often begin with a rather winner selection approach in the early stage of the catch-up process to ensure focusing resources on particular industrial players. However, transitioning to green TEP involves processes that are more complex than in conventional industries that are mostly consumer products. Sustainability issues are often unique on the basis of individual cases and are unlikely to be solved by a single general technology supplier. Sometimes, allowing the market to run at its own course might generate new solutions from different entrepreneurs and users for different societal needs. Targeting industrial winners is crucial to focus on channeling resources to the selected new entrants but inevitably attracting conflicts from the industry concerning other smaller players or actors of alternative technologies.

In the context of the green TEP, policy makers may also adopt the winner selection approach as part of their overall directionality strategy. Recently there has been increasing scholarly attention towards the issue of directionality under the notion of global green transformation processes (Smith et al., 2010; Weber and Rohracher, 2012; Mazzucato, 2016). Selecting winners and ensuring the success of certain companies will help moving the process of particular transformation in the desired direction. This can be achieved via manipulating industrial standards, product standards, environmental regulations, etc. (Yap and Truffer, resubmitted).

Niche vs regime protection Existing infrastructures in developing countries might be currently overridden by large state-owned enterprises running rather obsolete technologies such as in water and electricity supply. To drastically change the selection environment of the industry, policy makers could anticipate conflicts from the incumbents and should accept that obsolete incumbents have to be replaced by the new technology in the industry. However, when a new cleantech product is still in its early stage of development, driving its respective growth means that policy makers could be instead at risks of ruining sustainability transitions.

Related vs unrelated diversification Conventionally, countries often pursue related diversification strategies for their domestic regions. For instance, South Korea, Taiwan and Malaysia strategically synergized the local knowledge base in consumer electronics, semiconductor, light-emitting diode (LED) and solar photovoltaic (PV) industries. However, latecomer strategies under the green TEP may imply that conventional bet on related diversifications does not suffice to generate catch-up processes that are rapid enough to break developing countries away from middle-income traps and leapfrog to higher economic prosperity and greener living standards. In order to strategically position themselves in emerging cleantech GVCs, latecomers at the current juncture have to quickly respond to the so-called green windows of opportunity. Instead of just letting the industry grow on the basis of related knowledge base, endogenizing such windows requires active interventions from both policy makers and entrepreneurs to draw on broader-level systemic resources to proactively engender rapid development processes, such as mobilizing resources, legitimizing the technology, guiding and shaping industrial dominant designs, etc. (Boschma et al., 2017).

Production vs innovation focused Endogenizing the emerging windows of opportunity in the green TEP further complicates the dilemma between production and innovation focused strategy. Since the global cleantech industries are still emerging and so industrial dominant designs often have not been shaped, latecomer countries have to quickly participate in the shaping process to ensure that such development trajectory is in favour of their internal potentials (Yap and Truffer, forthcoming). However, since cleantech products are not like conventional consumer products, local markets often serve as important test beds in order for stakeholders to apply the technology to complex local contexts (Binz and Truffer, 2017). Therefore, latecomer countries have to juggle between production and innovation dimension simultaneously under the green TEP.

National vs regional development The decision of whether to build an industry on a national or regional development context is not straightforward anymore when it concerns cleantech industries. Since cleantech industries are mostly related to the infrastructure sector, i.e. energy supply, water treatment system, transport system, etc., they often require the domestic market in the initial stage to increase local production capabilities as explained above. Therefore, selecting particular regions as where the technology would be applied will determine which region would receive such infrastructural transformation and hence greener living standards (or not). Policy makers may therefore tie their industrial policies and regional development policies together when planning for the development of a cleantech industry. A national development approach for cleantech industries will have those infrastructure projects scattered across the country and so lead to much less obvious results in terms of upgrading to better living standards.

2.2.3 Global industrial interdependencies

Creating new GVCs or positioning in existing GVCs Since cleantech industries require actors to draw broader-level systemic resources (Boschma et al., 2017; Binz and Truffer, 2017), the conventional understanding of GVC governance which only focuses on relationships between flagship companies and contract suppliers (Gereffi et al., 2005) does not applied under the green TEP. The positions of a latecomer country in GVCs depends also highly on their strategies to gain access to different systemic resources hence having a say in the process of building up certain institutional effect, e.g. shaping a dominant industrial design, legitimizing a technology, etc.

FDI-leveraged policy versus indigenous innovation policy Under the green TEP, latecomer countries that adopt the FDI-leveraged policy in the earlier phase should quickly move away from the strategy and start growing the capabilities of indigenous companies. In line with Perez and Soete (1988) argument that windows of opportunity arise almost equally for all during a TEP shift, the global cleantech sector is largely emerging and most countries are undergoing the standardization process for the different industries. Latecomer countries should therefore quickly gain a strategic position in the global industries by participating in the standardization process so that the development trajectory is in favour of their internal strength (Yap and Truffer, resubmitted). Since developing countries themselves are undergoing dramatic transformation of the infrastructure, developing countries should develop homegrown capabilities to cater for such domestic needs and then seek opportunities to engender South-South transfer by supplying to other developing countries of which such infrastructure sectors are booming.

2.2.4 Technological trajectories

Incremental vs radical innovations Operating under the green TEP relates the dimension of technology to a broader aspect, i.e. sustainability. Therefore, the rationality for a product is no longer just its competitive features and price, but also its level of sustainability. Often, the development of a new cleantech product receives public discourse and controversies in the early stage on its quality performance (which is closely linked to environmental aspects). Policy makers and entrepreneurs therefore are often confronted with a trade-off option in this regard. The first option is whether they should just tap on globally existing technologies and create incremental innovations which carries less uncertainties (and so less disputes) but knowingly also less efficient to transit to higher sustainability. The alternative option is whether they should channel much resources to create a conducive institutional environment that induces radical innovations to drastically change the existing technologies and systems which is more likely to turn out as better than the incumbents.

Technological alternatives There are different technological alternatives within each industry. For instance, the most distinct alternatives in the solar PV industry is thin-film PVs versus multi-crystalline PV. Policy makers have to then decide which alternative to promote and so the kind of industrial structure created in the country as a result of these different technological alternatives. Policy makers may choose to focus on supporting just one alternative or equally supporting for the other alternatives. This trade-off dimension is also closely associated with whether policy makers of latecomer countries want to proactively shape industrial dominant designs. The dimension may however be seconded if the government and policy makers first prioritize the industrial policy realm. For instance, if the government or policy makers have decided on a winner selection strategy, the following broader policies will be targeting to grow the technology supplied by the selected winners, although the alternative technology might be equally good.

Building lighthouses vs fulfilling needs Another trade-off concerning latecomer leapfrogging in cleantech is whether to focus on building technology lighthouses or to deploy the technologies to across the country where it is needed. The governments of developing countries might be tempted to build technology lighthouses such as smart cities or green cities to strategically position themselves in the global arena, to attract FDI inflows, to signal political stability, to deliver as political key performance indicators, etc. However, these national exemplary cities might emerge at the expense of more remote and poorer regions in the country where these technologies are most necessary as solutions to under-developed infrastructure.

Summarizing, we may map out the tradeoffs encountered by a policy maker of a developing country and aiming for leveraging windows of opportunities provided by the green TEP change as depicted in figure 1. Policy makers may position their strategic choices along each of the dimensions and thus selecting a specific profile along the different continuums. We depict two illustrative examples in figure 1. The red profile describes an ideal type profile that would appear in an imagined strategic niche management policy example emphasizing the environmental policy aspect and aiming for a radical transformation of existing sectors. The blue line represents an ideal catch-up strategy exemplified by a typical middle-income trapped country, i.e. the history of the semiconductor industry in Malaysia as elaborated in the text. The actual shape of a strategy chosen by a country may consist of an almost free combination of each tradeoff. The map may however not only be used for descriptive purposes but may also be serve as a methodology for designing specific policy strategies *ex ante*.

In the following, we will analyze the strategies chosen by Chinese policy makers in the field of urban water management which led to a strong predominance of a new technology, which is unparalled everywhere else in the world: membrane bioreactors for treating wastewater. Water represents one of the most pressing environmental challenges of China's strongly forced urbanization. At the same time, urban water management structures are challenged globally by rapid global climate change (Larsen et al. 2016; Fünfschilling and Binz 2018). As a consequence, environmentally more robust water technologies are likely to find rapidly expanding markets on a global scale, soon. We therefore want to elaborate how the different tensions had been dealt with in the real world example of Chinese MBR, which alternative routes could have been taken by the Chinese actors, whether these strategies can be assessed as successful in terms of providing Chinese companies with leading positions in emerging GVCs and whether or not these changes will contribute to potential transitions to more sustainable urban water management structures in the future.

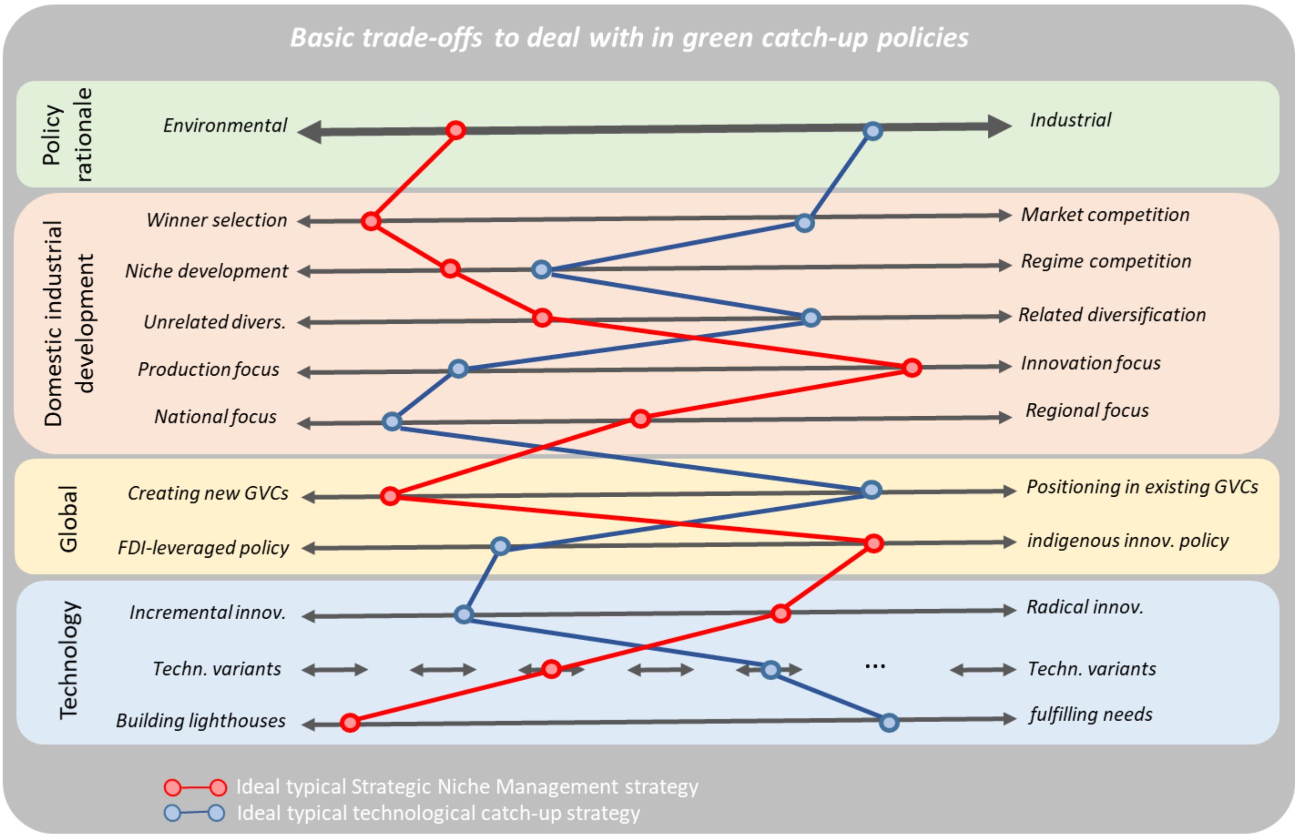

Figure 1: Mapping of the trade-off zones for green catch-up strategies along the four major decision domains.

3. MBR industrial development in China

Pre-Phase I (1980s - 1990s)

The first membrane R&D center in China was established in 1974 in Tianjin University, as assigned by the national government to begin research on membrane related technologies. The center began research on hollow fibre membranes but the research stayed inside the lab until 1995. Subsequent developments of membrane related technologies in China can be dated back to the 1980s when the Chinese government sought for solutions to treat the wastewater discharge at the Shanghai Institute of Nuclear Research (SINR) - a Chinese Academy of Sciences (CAS) institute. The government identified membrane development as one of the directions going forward for SINR (now Shanghai Institute of Applied Physics). In the 1990s, few key universities in China were developing MBR process engineering applications, without the capabilities to produce indigenous membranes. The universities include Tsinghua University, Shanghai Tongji University, Tianjin University, Harbin Institute of Technology and Research Centre for Eco-Environmental Sciences (RCEES), CAS.

Phase I (late 1990s – 2003): Trial and embryonic stage

As nuclear related projects reduced in the late 1990s or year 2000, membrane technologies was seen to be transferable to other related technologies for the society. Around year 2000, the government approved a national project, i.e. the ‘863 Project’, which financed three projects on membrane development. Headed by Tsinghua University, other participating universities were Zhejiang University and Tianjin University. Two small-scale MBR plants were operated respectively by researchers from Tsinghua University and RCEES. Meanwhile, Tsinghua University was also operating a small-scale MBR plant for hospital use. At that time, there were severe doubts about the practical applications of the MBR technology in the industry. Most WWT plants were using the CAS system. In 2000, a locally owned company (i.e. Origin Water) established a Membrane Technology R&D Centre with Mitsubishi and a research team in Tsinghua University in hope to commercialize MBR technology. Around the same time (2000-2003), Tianjin University spun off its first MBR company.

Phase I was also the marketization (or privatization) period of design institutes in China. Formerly, the role of design institutes was critical in deciding the technological applications for the UWM sector in China. However, market competition emerged among the design institutes as they were expected to be profit-oriented as a result of the privatization. The design institutes became more sensitive to the local industrial trends and they were rediscovering their roles in the local industry scene.

Phase II (2004-2010): Early growth

Early Phase II was also the period when China experienced rapid growth in petrol chemical industries, of which wastewater discharge standards of the respective industries were increased. There were continuous new records of mid-scale MBR WWT plants in China every few months. At that time, there were other forms of collaborations, including the one between the spin-off of Shanghai Institute of Applied Physics – SINAP and Shanghai Tongji University, to be the firsts in China that developed flat-sheet membrane materials. Meanwhile, Tianjin University was the first in China that developed materials for hollow-fibre membranes. In 2006, the government continued to finance MBR related projects in order to industrialize the technology. However, most financial resources were no longer channelled to universities and research institutes, but to large companies in China.

Following the Membrane Technology R&D Centre, the first large-scale MBR plant was built and operated in 2006 for Beijing 2008 Olympic Games using the process design of Tsinghua University, as well as Origin Water and the technologies of Mitsubishi. It was the largest MBR plant in Asia at that time and it attracted the interests of many in the field. At the same time, Origin Water, also built the first water reclamation plant in China. Subsequently, three annual training courses were organized consecutively by Tsinghua University to enhance the understanding of MBR applications and designs. Subsequently, companies began to seek collaborations with the university. During this period of time, locally produced membranes were still of low quality and most membranes were sourced from foreign companies in China or simply imported into China.

Phase III (2011-present): Exponential growth

Phase III indicates the exponential growth period of MBR industry in China. Since the beginning of Phase III, indigenous companies like Origin Water had accumulated sufficient technological capabilities to produce membranes on its own without reliance on foreign or imported membranes. Prices of membranes in China began to reduce and so membranes began to be produced in higher volumes inside China. Since 2013, Origin Water began to build underground wastewater treatment plants. Phase III subsequently grew to become a boom for Chinese MBR industry. Not only indigenous membrane exports is tremendously increasing, there are high entries of new local membrane producers in the country. In only three years' time (i.e. 2013-2016), the capacity of WWT in China increased two-fold. Most of the newly built WWT plants in the cities applied MBR technologies. Origin Water had become the largest MBR company in China (monopolizing about 90% of the domestic market) while also exporting their products across the world. Other indigenous companies such as SINAP is focusing on the export market and has also become one of the top MBR suppliers in the world.

The MBR industry in China is at a critical juncture of transformation, of which national and industrial standards are forming and emerging. Since the establishment of the first large-scale MBR WWT plant in 2006, the industry has now accumulated sufficient operating data for practicality evaluations. It is also the period of which voices of controversies began to emerge in the UWM sector and among the professional society, questioning the overly frequent applications of MBR technologies in newly built WWT plants in China.

We will in the following analyse how actors in China urban water management sector strategically aligned the different trade-off dimensions in order to engender a specific pathway for simultaneous MBR industrial development and mitigating water related issues. The analysis draws on a series of 44 semi-structured interviews with key informants of different stakeholder groups in China UWM sector, including academia who are also active policy experts; intermediaries (associations, alliances, consultancy firms, and design institutes); domestic technological companies; foreign technological companies; and key part suppliers. The annexed table lists the details of the interviewees and their assigned descriptor codes in this paper. All the interviews in this study were thoroughly transcribed and checked. The transcriptions were subsequently analyzed using the MaxQDA software, which is a reliable system for qualitative analysis. The relevant data were extracted and processed based on categories derived from the coded concepts (Gläser and Laudel, 2013). During the process, the theories were revised in order to match with the data (Yin, 1994; 2011; 2014). The extracted data were then identified and integrated into typologies to analyze the causal mechanisms of events (Yin, 2011). The findings were further triangulated through content analysis of government and company reports, as well as secondary data sources.

4. China strategic trade-offs in WWT segment

4.1 Primary policy rationale

Industrial catch-up policy versus environmental policy The extraordinarily rapid development of China MBR industry typically shows the trade-off tensions between industrial catch-up and environmental policies. Generally, policy makers in China tend to give to preferences to new but higher-tech industries over mature industries. This has been mainly labeled under the initiative of developing indigenous high-tech industries in China in the 12^{th} FYP in order for the nation to become an innovation country. In that regard, membrane related technologies have been reckoned as one of the high-tech industries that received considerable attention from policy makers of different realms. Besides having industrial policies aimed at further advancing Chinese membrane technologies, the country's environmental policies formally recommended the use of membrane related systems as a key measure to mitigate the country's water crisis. During this time, MBR companies (especially Origin Water) grabbed the window of opportunity and aggressively promoted MBR as an advanced technology that promises high level of innovation activities. This led to biased preferences of actors of different structural levels towards MBR systems instead of the CAS systems as they are indirectly incentivized to deliver the more high-tech option within their area of expertise, including which technology to be applied for new wastewater treatment plants in the local areas, which innovation projects to be funded, etc.

Furthermore, the discharge standards for China municipal wastewater treatment had been increased substantially over the last decade. Based on the interview insights, such increment of discharge standards had been described as drastic and outrageous, and was mainly driven by certain environmental policy makers as well as Origin Water. While the policy makers claimed to aim at solving the nation's water crisis in the shortest time possible, MBR companies had all the incentives to complement such initiatives as MBR systems can achieve higher discharge standard rates as compared to CAS systems. MBR therefore mostly turns out to be the new favourite during decision-making processes that involved choosing a seemingly more high-tech solution.

However, such development had instigated many dissatisfactions among the sectoral actors and professionals especially with regard to the quality performance of MBR systems. Some argued that MBR systems still require many technical improvements and innovations (which require much more financial resources) until they become as reliable as CAS systems. Moreover, it is also argued that MBR systems consume more energy and land-use than CAS systems, which resulted in the fact that MBR is actually less environmentally sustainable than CAS. Whether or not MBR is a more sustainable than the incumbent technology is still unclear. Furthermore, the drastic increment of discharge standards for municipal wastewater treatment has been reckoned as unnecessary as the effluent from traditional CAS systems is seen as sufficiently appropriate. In this context, it is argued that the most imperative action is actually to improve the cities' sludge management systems to ensure more holistic infrastructures for overall wastewater treatments to operate smoothly.

Despite all the professional discourse on the irrationality of using MBR instead of CAS, preference over MBR continued to grow among the pro-MBR sectoral actors and consequently Chinese MBR industry has been growing exponentially in the last decade. In other words, the policy makers and MBR companies have developed strong preference to develop the MBR industry at the expense of whether the technology is actually more environmentally sustainable than the incumbent CAS systems. Such aggressive development of the MBR industry led to a rather heated debate in the sector as well as in the professional society about whether the government's agenda lies in solving environmental issues or growing high-tech industries. This especially manifests when taken into account the tendency to intentionally point to the use of membrane related technologies in the country's environmental protection policy documents. Those environmental policies more often than not include elements that promote the use of high-end technologies in conserving and solving the environmental issues, although some professional parties think that improving on the pre-existing infrastructures is more urgent. Furthermore, influential companies like Origin Water is described by incumbent actors as irresponsible companies that only concern self-interests in profit-making at the expense of social responsibilities for environmental sustainability.

While there are professional parties argue that solving environmental issues via industrialization strategies is not feasible in long term, there are pro-MBR parties support the industrialization policies of MBR. In their point of view, the government was rational to have financed the R&D, commercialization and industrialization of MBR. The financial support from the government has induced the development of indigenous capabilities in membrane materials and MBR technologies. Such development has not only supported the growth of local environmental protection enterprises and the related industries such as membrane production, it has also nurtured the successful industrial leapfrogging of an indigenous MBR company (i.e. Origin Water). Such action is therefore appropriate provided that the MBR industrial players continue to improve the performance of their MBR products. This group of (pro-MBR) actors support the idea of solving environmental crises with high-tech innovations, by claiming that it conforms to the national economic catch-up vision in becoming an innovation country.

4.2 Domestic industrial development

Winner selection or market competition approach To conform to China double vision of simultaneously becoming an innovation country and making sustainability transitions, the Chinese government had opted for a winner selection approach to grow the indigenous MBR industry for its WWT segment. At a more general level, MBR systems increasingly became the dominant choice of policy makers and of the local governments (especially in Beijing) instead of the CAS systems although it was not clear yet whether MBR was actually more sustainable. As explained earlier, this was implemented through higher but arguably irrational formulations of water discharge standards that cannot be met by CAS systems, and elements in policy documents that point to using high-tech or membrane-related technologies to mitigate water related issues. All these led to an overall conducive business environment for MBR industry to grow in China. More specifically, the winner-selection strategy manifests when much preference was given to Origin Water even though the company was monopolizing almost 90% of the domestic MBR market. Most MBR projects were assigned to Origin Water, allowing the company with numerous test-bed opportunities to improve the quality of its MBR systems as compare to other local MBR companies. Since Origin Water is a vertically integrated MBR company, most of the time it was able to provide turnkey solutions for the projects. In certain situations, the company would also outsource part of its processes to other local companies.

Origin Water has also actively instigated a number of standardization processes for MBR systems in China. The company set up an MBR alliance, which comprises of some of the most important local MBR industrial players in China in order to gain governmental endorsements for the initiatives they do. Origin Water also collaborates with a leading research team in Tsinghua University to formulate a guideline for engineering designs for WWT plants. The company furthermore has been working together with Beijing design institute to formulate product standards for MBR systems. Such product standardization process had received support from the government by claiming that product standards will ensure the quality of the indigenous MBR products. However, because Origin Water is mainly driving such process, most of the standards follow the capability of the company. In other words, Origin Water formulates product standards that are in favour of its internal level of performances. Therefore, there have been controversies among the professional society that such product standardization is unfair to the other smaller local MBR companies in the market as these smaller players would not be able to meet those product standards and will be eliminated from the competition with Origin Water. On the other hand, pro-MBR actors especially Origin Water and Beijing design institute argue that product standards will ensure other companies to increase their innovativeness in order to meet the product standards. In the longer run, this would ensure product substitution of which other MBR companies may be able to compete their products with Origin Water and so ensure higher market competition in the industry. Nevertheless, at the current stage, the formulation of product standards has definitely favoured Origin Water and further strengthened its position in the local industry, eliminating smaller companies in many contexts.

Niche vs regime protection The government's strategy to grow the MBR industry furthermore comes at a price of eliminating the incumbents of CAS systems. In other words, the Chinese government is ready to grow a new indigenous high-tech industry at the expense of demolishing an old indigenous industry. During this process, not only pro-MBR actors gained preferences in different policy realms, the incumbents (i.e. pro-CAS actors) got sidelined. These incumbents do not just include companies, but also academia, researchers, and government mediators (in this case, the Chinese municipal design institutes). While academia and researchers are invited less to provide policy consultancies, the design institutes experienced diminishing influencing power in deciding technological applications and collaborated with MBR companies in order to learn how to apply the technology to municipal WWT plants. Since design institutes in China were conventionally state-owned and operated rather in a strongly centralized governance mode in the past, their diminishing power in recent years after privatization had allowed substantial room for bottom-up strategies by entrepreneurs in the sector.

Related or unrelated diversification trajectories The Chinese MBR capabilities in China did not just grow naturally out of the country's limited pre-existing knowledge in membrane related technologies since the mid 1970s. In the beginning, through favourable policies supported by the government, MNCs like General Electric (GE), Siemens, Mitsubishi, and Kubota entered China to set up their base while aiming for the growing demand of China WWT market. The Chinese MBR companies had to first assimilate technologies from these MNCs operating in China and then localize the knowledge in order to accommodate for the local physical context, which turned out to be highly complex due to the water conditions in China. The government, jointly with the leading company Origin Water, created an indigenous MBR industry by drawing from the existing resources at the global level and then localizing them by building a number of systemic resources. This includes mobilizing tremendous amount of financial resources to support MBR related R&D projects in the early stage, and then to invest for MBR wastewater treatment plants which turned out to be providing numerous test beds for the leading company, formulating environmental regulations that indirectly supports the growth of the MBR industry in the country, setting industrial standards that promotes product standardization and improves quality performances, creating legitimation for MBR technology to convince the professional society that MBR is the right solution to mitigate the country's water crisis, and so forth. Later, MBR gained substantial market shares in the domestic WWT segment and most of the new plant projects were assigned to local MBR companies especially Origin Water. Origin Water and a number of other indigenous MBR companies which benefited from such local favourable support have now grown to be technologically compatible to the MNCs and are now exporting their MBR products and systems to other countries in the world especially the developing countries.

Production vs innovation focused The Chinese MBR industry had thrived under the context of a production focused strategy. The industrial and environmental policies had created a large and growing domestic market demand for MBR systems, hence providing ample opportunities for indigenous companies to improve their production capabilities through learning test-beds and subsequently reduce costs of production substantially.

4.3 Global industrial interdependencies

Creating new GVCs or positioning existing GVCs The key actors of China MBR industry (e.g. pro-MBR policy makers, MBR companies, design institutes) had pursued both catch-up trajectories, i.e. nurturing Chinese MBR companies that would become vertically integrated OBMs in the global future MBR industry as well as specialized membrane suppliers. In the domestic municipal WWT market scene, much preferences had been given to these large integrated MBR companies such as Origin Water which can provide turnkey solutions for the WWT projects. On the other hand, the option of putting together a number of local upstream and downstream suppliers seem to be a less favourable option for the government hence specialized membrane suppliers find less business opportunities in the municipal WWT segment. The leading specialized membrane supplier (i.e. SINAP) however pursued an export-oriented strategy and aims at becoming a leading membrane supplier for MBR systems in the industrial WWT segment in the world.

China MBR industry therefore develops into two major distinct trajectories, i.e. domestic municipal WWT segment and export industrial WWT segment. While Origin Water dominated about 90% of the local MBR municipal WWT market, SINAP represents the leading indigenous (flatsheet) membrane supplier from China targeting exports for international industrial WWT market. While Origin Water has a key focus of first dominating the domestic municipal WWT market, the company also aims at replicating the strategy to other emerging markets. Having set China and especially Beijing as a successful transformed example for water treatment, Origin Water therefore seems to be promising to replicate the same kinds of arguments to policy makers in other developing countries which may eventually lead to successful South-South technology and industrial implications. In other words, as an OBM, Origin Water may potentially be leading its own GVC in the future. Meanwhile, SINAP is developing into a promising international membrane supplier with a strategic position that fits strongly in the existing growing industrial WWT GVC through constant innovations and accumulation of capabilities.

FDI-leveraged policy versus indigenous innovation policy China MBR industry had pursued the FDI-leveraged strategy during its early phase of development but had switched to pursuing indigenous innovation policies in the later stage. In the early phase, the Chinese government provided support and incentives for foreign MBR MNCs to set foot in China for the country's domestic water market. MNCs like General Electric (GE), Siemens, Mitsubishi and Kubota were among the most important foreign companies in China MBR industry at that time. As soon as local companies like Origin Water have assimilated sufficient technological capabilities from the MNCs (for instance Origin Water used to collaborate with Tsinghua University and Mitsubishi for MBR R&D projects in the early stage), the local business environment started to become rather restrictive to the foreign MNCs. For instance, these foreign companies are not invited to participate in meetings with policy makers to provide technical consultancies on the sector in general or on wastewater treatment projects. Moreover, most new projects were assigned to local indigenous MBR companies instead of foreign MNCs. The foreign companies in China therefore had been facing challenges to localize their technologies. Meanwhile, local leading companies like Origin Water constantly informed the government and policy makers on the potential of MBR in increasing Chinese indigenous innovation activities. Without enough localized projects as technology testbeds, the foreign companies were not able to localize their technologies in order to meet up with the local water complexities and discharge standards. Foreign MNCs such as GE, Siemens, Mitsubishi, and Kubota have not been able to establish a sustainable business model in China ever since indigenous companies obtained the required capabilities that subsequently reduced the local costs of production.

Most components of MBR modules in China are now sourced locally as the technological developments of these products have matured, such as valves and blowers. Some foreign companies still participate in the segments of higher-end parts and component supply such as aeration system. Local leading MBR companies have closed their technological gaps with the foreign companies in China. For instance, General Electric (GE) lost its technological leadership in Chinese MBR industry over the years as Origin Water caught up with their knowledge and technical capabilities on membranes. Foreign companies in general are now rather passive in China MBR industry and major developments of the industry had been mainly driven by indigenous MBR companies.

4.4 Technological trajectories

Technological alternatives The two major alternatives for MBR systems in China are hollow-fibre membranes (led by Origin Water) and flatsheet membranes (led by SINAP). The trade-off for technological alternatives is however seconded in China MBR industry given the government's winner selection strategy. In other words, the Chinese government prioritized more in ensuring the success of the selected winner Origin Water and hence majority of designed incentives for the domestic market favour the development trajectory of hollow-fibre accordingly. SINAP however focuses on exporting the membranes in flatsheet form. Furthermore, most MBR systems in China are currently built in centralized system mode, instead of decentralized system mode although the latter might be more efficient. There are controversies among the professionals that applying MBR systems into existing conventional centralized systems is faster and cheaper, as compared to demolishing the current structures and rebuild in a drastically different way. This provided an easier context for Origin Water to apply its MBR systems. Moreover, centralized systems usually involve larger installation scales, hence providing more incentives for Origin Water given higher profits and lower costs.

Building lighthouses vs fulfilling needs Since the initial stage the Chinese government and leading entrepreneur Origin Water focused on building most MBR WWT plants in Beijing in order for the city to become the lighthouse for that technology. This comes at the expense of actually bringing that technology to more remote places where such WWT systems are most needed. After Beijing had successfully become an exemplary city for MBR systems, Origin Water began to venture into more remote areas such as Xinjiang in recent years.

5. Conclusion

The case of China UWM showcased how actors in an emerging cleantech industry can coherently align the different trade-off dimensions in the proposed framework in order to create a congruent development trajectory for MBR. This has involved a process of system actors inclining more strongly towards industrial catch-up policy than environmental policy in China UWM sector. At the domestic industrial development level, the China UWM sector has adopted a winner selection approach rather than a market competition approach of which MBR technology is preferred as it is seemingly a higher technological solution compared to CAS (Yap and Truffer, resubmitted). On top of that, most MBR projects tend to be assigned to a Chinese-owned monopoly, i.e. Origin Water. Meanwhile, MBR actors managed to guide the system actors to pursue a niche protection strategy for MBR technology and pulled off an unrelated diversification strategy to build an indigenous MBR industry (Binz et al., 2016). At the interface of global industrial interdependencies, the Chinese MBR actors have strategically moved from being suppliers to foreign companies in the beginning to branded manufacturers targeting both domestic and export-oriented markets. In so doing, China UWM sector had also moved from a FDI-leveraged approach to an indigenous innovation policy approach. The regime actors in China UWM sector, however, were relatively weak in building a set of congruent strategies across the different trade-off dimensions for CAS technology to stay equally competitive in the sector. The efforts of aligning a coherent trade-off trajectory have contributed to an exponential growth of China MBR industry in the last decade. Nevertheless, the rapid industrialization of MBR in China is argued to have come at the expense of better environmental sustainability. The overall controversies concerning the technical rationality of adopting the technology and the way it is being deployed remains a highly heated debate among the professionals in China UWM sector.

The proposed framework in this paper offers a new lens to how alternative development pathways can be identified for catching-up countries especially under the emerging green TEP. In general, policy makers of developing countries under the new paradigm shift have to take into consideration the environmental sustainability dimension when planning for their rapid industrialization strategies. In more specific terms, achieving industrial catch-up and environmental sustainability transitions simultaneously requires these policy makers (as well as other system actors such as entrepreneurs) to re-contemplate a few key industrial policy trade-offs. At the domestic level of industrial strategies, system actors should revisit the conventional understanding of the trade-off between winner selection or market competition approach. Under the green TEP, the winner selection approach might be one of the most effective ways to stimulate a specific development trajectory as showcased by the China MBR story, i.e. to create a desired direction during such transformation process. This might however come at the price of immediately better environmental sustainability as discussed. Moreover, if developing countries were to eye the TEP shift as a game-changing period when new windows of opportunity for alternative catch-up trajectories might rise, it is imperative that these latecomers start exploring unrelated diversification strategies (Binz et al., 2016; Boschma et al., 2017).

At the global level of industrial interdependencies, catch-up countries have to revisit the conventional tension of whether to create new GVCs or to position in existing GVCs. In the new TEP where fundamental shifts are happening in terms of global industrial manufacturing landscape, market structures and socio-technical dimension such as cognitive and behavioral changes, catch-up countries should proactively identify new positioning strategy in emerging cleantech industries and create equally competitive value out of the pursued strategy. Endogenizing windows of opportunity under the green TEP therefore requires strategic balance of the trade-off dimensions in order to assess and discover alternative development pathways in an increasingly competitive industrial landscape.

This paper points to further research along the line of policy trade-off trajectories in order to better understand some fundamental concepts underpinning the transformation process towards a green TEP, such as the issue of directionality, latecomer industrial catch-up and leapfrogging, as well as sustainability transitions in developing countries. The proposed framework has identified a number of trade-off dimensions of which the possibility of actual combination of them in the practical world can be perplexing. However, the availability of broader options also proposes that system actors may strategically carve out new alternative strategies from such portfolio. It is important for future research to further analyze under what conditions certain pathways (and the different extents of the respective trade-offs) may be most ideal to lead to more successful catch-up and sustainability transition cases.

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Annex

Table 1. List of interviewees, 2016.

Stakeholder Group	**Interviewees**	**Code**	**Expertise** (New or conventional technology)	**Sum**
Academia (AC)/ Policy Experts (PE)	Chinese Academy of Sciences	AC/PE1	New	9
	Chinese Academy of Sciences	AC/PE2	New	
	Tongji University	AC/PE3	New	
	University of Science and Technology Beijing (School of Civil and Environmental Engineering)	AC/PE4	Conventional	
	Renmin University	AC/PE6	New	
	Beijing University of Civil Engineering and Architecture	AC/PE7	Conventional	
	Tsinghua University (School of Environment and State Key Joint Laboratory of Environmental Simulation and Pollution Control)	AC/PE8	New	
	Jiangsu Provincial Academy of Environmental Science	AC/PE9	Neutral	
	Chinese Academy of Sciences	AC/PE10	Neutral	
Intermediaries (IN)	International Water Association (AS)	IN/AS	Conventional	5
	Beijing General Municipal Engineering Design & Research Institute (DI x 2 interviews)	IN/DI1, IN/DI2	New	
	Tsing Hua University* as Specialist Committee (SC)	IN/SC	New	

	Origin Water* as MBR Alliance (AL)	IN/AL1	New	
	Tongji University* as MBR Alliance (AL)	IN/AL2	New	
	Beijing CS Guoyi Environment Protection Engineering as Engineering Design Companies (EDC x 2 interviews)	IN/EDC1, IN/EDC2	New	
Domestic Technological Companies (DTC)	EnviroSystems Engineering & Technology	DTC1	Conventional	20
	Beijing Ecojoy Water Technology	DTC2	New	
	Rui Jie Te Technology	DTC3	New	
	HuaDe Creation	DTC4	Neutral	
	GoHigher Environment	DTC5	New	
	Forenv Environmental Technologies	DTC6	New	
	Beijing Enterprises Water	DTC7	New	
	Poten Environment Group	DTC8	New	
	BMEI (2 interviews)	DTC9, DTC10	New	
	Shanghai SINAP Membrane Technology	DTC11	New	
	Shanghai Zizheng Environmental Technology	DTC12	New	
	Beijing Drainage Construction	DTC13	New	
	Beijing Origin Water Technology (2 interviews)	DTC14, DTC 15	New	
	Jiangxi JDL Environmental Protection	DTC16	New	
	Tianjin Motimo	DTC17	New	
	Beijing Bluesky Advanced Technologies	DTC18	Neutral	
	Beijing Mohua Technology	DTC19	New	
	SENUO Filtration Technology (Tianjin)	DTC20	New	
Foreign Technological Companies (FTC)	Veolia (China) Environment Services	FTC1	Conventional	6
	Beijing Tri-High Membrane Technology	FTC2	New	
	Pentair Water Purification Systems (Shanghai)	FTC3	New	
	Huber Environmental Technology	FTC4	New and Conventional	
	Sino French Water	FTC5	Conventional	
	Veolia Water Solutions & Technologies (Beijing)	FTC6	Conventional	
Key Part Suppliers, Domestic/ Foreign (KPSD/ KPSF)	Shangdong Huadong Blower	KPSD	N/A	4

	Rehau Polymers (Suzhou) Shanghai Branch	KPSF1	New	
	Shanghai Alfa Flow Control	KPSF2	N/A	
	Tacwell Engineering	KPSF3	N/A	
Sum				44

Note* These entries relate to interviewees who acted in a double role as academia/ policy experts or companies but also representing important specialist committee or alliances in the industry. The interviewees were explicitly addressed in these different roles. However, the corresponding interviews were only counted as one.