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Shaping selection environments for industrial catch-up and sustainability transitions: A systemic perspective on endogenizing windows of opportunity

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ABSTRACT

Transitioning economic sectors towards more sustainable futures is a major global challenge, in particular for non-OECD countries. Policymakers in these countries are confronted with a double challenge: how to implement cleaner technologies and infrastructures while at the same time promoting rapid industrial development. In catch-up studies, this trade-off has been increasingly interpreted as providing windows of opportunity for gaining strong leadership in new generations of cleantech industries. In this paper, we maintain that in order to specify how these windows of opportunity can be endogenized, a deeper understanding is needed about whether, how and by whom the directionality of innovation systems can be influenced. For this purpose, we propose an analytical approach that draws on the technological innovation system framework extending the current understanding of directionality in two ways: first, we complement the prevalent top-down perspective with a bottom-up view exemplified by the institutional entrepreneurship literature. Second, we posit that the focus has to be shifted from the manufacturing of single technologies to the transformation of entire socio-technical systems. The presented framework is validated by a case study on recent shifts in the dominant technology in China's urban water management sector. Major changes in the country's sectoral selection environment led membrane bioreactor technology to become the dominant design in urban water management – a development that is unmatched in any other country in the world. Owing to these transformations, China's technology firms outcompete multinational players and therefore they show strong potentials for industrial leapfrogging. However, although the promise to solve environmental problems played a decisive role in the shaping of the selection environment, it remains unclear whether the observed transformation leads the way to a more sustainable sector structure in the longer run. The case, however, still enables us to specify how windows of opportunity can be endogenized through the interplay of different actors trying to shape different layers of the selection environment in a specific sector.

1. Introduction

Sustainability transitions represent one of the core challenges to modern societies in dealing with environmental and social impacts that are associated with extant systems of production and consumption. A recent contribution to the literature even stated that new meta-rules are needed for changing socio-technical systems in order to counter the global challenges of environmental and social pressures, and that this will lead to a so-called second Deep Transition in human history (Schot and Kanger, 2018). In line with this claim, the techno-economic paradigm literature argued that we are witnessing "the Fifth Great Surge of Development" – an era driven by the information and communications technology revolution and the gestation of an ever more globalized world (Perez, 2013). It is said to be at a critical turning point, where global sustainability transitions are supposed to lead to the full deployment of the next new golden age (Perez, 2013, 2016). While globalization increasingly changes the spatial configuration of world economic activities, policy making and innovation research need to be ever more attentive to the progresses made in developing countries (Mathews, 2013; Perez, 2013, 2016). These countries are, however, confronted with a double challenge, as they have to implement cleaner technologies and infrastructures while at the same time supporting rapid industrial development.

A core question that rapidly developing economies are confronted with is whether to content themselves with finding a position in existing global value chains (GVCs) or whether they should aim at industrial leapfrogging (i.e. attaining technological or market leadership). It has been argued that a precondition for leapfrogging is that countries are

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able to take advantage of windows of opportunity (Lee and Malerba, 2017; Perez and Soete, 1988). The extant literature has, however, treated windows of opportunity as rather exogenous to the actors in latecomer countries and therefore these countries can mostly only fit into global technological trajectories that have originated elsewhere. Under the conditions of a sustainability-related techno-economic paradigm, and even more so in the context of a new Deep Transition, many new windows of opportunity are likely to emerge for latecomer countries. This paper therefore seeks to advance the current understanding in the catch-up literature on what latecomers can do to participate in the shaping of newly emerging technological trajectories.

Endogenously dealing with windows of opportunity during a green techno-economic paradigm relates to the question of how the shape of emerging trajectories can be influenced by specific actors. This has been discussed under the term “directionality” of long-term transformative change (Weber and Rohracher, 2012) and in relation to the role that the state should play in these endeavours (Mazzucato, 2013). Directionality includes the establishment of shared future visions and collective actions (Weber and Rohracher, 2012) and therefore goes beyond the confines of a core technology. It envisages the development of entire socio-technical systems. The issue of directionality is therefore not so much about whether a particular technology (e.g. polycrystalline solar photovoltaics) will gain a greater or lesser market share in the future, but rather whether this technology will contribute to fundamentally different future sector structures (e.g. a renewable-energy-based electricity sector). Directionality therefore refers to the proactive stimulation and prioritization of specific innovative activities in order to contribute to a particular desired direction of technology development. It is regarded as particularly crucial when facing grand societal challenges (Schot and Steinmüller, 2018; Smith et al., 2010; Weber and Rohracher, 2012). Some scholars have claimed that tackling the problem of directionality requires a more “vertical” view on innovation systems (Jacobs and Mazzucato, 2016). Other scholars also point to the importance of acknowledging the key role of top-down public policy intervention for promoting radical transformations towards more sustainable systems of production and consumption (Markard et al., 2012; Stern, 2007).

We build on these insights but maintain that an exclusive focus on innovation policies is too narrow to suggest alternative means for endogenizing windows of opportunity (see also Schot and Steinmüller, 2018). Instead, we propose an understanding of directionality that emerges as a system-level effect, building simultaneously on top-down interventions from government (Jacobs and Mazzucato, 2016; Weber and Rohracher, 2012; Mazzucato, 2016) and bottom-up strategies adopted by industrial companies, civil society actors, professional associations and researchers (Schot and Steinmüller, 2018). We will combine the directionality approach with one prominent bottom-up perspective in the field of industrial change, namely the institutional entrepreneurship literature (Battilana et al., 2009). As directionality does not directly result from strategies of individual actors but is an outcome of interlinked actions within an evolving innovation system, we draw on the technological innovation systems (TIS) framework (Carlsson and Stankiewicz, 1991) for further specifications. The TIS approach has been widely adopted by socio-technical transition scholars to analyse industry dynamics associated with green technologies in the context of sustainability transitions (Bergek et al., 2008; Markard et al., 2012).[1]

According to the TIS framework, successful maturation of new industries is the result of a balanced interplay between six core development processes (also called system functions and following the specific proposal of Binz et al., 2014, who built on Bergek et al., 2008, and Hekkert et al., 2007): the generation of knowledge, entrepreneurial experimentation, the mobilization of resources, the formation of markets, technology legitimation and finally guidance of the search (GS). We interpret directionality in TIS as being tightly associated with the specific form of the selection environment to which the technology is exposed. The selection environment is affected by particular considerations, valuations and incentives that influence the further course and shape of a technological trajectory, including its discontinuation. Directionality in general results from the interplay of all the TIS functions. GS, however, stands out as referring most explicitly to strategies of actors that try to influence the shape of the selection environment (Bergek et al., 2008). In terms of core mechanisms, GS encompasses the formulation of visions and expectations, standards, regulations and policies that ultimately impact the growth and shape of technological trajectories (Bergek et al., 2008; Hekkert et al., 2007). GS is thus a core driver of directionality in an innovation system. In this paper, we conceptualize directionality as emerging from the systemic interplay of all TIS functions but highlight GS as those top-down and bottom-up activities that different actors entertain in order to shape the sectoral selection environment in favour of or against alternative trajectories.

Drawing on these conceptual clarifications, we interpret the endogenization of windows of opportunity as a process by which latecomers proactively translate globally foreseeable opportunities or threats into a specific selection environment that privileges certain technological trajectories. An example would be a country that takes imminent global climate change as a rationale to implement strong industrial support measures for renewable energies in order to become a leader in the corresponding industries in the future (for the case of Germany and renewable energy support policies, see Hoppmann et al., 2014). Through this endogenization process, latecomers may influence emerging technological trajectories and by this “shape” or specify an otherwise unspecific “global” pressure on a specific sector. This framing provides a much more proactive perspective compared to conventional catch-up studies, which tend to presume that latecomers should wait until suitable positions open up in GVCs, mostly specified by transnational companies. We posit that a systemic understanding of directionality through the lens of TIS provides a suitable starting point for identifying how actors in latecomer countries can endogenize such windows of opportunity. The paper will therefore elaborate a tentative framework for analysing how actors can influence specific aspects of the selection environment of a sector by leveraging mechanisms of GS in order to become leaders in the corresponding field.

We will illustrate the appropriateness of our framework by a case study of recent radical socio-technical transformations that happened in the urban water management (UWM) sector in China. Chinese actors started from the assumption that global climate change was very likely to lead to increased problems of water scarcity in many countries of the world and that the current structure of the UWM sector was not well prepared for this challenge (Binz et al., 2012, 2016b; de Haan et al., 2015; Larsen et al., 2016). This still rather unspecific global window of opportunity was then translated into more specific criteria in the sectoral selection environment within about one decade. This led to a rapid shift in the dominant technology of the sector. It changed from following the globally dominant approach of conventional active sludge (CAS) treatment (Fuenfschilling and Binz, 2018) towards using the high-tech, niche technology of membrane bioreactors (MBR). Besides the technology, the core mission, societal visions, standards,

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[1] In the past, the TIS framework has primarily been applied to analysing the maturation of emerging greentech innovations or industries. Some commentators have argued that it represents only a partial transition approach because it neglects the non-technology-related aspects in the transformation of socio-technical systems; it is therefore not suited to analysing radical transitions and, as a consequence, cannot address transformations of entire economic sectors (Kern, 2015). However, we follow Markard et al. (2015) and Bergek et al. (2015) in their claim that nothing precludes the TIS framework from being extended to address broader socio-technical transformation processes.

regulations, and new power relationship between different actors in the sector also changed fundamentally. Our case shows the processes through which specific actors in China's UWM sector shaped the selection environment. The resulting transformation process led Chinese firms to surpass global incumbents both in technological development and in deployment of MBR: by 2016, Chinese companies had become the largest producers and users of MBR in the world. China is now considered as leading the innovation frontier of MBR technologies and the country's producers are starting to export their products across the world.

The case is well suited for reconstructing processes of endogenizing windows of opportunity through strategies of GS. Unlike what conventional wisdom would suggest, the outcome cannot be explained by the actions of the Chinese government alone. Nor was it simply successful lobbying by powerful companies promoting their own interests. And the observed developments cannot be explained by the inherent technological, economic or environmental superiority of the new technology over its technological rivals. Rather, we will show how the technological trajectory resulted from an intricate interplay of GS processes carried out simultaneously by diverse actors addressing several layers of the selection environment in order to push the maturation and rapid scaling of MBR innovation system. We will, furthermore, argue that industrial leapfrogging was only possible because Chinese actors were prepared to fundamentally rethink the dominant sociotechnical system in the UWM sector in terms of regulations, visions, expectations, standards and deep organizational changes. These developments could potentially lead to sustainability transitions in the longer run, as many of the GS activities had an explicit reference to the future need for superior environmental performance of the UWM sector. However, to date, it remains unclear whether the actions taken will actually pave the way for a more sustainable UWM sector in China or elsewhere. We therefore present a case that was only halfway successful in balancing the two goals of industrial leapfrogging and sustainability transitions. Still, we maintain that the case is instructive in terms of fundamental processes that have to be considered when endogenizing windows of opportunity.

The analysis draws on in-depth semi-structured interviews with 44 experts from the Chinese UWM sector, with triangulation through content analysis of government and company reports, as well as secondary data sources. The remainder of this paper is structured as follows: Section 2 reconstructs how existing catch-up and TIS studies can be combined to analyse how actors may try to shape sectoral selection environments. In particular, it proposes operationalization of the function of GS as a key inroad to influence the directionality in TIS. Section 3 introduces the recent history of the Chinese UWM sector and elaborates the major development phases of the MBR TIS. Section 4 presents the results of the empirical study on how diverse actors aimed at influencing the selection environment of the sector. Particular emphasis is put on the strategic interplay between the government and leading actors in the industry in promoting MBR as the dominant technological choice. In Section 5, we discuss how the lessons from this case contribute to an endogenized account of latecomer industrial leapfrogging and sustainability transitions. Section 6 concludes with implications for both catch-up and transition studies, particularly on the role of developing countries in a global sustainability transition process.

2. A systemic framework for analysing the shaping of selection environments

A common challenge from which latecomer countries suffer is the inability to embark on rapid economic development despite years of investing to catch up with advanced countries in high-end industries. This has been coined as constituting a "middle-income trap" for many attempts to implement economic development (Cherif and Hasanov, 2015). Existing frameworks for catch-up have made significant contributions in informing us how latecomer countries may compensate for weaker institutional conditions such as deficiencies in technological capabilities, finances, infrastructures and networks (Lundvall, 1992; Mathews and Cho, 2007; Rasiah, 2007). But the middle-income trap issue seems to have become ever more prevalent internationally. In this section, we want to critically take stock of extant theories on catch-up and identify how the portfolio of strategies for latecomer countries could be broadened in order to take advantage of and respond to challenges in the shift towards a sustainability-based techno-economic paradigm. We will first argue for a more endogenized understanding of the dynamics of selection environments, drawing on recent teachings from the functional approach of TIS in order to finally propose a framework for analysing how different actors can attempt to influence a selection environment and through this shape emerging technological trajectories.

2.1. The need for a broader perspective on catch-up dynamics

Earlier studies concerning catch-up have largely been inspired by a few successful latecomer cases such as Japan, South Korea and Taiwan, typically emphasizing the critical role of learning by sourcing external knowledge from multinational corporations (MNCs) in foreign advanced countries in the early phase of their catching-up process (Amsden, 1989; Edquist and Jacobssen, 1987; Fransman, 1985; Hamilton, 1983; Johnson, 1982; Kim, 1997). This emphasis on latecomer learning processes supported a rather linear understanding of the dynamics of competitiveness in catch-up studies, starting with the accumulation of technological capabilities (Figueiredo, 2008; Lall, 1992) from reverse engineering (i.e. imitation) of foreign technologies to indigenous innovations (Kim, 1997); and from being the contract manufacturers or original equipment manufacturers to becoming original design manufacturers and eventually achieving leading positions as original brand manufacturers (Hobday, 1995). Studies on strategic positioning of latecomers within GVCs largely focus on how latecomers can move up the GVC ladder through conducive linkages with MNCs (Humphrey and Schmitz, 2002; Pietrobelli and Rabelotti, 2005; Mathews, 2002, 2006; Vind, 2008; Wei et al., 2011). However, years after the successful cases, and especially the leapfrogging achievements of South Korean firms (Lee and Lim, 2001), a question remains challenging or even pressing for many other developing countries: what does it really take for them to also make major leaps in industries and development? Realities have shown that not every latecomer that began learning by engaging with MNCs will become an original brand manufacturer or lead the GVCs eventually (Vind, 2008). Industrial catch-up therefore has to be considered in broader terms in order to unfold new leapfrogging mechanisms that allow jumping ahead on historical development stages, executing radical breaks from established production and consumption structures and embarking on the development of new technological trajectories.

Latecomer leapfrogging is closely associated with the presence of windows of opportunity that arise owing to external forces such as technological breakthroughs, major shifts in market structures, financial crises or large shifts in politics (Brown and Linden, 2009; Lee and Malerba, 2017; Perez and Soete, 1988). The emergence of windows of opportunity has, however, so far been treated as an exogenous event to which latecomers merely 'respond'. The ability to catch these windows depends primarily on the technological capabilities accumulated in latecomer companies or regions in the past (Lee and Malerba, 2017). For instance, when a new demand emerges for a particular product, local firms would already have to have accumulated a certain level of capabilities in order to be able to develop and then commercialize these new products quickly enough. A few rather straightforward exceptions in the literature have been referred to, such as when windows of opportunity resulted from research and development (R&D) or marketing strategies of firms, latecomers co-developed technologies with advanced incumbents, or when latecomers lobbied their institutional environment (Lee and Malerba, 2017). The extant examples tend to prioritize technological capabilities as the foremost resource to endogenize windows of opportunity and presume that institutional conditions can at best be changed by specific forms of lobbying. So far, there has been little research that explicitly analyses how latecomers can shape their institutional environments using more than technology- or capability-focused strategies.

In catch-up studies the general perception prevails that latecomer industrial development is highly dependent on the industrial policies formulated by the government and that firms act within the national framework conditions provided by these policies (Fu et al., 2011; Lundvall, 1992; Pietrobelli and Rabellotti, 2009). Existing catch-up studies therefore tend to draw a clear boundary between the institutional conditions (for catching up) and the strategic realm of industrial firms. In other words, while catching-up firms focus on strategically managing resources, assimilating external knowledge and accumulating capabilities, they are not perceived explicitly as having leeway to influence their embedded framework conditions. In recent years, catch-up studies have paid increasing attention to the potentials of cleantech industries for latecomers to lead global industrial positions (Lee and Mathews, 2013; Mathews, 2013; Mathews and Tan, 2014a, 2014b, 2013; Tan and Mathews, 2015; Wu and Mathews, 2012). In these contexts, the arguments for latecomer transition to green growth and industrial leapfrogging still primarily presume a role for government in building institutional contexts and a role for firms in building technological capabilities while strategically leveraging foreign incumbent resources.

Latecomer leapfrogging is therefore still conceived as a linear trajectory especially for middle-income-trapped countries. The question of how other latecomers, through relatively more radical strategies, could effectively overcome their less privileged positions within a shorter timeframe remains a challenge. Recent theorizing in transition studies, and in particular the Deep Transition framework, suggests that latecomer countries should consider a much broader set of strategies in a sustainability-based era (Schot and Steinmüller, 2018). Options to catch windows of opportunity should not be limited to improving the absorptive capacity of the knowledge base in these countries. This will only lead to catching up within the bound of existing socio-technical systems. Instead, governments and companies should anticipate, explore and implement new socio-technical systems, which include new business models, organizational forms, visions and expectations, new user patterns, and other institutional context conditions. Endogenizing windows of opportunity therefore means that latecomers have to manage a broad set of activities that enables them to develop alternative socio-technical systems, which promise to be superior in terms of technologies and business opportunities as well as sustainability. To endogenize windows of opportunity, catch-up scholars therefore have to turn the perspective towards the proactive interplay of strategies by different actors in shaping the potential future trajectories of upcoming socio-technical systems. These processes will in particular also encompass a broader set of strategies than mere “lobbying”. Therefore, a systemic framework that explicitly outlines the strategic interplay of a broader set of actors is in need.

2.2. Guidance of the search and the endogenization of windows of opportunity

A salient systemic framework to analyse early phases of industry formation is the TIS (Bergek et al., 2008; Carlsson and Stankiewicz, 1991; Hekkert et al., 2007), a specific approach within the broader field of socio-technical transition studies (Markard et al., 2012; Markard and Truffer, 2008; van den Bergh et al., 2011; Weber and Truffer, 2017;). The TIS perspective posits that innovation success is related to systemic interactions between a broad range of actors, interacting in manifold formal or informal networks and developing supportive institutional structures. Later versions of this literature have shifted their attention to a more process-focused view. Six core TIS processes (or functions) had been identified as interacting in a balanced way during successful industry formation: knowledge generation, entrepreneurial experimentation, guidance of the search, legitimation, market formation, and resource mobilization (Bergek et al., 2008; Binz et al. (2014); Hekkert et al., 2007). The functional framework enables specification of how directionality is shaped in emerging TIS through the strategic interplay of different actors. Compared to extant catch-up studies, therefore, the TIS framework does not pre-assign bounded roles to specific actors. Rather, it allows each actor to play a proactive role in contributing to the aggregate outcome of an emerging socio-technical system. The functional approach therefore provides a systemic perspective for analysing alternative means for endogenizing windows of opportunity by different actors (be it governments, specific companies or civil society organizations).

Transition studies more broadly are well suited to complement the catch-up literature because they focus on cleantech innovations and their contribution to broader transformations of socio-technical systems. Among the transition frameworks, the TIS approach emphasizes the industry dynamics that go along with the emergence of more sustainable technologies and is therefore particularly suited to complement catch-up studies. Recently transition studies have started engaging with problems of catch-up while becoming more attentive to the geographical variations of transition processes (Coenen et al., 2012; Hansen and Coenen, 2015; Truffer et al., 2015). The question of how countries of the global South may contribute to sustainability transitions has very recently developed into a vibrant field (for an overview see Wieczorek, 2018; an early elaboration can be found in Berkhout et al., 2009). In particular, the TIS framework has also been applied in a number of developing countries (e.g. Blum et al., 2015; Tigabu et al., 2015) mostly claiming that the understanding of different functions had to be adapted to the specific local contexts. Some studies have addressed the topic of industrial leapfrogging (e.g. Binz et al., 2012; Murphy, 2001; Rock et al., 2009) or coupled dynamics between TIS structures located in industrialized and emerging countries (e.g. Dewald and Fromhold-Eisebith, 2015; Quitzow, 2015). Building on these insights, Binz and Truffer (2017) have formulated an encompassing framework on how to understand the formation of “global innovation systems”. They developed a multi-scalar model on how specific functions can be formed in different regions or countries and how these processes may add up through “structural couplings” to overall innovation success at a global level. In a similar vein, Boschma et al. (2017) have argued that a systemic perspective may inform regional development policies aiming at new path creation and thus contribute to leapfrogging.

From a TIS perspective, the shape of a technological trajectory is ultimately the outcome of the interplay of all the system functions. This interplay determines not only the quantitative growth of a homogeneous technology (which is the focus of the majority of existing TIS studies), but also asks how potential alternative trajectories can gain predominance in the course of system development (as exemplified by Markard et al., 2009, or Wirth et al., 2013, for instance). This latter process depends on how different functions play in favour of or against alternative pathways: forms of knowledge generation preferred by academics and industry researchers, innovation strategies leading to specific forms of entrepreneurial experimentation, the ease with which certain variants can raise resources or gain legitimacy, where market preferences are stronger, etc. All these factors co-determine which trajectory will eventually achieve predominance in a specific technological field.

Among the different systemic functions, however, GS stands out as the one that is most directly related to targeted strategies that different actors may engage in order to shape technological trajectories (Bergek et al., 2008; Hekkert et al., 2007). Early studies had very much restricted GS to selection criteria of a technical kind, i.e. in terms of the choice of technical variants and product design, through standards and regulations. Later, Johnson (2001) suggested that GS should also be applied to processes attracting new actors to join a new technological field. Common examples of GS are the formation of visions and expectations, standards, regulations and policies (Bergek et al., 2008). GS therefore provides a lens through which the strategies of different actors aiming at the shaping of technological trajectories can be analysed in a systemic context.

Despite the crucial role that TIS scholars attributed to GS for the shaping of the direction of TIS, existing studies have so far tended to be implicit about the detailed processes that are associated with GS. We will therefore elaborate an explicit framework that enables the identification of different processes of GS that contribute to the directionality of a technological innovation system, and by this provide an entry point for how windows of opportunity can be endogenized by actors in catching-up countries. Conceptually, we follow up on earlier contributions to TIS studies that elaborated on how TIS functions could be further specified, such as market formation (Dewald and Truffer, 2011), legitimation (Binz et al., 2016a; Markard et al., 2016), entrepreneurial experimentation (Lindholm-Dahlstrand et al., 2018) or the mobilization of resources (Karltorp et al., 2017).

2.3. Endogenizing windows of opportunity through the shaping of selection environments

We propose to analyse the means by which actors may shape the technological trajectories via a systemic perspective that involves all functions of the TIS framework. In order to elaborate how this perspective can be applied to the challenges of latecomer catch-up, we will focus on the function of GS and operationalize it for the specific purpose. GS contributes to the directionality of innovation systems by shaping the selection environments for technological alternatives. This may lead to widening or narrowing the scope of technological variations and deepen or truncate the depth of particular technological developments. GS promises to be particularly instructive when it comes to latecomer leapfrogging as it both allows the agency of specific actors to shape the context in their own interest and considers the limiting influence of the larger social and industrial context by its interdependence with the other system functions. This exemplifies the well-known paradox of embedded agency in understanding how actors can shape institutional contexts, which at the same time structure their actions and rationalities (Battilana et al., 2009; Holm, 1995; Seo and Creed, 2002).

We therefore propose to identify core processes of shaping the selection environment from two streams of literature. On the one hand, we consider government actions for creating directionality through the work of Weber and Rohracher (2012) and Mazzucato (2016). Directionality requires a context that starts with vision building to ensure a collective consensus about the direction to take. This process relies very much on the ability of actors to influence such visions (Weber and Rohracher, 2012). Implementation of policies should then be in line with those visions and shared expectations. Directionality furthermore requires soft instruments (coordination and information) and hard interventions (regulations, policies, standards and funding) to come into play to guide the direction of change (Weber and Rohracher, 2012). Directionality is therefore presumed to be a mainly top-down public policy approach to change and shape technological trajectories into desired directions, which results from the interaction of societal discourses about visions and expectations and ultimately materializes in specific policies and regulations. From a systemic point of view, we want to complement this approach with a more bottom-up perspective on how individual actors can try to shape elements of the selection environment. Different actors can try to influence public discourse and lobby for specific policies or regulations, as well as push for specific preferred technology trajectories directly. One prominent approach is provided by the literature on institutional entrepreneurship (Battilana et al., 2009). It also emphasizes the multi-layered and nested nature of institutional change by asking how actors aim at directly transforming institutions, how they engage in constructing networks and alliances with other actors, and how they engage in the shaping of public visions and discourses.

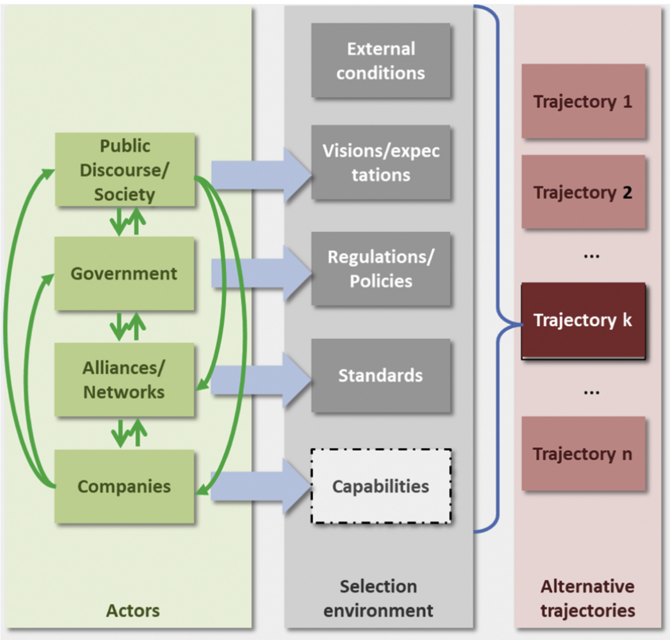

Fig. 1. Guidance of the search emerging from activities by different actors aiming at shaping the selection environment. Note: Blue arrows indicate layers of the selection environment that are presumed to be dominated by specific actors. Green arrows describe influences across different layers. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

We build on these earlier works and combine them into a tentative understanding of the process of shaping sectoral selection environments. We propose to conceptualize a selection environment as a nested set of "layers", which different actors may try to influence directly or indirectly (see Fig. 1). The higher-level layers relate to insights from the directionality literature and address the interplay between broader societal visions, expectations and specific policies and regulations. From the bottom-up perspectives, we relate to organizational capability structures and how actors team up to define binding rules such as technology and product standards (Battilana et al., 2009). The layers depend on each other and represent a partly nested structure of a selection environment. Policies and regulations should be congruent with larger visions and expectations in society. Standards and strategies should be congruent with the legal frameworks, etc. Different actors may address certain layers by specific forms of institutional entrepreneurship. One of the key challenges in attempts to shape the selection environments is the alignment of elements across different layers. The more congruent these elements are, the stronger the effect on the shaping of the technological trajectory. Alignment of the elements is, however, an interest-driven and conflictive process, which cannot be controlled by any actor alone. The ultimate outcome of the alignment process therefore depends in particular on the power balance between the different actors. We posit that in general certain actor groups have greater access to specific layers than other groups. Four areas of agency can be associated with the different layers (see blue arrows in Fig. 1): societal discourses mostly refer to and elaborate visions and expectations; governmental actors are responsible for formulating regulations and policies; industry networks or alliances are often set up to formulate compromises for technical and product standards; and individual organizations have the expertise to develop their internal capability structures.

Following this understanding, GS results from the interplay of actors trying to influence the different layers and fighting for alignment or dissociation of elements that are positioned at different layers. Actors will therefore act as institutional entrepreneurs both directly and indirectly trying to shape and align the layers of the selection environment. The overall formation of GS can therefore be seen as the aggregate outcome of the individual and collective actions by different actors interrelated across the different layers of the selection environment.

Building on insights from directionality, institutional entrepreneurship, catch-up and transition studies, we may now further specify what kind of processes are involved in the shaping of the selection environment. At the most exogenous layer, trajectories of technological development may be influenced by *external forces,* such as external shocks, shifts in relative prices, availability of raw materials or technological bottlenecks. These forces are normally beyond the direct control of individual actors. However, actors may aim to mitigate the influence of these external factors on the technological trajectory by exaggerating or attenuating the perceived urgency of these external developments in societal discourses (see, e.g. Fuenfschilling and Truffer, 2016; Rosenbloom et al., 2016).

Technological trajectories may also be impacted by specific *visions, beliefs and expectations* that particular user groups hold about the future development of a technology. Visions, beliefs and expectations about market potentials or future externalities of new products may directly impact technological trajectories. Visions can be important at the organizational level or collectively at the societal level (Konrad et al., 2012; Van Lente et al., 2013). Expectations held by users and routines are particularly important in shaping technological trajectories. Expectations of users are often shaped by current established routines and practices and therefore represent a strong incentive for incremental innovation in a product field. Industry or policy actors may seek to influence user expectations by, for instance, working on technology legitimation (Binz et al., 2016a).

Regulations do often aim at mitigating environmental or societal externalities caused by the unfettered development of a technology. Companies or research institutes will be encouraged by these regulations to discontinue technological variants that show higher levels of externalities and move towards less impacting designs. *Policies* can reduce barriers to innovations (Ruby, 2015). Financial incentives to innovate (e.g. tax exemptions) can stimulate actors' interest in developing a technology further, whereas the innovative work has to be funded by internal or external financing of R&D and/or the supply of venture capital (Rickne, 2001). Non-financial incentives include enhancement of positive reputations.

Standards can provide different learning opportunities to firm and non-firm actors, especially in latecomer contexts (Pietrobelli and Rabellotti, 2009). Standards are mostly introduced to guarantee technical specifications of components, materials or end products and for enabling interoperability across interfaces between different technological components. Standardization will in general affect the scope of technological variations. For instance, performance standards that pose demands at the technological-architectural level encourage systemic innovations, and prescriptive standards encourage product innovation at the component level. A particular form of standardization is achieved when a dominant design emerges in an industry. Its establishment typically leads to a radical narrowing of technological variations, which then may lead to a shakeout of firms (Klepper, 2002). Both regulations and standards lead to a narrowing of technological variation, but they are also preconditions for reaping economies of scale and ensuring stable market conditions. GS can take place when powerful actors in an industry gather and agree on internal standards and framework conditions. Specific associations or consortia are an organizational form that is often chosen to institutionalize these arrangements (Musiolik et al., 2012). Although the desired standards have not been officially formalized, the existence of associations or consortia can serve as a kind of pressure on other players in the industry, as they can reap early network externalities or shape expectations of users and non-profit organizations.

Finally, the development of trajectories also relies on prevailing *technological capabilities* in firms. Often, firms choose to further invest and develop a particular technology if the firm itself has accumulated competence and expertise in that realm. Having a competitive edge in certain capabilities compared to other industrial players provides the firm with higher possibilities to succeed in that field. Meanwhile, the central argument of catch-up studies maintains that the level of capabilities accumulated in firms, e.g. capabilities in R&D, innovations, manufacturing and designing, determine whether a firm can create new frontier products in global markets (Figueiredo, 2008; Lall, 1992; Lee and Malerba, 2017). Since the objective of this paper is to analyse how latecomers draw resources to catch up and leapfrog trajectories from a context that is broader than organizational capabilities, the paper will focus on the highlighted layers of the selection environment depicted in Fig. 1.

Our multi-layered conceptualization of GS provides an encompassing view on how windows of opportunity can be endogenized. So far, catch-up studies have tended to focus on latecomers moving up the GVC ladder and are therefore predominantly concerned with how companies can improve their capability portfolio in order to fit with the specific requirements of existing GVCs. Governments are supposed to support these capability formation processes by providing corresponding education structures, by science, technology and innovation policies, and by providing favourable regulations for attracting foreign direct investments. In general, these strategies are conceived in rather reactive ways in order to accommodate the technological requirements of already established technological trajectories governed by existing GVCs. By focusing on GS as part and parcel of an integrated TIS dynamics, our framework expands the strategic options for all the actors, as it emphasizes the possibility of shaping selection environments that lead to the emergence of new technological options. The different layers of the selection environment emphasize not only capability structures and regulations, but also societal visions, standards, and the interrelatedness of these elements. The GS strategies have to be seen in combination with other functions of the TIS development. This implies, in particular, to engagement in market formation, mobilization of resources, entrepreneurial experimentation and tackling broader legitimacy issues. The resulting systemic perspective enables latecomers to improve conditions for industrial leapfrogging and perhaps even leading the way towards sustainability transitions. The elaborated approach promises, therefore, an overall perspective for latecomers to find strong positions in newly emerging GVCs.

2.4. Methods

In order to illustrate how the shaping processes may play out in empirical cases, we will in the following section analyse the emergence of MBR as the dominant technology in China's UWM focusing on processes of GS in shaping the selection environment of this sector. The analysis draws on a series of 44 semi-structured interviews with key informants of different stakeholder groups in China's UWM sector. An interview guideline was prepared beforehand, which starts with general questions that help us reconstruct the MBR TIS development process in China, followed by specific questions targeting the different roles of these interviewees in influencing the selection environment of the sector. Interviewee selections began with a scoping study, for which the most important players were identified beforehand based on secondary reports and through an engagement with a water management research group in the Chinese Academy of Sciences, which provided us with an overview of the most influential actors in China's UWM sector. Subsequently, the snowballing method was deployed in order to lead to the most important players that have influenced specific elements and layers in the selection environment in the last 15 years. This includes leading (indigenous and foreign) companies in both MBR and conventional technologies, key incumbent actors of CAS technology to reveal the controversies in the process of MBR exponential growth, policymakers, and key intermediaries (associations, alliances, consultancy firms and Beijing design institute). This was especially crucial to ensure a broad and unbiased source of details collected in this study. Throughout this process, the interview guideline was revised based on the specific roles of the interviewees in the sector and on the new sources of information we received before to ensure more in-depth understanding of particular events that took place. Table A1 in the Appendix lists details of the interviewees and their assigned descriptor codes used in this paper.

All the interviews in this study were recorded, transcribed verbatim and thoroughly checked. The transcriptions were then codified using MaxQDA software by applying a first version of layers of the selection environment. The codes were then refined based on the identified strategies of different actors to influence the selection environment (Gläser and Laudel, 2013; Strauss and Corbin, 1998). In a first round, half a dozen transcripts were codified in parallel by a second researcher and coding strategies were discussed and consolidated. These refined codes were then again aggregated into a hierarchy of codes in order to provide a multi-layered account of shaping the selection environment (Yin, 2011). In this way the tentative conceptual framework was revised and refined in order to match with the data (Yin, 1994, 2011, 2014). To avoid interpretation biases and post hoc rationalization, the information from interviews was further triangulated with government and company annual reports, as well as with secondary data. The final coding scheme of the analysis is provided in the Appendix.

3. China wastewater challenges and the emergence of the MBR TIS

Over the past four decades, China underwent tremendous transformations in its UWM sector through its search for innovative solutions for water shortage, water pollution and unsafe drinking water. Generally, public discourse is running high on how the nation is dealing with its water resources. Among different segments of the national management of water, the growth of wastewater treatment systems has played a crucial role in mitigating problems of water shortage over the years. The Chinese government injected huge financial resources to build plants that treat household and industrial wastewater. At the same time, the government strategically connected this sector with the nation's economic and industrial catch-up policies.

Over the past ten years, there has been a fundamental shift among policymakers, water utilities, industrial technological companies, design institutes, engineering consultancies, and academic researchers in the preferred technology implemented in wastewater treatment plants, from the established global technological standard CAS to frontier technologies building on MBR modules. However, the emergence of this preference was controversial. Incumbent actors mostly argued about the immature, risky and expensive nature of this new technology and applied different forms of institutional work to maintain the established standards that were once supported by the Chinese government and are still predominant in the international professional community (the global regime, so to speak; see Fuenfschilling and Binz, 2018). Against that background it is all the more remarkable how over the course of one decade the dominant priorities in that sector could be turned around towards achieving world leadership in an otherwise rather conservative sector. In the following, we will use the TIS framework to reconstruct the most salient development phases of the MBR TIS in China. Section 4 then provides a more detailed analysis of GS emerging from the interplay between directionality exercised by governmental organizations and institutional entrepreneurship of leading indigenous companies in shaping the selection environment to promote MBR technology.

The *pre-development phase* of the emerging MBR TIS in China consisted of a number of government-led, isolated research initiatives, mostly focusing on knowledge generation and resource mobilization. Target actors were mostly national universities and research institutes. The first membrane R&D centre was established in 1974 in Tianjin University, assigned by the national government to begin research on membrane-related technologies. A few key universities in China were developing MBR process engineering applications in the 1990s, without the capabilities to produce indigenous membranes.

The late 1990s marked the *first development phase of the MBR TIS*, characterized by a massive expansion of resources, first attempts at entrepreneurial experimentation and a broadening of the actor base. Around the year 2000, the government approved a national project, the 863 Project, which financed three membrane development projects. Two small-scale MBR plants were operated by researchers from Tsinghua University and the Research Center for Eco-Environmental Sciences (RCEES), Chinese Academy of Sciences. Meanwhile, Tsinghua University was also operating a small-scale MBR plant for hospital use. At that time, there were doubts about the practical applications of MBR and the preferred choice for wastewater plants was still CAS. In the early 2000s, Tsinghua University established the Membrane Technology R&D Centre through a joint collaboration with the then new start-up Origin Water (which later became the unchallenged leader of the Chinese MBR industry) and a foreign company, Mitsubishi, with the hope of commercializing MBR. While the wastewater operators retained major doubts about the feasibility of MBR, the founder of Origin Water had strong faith in the potential of MBR technology. The company built up the relevant capabilities, in particular in the form of hollow-fibre membranes. Together with Tsinghua University, the trial projects of Origin Water started with small-scale decentralized treatment plants for households (Binz et al., 2016b). At around the same time (2000–2003), Tianjin University spun off its first MBR company.

From 2004, the MBR TIS proceeded to the *second development phase*, which experienced increasing institutionalization of the system with a growing focus on knowledge diffusion, early forms of market formation and a massive scaling of corporate ventures. The country experienced rapid growth in petro-chemical industries, which led to an increase in wastewater discharge standards for these industries. There were continuous new records of mid-scale MBR plants going into operation. At that time, new industry consortia emerged such as the one between

Shanghai Institute of Applied Physics (SINAP), Membrane Tech Co., Ltd and Shanghai Tongji University, who were the first to develop flat-sheet membrane materials in China. Meanwhile, Tianjin University pioneered the development of 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.

Following establishment of the Membrane Technology R&D Centre, the first large-scale MBR plant was built and began operations in 2006 for Beijing 2008 Olympic Games using the process design of Tsinghua University, Origin Water and Mitsubishi. It was the largest MBR plant in Asia at that time and attracted the interest of many experts. At the same time, Origin Water also built the first water reclamation plant. Subsequently, three consecutive annual training courses were organized by Tsinghua University to enhance the understanding of MBR applications and designs, which led companies to seek collaborations with the university. During this period, locally produced membranes were still of low quality and therefore most membranes were sourced from foreign companies. Overall, there was increasing demand for MBR plants including for water reclamation purposes.

Since 2011, China MBR TIS has transitioned to the *third development phase,* which is characterized by exponential growth. In this phase market formation has played a primary role with decreasing prices, a high number of entries into the MBR market and the massive expansion of indigenous production capacity. In 2014, the total built capacity of MBR plants in China was about 3.5 million cubic metres per day, of which Origin Water's daily treatment capacity reached about 3 million cubic metres per day. In 2015, the total treatment capacity of MBR plants in China increased exponentially to 6 million cubic metres per day, with about 85 new MBR projects. As of 2016, Origin Water has achieved a daily treatment capacity of 15 million cubic metres and the total treatment capacity of MBR plants in China was more than 16 million cubic metres per day. With that capacity, the company is currently controlling 8% of the total municipal water discharge of the whole of China (170 million cubic metres per day) and about 90% of the MBR market. In this phase, indigenous companies such as Origin Water have been able to self-produce membranes without reliance on foreign or imported membranes. Prices of membranes began to drop while being produced in higher volumes inside China. As a consequence, not only have indigenous membrane exports increased tremendously, but also many new membrane local producers have entered the field. Newly built or rebuilt wastewater plants in the cities are meanwhile increasingly selecting MBR technologies as their preferred choice. The MBR industry in China arrived at a critical juncture of transformation, in which national and industrial standards are emerging. Since the establishment of the first large-scale MBR wastewater plant in 2006, the industry has accumulated sufficient operating data for practicality evaluations.

Overall, we are witnessing a typical development cycle of a TIS from an early nurturing phase to a bridging phase and more recently even the beginning of a mass market phase (Bergek et al., 2008). Regarding the profile of predominant TIS functions, we also recognize a familiar pattern moving from a knowledge-focused profile to a more entrepreneurial and finally a market-based profile (to read more extensively on the different motors of innovation, see Suurs et al., 2010). This implies that TIS development in the field of MBR has been developing in line with theoretical expectations. What has been less addressed in the literature though is how specific trajectories get selected out of a set of alternatives. To understand how the UWM sector could undergo such a fundamental shift in its core technology, we will therefore have a closer look at how GS emerged across different layers of the selection environment.

4. Endogenizing industrial dominant technology

4.1. Major shifts in the selection environment

The emergence and rapid diffusion of MBR technology was a consequence of a rapidly changing selection environment in the Chinese UWM between the early 2000s and the 2010s. Before this transformation, the dominant technology of China's UWM gravitated heavily towards the internationally established standard of CAS systems, which we will call Selection Environment I. The selection process operated through a conventional top-down governance approach, where the government formulated environmental and industrial policies based on their discretion and following the global state of the art (Fuenfschilling and Binz, 2018). The government delegated the task of assessing and selecting promising technologies to the state-owned design institutes. At that time there were eight design institutes in total inside China, which played a crucial role in leading the selection processes, running feasibility tests for wastewater projects and advising the government or the end users (which were mostly municipal water utilities or industrial water users). These design institutes were especially experienced in engineering designs for the construction of treatment plants and formulated the industrial standards that made CAS seemingly the superior choice. Since design institutes were state-owned, they were also the key to influencing the formulation of regulations and policies in the sector. Industrial firms did not have an important role in the selection process, and they mainly interacted with the design institutes during the project tendering processes. Overall, Selection Environment I was highly bureaucratic, mainly determined by the design institutes, Ministry of Housing and Urban–Rural Development and the Ministry of Environmental Protection. Over the years, however, design institutes experienced diminishing power as a consequence of a general development in the Chinese industrial policy that aimed at privileging market-oriented approaches following the economic reforms in 1978.

At the end of this transformation, the structure of China's UWM selection environment (i.e. Selection Environment II) became much more diverse, featuring new goals such as water recycling and industrial competitiveness. MBR became the dominant choice in UWM projects, especially in the wastewater segment. A first fundamental transformation of the selection environment was associated with the power balance between the different actors. In the late 1990s the Chinese government decided to privatize the design institutes and to delegate decision-making power to leading companies, industry associations and mediators (the newly privatized design institutes, engineering design companies and technical consultants). In the new era, other smaller (private) design institutes also entered the industry. All the design institutes have to compete with other profit-oriented engineering design companies in the market. As a consequence, leading industrial firms gained leeway to influence policymakers directly or indirectly through close coordination with the design institutes or through strategic alliances in the industry.

Concomitantly with the shifting positions of key actors, the key performance criteria for UWM technologies also changed fundamentally. In the earlier stage, wastewater had to be treated according to an international low discharge standard (see Table 1). At the end of the transformation, the selection criteria became much more diverse: wastewater had to comply with very high quality standards that would allow treated wastewater to be recycled for other purposes, such as irrigation. In some contexts, even surface water quality had to be reached in the effluent, which is among the highest discharge standards in the world. New criteria such as end user prices, operational and maintenance costs of the products, and investment and sunk costs also started to play a role. Furthermore, the performance quality and efficiency of the products became a top priority in order for the technology

Table 1
Shifts in structure and content of the UWM selection environment.

	Phase I		Phase II	
Targets of GS intervention	Criteria of the selection environment	Key actors influencing the criteria	Criteria of the selection environment	Key actors influencing the criteria
External conditions			Save on scarce material resources (concrete, steel)	*OW, government*
			Market value of land	*OW, government*
			Lower end-user price	*OW, societal discourses*
			Lower investment or sunk costs	*OW, government*
Visions and expectations	General social welfare (i.e. access to clean water)	*Government*	Social responsibility to mitigate crisis	*societal discourses, government, OW*
			Future vision of clean environment/pure water	*Societal discourses, OW*
			China becoming an industrial world leader	*Societal discourses, government, OW*
			Increasing economic activities	*Societal discourses, government, OW*
			Futuristic image: water reclamation and recycling	*Societal discourses, government, OW*
Policies and regulations	Environmental protection (mitigating water pollution and crisis)	*Government*	Water recycling, water reclamation as score goals	*Government, OW*
	Wastewater treatment for reuse purposes (weak)	*Government*	Turn wastewater into resources by complying to surface water standard	*OW, government*
	Low discharge standards (compared to international average)	*Government*	Very high discharge standards (compared internationally)	*OW, government*
			Economic development: GDP, less developed regions	*Government, OW*
			Innovation and industrialization policy	*Government, OW*
Industry standards	Technical standards focusing on CAS as dominant technology	*Design institutes (delegated by government)*	Technical standards for performance, quality, efficiency, maintenance	*Government, environmental/ industry association, industry alliances*
	Engineering design standards (only applicable to CAS systems)	*Design institutes (delegated by government)*	Engineering design standards (new standards to accommodate MBR system)	*Strategic committee (Tsinghua University, OW, privatized design institute)*
			Materials and product standards for quality, not limiting innovations but increasing competition	*Informal coalition and formal MBR alliance (OW, design institutes, specialized companies, competitors)*

Note: OW – Origin Water.

to be profitable to different parties in the system. On a more symbolic level, wastewater was connected to regional development goals, such as adding market value to land and bringing benefits to less developed regions. Last but not least, the UWM sector was expected to host innovation capabilities and become an industrial export base for the country.

We see that the selection environment experienced a rapid and strong extension in terms of societal goals to be fulfilled. As a consequence, MBR technology appeared as the superior solution compared to the internationally established dominant design of CAS. How could such a fundamental shift happen so quickly in a rather conservative infrastructure sector such as UWM?

4.2. Shaping different elements of the selection environment

In order to understand how the transformation from Selection Environment I to II took place, we have to analyse how different actors have tried to influence various elements across the different layers of the selection environment. A number of controversies emerged among the professionals in government, industrial players, and research and academia. We will first elaborate the GS process in shaping the layers of higher-level supportive context, i.e. broader societal visions and expectations, as well as policies and regulations. Second, we will elaborate on the layers of industrial-level standards that supported the alignment and maturation within the industry itself. In all these layers, the simultaneous role of both top-down directionality and bottom-up institutional entrepreneurship were crucial to ensure GS in the innovation system.

4.2.1. Shaping a broader-level supportive context: visions, policies and regulations

The selected dominant technologies generally have to respond to broad societal concerns. The government and the industrial actors therefore have to align their strategies in congruence with major public discourses. At *the level of visions* (Fig. 1), the Chinese public is concerned with two main discourses: environmental sustainability and economic development. Specifically, the country's water crisis resonates with public concerns through impacts from water shortage, water pollution and unsafe drinking water. These concerns were combined with another national priority of supporting high-tech industries. At the beginning of the transformation, the UWM sector considered MBR as highly doubtful technology. When building the infrastructures for Beijing 2008 Olympic Games, the Chinese government had an ambition to build highly advanced systems to impress the world. In that context, Origin Water was able to convince the government that MBR was a globally advanced and innovative treatment technology. It finally won the bid to complete the first large-scale MBR plant in Beijing.

Targeting high-tech solutions, the government aimed to develop indigenous innovative firms in the UWM sector. This provided advantageous to MBR development, as Origin Water positioned MBR as fundamentally building on R&D (AC/PE8). MBR furthermore resonated with the government's vision, maintained since the early 2000s, of 'returning pure and natural water', which also coincided with the company's name (IN/DI2). Following its corporate tagline – "Undertaking social responsibilities, constructing ecological civilization" – Origin Water positioned itself as the 'hope' of the country (IN/DI2) for tackling the water crisis. During a later stage, Origin Water also advertised the contribution of general environmental protection projects to economic development and their positive impact on gross domestic product (GDP). It was expected that these projects could bring up to RMB10 billion per year for China (DTC14,15). Origin Water claimed that water recycling could turn the fate of less developed regions from facing water shortage to the ability to recycle wastewater (DTC14,15). In recent years, after successfully positioning Beijing as a city that showcased advanced MBR treatment plants, Origin Water began to push the water-recycling concept to provinces in the north of China such as Xinjiang and Inner Mongolia. It also called its MBR systems water-recycling plants instead of wastewater plants in order to create an expectation of receiving a source of clean water (DTC14,15).

In its *regulations and policies*, the development of the MBR industry in China was mostly aligned with broader environmental, economic and industrial policies of the country. Conforming to the dual vision of achieving environmental protection and national high-tech industries, the government involved mainly indigenous companies with large-scale operations such as Origin Water for formulating water discharge standards. Origin Water had also proactively sought to influence the formulation of discharge standards in this process (DTC14). Companies with high technological potential but smaller projects were frequently not invited to the relevant meetings (FTC6). According to the 12th Five Year Plan (FYP) (2011–15), wastewater plants that were implementing the Class 2 discharge standard had to meet the Class 1B discharge standard (a higher standard for effluent) by the end of the 12th FYP, and certain selected areas had to meet the Class 1 A discharge standard (an even more stringent quality) or higher (DTC14,15). Because of this, dissatisfaction emerged in professional society as China's environmental policies included elements that indirectly promoted the use of high-tech solutions for conserving the environment (AC/PE7; IN/DI2). It became unclear whether the government's agenda actually lay in environmental protection or in growing high-tech industries. Many professionals think that the discharge standards have increased to an inappropriate level (IN/AS; AC/PE4; AC/PE7; PE3; IN/DI1) and that solving environmental issues via industrialization strategies is not feasible in the long term (IN/AS). Furthermore, regions that faced water shortage were forced to achieve at least 10% of reclamation rate from wastewater treatment in 2015. To ensure fulfilment of this target, the government issued a series of environmental regulations on water reclamation, which provided new application opportunities for MBR in China. Before the end of the 12th FYP, the State Council of China released the "Opinions on Strengthening the Construction of Urban Infrastructure" (National Law [2013] no.36) in 2013, stating specifically the need to ensure that the effluents of urban wastewater plants met the new requirements of the national water discharge standards or surface water, i.e. level IV (the standard used for surface water) to eliminate level V (a lower standard) type of water. The level IV standard of surface water is expected to be higher than the class 1 A discharge standard described above. In one of Origin Water's influential reports to the government in 2014 – the Situation, Analysis and Countermeasure Report of China Water Problems – Origin Water emphasized the importance of water reclamation in responding to the national goals of the 12th FYP, which included achieving 98% of wastewater treatment in Beijing (DTC14,15). The report served as an important reference point for the government in formulating water discharge standards and planning for wastewater plants in cities.

Since the release of the State Council's new requirement for water discharge standards in 2013, Origin Water argued that MBR technology was the only option able to meet the surface water level IV standard, a detrimental threat to CAS, which would not be able to deliver on these criteria. In its 2014 countermeasure report to the government, the company contrasted the effluent quality of MBR and CAS. It was claimed in the report that conventional water treatment options were only able to reach Class 1 A discharge standard whereas the MBR treatment could meet the surface water IV standard (DTC14,15). Origin Water also stressed in the report that it was critical to "increase the speed of eliminating obsolete technologies, to improve the quality of natural resources and to benefit the livelihood of people". In September 2014, the first "new water resource centre" was realized in Beijing at Chui Hu as a demonstration project, with a treatment capacity of 20,000 cubic metres/day using the new technology of Origin Water (i.e. MBR + Duraflow membrane) (DTC14,15). The effluent met the surface water level IV standard.

As policies were increasingly formulated in favour of the MBR industry, there were increasing disputes in the industry over the governmental preferences for MBR. Origin Water played a crucial role in justifying the rationality of choosing MBR over conventional treatments and alternative solutions in its reports. Therefore, Origin Water also tried to influence the technology selection process of the government by drawing on financial or economic factors. While incumbent actors of CAS argued that MBR suffered from the disadvantage of higher investment and operation costs compared to CAS, Origin Water argued that 70% of the cost structure of CAS was for civil engineering, which covered low technology and depended on scarce and increasingly expensive resources such as steel, land and cement; on the other hand, only 30% of a MBR plant was for civil engineering and 70% of the cost was for manufacturing equipment (AC/PE3). The cost of MBR equipment would, however, be likely to profit from the effects of a learning curve due to ongoing innovations. This would eventually lead to a point where both methods could be offered at the same cost, while MBR would still provide higher quality (AC/PE3; DTC14,15). CAS would furthermore occupy twice as much land. As of 2014, the construction investment cost for MBR plants was approximately RMB2,000 per tonne, whereas the respective cost for CAS plants reached approximately RMB1,800 per tonne (DTC14,15).

These critiques notwithstanding, MBR moved increasingly centre stage in Chinese public policy for the UWM sector. Finally, in the realm of *innovation and industry* policy, the Chinese government specified the "Technical Policy on Municipal Water Reclamation 2006" which showcased the government's interest in the R&D, marketing and promotion of membrane-related technologies in the wastewater industry. In 2010, the government issued the "Policy for Nurturing New and Strategic Industries", which identified high-tech membrane materials as one of the strategic new industries for the country (IN/DI1). In 2011, the Science and Technological Development Plan under the National 12th FYP increased the use of indigenously produced membranes by more than 30% in China. The government stated its ambition to industrialize these technologies and to build a consortium-like group of national industry champions that would be highly capable in membrane technologies. In June 2012, the Energy Saving and Environmental Protection Industry Development Plan under the 12th FYP stated "focus on capturing the MBR technical equipment industry" and "focus on R&D and industrialization of demonstrating or experimenting membrane materials". In September 2012, the Ministry of Science and Technology released the "High Performance Membrane Material Science & Technology Development 12th FYP Special Plan", which stated the ambition of nurturing 'leading enterprises/tycoons' in China, to have more than 10 membrane companies listed on China's stock market. Furthermore, several agglomeration areas of the membrane industry were laid out in order to support industrial clusters in that technology. In this context, Origin Water and its allied partners were successful in convincing the government that MBR was a highly innovative technology and deserved high investment from the government to incentivize MBR R&D and to build MBR plants for wastewater (AC/PE8; DTC14,15). Using the new concepts of water reclamation and recycling, Origin Water furthermore proved to the government the company's technological success compared to incumbent foreign companies. The company led ahead of MNCs such GE, Mitsubishi and Kubota in terms of their technological performance. With those results, Origin Water presented Chinese indigenous MBR products as world leading and showing promising potential to the government for future profitable exports.

How can we interpret these activities and processes in more conceptual terms relating to our framework of actors shaping the selection environment? First of all, we can see that both the government and key industry actors played a critical role in shaping visions, policies and regulations. Societal visions and expectations opened up a broad field for the MBR companies to redefine the core mission of the water sector. This has not been a trivial case, as UWM is *per se* dealing with solving an environmental problem, namely cleaning polluted waters. Regarding environmental regulations and policies, the government was inclined to implement higher water discharge standards. However, it was only after implementing the highest standards, compared internationally, that MBR gained a strong advantage over its competitors. In its innovation and industry policy, the Chinese government was basically in favour of promoting indigenous high-tech industries. However, this did not automatically make MBR the new dominant choice in the wastewater treatment industry. It was therefore crucial to combine the two arguments of environmental superiority and high export potential in order to convince the Chinese UWM sector to implement an immature, internationally not well established and also more costly alternative.

The shaping of the higher layers of the selection environment in Chinese UWM has therefore to be seen as a co-construction by government and leading actors in the industry. Neither of the parties would have been able to steer this process on its own and only through their interaction was a trajectory chosen that was radically different compared to most other countries in the world. We also see that arguments of industrial leapfrogging and sustainability transitions supported each other in the course of the process and led to a fundamental transformation of the societal position of alternative technological options. CAS, which represents the global standard in UWM, suddenly became framed as an old and poorly performing rival of the new "sustainable" alternative.

4.2.2. *Shaping industrial-level standards*

The fundamental change in the selection environment can, however, be explained not only by changes in visions, regulations and policies. As MBR represented a still immature industry, actors had to invest substantially in order to contribute to industry maturation, for which the shaping of the selection environment proved crucial. We will elaborate below how different standards contributed to industry maturation. We report standards at three levels: (1) technical performance and design standards, which ensure the quality and efficiency of MBR systems; (2) engineering design standards, which lay out how MBR plants should be accommodated into the existing centralized treatment plants; and (3) material and product standards, which specify the required sizes, measurements or materials of particular MBR systems (DTC14,15). While the Chinese government formally led and approved standards, advanced industrial actors played a crucial role in initiating many of the processes and in navigating the standardization outcome through formal and informal power alliances in their industrial networks.

The promise of the first large-scale MBR project for the Beijing Olympic Games steered government interest towards the MBR industry (IN/SC). To ensure *performance, quality and efficiency*, the state government of China issued the Catalogue of Environmental Protection Industry Equipment Encouraged by the State in 2007, which defined the first national design criteria for MBR systems in China. It encompassed technical standards on effluent water quality, operation flux, water-recycling rate, membrane and system operation lifetime, and design guidelines for wastewater reuse projects. In 2008, the

Environmental Protection Ministry proposed the formulation of Aerobic Biological Wastewater Treatment Technology Standard – MBR Standard (DTC16), for which China Association of Environmental Protection Industry drafted the preliminary version. Other participants in the drafting process were Jiangxi JDL Environmental Protection R&D Centre and three companies, Origin Water, Hangzhou Ming Qing Environmental Protection Company and Huizhou Xiongyuebao Environment and Technology (DTC16). As the MBR industry progressed in China, more advanced standards for membrane fouling lifetime, porosity and energy consumption were, however, not yet introduced.

Having experienced exponential growth and gaining substantial influence in the industry, Origin Water began to initiate the formulation of MBR *engineering design standards* for municipal wastewater plants from late 2014. In Selection Environment I, traditional design institutes were generally not familiar with accommodating MBR plants in engineering construction designs (IN/DI1,2; DTC14,15). It was a major hindrance to all players in the industry to apply MBR technology in wastewater systems. Origin Water strategically "internalized" the role of design institutes by acquiring a few of them and formed strategic networks with large and influential ones since design institutes traditionally played a decisive role in technology selection. By being virtually integrated in the value chain of Origin Water, the design institutes tended to become more favourable towards MBR products. Over the years, Origin Water provided training support for engineering design for MBR plants to external design institutes and those it had acquired (DTC14,15). As the new discharge standards were gradually imposed, in 2015, Origin Water formed a strategic committee with one of the most influential design institutes in China, Beijing General Municipal Design Institute, and the MBR team in Tsinghua University to initiate the formulation of engineering design standards in order to replace the conventional standards, which were still oriented to CAS systems (DTC14,15). However, this process raised discontent in the sector as companies were increasingly gaining presence in influencing the selection process and the role of design institutes was diminishing (IN/DI2). Since market competition emerged, some parties think that the design institutes have lost much of their neutral standing in selecting the best technologies for the UWM sector (IN/AS; IN/DI2).

Gathering the relevant top leaders in a committee to formulate engineering design standards for MBR systems unleashed a decisive push in shaping MBR as the dominant choice in China wastewater segment. The committee applied to the Ministry of Housing and Urban-Rural Development to initiate the specification of MBR engineering design standards to serve as design guidance when deploying MBR in municipal wastewater treatment systems – the "MBR Design Code for Municipal Wastewater Treatment" (AC/PE8; IN/SC). It was a crucial step to ensure a wider adoption of MBR systems, specifically focusing on the combination of the biological process with membranes. The standardization process arrived at the final stage of inspection in 2016 and the outcome of the standards will work as official references to different actors in the MBR industry (IN/SC).

In terms of *materials and product standards*, Tianjin University pioneered the formulation of China's national standards for membrane materials in 2006. These standards were applicable to a number of membrane-related technologies and marked the beginning of the nation's focus on indigenous capabilities in membrane materials. However, a decade since the first membrane material standards were formulated, they are now deemed less rigorous and rather common (AC/PE8, IN/SC). In terms of *product standards*, most of the MBR suppliers in China have their own products, and each supplier has its own product measurements and sizes. There was therefore no official materials and product standard for MBR technology in China before 2016.

Since the industry standards in place for China's MBR were insufficient to ensure that performance and quality were comparable to the established system, Origin Water had begun proactively promoting the need for a level of product standardization to overcome the current limitations of the technology. The government supported that initiative because more stringent materials and product standards could be expected to lead to an indigenous MBR industry with higher-quality products. As the products in the MBR industry vary in different companies, it is difficult to streamline their performance standards. However, as more and more companies entered the MBR industry, the quality of products varied and poor performance sometimes caused public disputes over MBR disadvantages. Moreover, without setting minimal requirements, products of Origin Water could be easily replaced by products of smaller or new companies offered at a lower price (DTC14,15). To secure its first-mover position in the MBR municipal market, Origin Water dedicated much effort into advocating the need to improve the performance of MBR systems. Specific examples are minimal quality requirements of membrane materials and membrane modules, and energy consumption level. Most of these standards are formulated by the Ministry of Environmental Protection in China. Origin Water strategically leveraged these conditions to propose the need for official MBR materials and product standards in the country.

However, the industry is also confronting some difficult trade-offs in its product standardization strategies, as overly precise standards could pose limitations to innovations (DTC14,15). It is controversial that MBR materials and product standards are emerging in China under the discretion of the government. Some parties think that having standardized MBR modules (with specific sizes and measurements) will limit the innovative capacity of industry players, which is critical to the future practicability of MBR (AC/PE8; IN/DI2). It is also perceived that current MBR materials and product standards work in favour of large companies such as Origin Water (IN/DI2; DTC12; DTC17), and smaller companies have difficulties in reaching the standards. Therefore, materials and product standards will lead to a further monopolization of the industry (IN/DI2). Actors agreeing with the standardization process, however, emphasize that materials and product standards will ensure the high quality of China's indigenous MBR products in the market and lead to higher export potential, as technical standards serve as reference points to increase product substitutability and induce competitive innovations that eventually eliminate monopolistic markets (IN/DI1; DTC14,15; AC/PE8). Therefore, Origin Water formed an *informal coalition* with a few large design institutes, including Beijing General Municipal Design Institute, in order to formulate materials and product standards for MBR at the appropriate level to ensure there is enough room left for innovations (IN/DI1,2; AC/PE8; DTC14,15).

At a more general level, alliances had also been important in positioning MBR products relative to MBRs main competitors. To establish the position of MBR products in a hostile environment dominated by pro-CAS actors, Origin Water sourced critical representatives in the MBR value chain and created a *formal MBR alliance*, including design institutes, engineering design companies, research universities, suppliers and buyers, as well as competitors in the flatsheet membrane TIS. The role of the MBR alliance is to convince the government of their abilities to generate innovative activities across the value chain that will solve technological bottlenecks such as high-energy consumption and high operation costs (DTC14,15). It also provides the members a certain formal status or privilege in project-tendering processes since it indicates that the adoption of MBR products will benefit all actors in the value chain and not just Origin Water (DTC12). Moreover, the alliance has gathered specialized expertise and provided a reputable status to all its members in countering public controversies and industrial disputes.

Rephrasing these shaping processes in more conceptual terms, we can say that institutional entrepreneurship was critical in promoting the maturation of the emerging MBR industry. The process of formulating engineering design standards gave rise to the strategic committee,

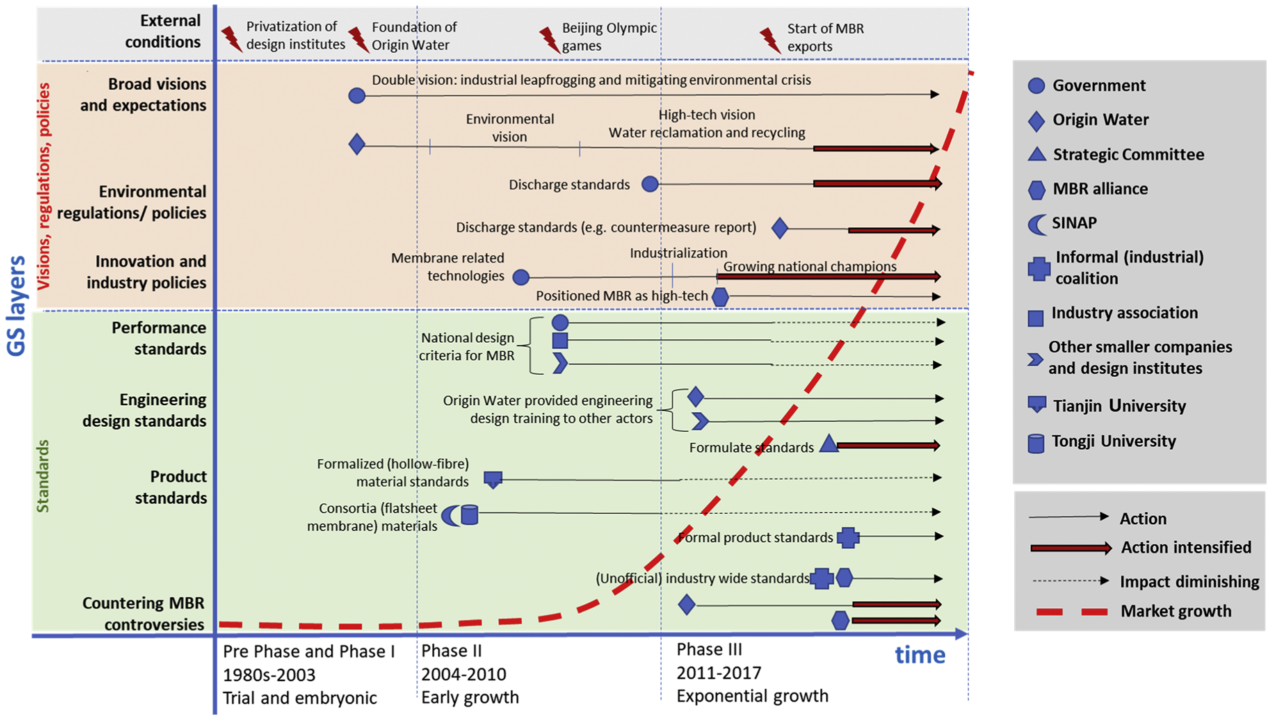

Fig. 2. Temporal sequence of the events leading to the dominance of MBR in the Chinese UWM sector.

which besides Origin Water encompassed Tsinghua University and a design institute as major players. The international reputation of the MBR research team in Tsinghua University and its contribution to the country's commercialization of MBR made the standardization process appear much more convincing to the government. On the other hand, the informal coalition was actively driving and formulating materials and product standards. Both the informal alliance and the formal MBR alliance played a crucial role in guiding other players in the industry. The formal and informal technical standards served as the reference points for corporate strategies and for the smaller industry players. The leading company Origin Water alongside the strategic committee, the informal coalition and the MBR alliance, would not have been able to shape the emerging engineering design and product standards and provide recognized industry-wide reference points, if the Chinese government had not delegated sufficient leeway for them to participate in steering the processes. The aggregated efforts across these different layers of the selection environment ultimately led the MBR industry to develop and mature, enabling it to cash on to the high level expectations that had been raised regarding environmental performance and export potential of this technological alternative. Table 1 summarizes the findings in this section in terms of the major elements (i.e. the resultant criteria) in the different layers of China's UWM selection environment. Fig. 2 summarizes the temporal sequence of the major events.

5. Discussion

The increasing predominance of MBR technology in the Chinese UWM sector was a result of interrelated GS strategies of government and several key actors (leading company Origin Water, design institutes, engineering design companies, associations and alliances). The Chinese government formulated the country's environmental, industrial and development policies in a top-down mode according to broader-level societal visions and expectations. Conforming to the dual national strategy, the government was easily attracted to the promises presented by actors promoting MBR and subsequently provided increasing support for the technology. The government's selection process in formulating regulations and policies was then increasingly influenced by bottom-up institutional entrepreneurship strategies initiated by different industrial actors. At the same time, the MBR actors had to accommodate the rapid development needs of the industry by building up the different TIS structures and functions. We elaborated in particular how the different layers of the selection environment were shaped through GS activities and how the actors managed to formulate an increasingly well-aligned structure of the selection environment. This shifted the core of the socio-technical configuration of the sector structure: a new dominant design of the treatment plants, much higher performance standards in water quality, a shift in the core mission of the sector from treating wastewater to recycling "useful" water, etc.

The seemingly linear development and reconfiguration process that we have reconstructed in Section 4, however, did not include a number of complexities that accompanied the transformation process. In particular, the actual MBR trajectory that we saw developing came at the expense of alternative routes not taken, which would potentially have increased the ultimate sustainability of the whole transformation process. While the primary competition was between MBR and CAS, another competing trajectory was between centralized and decentralized applications of MBR technology. The actors promoting MBR ultimately opted for adding the membrane modules to existing centralized treatment plants. This led to an incremental change in the technological core of the UWM sector. One of the key elements of the current socio-technical regime, the highly water-intensive system of sewers to collect the wastewater and transport it over long distances, was not challenged by this strategy. An alternative route would have been to apply MBR modules in decentralized water treatment systems. This would have led to more radical sectoral transformation pathways emphasizing short water cycles and getting rid of expensive sewer infrastructures (Larsen et al., 2016). Therefore, some commentators claim that the currently emerging trajectory will primarily reinforce existing path dependencies and lead to a less sustainable urban water sector in the future, despite all the strong environmental claims that were advanced in the process. Interestingly, Origin Water started manufacturing and installing decentralized MBR systems in the early stages of the industry formation (Binz et al., 2016b). Only later did they decide to turn to centralized applications, because this promised higher growth rates and returns. Also, it enabled Origin Water to argue for a faster transition to present itself as a high-tech industry with big environmental impact due to higher scales in centralized systems. The actual developments can therefore be seen as a reconfiguration pathway rather than a more radical de- and re-alignment transition, which would have happened if the decentralized option had been chosen (Geels and Schot, 2007). Another alternative trajectory relates to Origin Water's preference for hollow-fibre membranes in local municipal wastewater treatment plants instead of flatsheet membranes, which had proven very successful in industrial wastewater treatment applications. This led ultimately to two diverging trajectories within China MBR industry, as Chinese flatsheet membrane companies were forced to leave the municipal market but quickly became successful in exporting to foreign markets.

We may now turn to our original question of what latecomers can do to position themselves in new technological trajectories while engaging with sustainability transitions. Based on the conceptual approach presented in this paper, we can reformulate this question as: how can different actors in latecomer countries enact a broader set of strategies oriented towards the shaping of selection environments? Instead of 'responding' to exogenously appearing windows of opportunity, latecomers can try to proactively translate the imminent global challenges and opportunities into the characteristics of the selection environment of corresponding sectors. Instead of primarily focusing on technologies and manufacturing, the endogenization process should consider entire socio-technical systems. As our analysis showed, China UWM actors endogenized the rather vague window of opportunity of the global water crisis by formulating a whole interrelated set of (partly radically) new visions, expectations, policies, regulations and technology standards. The processes of GS, as part and parcel of broader TIS development, offered a systemic perspective on how windows of opportunity can be endogenized. The approach suggests a wider portfolio of strategies for a multitude of actors. The different layers of the selection environment may serve as target actions for key actors aiming for industrial leapfrogging and sustainability transitions. Emphasis has, furthermore, to be put on the alignment of the different elements across different layers.

How can we assess the transformations that we had reported for China's UWM sector in terms of leapfrogging and sustainability transitions? We maintain that the enactment of the GS processes led potentially to successful industrial leapfrogging of the indigenous MBR industry. The leading company Origin Water grew exponentially and contributed to the emergence of a whole MBR industry. Through the building up of technological competences and even more because of the accumulation of experiences in deploying the technology on a large scale, it managed to become a leader in the field of water recycling and water reclamation technologies. The opportunity to implement a vast number of large-scale projects provided Origin Water with key advantages for becoming a global leader in the industry. Deep financial resources from large-scale projects and accumulated experience in operating MBR plants provided the company with sufficient testbed opportunities and platforms to revise its MBR systems and to feed these lessons back to its R&D. As a consequence, Origin Water has outperformed advanced MNCs such as Mitsubishi, General Electrics (GE) and Siemens within China's domestic market. The monopolistic dominance of Origin Water in the MBR market has pushed these MNCs to withdraw from the intense competition in the industry in China. Without having a say in the development trajectory of the industry, GE and Siemens aborted this business segment in China although they initially set up their MBR business in China in order to tap the local emerging markets. Based on this indigenous advantage, Origin Water has recently started to export its MBR products to a number of countries, including Australia, Russia and the Philippines. These products are now reckoned as world leading, arguably more competitive than incumbent MNCs in the global MBR industry in terms of technological performance, innovation and costs. Supplying MBR systems that fulfil one of the highest discharge standards and solve one of the most complex water issues in the world provides the Chinese companies with a hard-to-copy competitive advantage in global markets. Since China now exemplifies a developing country that is seemingly successful in implementing a more advanced technology for its wastewater treatment systems, it may pave the way for other developing countries that are challenged by similar threats to follow the same trajectory. We may conclude, therefore, that leading industry actors jointly with the Chinese government had managed to successfully embark on an industrial leapfrogging trajectory for future water treatment technologies.

The case of China's UWM sector also partly shows that in order to be successful in leapfrogging, it is not sufficient to focus only on the innovation and manufacturing of the core technology. Rather, the transition of the entire socio-technical system has to be envisaged. Concomitantly with the core technology (i.e. MBR), the entire institutional context had to be reformulated quite fundamentally in terms of visions, performance targets, standards, the core organizational structure of the sector, and the power relationships between the major actors. However, this fundamental restructuring of the socio-technical system does not imply that the Chinese UWM sector is actually on a sustainable track yet. The prevailing controversies in the sectors, issues with energy efficiency, the abandonment of the decentralized water systems trajectory, and a still somewhat opaque interaction between government and major industrial actors leave doubts about whether sustainability trade-offs have been taken into account in totality (Yap et al., 2018). We maintain, however, that even if our case only represents a socio-technical transformation with unclear sustainability implications, it encompasses key features and mechanisms that would also come into play in a full-sized sustainability transition.

The case presented bears crucial learning implications for other latecomers, especially middle-income-trapped countries. One important element that has largely been missing in the catch-up literature is that latecomers should focus on aligning socio-technical elements across multiple layers of the selection environments. In other words, it is not sufficient to channel resources only into building capabilities or growing particular indigenous industries. Rather, latecomers should aim at actively ensuring that standards and regulations are congruent with broader-level societal visions and expectations. More often than not, middle-income-trapped countries have abandoned particular catch-up roadmaps because politicians have had to switch agendas when their industrial policies did not resonate with broader-level visions, causing them to lose support from their constituencies. Only when these diverse activities are sufficiently well aligned can the desired development trajectories be influenced and countries gain a leading role in future GVCs. An illustration that this option is open not only to extensive countries such as China but also to smaller countries is the successful globalization of the Danish wind industry as reconstructed by Karnøe and Garud (2012). The case of Denmark in particular shows that a core precondition for successful endogenization of windows of opportunity is a longer-term consistency of industrial policies and strategies of different private actors.

Our case also illustrates the importance of the relative power balance between the State and industry actors. One of the key conditions for enabling the radical transformation in China's MBR industry was the changing role of the state-owned design institutes. Along with this, companies gained more leeway to contribute to standard setting and engaged increasingly in the formulation of broader-level visions. However this process can also be highly risky, as the increasingly dominant role of the leading company Origin Water in the shaping of the MBR trajectory amply illustrated. As a lesson for middle-income trapped countries, we can therefore only point at a core prerequisite for successful endogenization: a well-balanced sharing of roles between different actors has to be institutionalized in order to define potentially successful trajectories. It is beyond the reach of this paper to provide detailed guidance of how this can be achieved. However, our analysis emphasizes that this is one of the key success factors to be analysed in the future. Finally our case also contributes to the recent debate in innovation studies of whether top-down governance (i.e. the role of the State) or bottom-up initiatives (e.g. institutional entrepreneurships) play a more decisive role in addressing societal challenges. The case of China's UWM shows that both are equally decisive and emphasizes that strategic interplay is the key for system-level directionality. A typical reason for unsuccessful catch-up is the failure to grant sufficient room for entrepreneurs to engage in setting technological standards and in formulating visions. Actors therefore might miss out on aligning the different elements of the selection environment for providing clear guidance in the innovation activities of corresponding innovation systems.

6. Conclusion

Latecomer industrial leapfrogging has been a central focus in catch-up studies. The emerging green techno-economic paradigm opens up new windows of opportunity for latecomer strategies. However, latecomers may have to adopt more proactive approaches than have been discussed in the literature so far: they have to seek to endogenize the windows of opportunity. These strategies go beyond building up absorptive capacity or accumulating technological capabilities in latecomers, and rely strongly on the ability to develop entirely new socio-technical systems in order to direct the next generation of global industrial leaderships. While capability accumulation remains a crucial factor, the process of industrial leapfrogging demands latecomers (be it individual industrial actors, networks or policymakers) to be simultaneously proactive in aligning not only a broad variety of elements relating to visions and expectations, regulations, policies and standards, but also new markets and institutional structures (see also Binz and Diaz Anadon, 2018; Boschma et al., 2017; Karnøe and Garud, 2012). In other words, endogenizing windows of opportunity depends on the ability of a broad variety of actors to leverage GS processes in a reflexive and mutually coherent way.

This paper makes an important contribution to existing catch-up studies by detailing how actors in a latecomer context can strategically target different layers of the selection environment. The TIS framework in general provides a systemic perspective in which these strategies can be analysed and reflected, and so possible alternatives that were not identified by conventional catch-up theories can be addressed. For instance, our study highlights the crucial role of latecomer industrial actors in aligning the directions of societal discourse, regulations and policies as well as the industrial development trajectory to shape the dominant socio-technical configuration in a sector. In this context, the conventional target of catch-up studies appears in a new guise: technological capabilities are indeed an important element in the overall selection environment, but they will most often be unable to create new development trajectories if approached in isolation.

We must however admit that the current proposal is not complete. The present paper focuses almost exclusively on strategies that deal directly with the GS function. However, the systemic approach that we start to elaborate would also suggest strategic consideration of other system functions. In particular, the formation of new markets through explicit and innovation-oriented deployment policies, the support of entrepreneurial experimentation through providing spaces for experimenting with entire socio-technical system alternatives, the conscious management of legitimation processes (e.g. by engaging with broader societal discourses about preferred directions of development) and finally the mobilization of resources suggest an even broader portfolio of approaches (see Schot and Steinmüller, 2018 or Weber and Rohracher, 2012 for elaboration of more encompassing innovation policy frameworks aiming at sustainability transitions). In this paper, therefore, we have perhaps been able to identify only an important first stepping stone in this journey.

The Chinese MBR case is an example of how both top-down policies and bottom-up entrepreneurship contribute to the shaping of dominant technological trajectories. This contradicts the commonly held view that China represents an extreme case of a centrally coordinated top-down policy culture and therefore a case too unique to be replicated. The effort of China gradually decentralizing its governance structure can already be witnessed since the country's economic reform during the late 1970s. In the present case study, the privatization of the large design institutes in the 1990s led to more leeway for agency by entrepreneurs. In recent years, we have seen an increasing number of industry formation processes that have been driven by active entrepreneurship in the cleantech sector. A particularly instructive case is the solar photovoltaic (PV) industry. The industrialization process of China PV and its successful catch-up has been argued as critically driven by business entrepreneurs, mostly those that are internationally connected or returnees from abroad (Binz and Diaz Anadon, 2018). These entrepreneurs sought to anchor a broad set of innovation system resources available at the international level into the national industry in order to build up a strong export base in PV. The Chinese government played only a marginal role in these developments (Binz and Diaz Anadon, 2018; Zhang and White, 2016). We therefore posit that the processes of GS that we identified in this paper are not limited to the specific political culture of China but may also be expected to play out in similar ways in other countries.

Finally, our attempt of bringing transition studies into dialogue with catch-up studies has only begun. We hope to have opened up new perspectives for understanding how latecomer industrial leapfrogging can be perceived as a systemic process with endogenized mechanisms of shaping windows of opportunity. The extension of our framework to other TIS functions, as well as the dynamics embedded across multiple system components, provide a promising future research field for latecomer industrial leapfrogging. For transition studies in general and the TIS framework in particular, we have presented a way to relate the frameworks to broader concepts in industrial dynamics such as directionality and institutional entrepreneurship. This is likely to yield new perspectives for sustainability transition studies concerning a globalized context in general or the progress of developing countries in particular.

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Appendix A

Table A1
List of interviewees, 2016.

Stakeholder Group	Interviewees	Code	Expertise (New of 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	Neutral	
	Poten Environment Group	DTC8	New	
	BMEI (2 interviews)	DTC9, DTC10	Neutral	
	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	Neutral	4
	Rehau Polymers (Suzhou) Shanghai Branch	KPSF1	New	
	Shanghai Alfa Flow Control	KPSF2	Neutral	
	Tacwell Engineering	KPSF3	Neutral	
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.

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