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Technology-Driven Transition in Urban Food Production Practices: A Case Study of Shanghai

Mohsen Hosseinifarhangi ^{1,*}, Margherita E. Turvani ¹, Arnold van der Valk ² and Gerrit J. Carsjens ²

¹ Department of Architecture and Arts, University IUAV of Venice, 30135 Venice, Italy; margheri@iuav.it

² Landscape Architecture and Spatial Planning group, Wageningen University & Research; P.O. Box 47, 6700 AA Wageningen, The Netherlands; arnold.vandervalk@wur.nl (A.v.d.V.); gerrit-jan.carsjens@wur.nl (G.J.C.)

* Correspondence: s.hosseinifarhangi@stud.iuav.it; Tel.: +31-682-742-596

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Abstract: The continuing decline of arable land per person and global human population growth are raising concerns about food security. Recent advances in horticultural technology (i.e., growing using light-emitting diode (LED) lighting, hydroponics, vertical farming, and controlled environments) have changed the ways in which vegetables can be produced and supplied. The emerging technology makes it possible to produce more food using fewer resources, independent of the weather and the need for land. They allow bringing agricultural practices inside urban built up spaces and making horticultural production an integrated part of the daily life of urban residents. However, the process and consequences of this technology-driven transition on urban planning and development are hardly understood. This paper uses the theory of multi-level perspective (MLP) on sustainability transitions and actor–network theory (ANT) to explore this technology-driven transition and its adoption in urban planning and development. The high-tech horticulture zone development in Shanghai was used as a case study. The results show the importance of both social (i.e., policymakers and planners) and material (i.e., technologies and policy documents) actants in the transition of the sociotechnical regime. Furthermore, the transition toward sustainable urban horticulture practices requires the simultaneous preparation of supportive and compatible spatial development, agricultural and sustainable development policies, and adequate policy implementation and evaluation tools to increase the competitive strength of innovative practices.

Keywords: technology driven transition; actor–network theory; multi-level perspective; urban planning; high-tech urban agriculture

1. Introduction

The urbanization of China’s population, declining quality of food, rising food prices, growing dependency on food imports, and challenges posed by climate change have forced the Chinese government to put agricultural transformation in its national agenda. Over the last two decades, more than 123,000 square kilometers of China’s farmland were lost due to urbanization [1]. According to China’s Ministry of Environmental Protection, roughly 200,000 square kilometers suffer from soil pollution [2]. Exacerbating the dilemma, megacities like Shanghai, home to nearly 24 million people, are converting agricultural land to urban land for housing development and new infrastructure [3]. As one of most dynamic megacities in the world, Shanghai is actively encouraging innovative solutions to feed its growing population and resolve land-use conflicts [4]. Shanghai’s peri-urban landscape is dominated by small-scale agriculture, typical for China’s agriculture in general. The small family farms are considered as social security for the majority of the residents registered in rural areas of China [5].

However, rapid urban growth is threatening this long-established system, resulting in a significant loss of agricultural land. The Shanghai local government considers high-tech urban agriculture (HTUA) as a promising new approach to produce food for the urban residents. In this study, HTUA is defined as food production practices that use modern technologies and innovative methods (i.e., hydroponics, indoor horticulture, and vertical farming) for food production inside or around cities. It involves the cultivation of crops, as well as harvesting and post-harvest processes, such as packaging, reusing wastes, and distribution of vegetables and herbs. HTUA practices can be nearly 90% more water efficient and yield twenty times more than conventional agriculture [6,7]. The controlled environment systems used in HTUA make food production resilient to climate extremes [8,9]. Additionally, local production eliminates several steps in the vegetable supply chain and reduces carbon pollution due to transportation. The large amount of energy that is consumed to produce plants is considered the main downside of HTUA [10,11]. However, the land and water efficiency and economic viability make HTUA a promising alternative food production practice. Furthermore, technological advancement in energy-efficient lighting systems and the use of clean energies can increase the environmental sustainability of HTUA practices [12].

Agricultural modernization in China has been weak and slow compared with the advancements in the modernization of industry, science, defense, and technology [13]. Economic development has helped large cities to enjoy an abundance of financial resources and a considerable amount of talent, advanced technology, and capital. This favorable setting nurtures massive market demand and leads Chinese megacities to become pioneers in the modernization of national agriculture. Shanghai is an ideal place for the development of HTUA. As in many other metropolitan areas, the price of land tends to be high. This makes building up, as opposed to out, a financially feasible option. Almost half of the vegetables and herbs consumed daily by the residents of Shanghai are leafy greens, such as spinach, kale, bok choy, and watercress, which makes HTUA a promising answer to help feed the rising population [14]. In 1994, the local government of Shanghai, in collaboration with state-owned companies (SOCs) and the Chinese Academy of Agricultural Sciences (CAAS), began developing the Sunqiao modern agriculture zone in a peri-urban area of the city. Development of the Sunqiao zone is the local government's strategy to implement the 12th and 13th national Five-Year Plans and the No. 1 policy documents, which push for technology-driven transitions in the agricultural sector [15]. The main goal in the development of the Sunqiao modern agriculture zone is to position Shanghai as a national and global leader in urban food production. Sunqiao incorporates more than just the creation of farm factories and indoor farms; it provides a robust public realm that merges indoor and outdoor agricultural experiences [3,16].

To understand the institutional barriers and driving forces in technology-driven transitions of urban agriculture practices in Shanghai, this paper studies the technological development and adoption trajectories. It looks at the influence of the interactions of social and material entities and reconfiguration of their relationship on the integration of technologies in urban planning [17–20]. This paper brings together the theory of multi-level perspective (MLP) on sustainability transitions and actor–network theory (ANT) to explore the technology-driven transition toward HTUA in Shanghai and its adoption in urban planning and development. The high-tech horticultural zone development in Shanghai was used as a case study.

2. Contribution of ANT to Sociotechnical Transition Studies

MLP is a framework and theory that conceptualizes overall dynamic patterns in sociotechnical transitions [21–24]. It explains the emergence of new sociotechnical practices as a result of two driving forces, the pressure from the sociotechnical landscape (the exogenous environment of cultural patterns and macrolevel economics and politics) and the alignment of small networks of niche innovations and actors. When both come together, so-called “windows of opportunity” arise for destabilizing existing sociotechnical regimes and a breakthrough of new sociotechnical regimes occurs [24]. There are two reasons that justify the incorporation of ANT into the MLP framework. First, the concept of a niche in

the MLP transition framework ignores the diverse origin of technologies that are adapted and adopted by niche developers [25–27]. A transition towards HTUA and its emergence in urban development projects depends on the incorporation of a range of technologies like growth using light-emitting diode (LED) lighting and hydroponics by several entities in the incumbent regime. The technologies that are adapted and adopted by niche actors need to be distinguished from market niches [25,26]. Niches in MLP are protected spaces that are dominated by bottom-up forces, such as grassroots initiatives and start-ups [24]. However, MLP ignores the interaction between incumbent technology developers within the regime level and actors in the niche level. It also neglects the importance of top-down strategies, such as governmental organized R&D projects for the development of technological novelties at the niche level. Second, the interaction of social and material entities and the attribution of agency in the process of transition are not specified in the MLP framework [22–24]. The MLP is “too descriptive and structural, leaving room for greater analysis of agency” [28] (p. 1492).

This paper proposes a new analytical framework by bringing concepts of ANT into the MLP framework. ANT addresses the interaction between social and material entities over time and space. According to ANT, “the ideas, values and intentions of social actors become inscribed in a technology through interaction [29] (p. 94). The process through which this occurs involves the creation of networks of aligned interests: actors form alliances, enroll other actors, and use non-human actors (artefacts, technologies) to secure their interests. This process embodies the process of the adoption and adaptation of technologies. Incorporation of ANT as a constructive approach has been suggested by Genus and Coles to “show concern for actors and alternative representations that could otherwise remain silent” [30] (p. 1441). ANT is a powerful conceptual tool used to study, analyze, describe, and explain sociotechnical systems and their dynamics. These systems are built up by the interactions between humans, technology, social entities, and organizations, where all of these are considered entities or actants able to build networks of interaction and negotiation. ANT can help to understand the internal processes in the network of actors in the sociotechnical regime and the role of agency of the landscape and niche level actants on destabilizing the existing regime [20,29,31–33].

ANT explains that aligned interests are created by enrolling allies and the translation of their interests such that their participation will lead to a continuation or maintenance of the network. The translation concept of ANT includes: (1) seeking new alliances; (2) enrolling new members or network nodes; (3) employing non-human entities, e.g., computers, buildings, etc., to increase and stabilize the network; and (4) creating and exploiting black boxes. “A black box could be a computer, a car, a television or any other technical object that operates as it should. When this occurs, the complex sociotechnical relationships that constitute it are rendered invisible, or black-boxed” [31] (p. 6). The process by which novelties become a black box in ANT is referred to as punctualization [34].

ANT offers a flat ontology of human and non-human actants. The flat ontology of ANT considers the being-ness of all human and non-human entities to the same degree [35]. The role and importance of actants is evaluated based on their ability to affect another actant or their relationships with others. According to ANT, actants are entities with agency that leave traces and affect the trajectories in a technology-driven transition. However, ANT has been criticized for neglecting the social, political, institutional, and cultural context [36]. The combination of ANT’s flat ontology of human and non-human actants and MLP’s analytical levels allows one to analyze both the attribution of agency and the impact of context on technology driven transition [24].

The transition in urban agriculture practices is a complex phenomenon. The transition process involves many heterogeneous actants and actor-networks that try to reach their goals and primary objectives of transition. The transition is the outcome of interaction between social (i.e., policymakers and planners) and material (i.e., technologies and policy documents) actants. ANT highlights the role of non-human actants, especially technology, in the process of transition [37]. Actor-networks are shaped by the connections or alliances between heterogeneous human and non-human actants. Any actor is considered as strong as its alliances with other actors. These alliances are created through intermediaries, which can be technologies, planning approaches, or policy documents, or any other

actant with agency in a transition process. The role of intermediaries is to bring actants into contact with each other [38–40].

Agricultural practices and urban areas are traditionally two separated actor-networks with few direct and indirect connections between the actors of both networks. Some of the most obvious connections are the consumption of agricultural products by urban residents and the connection between supermarkets/restaurants and farmers/retailers. However, urban agriculture involves well-connected agricultural and urban practices. The characteristics of urban agriculture cannot be explained from the conventional agricultural and urban practices as single entities but are the result of shaping a new actor-network. In high-tech urban agriculture (HTUA) practices regarding the technological aspects will highly affect the characteristics of the new actor-network. As an urban phenomenon, it is important to understand the circumstances of configuration and reconfiguration of material and social actants, including technologies, policy documents and land-use plans, spatial development plans, and decision-makers, and their adoption in urban development projects. The combination of MLP and ANT can be used to investigate the way in which plans and visions for technology push transitions, resulting in the development and adoption of breakthrough technologies by niche developers and the entanglement of new sets of actors and networks in sociotechnical regimes (Figure 1).

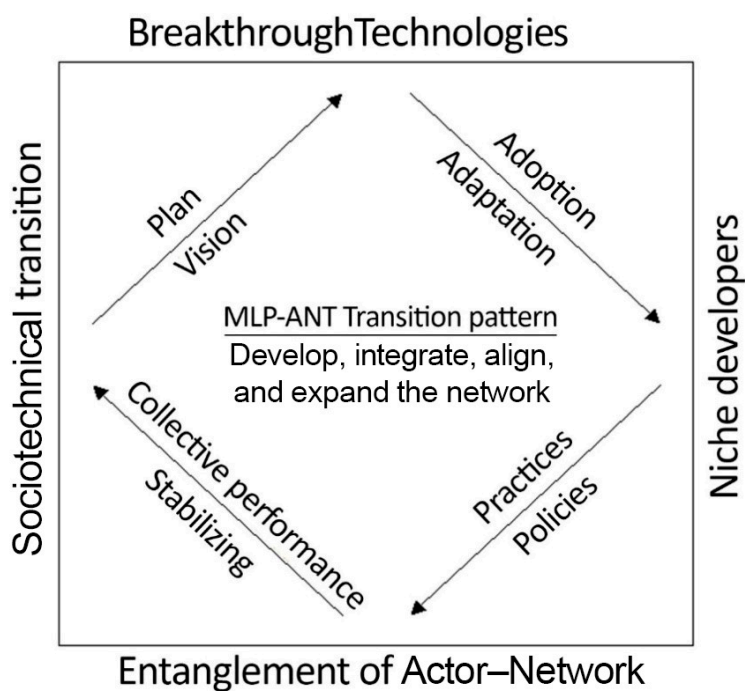


Figure 1. Transition pattern based on actor-network theory (ANT)-multi-level perspective (MLP) theories.

A central element in ANT is the concept of translation [40]. Translation is defined as the creation of a network of aligned interests through negotiation. “Actors form alliances, enrol other actors and use non-human actors (artefacts, technologies) to secure their interests [. . . and] the resulting actor-networks are made up of human and non-human actors” [29] (p. 94). The interaction between human and non-human entities (actants) takes place simultaneously at the different MLP levels. Using the concept of translation in the MLP’s framework, the transition process can be described in three stages: disentanglement, punctualization, and re-entanglement (Figure 2).

2.1. Disentanglement of the Incumbent Regime

The pressure from the landscape can destabilize the incumbent sociotechnical regime. The destabilization of the regime results in the emergence of technological novelties, which tend to make the entities inside the sociotechnical regimes interested in transformation. The influential actants

in technologically driven transitions are niche developers, landscape actants, and the entities within the sociotechnical regime. The identity and role of these entities in the transition is based on preset goals that are defined by core values or focal actants.

2.2. Punctualization Process of Novelties

Technological novelties that have been developed by niche actors aim to transform the sociotechnical regime. Any change in sociotechnical systems will face resistance from incumbent regimes. The resistance of incumbent regimes will create obstacles for the entities that want to achieve a new stability through transformation. The primary entities overcome the resistance in four moments of the punctualization of novelties [40]. In the first moment of problematization, the focal actant in the transition process defines an obligatory passage point for all involved actants. An obligatory passage point is an element that mediates all interactions between actors in a network, which defines the action program. It is set in a way that involved entities, that by passing through it, will be able to overcome their obstacles and will reach preset goals. During the intersement, the second moment of translation, the identity and role of the primary entities in the transition process will be negotiated and defined. The third moment of enrolment answers the question of how the roles are defined and coordinated. It results in a set of strategies for defining and interrelating the roles that are given to heterogeneous actors. In the last moment of mobilization of allies, the focal actants ensure that the representative actors in the network are properly representing society. In this stage spokespersons for all involved entities will be identified [37]. For the creation of aligned interests in the translation process, intermediaries and immutable mobiles will be deployed [40]. Intermediaries circulate between the different actants and define the relationships between them. Intermediaries can take a variety of forms, including literary inscriptions, technical artefacts, and money. Immutable mobiles refer to those properties of the intermediaries that do not change while passing through time and space [40]. An immutable mobile is something that can be interpreted in the same manner in different contexts and is not context-dependent [41].

2.3. Re-Entanglement of Punctualized Actor-Networks and the Creation of a New Sociotechnical Regime

A successful translation leads to the re-entanglement of new assemblages (actor-networks) inside the regime. New actor-networks, sociotechnical systems shaped by novelties, will be punctualized. The punctualized actor-networks and the collective performance of its entities restabilize the regime and decrease the pressure from the landscape. The collective performance of the actor-network transforms the incumbent sociotechnical regime. In this stage, the incorporation of new technologies will result in the development of new social practices. The actor-networks that have been shaped by punctualization will become black boxes in the sociotechnical regime. The stability of the actor-networks and the loyalty of the actants involved will depend on spokespersons. A spokesperson represents all material and social entities in the actor-network. The main role of a spokesperson is to stabilize the actor-network by convincing allies to join the actor-network and keeping involved actants loyal to their roles [42].

2.4. Gain and Loss in Technology-Driven Transitions

The social entities involved in transition processes are in continuous interaction with others to gain power, control, and dominance. To do so, a social entity requires economic, symbolic, and cultural values during the transition process. These values can be achieved by financial assets, recognition in the transition's network, education, and the creation of cultural knowledge. The configuration of relationships between influential and influenced stakeholders can result in the gain or loss of these values for the involved social entities. Other crucial features that social entities can gain or lose through the transition are support, connection, function, and responsibility.

Additionally, creating new practices results in the development of new materials, competence, and meanings. The material entities entering the sociotechnical system are affected by policy implementation approaches and the context in which they are emerging. The impact of context (social,

political, institutional, and cultural) can engender changes in the characteristics of material entities involved in the transition process. These changes include the gains and losses of certain features of material entities, which represent the impact of the socio-material context of technology-driven transitions. Gains and losses in the translation process can be observed in features of technologies, such as shapes, forms, scale, and meaning.

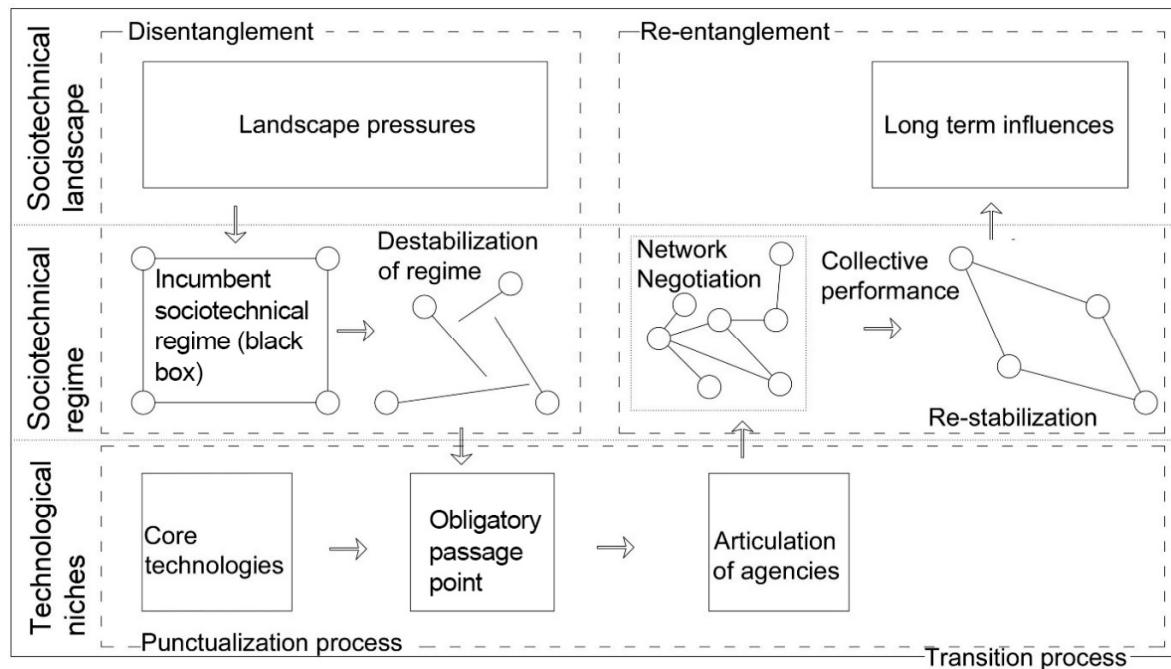


Figure 2. Three stages of translation of transition.

3. Methodology

This research was largely exploratory and used a qualitative research approach. The development and adoption of technical innovations was studied using a case study of HTUA in Shanghai [43]. The focus of the analysis was on how technological novelties were understood by planners, authorities, decision-makers, and urban regulations, and how the interaction between technological novelties (non-human actants) and the social entities (human actants) affected the transition trajectories toward HTUA.

ANT was used in this research as a conceptual framework that prioritizes “relations over their characteristics” [44] (p. 536). Under this framework, the actants were identified, and networks in which they are embedded were explored, to identify ways in which the transition of sociotechnical regimes are bound up with the different actants. ANT offered a concrete conceptual and methodological framework for empirical data collection. ANT principles were used to trace connections between involved actants in HTUA practices in Shanghai. The main ANT principles used to identify actants and trace their relationships were: (1) The ANT research method is boundaryless and holistic; therefore, connections may also be found with actants outside the sociotechnical context under investigation. (2) In ANT, only actants that leave traces genuinely exist, and therefore will be part of the data. (3) Actants are differentiated into four categories: humans and associations, representatives of nature, technologies (infrastructure, regulatory, and accounting), and buildings and structures. The overall steps taken in the case study are shown in Figure 3.

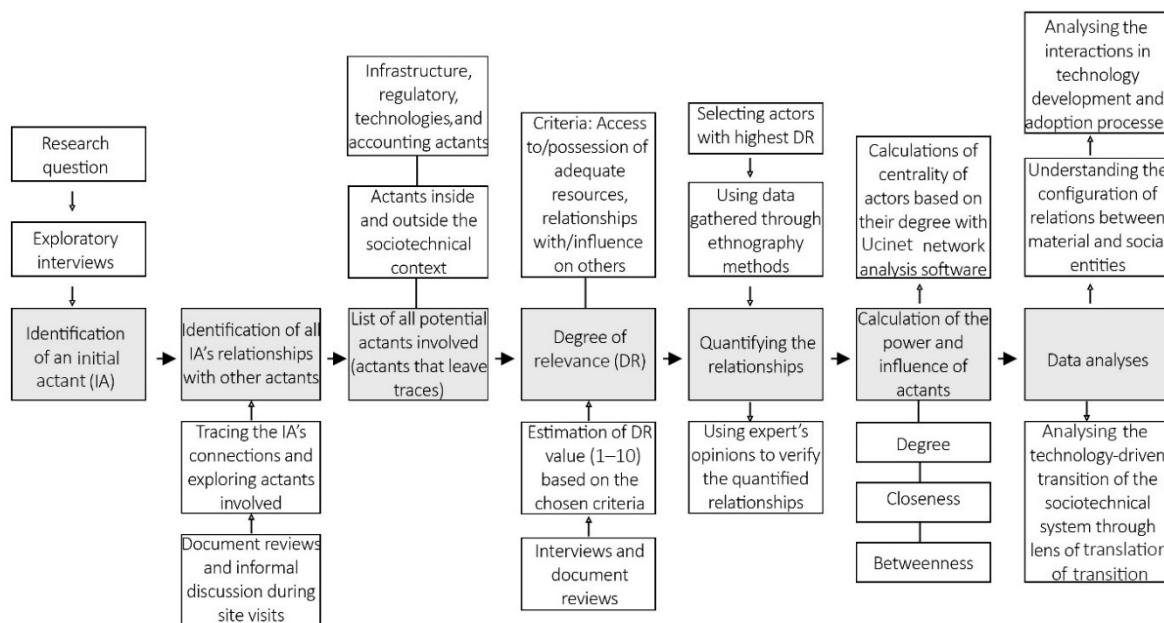


Figure 3. Methodological framework for the case study.

The empirical data were gathered through ethnographic research between August 2016 and February 2017. The ethnographic research approach involved multiple data collection methods: a literature review, document and report study, observations, site visits, participation in R&D projects, meetings, events and activities related to HTUA in Shanghai, and semi-structured interviews and discussions.

The initial actants, the starting point of study, were the actants involved in the development or management of knowledge and innovation and community gardening, Tongji-Plantagon research center for innovative urban agriculture and the Sunqiao modern agriculture zone. The identification of influential actants in the transition process in Shanghai was done through a document review (Table A1) and informal discussion during site visits, events, meetings, and R&D collaborations (Table A2). The information gathered were used to explore the connections of initial actants and identify other influential actants in agricultural technology development and adoption in Shanghai. During the site visits, people were asked to describe the relevance of the different groups of actants (i.e., technologies, knowledge institutes, governmental organizations, and natural resources), and afterward, these actants were further analyzed using a document study. Based on the gathered information, we gave each actant a degree of relevance from 0 to 10 using the criteria: possession of or access to resources for technology transfer or technology developments, and the actant's relationship with decision makers and sources of power. The actants with a relevance equal to or higher than 6 were considered as influential actants in the transition process [19,45,46] and selected for further analysis.

Semi-structured interviews and discussions were conducted to identify, trace, and explore connections between actors within political regimes, technical regimes, and the niche level (Table A3). Since many interviewees in Shanghai did not allow the interview to be recorded, discussion notes were made. The power and influence of actants were calculated based on the relationships between actants and other influential actants. This was done using the social network analysis program Ucinet (Version 6.628, Analytic Technologies, Harvard, MA, United States of America) [19]. The power and influence were calculated based on three indicators: the degree of centrality, the betweenness, and the closeness. The degree of centrality involves the number of direct relationships between an actant and other actants. A matrix table was made to quantify the relationships among actants involved (Table A4). These relationships were ranked using a three-point scale: 0 (no relationship), 2 (indirect relationship), 4 (direct relationship). The assigned ranks were verified using the expert opinion of researchers at Tongji University with extensive knowledge of the context and actants involved in

transition trajectories. The betweenness is an indicator that reflects the actant's placement between other pairs of actants. Actants located on the geodesic paths between other pairs of actants in a network have a larger betweenness. In other words, other actants are depending on these specific actants to make connections with other actants, which increases the power of such actants in the actor-network. The closeness of an actant reflects the total distance to other actants in the network. Actants with lower closeness values are relatively closer to the other actants and therefore more central in the network.

4. Transition Trajectories in the Food Production System of Shanghai

This section describes the results of the analysis of the transition trajectories in the food production system of Shanghai. The transition is described using the three stages of the concept of translation: disentanglement, punctualization, and re-entanglement.

4.1. Disentanglement of the Existing Food Production Regime

In the first stage of translation, the existing sociotechnical regime will face pressure from actants at different MLP levels (macro-landscape, meso-regime, and micro-niche). The pressure from different levels results in the creation of a window of opportunity for developing technological novelties by niche developers and their adoption in urban practices. The current situation of the food production regime in Shanghai, and the landscape and niche pressures on the regime, are presented in Figure 4. The existing or incumbent regime in Figure 4 is shaped by the conventional food production system. The new regime is the sociotechnical system that has adopted the technological novelties. The transition trajectories in Shanghai were mainly driven by top-down governmental niche development strategies. The involvement of governmental organizations and state-owned businesses in the transition of food production practices in Shanghai has resulted in a direct relationship between landscape pressures and the niche level. The niche developers follow the guidelines of the government and the Communist Party to deal with the landscape pressure. Therefore, the landscape pressure on the regime is directly imposed on the niche level as well.

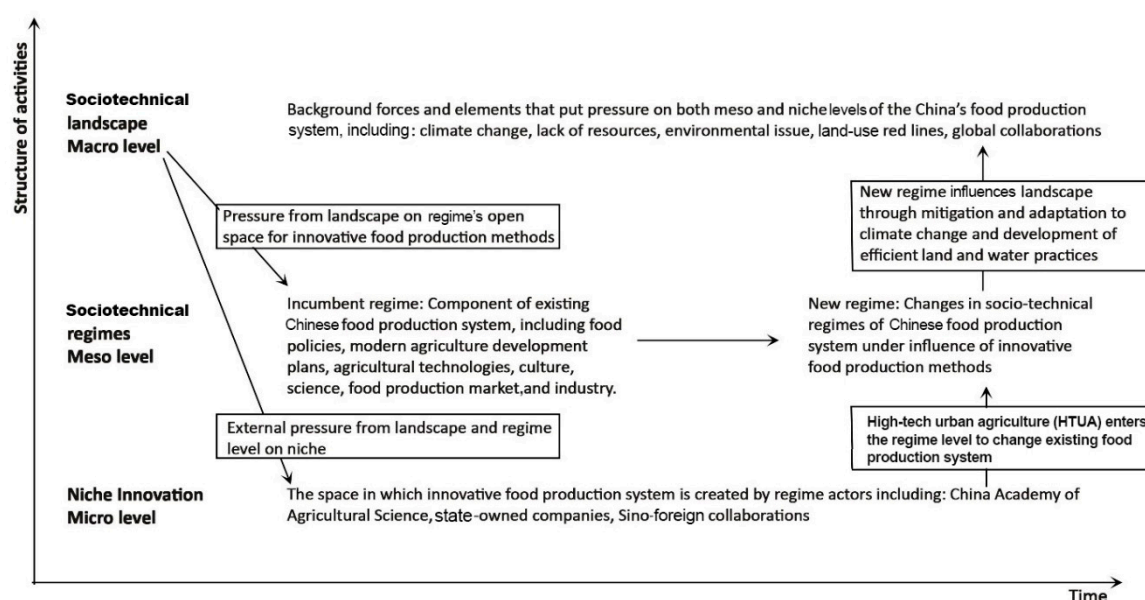


Figure 4. Instability in the sociotechnical regime of the Chinese agricultural sector through niche and landscape pressures.

4.1.1. Landscape Pressure

Landscape pressure on the food production system in Shanghai was the result of a continuing decline in arable land per person and the decrease in farm labor forces. The rapid expansion of Chinese

cities and pressure on land resources are the main destabilizing factors (interview SH-04). According to a researcher in Tongji University, College of Architecture and Urban Planning, the conversion of agricultural land in and around Shanghai for developing housing and urban infrastructures, as well as the erosion and pollution of arable lands, have worsened the land problems of Shanghai's agricultural sector. Researchers at CAAS estimate that around 20% of the Chinese farmland is polluted with levels of toxins above China's standards. In the suburbs of Shanghai, farmland suffers from pollution, garbage, and sewage. Contamination of soil with heavy metals, i.e., cadmium, arsenic, and lead, as well as wind erosion and desertification, are other factors influencing the decline of agricultural productivity in Shanghai. Furthermore, climate change contributes to reduced rainfall and depletion of surface and groundwater. Moreover, changes in the Communist Party ideologies provide more freedom for citizens who possess an agricultural (rural) hukou to migrate to urban areas, increasing the urbanization rate and reducing the agricultural labor force in rural areas. These challenges are reducing the production capacity of the existing food production system and they are threatening the future food security in Shanghai.

4.1.2. Instability in the Regime

The chief planner of Sasaki group (interview SH-21) mentioned that the instability in the sociotechnical regime of food production in Shanghai is associated with market demands and the expansion of cities. A researcher at Tongji University (interview SH-17) argued that the rise of the middle class, especially in megacities such as Shanghai, has affected market demands. Consumers want high-quality food and vegetables. Due to a lack of trust in China's agricultural industry, consumers prefer to spend more money to buy imported products. Open-door policies provide the possibility for foreign producers to increase their exports to China, which affects China's economy and agricultural sector. Interviewee SH-17 also stated that cities aim to expand their areas of productive farmland, which creates conflicts with urban spatial developments. Policies to prevent the conversion of agricultural land to other functions may hinder the growth of cities.

4.1.3. Niche Pressures

HTUA has attracted government and scientist's attention in China. The manager of Knowledge & Innovation and a community garden (interview SH-07) described the development of high-tech plant factories as an alternative food production method that requires less water and land resources while having a higher yield than conventional agriculture (Figure 5). These plant factories do not require any pesticides and are protected against pollution and unaffected by climate change and weather conditions. These characteristics make them an eligible alternative to conventional agricultural practices in China, and their potential and eligibility are an influential factor in the disentanglement of the incumbent food production regime. The main influential actant in this niche development is the state government, which plays an important role in the organization of R&D activities. CAAS has been assigned by the government to conduct the R&D projects.



Figure 5. Shanghai's Sunqiao solar plant factory.

4.2. Punctualization of HTUA Practices in the Food Production System

Increasing pressure on the agricultural sector due to the degradation of arable land, China's self-sufficiency target, and efforts to mitigate climate change, have destabilized the food production regime. To re-stabilize it, innovative food production methods created at the niche level attempt to enter the meso-level and change the regime. Punctualization of new technologies is the second stage of translation. In this stage, social and material entities, including technologies, regulations, policies, and various stakeholders that are influential or influenced by the technology-driven transition in the agricultural sector, shape a network of aligned interests. In this section, first, the identified actants (human, technologies, buildings, and representatives of nature) and their relationships are described. Second, the configuration of interactions between social and material entities involved in the technology-driven transition is described, using the four moments of the punctualization process (problematization, interessement, enrolment, and mobilization).

4.2.1. Identification of Involved Actants in the Transition Process toward HTUA

Table 1 shows the main human and nonhuman actants involved in developing agricultural technologies and their adoption in Shanghai. These actants were assigned a degree of relevance based on access to and possession of resources, relationships, and influence on decision-making. Although the Chinese government attempts to assign more weight to the role of the private sector and decentralize urban system developments, the top-down approach to policy implementation and organizational hierarchies have a negative influence on the possession and access to resources and influence on decision-making by private actors. Actors connected to the government and organizations owned or run by the state are the most influential actors in the transition process (Figure A1). Of the long list of involved actors that was created, only the actors with a degree of relevance of 6 or higher were used in the further analyses.

Table 1. Influential actants in transition towards HTUA in Shanghai.

Categories	Actant	Abbreviation	Level	Main Role	Public/Private	Degree of Relevance
Human and associations	State Government	SG	National	Funding and subsidies	Public	9
	China Academy of Agricultural Sciences	CAAS	National	Research and development	Public	8
	Institute of Environment and Sustainable Development in Agriculture	IEDA	National	Research and development	Public	9
	National Development Reform Commission	NDRC	National	Policy reformulation	Public	7
	Ministry of Agriculture	MoA	National	Implementation of policies	Public	8
	Ministry of Housing and Rural & Urban Development	MoHURD	National	Implementation of policies	Public	7
	Ministry of Science and Technology	MoST	National	Implementation of policies	Public	6
	Ministry of Land Resources	MoLR	National	Implementation of policies	Public	6
	Municipality of Shanghai	MSH	Local	Control and assessment of development plans	Public	7
	China National Cereals; Oils and Foodstuffs Corporation	COFCO	National	Funding, research and development	Public	7
	VeggiePal Ltd	VP	Local	Research and development	Private	6
	Best Green Life	BGL	Local	Research and development	Private	6
	Dedodesign-Edible Cities	DE	Local	Research	Private	6
	Innovative Urban Green	IUG	Local	Research	Private	6
	Urban Greenery Bureau	UGB	Local	Implementation of policies	Public	7
Communist Party of China	CPC	National	Regulation of national policies and plans	Public	9	
Representative of nature	Land resources	LR	National	Pressure on regime	Public	5
	Water resources	WR	National	Pressure on regime	Public	5

Table 1. Cont.

Categorises	Actant	Abbreviation	Level	Main Role	Public/Private	Degree of Relevance
Technologies (infrastructure, regulatory, accounting)	Five-Year guideline	FYG	National	Regulation of development strategies	Public	8
	No. 1 document	NOD	National	Regulation of agricultural development plans	Public	9
	Tongji-Plantagon Research Centre	TPRC	Regional	Research center	Semi-public	6
	Hydroponics technologies	HS	National	Vegetable production technique	Private and public	7
	Vertical farming technologies	VF	National	Land and water efficient production technique	Private and public	8
	Vertical and roof gardening policy	VRP	Regional	Promotion of vertical farming and greening	Public	8
	Agricultural Science and Technology Innovation Program	ASTIP	National	Promoting and supporting agricultural technology development	Public	9
	Master Plan of Shanghai	MPSH	Regional	Regulation of spatial development	Public	6
	Municipal Agriculture Development Plan	MADP	Local	Regulation of agricultural land uses	Public	6
	Building and structure	Shanghai Metropolitan Area	SHMA	Regional	Spatial context	Public
Sunqiao Development Zone		SDZ	National	Spatial context for development of plant factories	Public	8
Knowledge and Innovation Community Garden		KICG	Local	Community run urban agriculture facilities	Semi-public	7
Key Laboratory Urban Agriculture South		KLUS	Regional	Research and development centres	Public	7

Actants with a degree of relevance of 6 or higher were mainly state-owned companies (SOCs), state government policies, and core technologies that were applied in HTUA practices in Shanghai. Next, the centrality, betweenness, and closeness of the actants were calculated. The relationships of each actant with other involved actants were rated (Table A4). The collected data were analyzed in UCINET to visualize and measure the centrality, betweenness, and closeness of each actor (Table 2 and Figure A2).

Table 2. Ucinet statistics showing the centrality, betweenness, and closeness of the focal actors (1. Degree: Degree of centrality; 2. 2local: 2-local eigenvector centrality; 3. BonPwr: Bonacich's degree based power 4. 2Step: 2-step reach; 5. ARD: Average Relative Distance; 6. Closene: Closeness centrality; 7. Eigen: Eigenvector centrality; 8. Betwee: Betweenness centrality 9. 2StepBe: 2-step betweenness centrality).

		1	2	3	4	5	6	7	8	9
		Degree	2local	BonPwr	2Step	ARD	Closene	Eigen	Betwee	2StepBe
1	SG	27.000	627.000	5266.988	27.000	27.000	27.000	0.210	3.477	3.477
2	CAAS	27.000	627.000	5266.988	27.000	27.000	27.000	0.210	3.477	3.477
3	IEDA	24.000	577.000	4825.271	27.000	25.500	30.000	0.193	1.714	1.714
4	NDRC	27.000	627.000	5266.988	27.000	27.000	27.000	0.210	3.477	3.477
5	MoA	26.000	608.000	5104.284	27.000	26.500	28.000	0.204	3.053	3.053
6	MoHURD	18.000	456.000	3780.851	27.000	22.500	36.000	0.151	0.199	0.199
7	MoST	23.000	559.000	4676.165	27.000	25.000	31.000	0.187	1.007	1.007
8	MoLR	22.000	542.000	4518.733	27.000	24.500	32.000	0.180	0.596	0.596
9	MSH	25.000	601.000	5033.456	27.000	26.000	29.000	0.201	1.1391	1.1391
10	SHMA	25.000	601.000	5033.456	27.000	26.000	29.000	0.201	1.1391	1.1391
11	COFCO	23.000	566.000	4720.412	27.000	25.000	31.000	0.189	0.703	0.703
12	FYP	27.000	627.000	5266.988	27.000	27.000	27.000	0.210	3.477	3.477
13	NOD	27.000	627.000	5266.988	27.000	27.000	27.000	0.310	3.477	3.477
14	VP	19.000	487.000	4033.232	27.000	23.000	35.000	0.161	0.043	0.043
15	BGL	19.000	485.000	4020.473	27.000	23.000	35.000	0.161	0.093	0.093
16	SDZ	22.000	543.000	4514.072	27.000	24.500	32.000	0.180	1.004	1.004
17	TPRCDE	14.000	354.000	2913.945	27.000	20.500	40.000	0.116	0.143	0.143
18	KICG	19.000	484.000	4005.234	27.000	23.000	35.000	0.160	0.255	0.255
19	IUG	14.000	350.000	2882.301	27.000	20.500	40.000	0.115	0.310	0.310
20	HS	24.000	570.000	4770.721	27.000	25.500	30.000	0.191	2.122	2.122
21	VF	26.000	610.000	5114.949	27.000	26.500	28.000	0.204	2.873	2.873
22	VRP	27.000	627.000	5266.988	27.000	27.000	27.000	0.210	3.477	3.477
23	UGB	24.000	579.000	4845.541	27.000	25.500	30.000	0.194	1.292	1.292
24	ASTIP	26.000	614.000	5150.852	27.000	26.500	28.000	0.206	2.441	2.441
25	CPC	27.000	627.000	5266.988	27.000	27.000	27.000	0.210	3.477	3.477
26	MPSH	20.000	485.000	4047.749	27.000	23.500	34.000	0.162	1.165	1.165
27	MADP	25.000	601.000	5033.456	27.000	26.000	29.000	0.201	1.391	1.391
28	KLUS	27.000	627.000	5266.988	27.000	27.000	27.000	0.210	3.477	3.477

The highest degree of centrality (column 1) was assigned to the state government, CAAS, NDRC, No. 1 document, vertical and roof gardening policy, the Communist Party, and KLUS. These actants could be regarded as the most influential. The influential role of CAAS in this actor-network resulted from its direct connection with many nonhuman actants, in particular technologies (infrastructure, regulatory, and accounting). The connections between CAAS and actants in the technology category have provided a more privileged position to CAAS than other influential actors, such as the MoA and NRDC.

The betweenness (column 8) shows that the state government, CAAS, NDRC, MoA, Five-Year Plans, No. 1 Document, vertical and roof gardening policy, and the Communist Party were in a favored position. This can also be observed in Figure 6. The policy documents and policy making actors could be interpreted as the most influential nodes in terms of their control over regulations, connections, and immutable mobiles.

High values for closeness (column 6) indicated that a node was highly peripheral (Tongi-Plantagon research center, Innovative Urban Green), whereas small values indicated that a node was more central (state government, CAAS, and KLUS). The peripheral actors were more isolated than the central nodes.

The eigenvector in column 7 can be interpreted as popularity or status of the actant. Actants with high eigenvector values not only have many connections, but also have ties to many other well-connected actants. High values were especially assigned to the state government, CAAS, NDRC, FYP, and KLUS.

4.2.2. Translation Process of Technological Novelties into Urban Food Production Practices

The state government and the Communist Party form the absolute power in decision-making in the transition process of Chinese food production systems. CAAS, as a governmental organization and subdivision of the MoA, possesses agency in decision-making processes and policy formulation. The political context and agency of the national government make the governmental organizations the most influential actors in the transition process. The results from the previous section and the UCINET analyses show that CAAS had a high degree of centrality and betweenness, which put it in a favorable position to control interactions between other actants and influence their relationships (Table 2). These characteristics made CAAS the focal actant of the transition toward HTUA in Shanghai.

CAAS is responsible for finding adequate solutions for dealing with landscape pressure and stabilizing the agricultural system regime. However, the expansion of cities, conversion of arable land to urban land, and increasing soil pollution as a result of industrial waste are making progress challenging.

In the National Sustainable Agriculture Development Plan (2015–2030), agricultural innovation and technology development for achieving self-sufficiency are considered essential features of the future agricultural sector in China and a main responsibility of MoA and its suborganizations, such as CAAS. Technological novelties in HTUA take shape in the form of modern agriculture development zones, plant factories, and hydroponic greenhouses. These are being developed and funded by suborganizations of the central government, including CAAS and leading SOCs.

To analyze the transition trajectories within the translation framework, while considering CAAS as the focal actant, this study used the translation model of power. This model shows how a focal actant convinces various agents with different objectives to join the network for reaching their goals through the alignment of interest with others. In the transition to HTUA, CAAS' actions and agency aim to align the interests of the state government, the Communist Party, food production-related policy documents, SOCs, ministries, and local governments. The power of CAAS as a focal actant can be understood as a result of the intense activity of defining the problem, enrolling, convincing, and enlisting during the translation process of transition (Figure 6). The main entities in the transition process are niche development actants, entities at the landscape level, and influential actants within the regime level. In Figure 6, the influential entities in the regime are divided into political and policy, technological, and social regimes. The political and policy regime is the most powerful entity in the decision-making processes of transition, using a top-down approach to remove the obstacles to achieving national goals, such as dealing with the scarcity of land and water resources in China. The entities in the technological regime are industries and SOCs that work together with CAAS to transfer technologies from other countries and develop tailored food production systems for the Chinese context. The niche level consists of grassroots initiatives run by SOCs and Sino-foreign enterprises.

During the problematization moment, CAAS launched the Agricultural Science and Technology Innovation Program (ASTIP) in 2013. The main goal of the program was to develop a research infrastructure to overcome the bottlenecks for the development of a self-sufficient and advanced agricultural sector (i.e., climate change and degradation of arable land). By launching the program, CAAS defined the problem and the need for a transition to a more sustainable food production system. It introduced the ASTIP as the obligatory passage point (OPP) for the other entities. By defining the nature of the problem, CAAS forced others to accept the way forward, namely entering into an alliance with other actants within the actor-network of transition. The ASTIP has three phases, which are concurrent with the 12th, 13th, and 14th Five-Year Plans (2013–2025). The first phase (2013–2015) focused on exploring a promising organization to enhance innovative agriculture. In the second part of program (2016–2020), lessons learned during the first phase were reviewed, and targets were set

for international cooperation, capacity development, and the improvement of R&D infrastructure. The third phase (2021–2025) aims to expand all parts of the program.

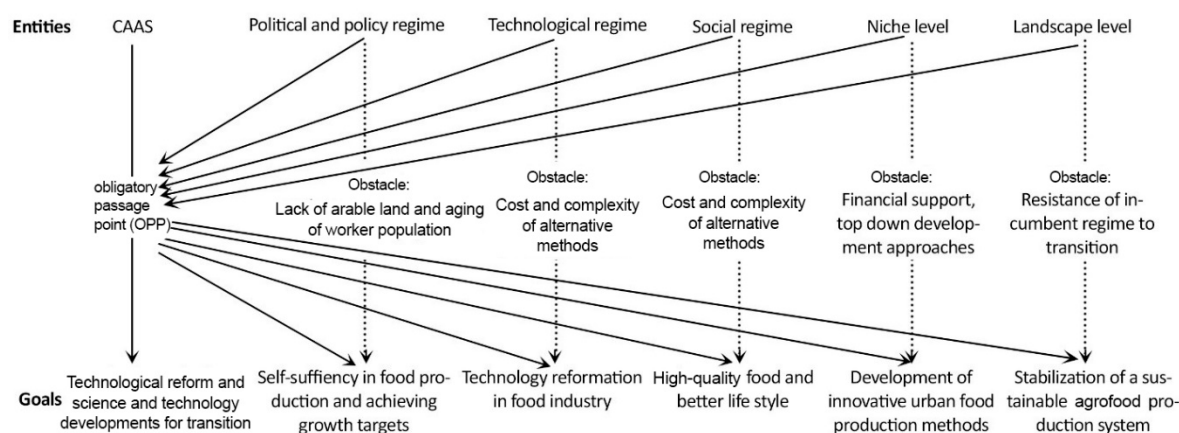


Figure 6. Translation of transition to HTUA in action. Source: adapted from Callon [36].

This technology-driven transition and the emergence of HTUA were guided by the 12th and 13th Five-Year Plans, which expect Chinese megacities to achieve the following three major goals by 2020:

- Agricultural modernization and concentrated zones for high tech food production through multifunctional land use.
- Coordinated development of urban–rural connections and increased agricultural production capacity.
- Integrated development and modernization of industry, agriculture, defence, and science and technology (S&T) for enhancing agriculture’s supporting role in industrialization and urbanization.

To achieve these objectives, the 12th and 13th Five-Year Plans gave priority to five areas: (1) Developing city-serving agriculture and modern urban agriculture projects. The transition process in Shanghai’s urban food production system was sped up through the development of the earlier-mentioned Sunqiao modern agriculture zone and the integration of urban agriculture in the spatial development of the Minhang zone. The Minhang zone is being developed between 2010 and 2020 in a collaboration between RUAF (Resource Centres on Urban Agriculture & Food Security), CAAS, and the local government. The project focused on developing high-quality production plants, environmental protection, and recreation within the existing policy frameworks and regulations. The main policy and regulatory framework is the “agriculture–industrial–policy.” It considers local urban agricultural practices as a method for enhancing profits and farmer incomes, as well as facilitating the development of niche projects. It was launched next to urban and peri-urban planning frameworks to integrate urban agriculture practices in spatial developments. (2) Priority was also given to shortening the distance between food producers and consumers, as well as prioritizing the development of fresh agro-products through the Vegetable Basket Program, a program of the MoA focusing on year-round fresh vegetable production. (3) Eco-friendly agriculture was promoted through facilitating ecological improvements to modern urban agriculture development projects that contribute to improving the environment. (4) Incentives were launched for high-yield agriculture and technology-/innovation-driven agriculture. (5) Government funds were allocated to support various niche projects and urban practices to modernize farming and alleviate landscape pressures. Up to 2020, the state-governed Agricultural Development Bank of China allocates loans to finance key projects promoted by the MoA. This financial aid tends to support niche projects that attempt to improve efficiency, increase harvests, increase consistency in harvests, and modernize agriculture.

The focal actant, CAAS, has attempted to make other influential actants interested in the transition to HTUA, as well as to define their roles in the transition process and regulate interactions between actants. To accomplish the interessement moment, CAAS put other actors into place by drawing their

interest in the transition to HTUA and negotiating the terms of their involvement. The main strategies of CAAS, in accordance with China's Agricultural Modernization Policy Framework (Information Sheet No. 6), were:

1. Development of an R&D infrastructure for HTUA through SOCs and CAAS suborganizations to convince other actants to accept their role in the transition from conventional agriculture to HTUA.
2. Policy reformation proposals that assign high priority to the modernization of food and S&T developments in the national and local government agendas.
3. Employment of Five-Year Plans, No. 1 Documents, and city titles as intermediaries. Since the 1980s, the Chinese government has awarded various titles to cities (e.g., garden city, healthy city, eco-city, etc.) to encourage the local authorities to develop more sustainable cities [47].

The director of Innovative Urban Green (interview SH-12) stated that the transition of the agricultural sector in China is and has been driven by the public sector, regardless of the increasing involvement of the private sector and government-organized non-governmental organization (GONGO). However, HTUA is an emerging topic in China and has not been clearly addressed yet by specific national policy (interview SH-04). To achieve the goals of the intersement moment of translation, CAAS has used its agency to ensure that agricultural policies also address the technological development and urbanization of agricultural practices. Reforms of policies and spatial development plans in China must be proposed by the state government's ministries and approved by the National Development and Reform Commission (NDRC). The NDRC is in charge of formulating and implementing strategies for national economic, technological, and social development, as well as annual, medium-, and long-term development plans. In response to landscape pressure, the NDRC coordinates economic and social development to propose targets and policies concerning the development of niche projects that contribute to the national economy. The NDRC possesses agency for empowering niche developments by coordinating dedicated plans involving central government's investments and key construction projects in technology-driven transition. Convincing the NDRC to accept their role in the transition network was one of the most crucial steps undertaken by CAAS (Figure 7). ASTIP is the main CAAS action plan that was proposed to NDRC for the transition in the agricultural sector. Reformation of modern agriculture development plans and proposed reformation of policies have led to CAAS's goals for the intersement moment. The reformation of policies can be observed in China's food security policies: the Five-Year guidelines (from the 8th to the 13th), the No. 1 central documents from 2010 to 2016, the modern agriculture plan, and the Vegetable Basket Project. The aim of CAAS' policy and planning reformation proposals is to define the above-mentioned policy documents and development plans as intermediaries between actants of transition. However, during the site visit at the CAAS plant factories and in the interview with a CAAS researcher (interview SH-24), it was stressed that in addition to national policies, CAAS also relies on provincial and municipal priorities related to regional agricultural resources.

Negotiations led to the third moment of translation, enrolment, where actants accepted their roles through negotiations with CAAS and enrolled in the network. CAAS defined the way actants relate to one another within the actor-network, creating a network of alliances for the transition to HTUA. During enrolment, the involved actors agreed on their interests and how these were aligned with CAAS. The responsible person for public relations at Shanghai Pudong Agricultural Development Group (interview SH-23), the developer of Sunqiao plant factories, stated that discussions about the strategic role of agriculture for China's stability and the costs and complexity of HTUA led to the resistant actors in the incumbent regime joining the actor-network. Therefore, CAAS had to invest in additional intersement devices to ensure successful enrolment, which included: (1) establishing key laboratories for developing HTUA inside megacities and technological niches, and (2) creating immutable mobiles for the enrolment of material entities.

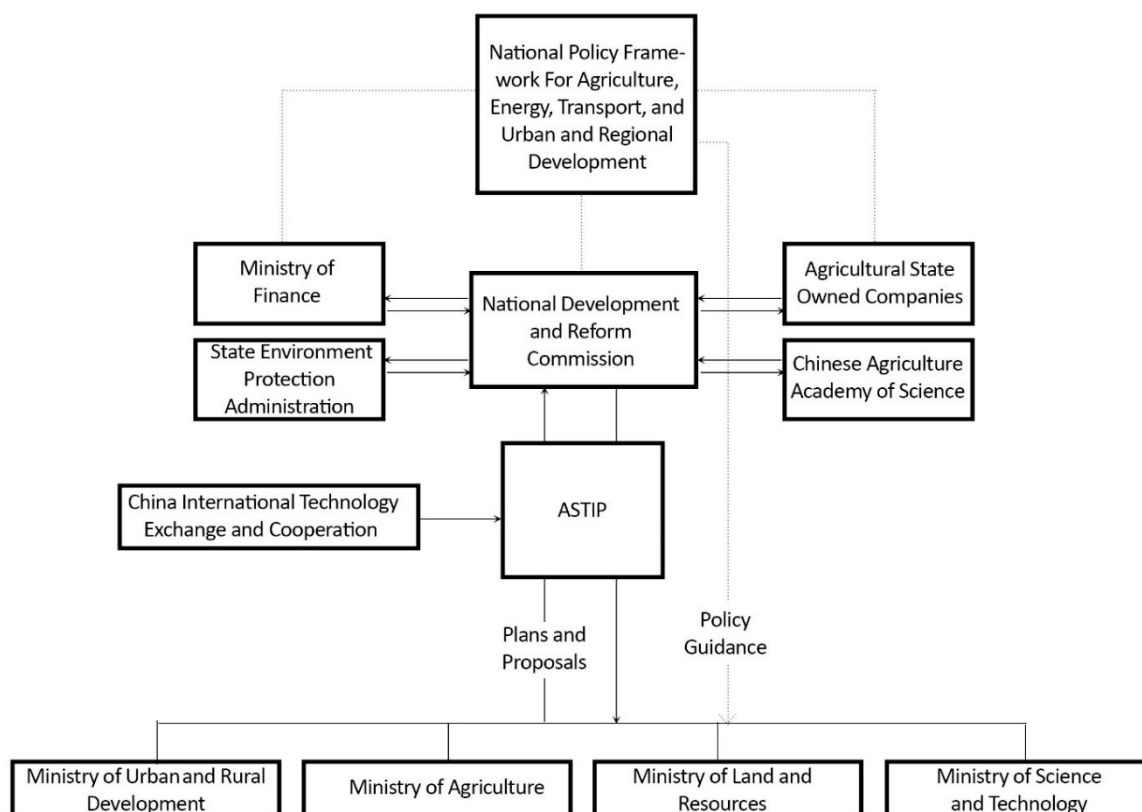


Figure 7. Institutional step for planning at the central level.

The Key Laboratory of Urban Agriculture (South) (KLUAS) of the MoA was established by merging the Eco-Agricultural Research Centre and the Eco-Agriculture and Food Safety Laboratory. It was sponsored by a partnership between Shanghai Jiaotong University of Shanghai and Chongming County People's Government. It was the first research institution to specialize in basic scientific research and technological development in urban agriculture. The main activities of KLUAS are:

- innovation in urban agriculture practices,
- security and control of agricultural products,
- innovation in using high-efficiency production techniques and low-carbon technology, and
- strategic planning of urban agriculture

With CAAS's leadership, the financial and technical support of the policy regime has been successful in developing numerous innovative niche projects and technological novelties for innovative urban agricultural practices (interview SH-09). Agricultural technologies are the most influential material entity in the technology-driven transition of urban agricultural practices. The strategic approach of CAAS was to develop and enroll new technologies in the actor-network such that they became immutable mobiles in the transition process. Observations of CAAS activities show that indoor and vertical farming pilot projects were implemented to make other stakeholders interested.

To ensure continuity in the transition process, the focal actants needed to monitor interests to stabilize the actor-network. Typically, influential actants in this process are the active supporters and critics of the transition. In the mobilization moment, CAAS attempted to reduce the number of critics and increase external allies, and avoid controversy, as this might unenroll actors or remove the support of external allies. Thus, measures were taken to ensure the stability of the actor-network. Next to the ASTIP program, CAAS promoted the MoA's Vegetable Basket Project. This project focused on strengthening the capacity and consistency of fresh vegetable production year-round. The first stage focused on the steady production of vegetables. In the second stage, standardized and high-tech

vegetable production fields and factories were stimulated. This stage focused on product quality, safety, and production labels, such as pollution-free, organic, and geographical indicators of agro-products. In addition, more attention was given to the development of HTUA, including financial incentives for niche developers to reduce the risks associated with investments in HTUA.

To mobilize forces for collective performance, all (social and material) actants required a spokesperson to speak on their behalf. This spokesperson should possess the ability to interpret the interests of nonhuman actors. According to a professor at the landscape group of Tongji University (interview SH-01), the main spokesperson for HTUA technologies and the actor-network of transition to HTUA in China was the director of CAAS. His role in technology development processes, as well as his connections with governmental organizations, universities, and research centers made him eligible for the job. In his communications, the director of CAAS emphasized the role of HTUA to deal with the societal challenges of feeding a growing population with limited resources, growing public attention and demand for safe food without pesticides and chemical residues, and loss of harvest caused by increasing natural disasters. The local spokesperson for HTUA in Shanghai, the director of CAAS, used several strategies to represent and mobilize the actor-network of transition. These strategies included presenting HTUA developments at conferences and press interviews, and using scientific publications, expositions, and workshops to introduce HTUA and related technologies. The other factor that affected the connections and relationships in the actor-network was the Chinese concept of “*guanxi*.” This essentially relates to a special type of mutualistic relationship in which individuals support and promote each other to other individuals or organizations, forming a network that permeates professional and personal aspects of their lives. The influence of *guanxi* on policy making and planning in China cannot be underestimated, particularly at the municipal and provincial levels. In addition to oral presentations by spokespersons on transition, the visualization of masterplans for developing HTUA was an effective tool to represent technological novelties. These visualizations were used by both intermediaries and spokespersons in the transition process, and were an effective tool of communication between niche developers, decision-makers, and the public in the transition process toward HTUA in Shanghai.

4.3. Re-Entanglement of HTUA in the Food Production System and Transition of the Incumbent Regime

In the last stage of transition, re-entanglement, the actor-network of transition is shaped, and new assemblages emerge in the sociotechnical regime. The actor-network of transition toward HTUA in Shanghai was shaped through the alignment of interests among involved actants from various levels, such as local and national governments, subdivisions of the MoA, SOCs, and niche developers. Figure 8 illustrates the actants involved in this transition and their relationships. It shows how the new regime was shaped under the pressure of the niche and landscape levels. Since the re-entanglement phase of the transition is still ongoing, there are no data available yet regarding the productivity of the HTUA practices in Shanghai.

Niche HTUA projects in Shanghai are comprised of plant factories, hydroponic systems, and vertical farming techniques. These provide high-quality food, are not sensitive to natural disasters, and increased the output and resource efficiency. In the re-entanglement phase of transition, HTUA practices and the technologies that are applied for cultivation of plants have been locally diffused and became part of the socio-technical regime of food system in Shanghai. However, re-entanglement of new food production systems is a continuous process and requires the development of infrastructures and the formulation of policies and regulations to replace the incumbent practices with new ones.

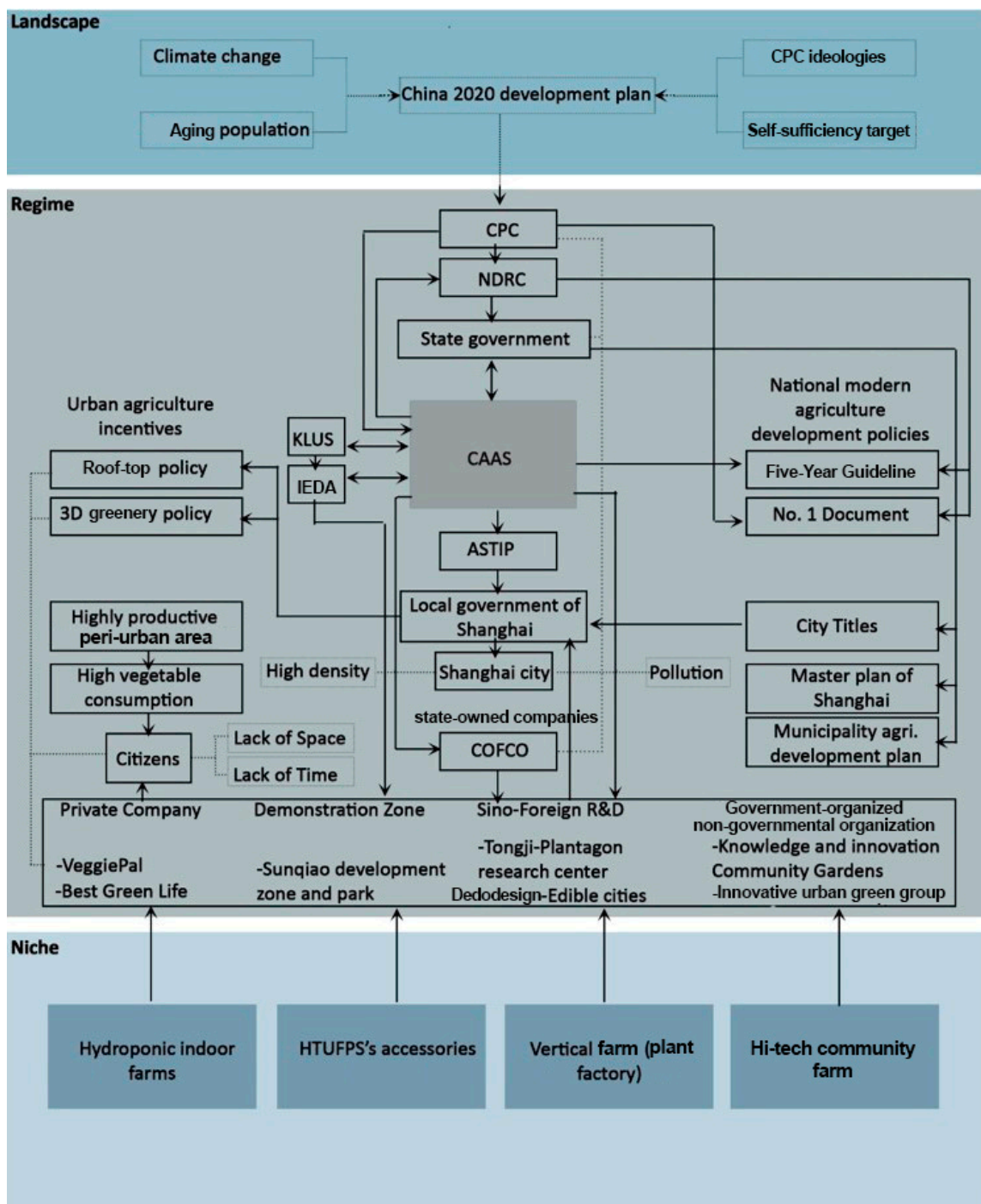


Figure 8. Illustration of the actor-network of transition to HTUA.

In the re-entanglement phase, the technological novelties that were created in a protected environment, outside of the sociotechnical context, will enter the regime level. In Shanghai, three different types of urban practices were re-entangled in the sociotechnical regime (Table 3). Table 3 shows that the diffusion of new practices in Shanghai involved new materials (vertical farms and indoor gardens), competences (knowledge and know-how), and meanings (recognition of HTUA as a food production method by society and the emergence of new research and education trends).

Table 3. Entangled HTUA assemblages in Shanghai.

Type of HTUA	Practices	Stakeholders	Functions	Scale
Plant factories (urban development project)	Sunqiao modern agriculture zone	Pudong agriculture group, CAAS, COFCO, state government, Sasaki, Sunqiao Modern Agriculture United Development Co. Ltd.	Large-scale vegetable production, vertical farms, R&D center for plant factories, educational center, tourist attraction, urban–rural linking	Large
Household high-tech indoor gardens (development of materials)	VeggiePal	Private Technology University of Shanghai	Indoor farm for households and restaurants	Medium
	Green farm City crop Urban cultivator Keisue Everyday green Avatar Vegegrow Powerplant Home lohas	Private	Indoor farms	Small
Community high-tech agriculture (development of competences)	Knowledge and innovation community garden	GONGO	Community centers, education	Small
	Jinshan High-tech Agriculture Exhibition Hall		Exhibition, education, community center	
HTUA research and education facilities (creation of cultural meanings)	Jiaotong high-tech research farm	Jiaotong University, CAAS	Research center, education	Medium
	Tongji-Plantagon	Tongji University, Foreign firm	Research center, education	
	Edible cities	Sino-foreign firm	Urban design workshops and education	
	Innovative Urban Green IUG	Tongji University, Municipal government	Urban planning education center	
	Dushi green Shanghai	CAAS, Shanghai Dushi Green Engineering CO., LTD	High-tech greenhouse research center	

5. Discussion

The objectives of this paper were to study the transition toward high-tech urban agriculture and its adoption in urban planning practices in Shanghai. A combination of multi-level perspective (MLP) and actor–network Theory (ANT) was used to identify institutional barriers and driving forces in this transition. The main findings are synthesized below.

5.1. Empirical Findings

The development of agricultural technology and the application in urban food production practices in Shanghai were led by the Chinese Academy of Agricultural Science (CAAS) and the Agricultural Science and Technology Innovation Program (ASTIP). The transition pathway in Shanghai was organized by the state government through top-down R&D activities. Agricultural technologies were imported by CAAS from other countries, in particular the Netherlands. The state government allowed the involvement of foreign businesses in the transition through open-door policies, such as the establishment of the Special Economic Zone in Shanghai. The imported technologies were adopted by incumbent industries, such as lighting and home appliance manufacturers, and adapted to create new equipment and products for HTUA practices. These products and equipment were brought into national and international markets by Chinese agricultural technology firms. The niche developers in this transition pathway (i.e., SOC) collaborated with agricultural technology firms to adopt agricultural technologies in new urban food production practices, such as the Sunqiao modern agriculture zone. To ensure that the interested actors became involved in the transition process and part of the actor network of transition, CAAS developed the key laboratories and demonstration zone for urban agriculture. The result of the collective actions of the actor-network of transition was the identification of plant factories as immutable mobiles; in other words, they were introduced as the promising solution for the challenges of the agricultural sector in China. To mobilize the actor network, the vegetable

basket program was promoted by the local government, MoA, and CAAS to connect the urban food production and consumption practices. Additionally, spokespersons were appointed to represent the actor network of transition and to mobilize the involved actors. The director of CAAS as the main spokesperson had the responsibility of introducing plant factories and their positive contribution to the economy and society.

The research shows that political and economic interests were the main driving forces behind the transition process in Shanghai. These findings are in line with Miller, who concluded that the rise of HTUA practices is a result of the adaptation of technologies by “dominant political and economic interests” for providing food security [48] (p. 11). Hallock describes HTUA as a capitalist form of urban agriculture with the “ability to standardize the food cultivation process, and to incorporate it into factory like production systems” [49] (p. 7). This clearly applies to Shanghai, where the top-down approach of CAAS and the involved SOCs was effective for the development of large-scale practices. Large-scale plant factories with a focus on high yields were supported and subsidized, driven by the central government’s aims of increasing the local production capacity and becoming less dependent on the import of agricultural products. Therefore, the HTUA have become oriented toward large-scale commercial vegetable production practices. CAAS also persuaded local planning organizations to remove any regulatory barriers. It shows that the government continues to play a dominant role in the development of urban agriculture in Shanghai [50–52]. However, this dominant role also made it such that private enterprises involved in niche developments could not compete with the SOCs, and therefore, many of these private companies went bankrupt. This may have reduced the role of talented pioneers in the development of novelties. The focus on large-scale food production may also have resulted in the loss of its potential for improving urban lifestyles and integration into urban residents’ lives.

Furthermore, the results show that strategies for representing material entities (technologies) were crucial in the integration of agricultural technologies in urban practices. The representation of technologies by visualizations was an effective tool for making investors and the public interested in HTUA in Shanghai. The developers of the Sunqiao modern agriculture zone hired architectural companies to create visualizations of their projects. The architects created futuristic designs that were not based on in-depth knowledge of HTUA technologies. Although the visualizations were highly effective in attracting investors and public attention, they also raised concerns about the feasibility of HTUA practices among agricultural experts and decision-makers. Consequently, the decision-makers consulted agricultural experts to validate the feasibility of the proposed practices. These results show that visualizations can only play an effective role as an intermediary between niche developers and decision-makers if technology experts are involved in the design process. These findings are in line with Billger, Thuvander, and Wästberg who argue that visualization is an effective tool for communication among stakeholders in planning processes, but also involves a risk of “potential misuse, misinterpretation and misempowerment” [44] (p. 12). To plan for technology-driven transitions, the identity of material entities (technologies) and their characteristics must be understood by planners. Bridges between knowledge institutes, architecture, and planning organizations are therefore essential for providing clear and representative visualizations.

The position of the focal actants of the transition in Shanghai and their connection with power and decision-makers resulted in more flexibility toward practices that could not meet all urban regulations and standards. The involvement of governmental organizations and their influence on decision-making at local levels affected the regulatory actants in the transition process and removed regulatory barriers. Moreover, the creation of connections between niche developers and urban regulations, through the influence of central governments on municipal urban development practices and regulations, aligned the interests of various actants in the transition process. The sociotechnical context in Shanghai allowed for the development of large-scale practices without any adaptation to urban regulations. Social entities, in particular niche developers, gained support, and material entities (i.e., technologies) gained legitimacy for their application in urban food production practices.

5.2. Theoretical and Methodological Implications

This research used the concept of translation for studying technology-driven transitions [40]. The concept was adopted by other scholars in planning studies to analyze actor-networks [19,53]. For example, Tietjen and Jørgensen used the concept of translation to analyze the agency of different actors, especially the role of planners, in strategic planning processes. However, in this research, we integrated the concept of translation in the MLP framework. This allowed us to study the agency of different bottom-up and top-down interactions between social and material entities in the transition process. The MLP framework as described by Geels mainly focuses on bottom-up forces in transition pathways and the role of agency in the transition process is ignored [28,30]. In this research, we did not focus on grass roots initiatives only, but technological novelties were studied by the agency of grass roots initiatives and incumbent technology developers, as well as top-down technology development and application strategies. The concept of translation allowed us to analyze the agency of various social and material entities (niche developers, incumbent firms, public policies, decision-making processes, urban regulations, and technologies) in the interplay between actants in the three analytical levels of the MLP framework (landscape, sociotechnical regime, and niche). The concept allowed us to describe the transition trajectories in the case study in three stages and to identify the impact of public policies and the gains and losses of social and material entities.

The disentanglement phase helped us to gain a better understanding of the pressure that the landscape and technological novelties put on the incumbent sociotechnical regime, and also the way in which the regime pushed the development of novelties forward. HTUA in Shanghai emerged under pressure from the landscape and the readiness of technological novelties in the niche level, as well as the risks and inefficiency of incumbent food production systems in the current regime. The punctualization phase allowed for the conceptualization of the processes in which novelties were standardized and converted to black boxes, distinguishing between bottom-up niche developers and top-down R&D efforts. The re-entanglement phase allowed for the study of the transition trajectories, the actions of individual actants, and the impact of collective actions of the actor-networks, which gave a better understanding of the adoption of new technologies and their adaptation during local diffusion.

The study shows that nonhuman actants (i.e., artefacts and technologies) have an influential role in transition processes. The integration of technologies into planning practices—the main objective of translation—is affected by the agency of materials in different stages. The Shanghai case showed that agricultural technologies were developed using knowledge and technologies imported by the government and supervised by CAAS. Incumbent industries adopted these technologies to create new products brought into the market by agricultural technology firms. Thus, agricultural technologies behaved as immutable mobiles that were exchanged between the social actants involved and shaped new relationships between them. In this case, the agency of material entities (technologies) created a new business environment among the social actants involved. Artefacts, such as masterplans and architectural visualizations played a crucial role in regulating interactions between planners and decision-makers for achieving planning permissions, which confirms the research of Rydin [13] (p. 32), who emphasized that planning practices depend on “the role of planning documents as intermediaries and the potential they offer to govern at a distance.” However, the research shows that agricultural technologies are another material entity in the translation toward HTUA that can shape or change the relationships between social entities involved in the transition process.

Ethnographic methods were used for data collection. The most influential actants in the transition process were traced and their relationship with other actants identified using observations, site visits, and interviews. The relationships between actants were ranked and the centrality of each actant was calculated to identify the focal entities in the transition process. However, an accurate quantification of the relationships between the actants in Shanghai were shown to be difficult. We used ethnographic research methods involving close and prolonged observation of technology development projects and public and private companies. The close interaction with the actants may have resulted in a certain bias of the researchers. Future studies should adopt a wider mix of qualitative and quantitative approaches,

such as surveys, to quantify the relationships and calculate the betweenness centrality between involved actants. Separate surveys can be conducted among niche developers, decision-makers, and final users to cover different perspectives in the quantification of relationships.

6. Conclusions

The transition toward HTUA in Shanghai is dominated by a top-down approach, with a prominent place for the national science academy CAAS and SOCs. The connection between these entities and decision-makers at the local and national level has resulted in the rapid development of vertical farms and plant factories in Shanghai, in line with the aims of China's national policies. The transition is characterized by a high dependency on technologies developed by foreign companies or collaborative Sino-foreign R&D projects. The main advantage of the centrally planned transition process in Shanghai is the funding and support of the national government, which reduces the risks for niche developers. Furthermore, it allows for the investment in resources for developing practices with long-term profits. Even niches that are not economically viable currently, but promising for solving future challenges, have opportunities to develop. Since all resources are being allocated to achieve one main goal, the technology adoption and adaptation processes are executed efficiently. Central planning for transition of the agricultural sector has been highly effective for accelerating technology transfer processes and initiating large-scale experimental projects. In addition to the top-down approach in the transition toward HTUA practices, many private businesses have begun initiatives in Shanghai (i.e., VeggiePal, Best Green Life, and Innovative Urban Green). These grassroots initiatives are fragmented and disconnected from the centrally planned transition process. The government does not consider these businesses effective actors in the transition process, and consequently, many local initiatives went bankrupt. This has limited the capacity for grassroots development of novel and cutting-edge technologies and reduced the creativity and innovation in the agricultural sector. Therefore, it can be recommended that the private sector is given a more important role in the development of new technologies and experimental phase of technology applications. Providing the private sector with motivating incentives and connecting them with SOCs and CAAS could be beneficial for both groups of actants. Co-investment of the government in innovative projects through public-private partnerships can remove financial obstacles for start-ups. As a result, SOCs and CAAS will get access to cutting-edge technologies that have been developed locally. This will also make China less dependent on imported technologies.

This research has shown that the integration of HTUA technologies into planning practices—the main objective of HTUA transition—is affected by the agency of materials in different stages. Non-human actants, such as master plans, visualizations, and technologies play a crucial role in shaping or changing the relationships of the social entities involved in the transition process. The developed approach, integrating the concept of translation in the MLP framework, can be used by other scholars, both for studying the role of artefacts and institutions in the emergence of various technological novelties and for studying the transformations in sociotechnical systems that result from them.

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Appendix A

Table A1. Consulted policy documents, action plans, and programs.

Policy documents and agendas	12th Five-Year Plan (2011–2015) 13th Five-Year Plan (2016–2020) China's 2015 Central Policy Document No. 1 China's 2016 Central Policy Document No. 1 China's 2017 Central Policy Document No. 1 China's Agricultural Modernization – Information Sheet No. 6 China's strategy for ecological agricultural development Agenda for sustainable development
Action plans and programs	Vegetable basket program Agricultural Science and Technology Innovation Program Three-dimensional greening 12th National modern agriculture development plan 2011–2105 13th National Sustainable Agricultural Development plan 2016–2020 13th National modern agriculture development plan 2016–2020 Three-Year Plan on “internet plus” modern agriculture National plan on new urbanization 2014–2020 National sustainable agricultural development plan 2015–2030 Green building action plan No.1 document

Appendix B

Table A2. Site visits, events, meetings, and R&D collaborations in the course of data collection in Shanghai.

Site visits	CAAS plant factory Knowledge and innovation community gardens Sunqiao modern agriculture zone Shanghai community garden centre
Events	Pop-up event, Edible Cities Dedodesign Initiatives at New York University Tongji regeneration of Shanghai and vertical greening congress Tongji landscape group presentation on innovative urban food production
Meetings	Tongji-Plantagon meetings Researchers' nights at Euraxess
R&D collaborations	Mocele farm Veggiepal Innovative urban green Best green life – vertical greening solutions

Appendix C

Table A3. Semi-structured interviews and informal discussion. Case study of Shanghai.

Interviewee	Position	Affiliation	Location	Date
SH-01	Professor, Entrepreneur	Tongji University, Knowledge & Innovation and community garden, Government-organized non-governmental organization	Shanghai	Sep. 2016
SH-02	Entrepreneur	Lifestylegreen (SME)	Shanghai	Oct. 2016
SH-03	Entrepreneur	VeggiePal (Startup)	Shanghai	Oct. 2016
SH-04	Professor	Tongji	Shanghai	Nov. 2016
SH-05	Professor	Tongji	Shanghai	Nov. 2016
SH-06	Professor	Tongji	Shanghai	Nov. 2016
SH-07	Manager	Knowledge & Innovation and community garden	Shanghai	Nov. 2016
SH-08	Director	Knowledge & Innovation and community garden	Shanghai	Nov. 2016
SH-09	Professor	Tongji-Plantagon research centre	Shanghai	Nov. 2016
SH-10	Professor	Tongji	Shanghai	Nov. 2016
SH-11	Professor	Tongji	Shanghai	Dec. 2016
SH-12	Director	Innovative urban Green	Shanghai – informal discussion	Dec. 2016
SH-13	Entrepreneur	Foreign Start-up, Vegger	Shanghai	Dec. 2016
SH-14	Professor	Jiaotong, KLUS	Shanghai – informal discussion	Dec. 2016
SH-15	Entrepreneur	Urban Farms	Shanghai – informal discussion	Dec. 2016

Table A3. Cont.

Interviewee	Position	Affiliation	Location	Date
SH-16	Entrepreneur	Dedodesign	Shanghai	Dec. 2016
SH-17	Professor	Tongji	Shanghai	Dec. 2016
SH-18	Founder	Mocle farm	Shanghai	Dec. 2016
SH-19	Entrepreneur	Zuzi Technology Co., Ltd,	Shanghai – informal discussion	Dec. 2016
SH-20	CEO	Tongji-Plantagon	Shanghai – informal discussion	Jan. 2017
SH-21	Chief Planner	Sasaki	Online	Jan. 2018
SH-22	Planner	Sasaki	Online	Jan. 2018
SH-23	PR	Shanghai Pudong Agricultural Development Group	Online	Jan. 2018
SH-24	Researcher	CAAS	Online	Jan. 2018

Appendix D

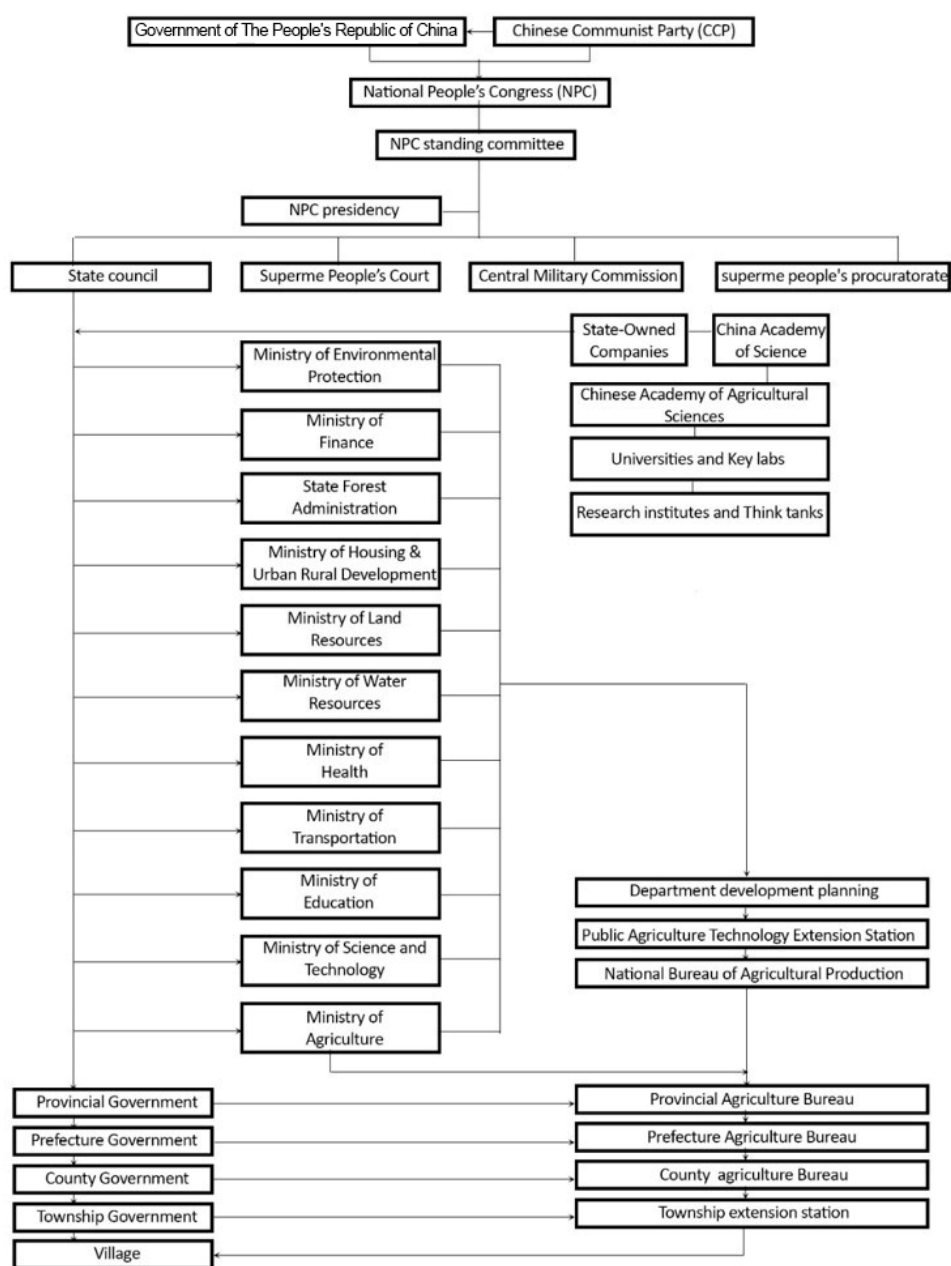


Figure A1. Overview of the political structures in China affecting the agrofood production system.

Appendix E

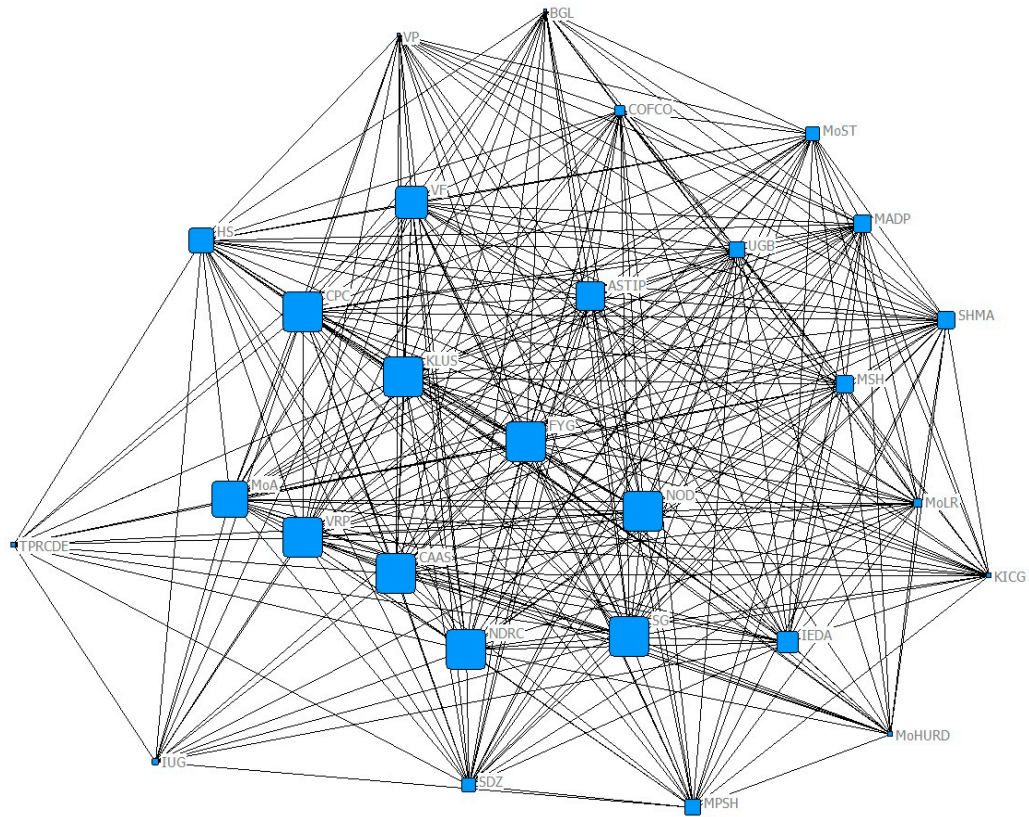


Figure A2. The illustration of the network of actors in the transition to HTUA.

Table A4. Cont.

	BGL	SDZ	TPRCDE	KICG	IUG	HS	VF	VRP	UGB	ASTIP	CPC	MPSH	MADP	KLUS
SG	3	5	3	3	3	2	2	4	3	4	6	5	4	3
CAAS	4	5	5	4	4	6	6	5	5	5	6	3	3	6
IEDA	1	3	1	2	2	5	5	5	4	4	3	1	2	5
NDRC	3	3	2	3	2	3	4	5	5	5	5	4	5	2
MoA	2	3	4	5	4	3	3	5	3	5	5	1	3	4
MoHURD	1	1	1	1	1	1	1	3	3	2	5	5	3	4
MoST	2	3	1	2	1	4	4	2	1	4	5	1	2	3
MoLR	3	4	1	1	1	1	2	3	3	2	5	5	3	3
MSH	3	5	1	6	1	3	4	5	6	3	3	5	5	3
SHMA	3	4	1	3	1	3	3	5	6	2	3	6	6	3
COFCO	2	3	1	1	1	5	5	3	2	3	6	2	2	3
FYP	2	4	2	3	2	2	2	3	3	5	6	5	4	3
NOD	2	4	2	3	2	3	3	4	4	6	6	4	4	4
VP	1	1	1	1	1	5	5	4	4	3	2	1	2	3
BGL	0	1	1	1	1	5	5	4	4	3	2	1	2	2
SDZ	1	0	2	1	1	5	5	5	5	4	3	4	5	4
TPRCDE	1	2	0	1	2	5	5	2	1	2	2	1	1	4
KICG	1	1	1	0	1	4	4	5	5	2	2	3	3	3
IUG	1	1	2	1	0	4	4	2	1	1	2	2	1	4
HS	5	5	5	4	4	0	6	3	2	4	2	1	2	5
VF	5	5	5	4	4	6	0	5	4	4	2	2	3	5
VRP	3	5	2	5	2	3	5	0	6	2	3	3	4	3
UGB	3	5	1	5	1	2	4	6	0	2	3	4	5	3
ASTIP	3	3	2	2	1	4	4	2	2	0	5	3	5	5
CPC	2	3	2	2	2	2	2	3	3	5	0	3	3	2
MPSH	1	4	1	3	2	1	2	3	4	3	3	0	5	2
MADP	2	5	1	3	1	2	3	4	5	5	3	5	0	4
KLUS	2	4	4	3	4	5	5	3	3	5	2	2	4	0

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