„Recycling of organic residues from agricultural and municipal origin in China”

中国农业、养殖业和城镇有机废弃物资源化

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Two complementary research groups

IfaS
FH Trier (IfaS) Research group

universitätbonn
Bonn-Braunschweig Research group

Recycling team: FH Frier (IfaS)

Leader: Prof. Dr. Peter Heck

Coordinators:

- Dr. Hongyan Lu
- Dr. Katrin Müller-Hansen

Institute for Applied Material Flow Management

(IfaS http://www.stoffstrom.org/)

Environmental Campus Birkenfeld

University of Applied Sciences Trier, Germany

Recycling of organic residues from agricultural and municipal origin in China

中德合作项目

″中国农业、养殖业和城镇有机废弃物的资源化″

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Executive summary

This project takes advantage of different interdisciplinary research groups and the involvement of German small and medium-sized enterprises to develop integrated strategies and solutions for the recycling of organic residues in China. It aims at reducing pollution, abating greenhouse gas emissions, improving nutrient cycling, generating renewable energy and increasing regional added value in the Chinese countryside. In one approach, three research sites in Shaanxi and Shandong provinces have been selected to develop economically viable and ecologically sound recycling projects through regional material flow management, stakeholders' involvement, innovative financial schemes and technology transfer. A parallel approach will take into account planning, technical improvement regarding animal production techniques, feed optimization, manure storage and treatment for minimizing emissions, as well as hygienization, designation of organic fertilizers for specific usage, carrying capacity of cropland, economic factors, administrative issues and environmental regulations. Starting from the technical situation of a selected pilot pig raising farm near Beijing, an improvement of the regional situation, as well as intensive animal husbandry in peri-urban areas of other large Chinese cities is envisaged. The whole project is conceived for a 3-year duration as a first phase.

Two complementary research groups

universitätbonn

Recycling team

Identifying potentials and developing **a new** economically & technically **viable system**

Nutrient Cycling team

Interdisciplinary approach for **optimizing** and adaptating an exemplary plant (case study)

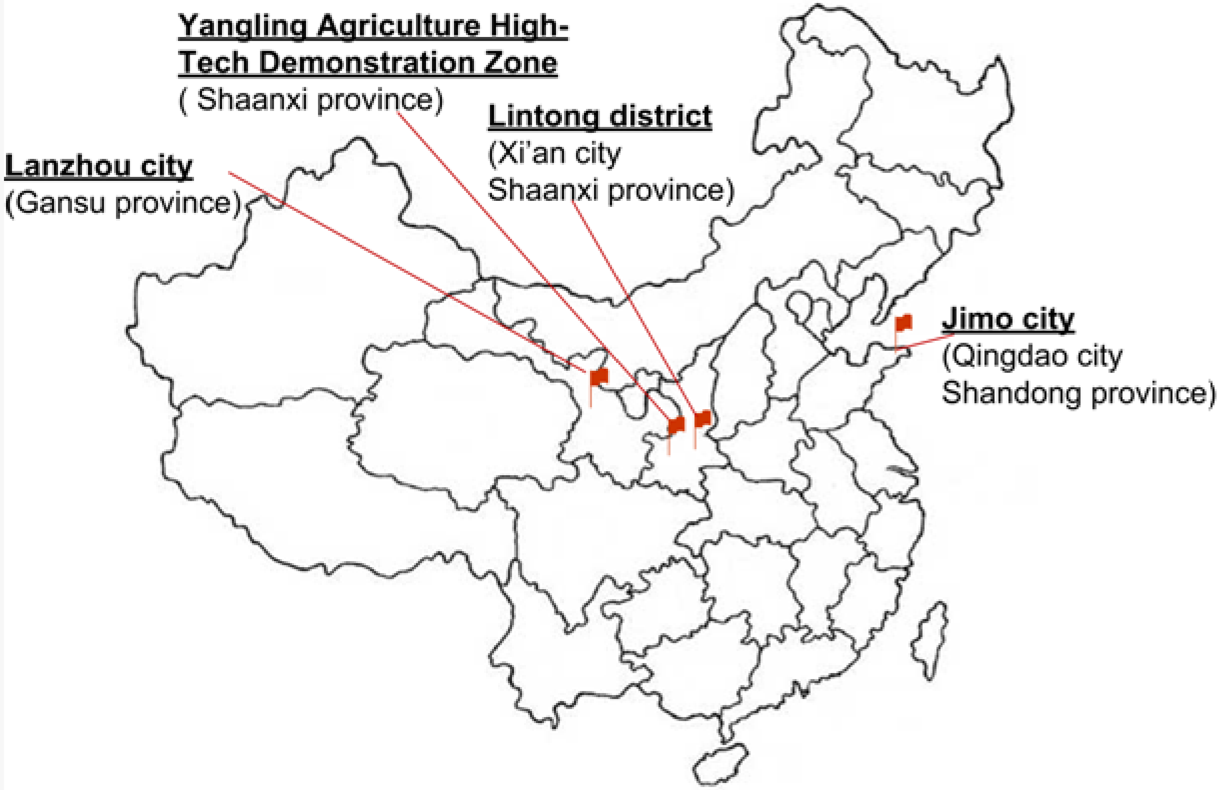
Joint goal: recycling of regional organic residues

Recycling team

– Coordinator: **Institute of Applied Material Flow Management (IfaS)**, University of Applied Sciences Trier

– **12 partners** from China and Germany

Recycling team: Four research sites



Recycling team: Goals (I)

– developing new, **systemic material flow management concepts**

– combined with **micro-economic methods and strategies**

– establishing **pilot projects** at our research sites in China

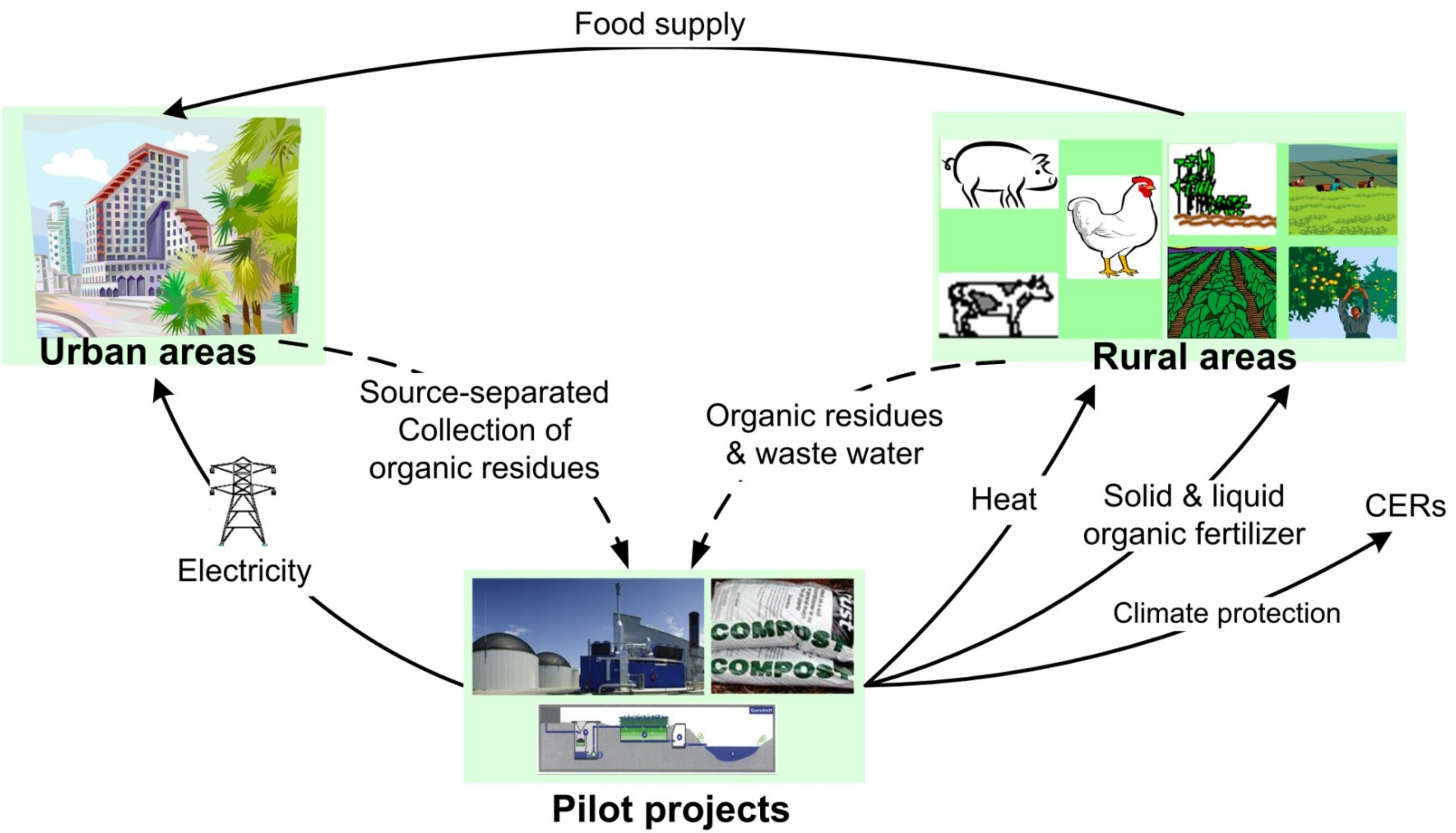
Recycling team: Goals (II)

– recycling organic residues
– reducing pollution
– abating greenhouse gas emissions
– producing organic fertilizer
– generating renewable energy
– increasing regional added value

Recycling team: Approaches

- **Regional material flow management**
- **Stakeholders' involvement**
- **Innovative financing and implementation schemes** (Public Private Partnership (PPP), Build Operate Transfer (BOT), Build Operate Own (BOO))
- **Technology transfer**

Recycling team: Material flow management through pilot projects



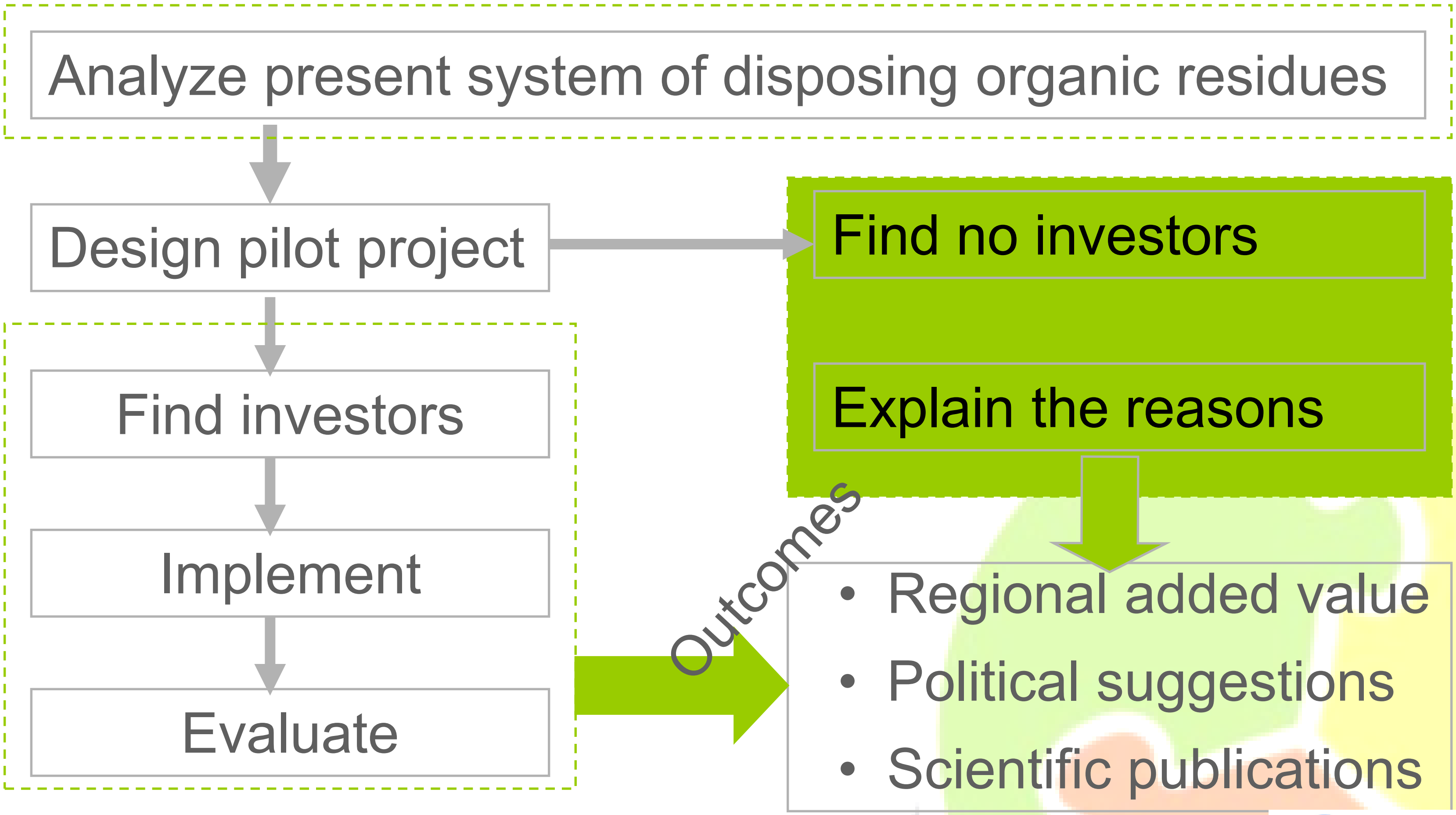
Recycling team: German partners

IfaS	Institute for Applied Material Flow Management (IfaS)	Project development & management
agraferm technologies	Agraferm company	Biogas generation
LINDENBERG ANLAGEN	LINDENBERG company	Cogeneration
X-TERN international	X-TERN company	District heating
Umwelt Elektronik	Umwelt Elektronik company	Composting
Lee s.à.r.l.	LEE company	Economic analysis
areal GmbH	Areal company	Water management

Recycling team: Chinese partners

	Organization	Roles
Research site related	Circular Economy Research Institute of Shaanxi Province	Coordinator at research site (Lintong&Yangling)
	Development and Reform Bureau of Yangling Agriculture High-technology demonstration zone	Coordinator at research site (Yangling)
	Friends of the Earth (Hongkong)	Coordinator at research site (Jiangxi)
	Qingdao Environmental Protection Bureau	Coordinator at research site (Qingdao)
	New Ventures China	Coordinator at research site (Beijing Changping district)
Cui Tiening	Beijing University of Technology	Policies consultant
	China Huadian Group New Energy Development Co., Ltd.	Potential investor

Recycling team: Key milestones of project development



2 Fachhochschule Trier, Institut für angewandtes Stoffstrommanagement

Zuwendungsempfänger: Institut für angewandtes Stoffstrommanagement, Fachhochschule Trier	Förderkennzeichen: **0330847A**
Laufzeit des Vorhabens: 01.09.2008 – 31.03.2012	
Berichtszeitraum: 01.09.2008 – 31.03.2012, Berichterstatter: Dr. Hongyan Lu, Dr. Michael Knaus, Katrin Müller-Hansen (Sinologin, M.A.)	

Inhalt

2.1 Aufzählung der wichtigsten wissenschaftlich-technischen Ergebnisse und anderer wesentlicher Ereignisse (IN ENGLISH)

2.1.1 Deutsche Zusammenfassung

Die Forschergruppe FH Trier arbeitete eng mit deutschen und chinesischen Partnern zusammen, um technisch, ökonomisch, ökologisch und sozial tragfähige Pilotprojekte zur Generierung von Energie und organischem Dünger aus organischen Reststoffen aus der Landwirtschaft und dem städtischen Bereich in China zu entwickeln. Im Schlussbericht zu dem deutsch-chinesischen Kooperationsprojekt dokumentiert die Forschergruppe FH Trier die Ergebnisse und Erkenntnisse aus der Entwicklung von vier Pilotprojekten und einer Fallstudie des derzeit erfolgreichsten Biogasprojektes in China, der Shandong Minhe Biogasanlage, sowie die daraus abzuleitenden Politikempfehlungen.

Die Forschergruppe FH Trier entwickelte Konzepte für Biogaspilotprojekte an vier Projektstandorten (Yangling und Lintong, Provinz Shaanxi, Jimo, Provinz Shandong und Lanzhou, Provinz Gansu) und versuchte diese umzusetzen. Die vier Projektstandorte unterscheiden sich erheblich hinsichtlich ihrer Rahmenbedingungen. Alle vier Standorte konnten jedoch einen sehr schnellen Anstieg des lokalen BIP verzeichnen, der über dem durchschnittlichen BIP-Anstieg in China liegt. Einhergehend mit dem schnellen Wirtschaftswachstum, spielen nachhaltiges Abfallmanagement und Umweltschutz eine immer wichtigere Rolle für die lokalen Regierungen und die Bürger. Die Spannbreite der vier Projektstandorte bereitete eine gute Basis für die Identifikation von Pilotprojekten mit unterschiedlichen Anlagengrößen und Substratarten für die Fermentierung.

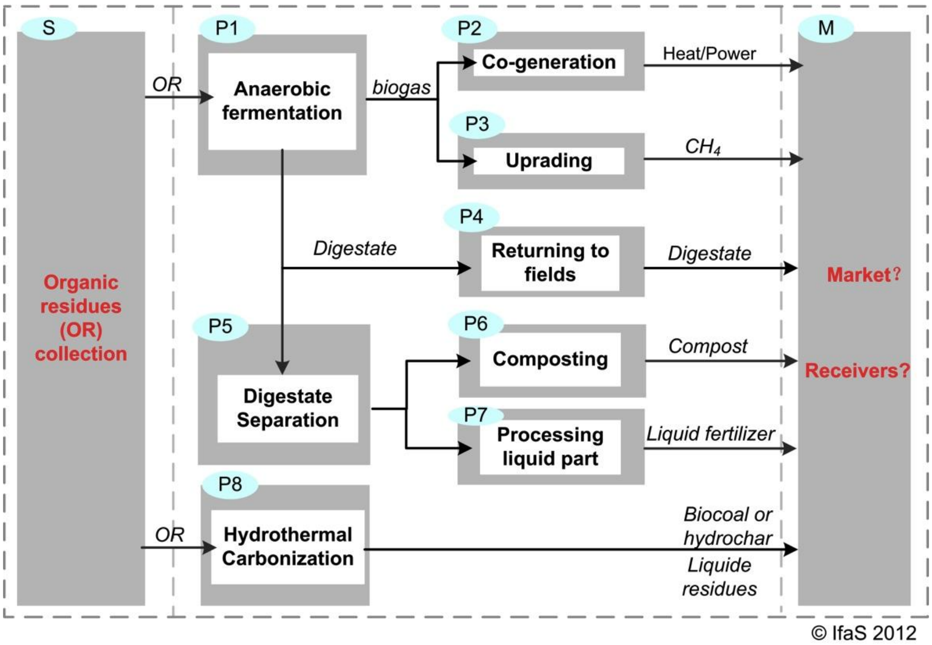
An den vier Projektstandorten erstellte die Forschergruppe FH Trier auf Basis des Ansatzes des regionalen Stoffstrommanagements und unter Berücksichtigung der Bedürfnisse der lokalen Regierungen sowie der Wünsche potenzieller Projektentwickler Geschäftspläne für vier Pilotprojekte mit unterschiedlichen Substraten. Zwei der konzeptionierten Pilotprojekte wurden gebaut, weisen jedoch nicht die angestrebte Performance auf.

Im Zuge der Entwicklung und Optimierung der vier Pilotprojekte anhand der Erstellung von Stoffstrommanagementkonzepten, der Vernetzung der jeweiligen Stakeholder, der Erstellung von Geschäftsplänen und der Identifikation von Projektentwicklern, gelangte die Forschergruppe FH Trier zu folgender Erkenntnis: Der Grad der Kooperation entlang des Stoffstromsystems von Substratbeschaffung, Energieerzeugung, Verwertung der Reststoffe aus der Fermentierung und Förderpolitik ist der entscheidende Faktor für die erfolgreiche Etablierung und den Betrieb ökonomisch und ökologisch tragfähiger Praktiken und Vergärungsanlagen zum Recycling organischer Reststoffe in China.

Der jeweilige Grad der Kooperation entlang des Stoffstromsystems wurde für die vier Pilotprojekte aufgezeigt. Ein hoher Grad dieser Kooperation wurde anhand der Fallstudie der Shandong Minhe Biogasanlage dokumentiert.

Eines der wichtigsten Nebenergebnisse war, dass es dringend der Steigerung des Bewusstseins der Öffentlichkeit und der Optimierung der Förderpolitik auf Seiten des Inputs (Substrate) und des Outputs (Strom, Wärme, organischer Dünger) bedarf.

Grafik 1 dient als Analysetool für die Bemessung des Grads der Kooperation entlang des Stoffstromsystems der vier Pilotprojekte und der Fallstudie mit dem Ziel der Zusammenfassung der wichtigsten wissenschaftlichen und technischen Ergebnisse.



Organic residues (OR), Substrate (S), Process (P), Market (M)

Grafik 1: Analysetool für die Bemessung des Grads der Kooperation entlang des Stoffstrom-Systems

Da die Forschergruppe FH Trier den Grad der Kooperation entlang des Stoffstromsystems als den entscheidenden Faktor für die erfolgreiche Etablierung und den Betrieb ökonomisch und ökologisch nachhaltiger Praktiken des Recyclings organischer Reststoffe in China identifiziert hat, liefert Tabelle 1 eine Zusammenfassung der Einflussfaktoren.

Tabelle 1: Einflussfaktoren des Stoffstromsystems

Pilotprojekte	Status der Pilot-projekte	S	P1	P2	P3	P4	P5	P6	P7	P8	M
Yangling	Nicht gebaut	-	+	+			+	+	+		+
Lintong	Gebaut und Mängel beim Betrieb	+	-	-		-					-
Lanzhou	Gebaut und Mängel beim Betrieb	+					-	+	-		-
Jimo	Nicht gebaut	-	+	+		+	+	+	+	+	-
Fallstudie: Minhe biogas plant	Gebaut und erfolgreicher Betrieb	+	+	+	+	+	+	+	+		+
Legende: ■ Nicht relevant "+" positiv "-" negativ											

Weitere wichtige Nebenergebnisse des Projektes sind die Verbesserung der Beziehungen zu den Partnern in China, der Aufbau neuer Partnerschaftsbeziehungen, die Formierung standort- und themenspezifischer KMU-Konsortien, der Netzwerkausbau der beteiligten deutschen Unternehmen in China, die Schulung zahlreicher Jungakademiker und Nachwuchsführungskräfte durch die Mitarbeit im Projekt und die Anfertigung projektbezogener Masterarbeiten. Außerdem wurde ein Biogaskalkulator in englischer und chinesischer Sprache entwickelt, der es ermöglicht, das Potenzial zur Generierung von Energie und Reduktion von Treibhausgasemission für verschiedene Substrate zu errechnen (Vorkalkulation). Der Biogaskalkulator richtet sich an chinesische Kommunen und sonstige wichtige Stakeholder, die somit in die Lage versetzt werden, eine erste Potenzialsabschätzung zu möglichen Biogasprojekten zu treffen. Das Tool ist somit geeignet, den weiteren Ausbau und die Umsetzung von Biogasanlagen in China positiv zu unterstützen.

Der vorliegende Bericht sowie der Biogaskalkulator werden auf der Projekthomepage (www.organicresidues.com) veröffentlicht.

2.1.2 Project Progress Overview

FH Trier Research Group cooperated closely with German and Chinese partners[1] in order to establish technically feasible and economically viable pilot projects of transforming organic residues from agriculture and source-separated residues from municipal origin into energy and organic fertilizer, as shown in Figure 1. With this Sino-German cooperation project, FH Trier Research Group documented the findings and suggestions learned from the path of establishing four pilot projects and an in-depth case study of the most successful biogas plant, named Shandong Minhe Biogas Plant, in China.

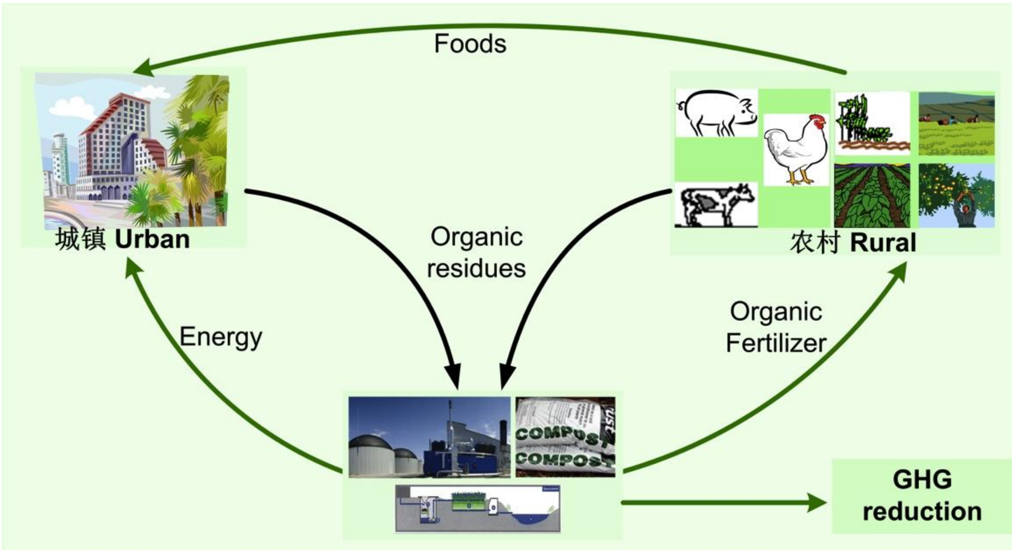


Figure 1: Vision of the new material flow system represented by pilot projects

FH Trier Research Group tried to develop four pilot projects at four research sites, namely Yangling and Lintong in Shaanxi province, Jimo city in Shandong province and Lanzhou city in Gansu province. The project sites are shown in Figure 2 below. The four research sites show big differences in the total economy, administrative area and population, but they all gained a very fast local GDP growth rate, faster than the average GDP growth rate of China (see Table 1). Along with the fast economic growth, sustainable waste management and environmental protection are increasingly concerned by local governments and citizens. The variety of the four research areas provided a good foundation for FH Trier Research Group to identify pilot projects with different focuses, especially different types of substrates for being recycled.

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[1] For an introduction of the members of FH Trier Research Group (Institute for Applied Material Flow Management and German SMEs) as well as the Chinese partners please visit the project homepage www.organicresidues.com.

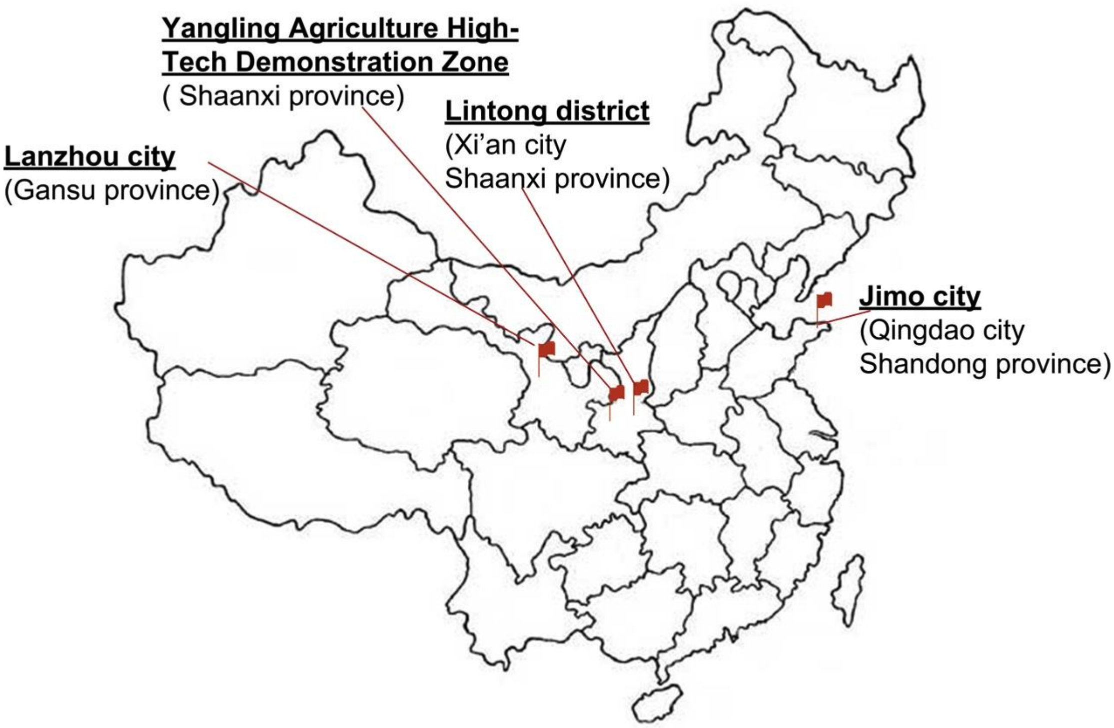


Figure 2: Locations of the four research sites

Table 1: General information for the four research sites

	Research sites	Area (km^2)	Population (% of agricultural population)	Local GDP in 2010 (Yuan RMB)	Local GDP increased by 2009
1	Yangling	94	200.000 (96%)	4.7 billion	15.5%
2	Lintong district	915	700.000 (80%)	14 billion	14%
3	Jimo	1,780	1,075,000 (87%)	57.3 billion	13.8%
4	Lanzhou	13,271	3,616,100 (48%)	110 billion	12.8%

Within the four research sites, based on regional material flow management approaches, local governmental concerns and the wishes of potential pilot projects developers, FH Trier Research Group targeted different organic residues as substrates for developing business plans of the four pilot projects, shown in Table 2. Among them, two pilot projects were constructed and two remaining as concepts. Although two pilot projects were constructed, they are not showing the desired performances. (Further information will be provided in the following Chapters).

Table 2: Progress overview of the four pilot projects

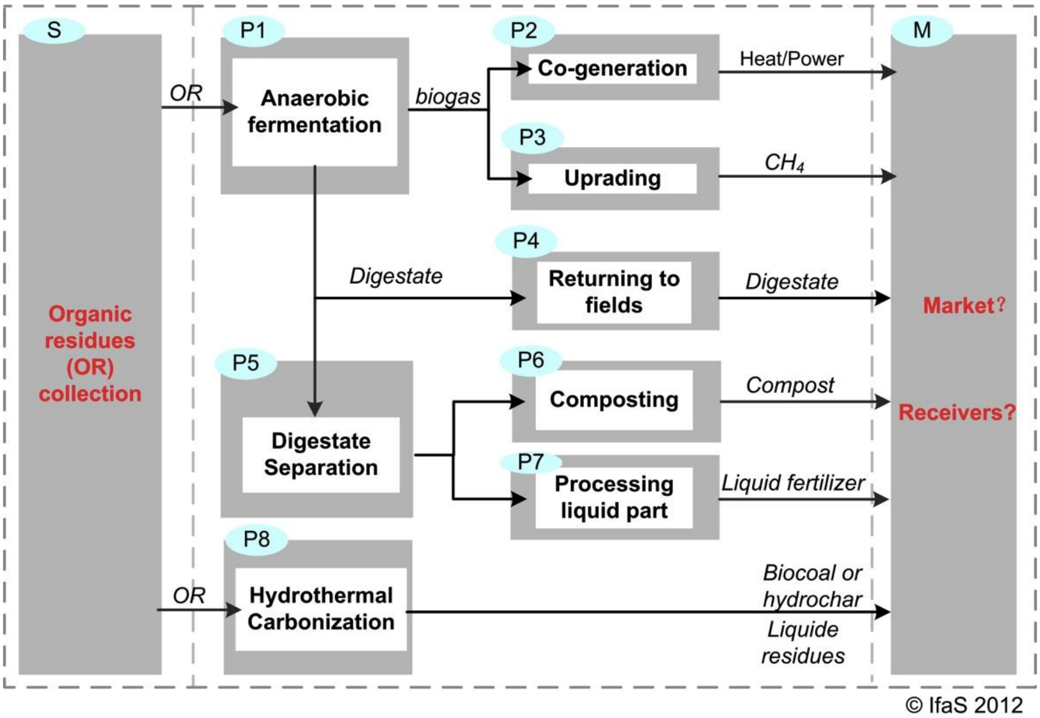
	Research sites	**Pilot projects**	
		Substrates	**Status**
1	Lingtong district	Manure from one cow farm	Constructed
2	Yangling	Manure from 21 farms	Not constructed
3	Jimo	Sewage sludge	Not constructed
4	Lanzhou	Restaurants' food waste	Constructed

Through the processes of trying to develop and optimize four pilot projects, by employing systemic material flow management concepts combined with connecting shareholders, developing business plans and identifying developers, FH Trier Research Group found that **insufficient cooperation along the material flow system consisting of substrate collection, energy production, digestate utilization and subsidy system** has been the key influential factor for establishing and operating economically and ecologically viable practices of recycling organic residues in China.

The situations of insufficient cooperation along the material flow system were explained along the major material flow paths of each pilot project and a good cooperation along the substrate collection, energy production, digestate utilization and subsidy system was presented by a case study in Shandong Minhe biogas plant.

One of the major findings was that increasing the cooperation along the material flow system and subsidy system level for projects of recycling of organic residues in China urgently requires the optimization of public awareness and governmental policies at input and output sides. This finding will be discussed in detail in the following Chapters.

Figure 3 is used as a framework for analyzing the cooperation along the material flow system of the four pilot projects and the case study plant for summarizing the main scientific and technical results.



Organic residues (OR), Substrate (S), Process (P), Market (M)

Figure 3: A framework for analyzing cooperation along the material flow system

As FH Trier Research Group identified that insufficient cooperation along the material flow system has been the key influential factor for establishing and operating economically and ecologically viable practices of recycling organic residues in China, a summary of the positive and negative factors influencing the status of cooperation along the substrate collection, energy production, digestate utilization and subsidy system of the four pilot projects and the case study biogas plant is given in Table 3. Detailed information about the project implementation and results, the positive and negative factors influencing the status of cooperation along the material flow system of the four pilot projects and the case study biogas plant will be documented in the following Chapters.

Table 3: Summary of influencing factors

Pilot projects	Status of pilot projects	S	P1	P2	P3	P4	P5	P6	P7	P8	M
Yangling	Not constructed	-	+	+			+	+	+		+
Lintong	Constructed and in poor operation	+	-	-		-					-
Lanzhou	Constructed and in poor operation	+					-	+	-		-
Jimo	Not constructed	-	+	+		+	+	+	+	+	-
Case study: Minhe biogas plant	Constructed and in good operation	+	+	+	+	+	+	+	+		+
Legend: ■ Not relevant "+" Positive "-" Negative											

Further side results of the projects are that the relations with the Chinese partners were intensified, that new partnerships were set up, that site-related and topic-related SMW consortia were formed, that the involved German companies were able to enlarge their network in China and that a large number of young scientists and young professionals were trained through involving them in the projects and through writing project related master theses. Last but not least a biogas calculation tool was developed in English and Chinese language for calculating the energy generation and CO_2 reduction potential of various substrates (pre-calculation). The calculation tool allows Chinese local governments and other stakeholders to tentatively assess their biogas potentials and help to market and create new biogas project opportunities.

This report as well as the biogas calculation tool will be published through the project homepage (www.organicresidues.com).

2.2 Scientific and Technical Results

2.2.1 Scientific and Technical Results from Developing a Pilot Project in Yangling

Yangling pilot project was planned within the Yangling Agriculture High-tech Industry Zone, the only national grade demonstration zone in China for research and promoting high-technologies in the agricultural field since 1997. In Yangling, there were 32 food processing companies and about 30.000 milk cows, 10.000 meat cows, 35.000 pigs and 800.000 chickens by the end of 2010. Yangling pilot project was designed to build a biogas cogeneration plant with installed electricity capacity of 1MW. Its substrate was collected from 21 livestock farms, their locations were shown as Figure 4. Total input was 45,444 tons/a including 25.5% of dry matter. The theoretical output of biogas was 4.07 million m^3 (55% of CH_4 content). This pilot project could produce 21,666 tons of solid residues and 28,586 tons of liquid residues. According to the calculations of ***agraferm technologies AG***, the output of electricity and heat are 8,157,355 kWh/a and 8,565,223 kWh/a. The detailed material flow chart of the pilot project is shown at Figure 5. Investment payback periods were between 3 to 14 years according to the economic sensitivity analysis shown at Figure 6.

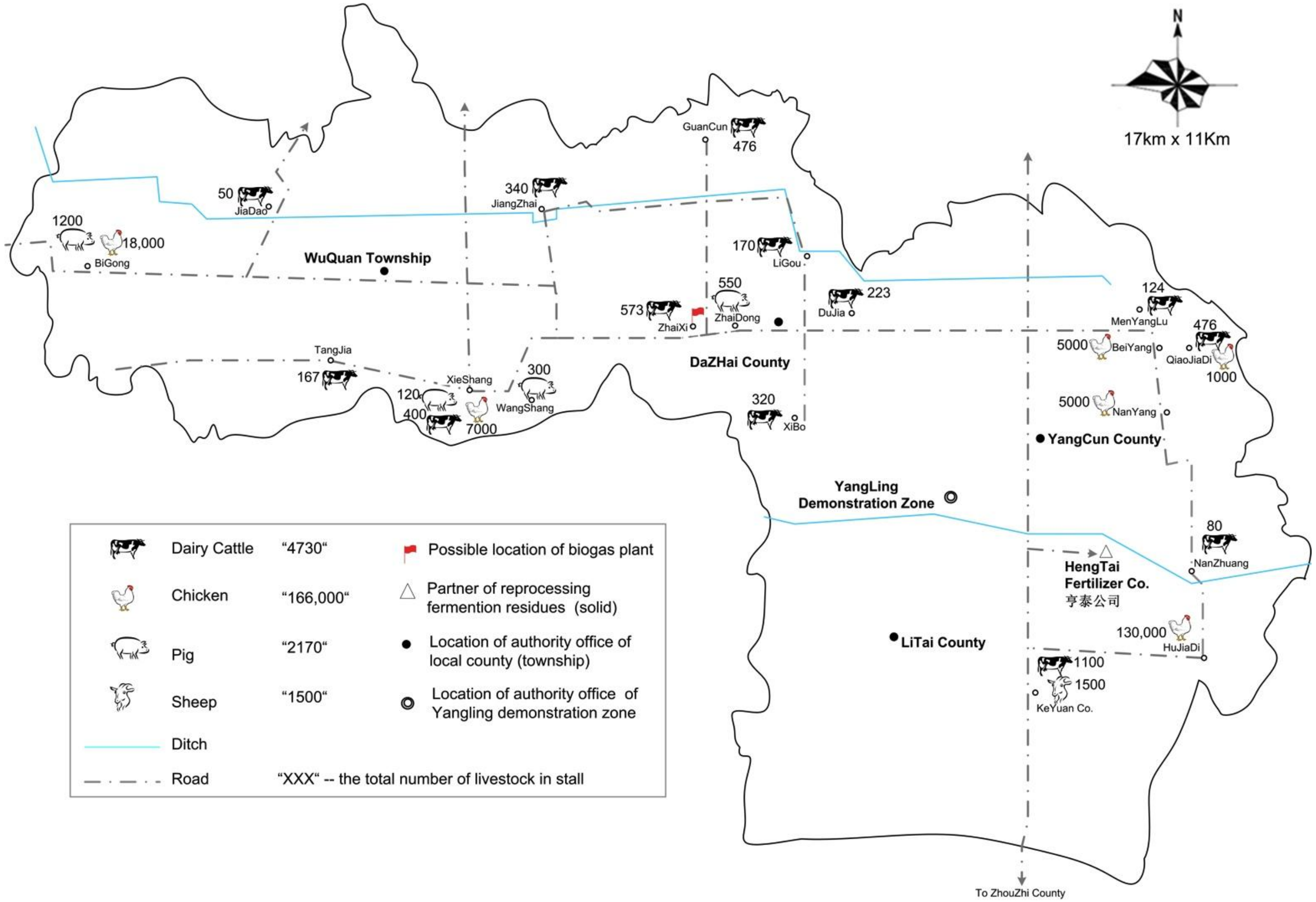


Figure 4: Locations of the 21 farms to provide animal manures for the planned pilot project in Yangling

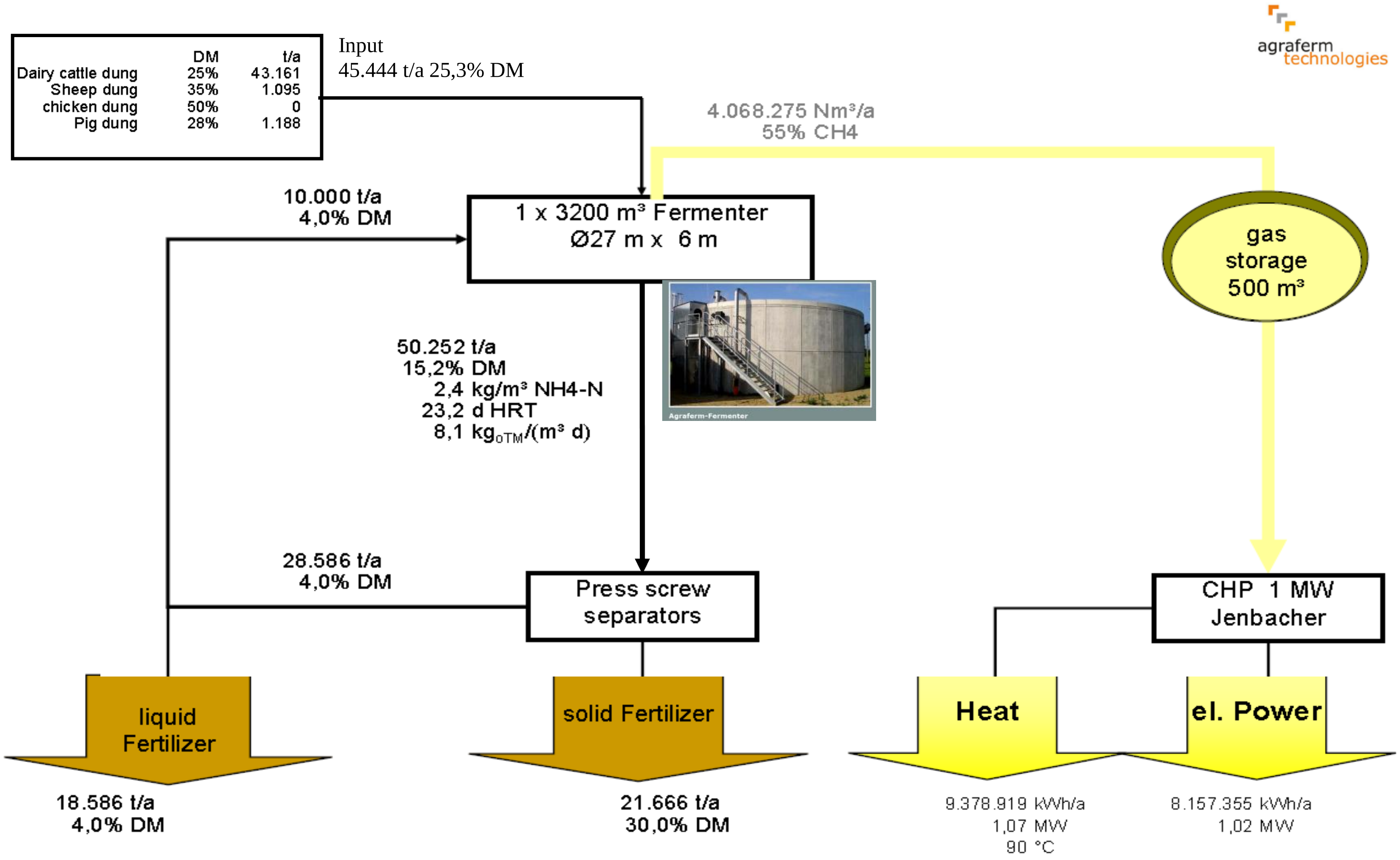


Figure 5: Material flows of the pilot project in Yangling (agraferm technologies AG)

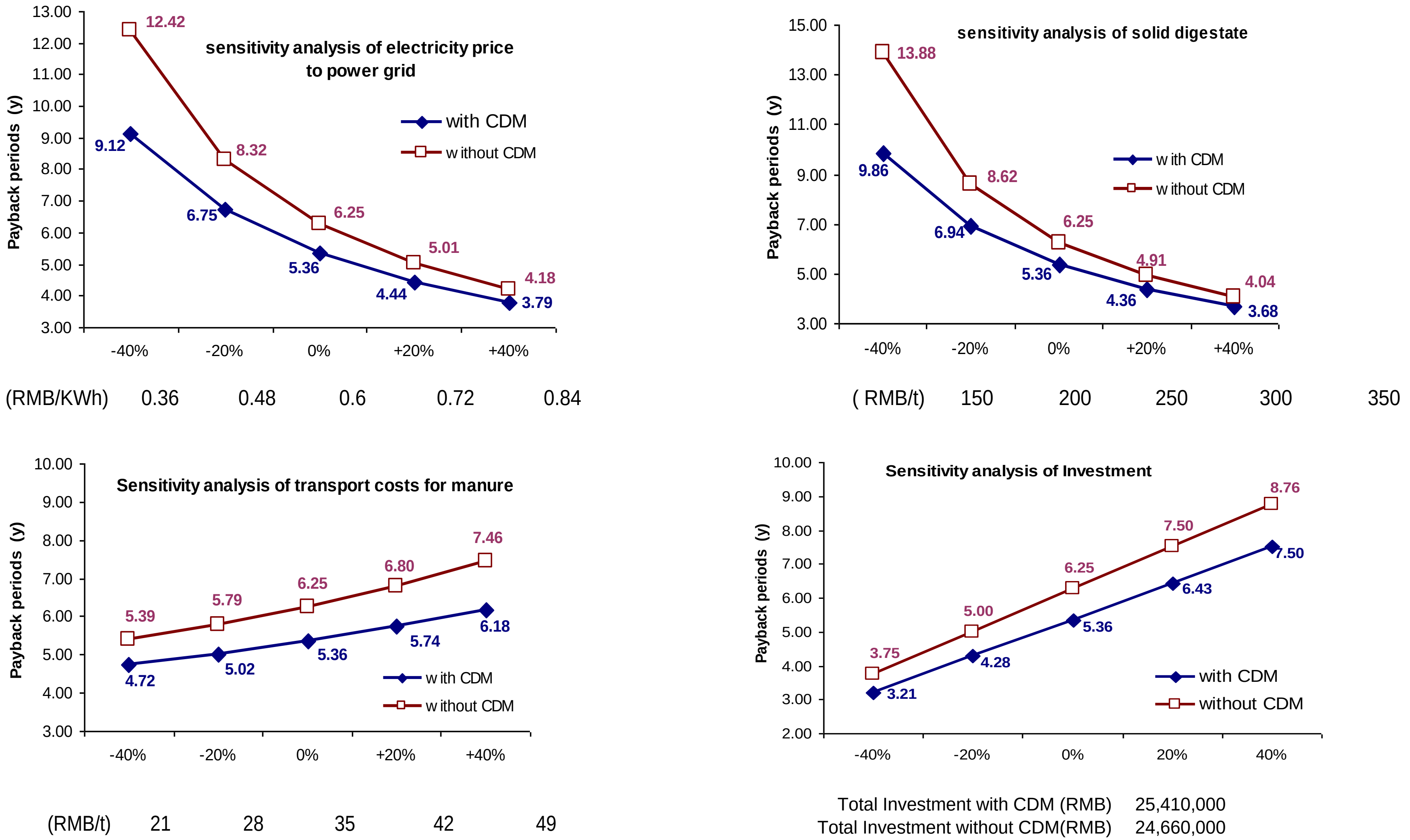
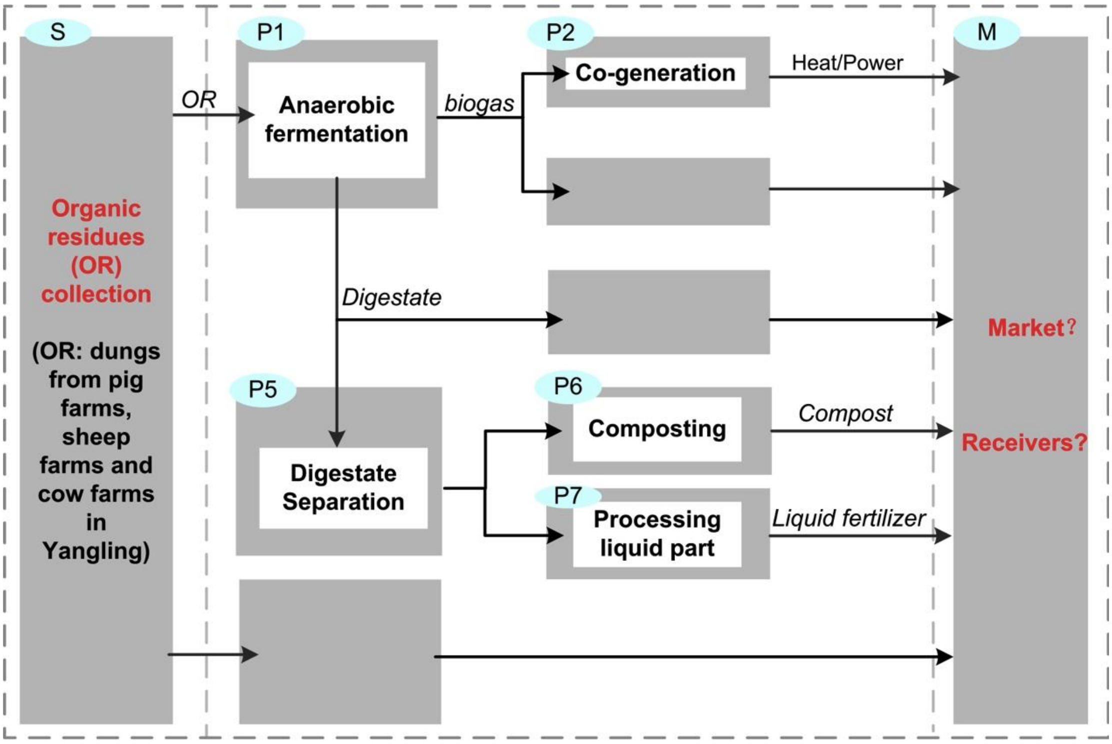


Figure 6: Economic sensitivity analysis of Yangling pilot project (agraferm technologies AG)

Cooperation level analysis:

Although the economic viability of Yangling pilot project was acceptable for the pilot project developer, a state-owned electricity generation company, Yangling pilot project was not developed due to the challenge of reaching an agreement among the 21 animal farms for supplying substrates. Along the material flow system, steps of proposed Yangling pilot project, shown at Figure 7, the middle processes from P1 to P7 could be properly managed with proven technologies and experiences of German companies. On the outputs side, the market and sales for electricity, heat and digestate, were manageable as well. The challenge was to arrange a stable supply of input material and establish long-lasting contracts with input material suppliers (21 farmers).



Pilot project	Developer	Status	S	P1	P2	P5	P6	P7	M
Yangling	A state-owned electricity generation company	Not constructed	-	+	+	+	+	+	+
Legend: ■ Not relevant "+" Positive "-" Negative									

Figure 7: Level of cooperation along the material flow system of Yangling pilot project

Electricity could be feed-in the power grid as the installed electricity capacity was bigger than 500KWel[2]. Heat could be used to cover the process-internal heat demand as well as partly supplied to a school nearby the pilot plant. One of the strengths of the Yangling pilot project would have been the opportunity to cooperate with a local organic-inorganic fertilizer company. This company would have utilised the liquid digestate as fertilizer for vegetables and other crops and utilised the solid digestate as raw-material for producing organic-inorganic compound fertilizer. In addition, there are eight vegetable farms in Yangling which would like to use the liquid and solid digestate from the pilot project.

Although suitable technologies and utilisation options for electricity, heat and digestate were available, the material flow system of Yangling pilot project was not realised based on the insecure input supply. Although various stakeholder meetings were arranged, neither the owners of the 21 farms nor the local government could manage to convince all stakeholders to sign a supply agreement for the construction of a centralized biogas plant. While some farms worried about the sanitation risks of collecting manures among different animal farms, others had the intentions of building their own biogas plants with governmental subsidies for construction costs. Hence, based on the insufficient coordination for a stable supply of substrates, the project developer finally decided not to invest in the Yangling pilot project. This insufficient coordination partially is a result of the current subsidy system, which is oriented towards the construction costs and not towards the performance of the biogas plants. Hence, even small-scale farms have an incentive to built small biogas units, which are either more costly or lower in performance compared to centralised larger plants. This point of view would be expanded in more details together with the findings of Lintong pilot project.

[2] According to the governmental regulation, electricity is allowed to be connected to power girds only if the installed electricity capacity of biogas plants is bigger than 500KWel. National Development and Reform Commission (NDRC). 2006. *Regulation on the Administration of Power Generation from Renewable Energy*, NDRC Price (2006)No.7.

2.2.2 Scientific and Technical Results from Developing a Pilot Project in Lintong

Lintong district of Xi'an city has been facing the serious pollution from uncontrolled discharging of manure and waste water from breeding livestock. According to the answers received on our questionnaire, over 700,000 ton manure and 500,000 ton waster water were discharged from breeding livestock in Lintong district annually, whereof nearly 50% is concentrated at milk cow farms. Only some of the naturally drying cow manure was sold as fertilizer from time to time. Waste water of cow farms was either stored in lagoons nearby the farms or directly discharged into nearby water bodies. Over 60% of milk cows, 90% of pigs, 95% of chicken and all of cattle and sheep were owned by individual households, which means decentralized breeding was a dominating mode in Lintong (see Table 4 in details). This situation created challenges for establishing sustainable manure management in Lintong, similar to the situation in the Yangling pilot project.

The owner of the biggest milk cow breeding community in Lintong, with 1000 milk cows was very active to cooperate within the Sino-German Recycling project to develop an economically and ecologically viable pilot project at her farm, producing clean energy, organic fertilizer and reduce environmental pollution. The farm was surrounded by over 600 households and seven small animal farms within a radius of 800 meters, as shown at Figure 8.

Table 4: Amount and distribution of livestock in Lintong

Livestock	Amount of livestock on hand (heads)	Sources %		
		Individual households	Breeding communities	Company owned
Milk cow	4,6500	60%	30%	10%
Cattle	20,000	100%		
Pig	260,000	90%	2%	8%
Sheep	140,000	100%		
Poultry	3,400,000	95%		5%

(Source: Circular Economy Research Institute of Shaanxi, 2008, based on a questionnaire developed by FH Trier Research Group.)

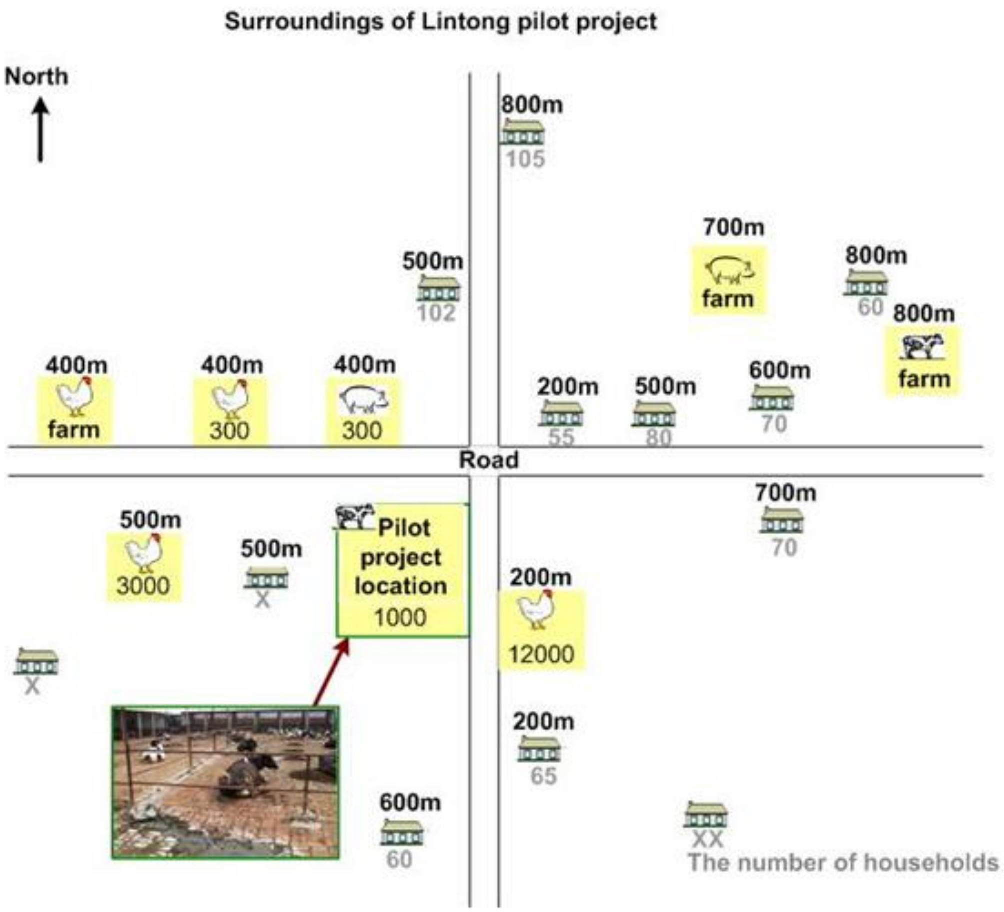


Figure 8: Surroundings of the Lintong pilot project

FH Trier group suggested to the farm owner that the pilot project could take use of the regional organic residues from other animal farms and agricultural activities to install a minimum of 500KWel in order to be able to feed-in the electricity to the power grid and therefore be benefiting from the subsidized electricity tariff [3] according to the Chinese renewable energy law. But the farm owner was reluctant to cooperate with other animal farms and mainly wanted to use the available governmental subsidies to construct a farm-own plant. Based on 5,000 t/a of animal dung and 5,000 t/a of waste water from the farm, a pilot project was proposed with an installed electricity capacity of 51KWel including three key units as anaerobic digestion, combined heat and power generation and composting, based on the calculations of FH Trier Research Group. Mass balance, major inputs and outputs of the three key units and estimated total investment of the proposed pilot project are provided with Figures 9, 10 and 11.

[3] Provincial baseline tariff for power from coal power plants fed into the grid with desulfuration devices + 0.25 yuanRMB/kWh.

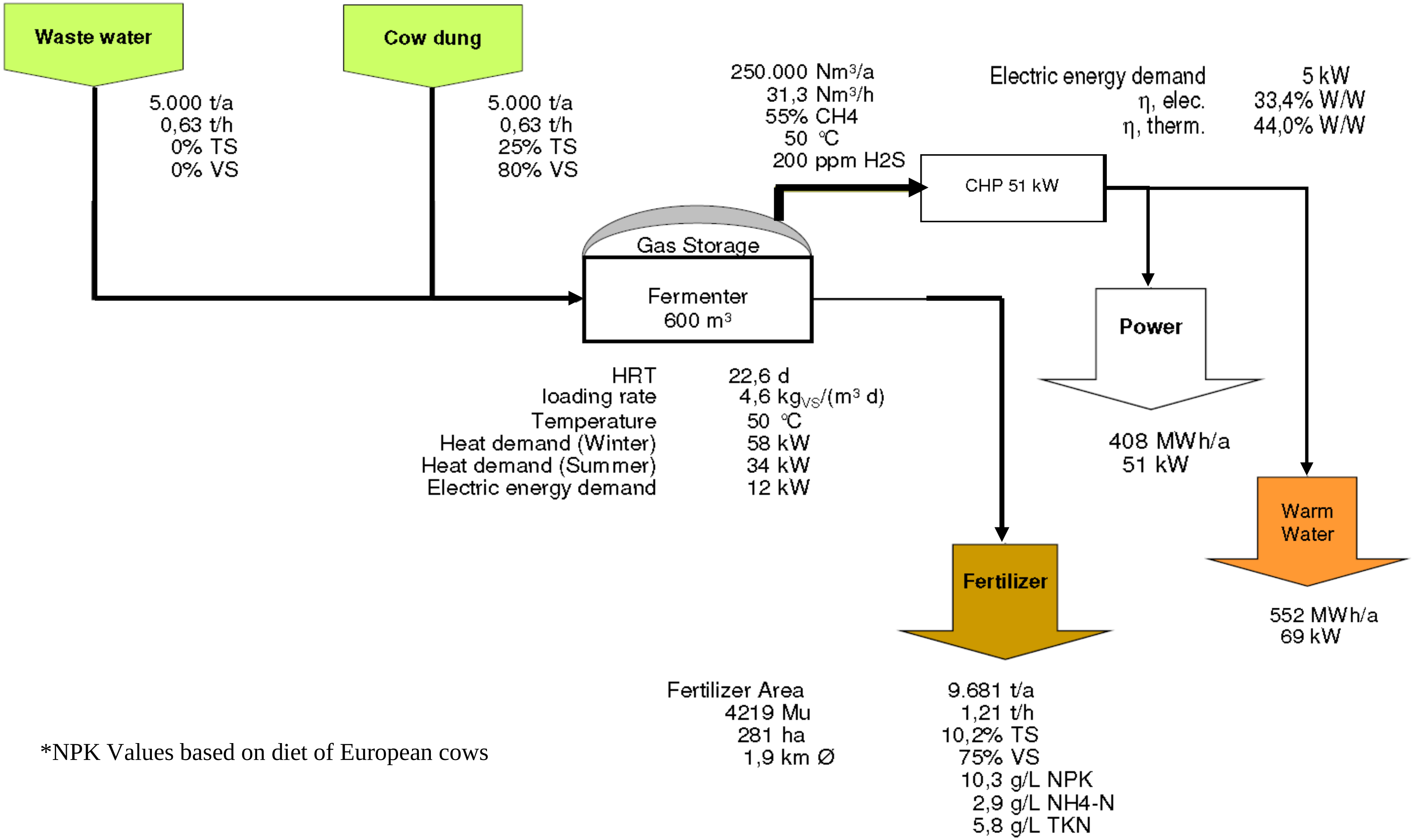


Figure 9: Mass balance of the proposed Lintong pilot project (agraferm technologies AG)

	Input			Output		
a	Biogas generation	(10% of electricity demand for own process)				
	Cow dung	25% DM, 80%oDM	5,000 t/a	Biogas	(55% CH_4)	250,000 Nm^3/a
	Waste water		5,000 t/a	Fermented residues	10,2%TS, 75% VS	9,681 t/a
b	CHP unit	(10% of electricity demand for own process)				
	Biogas		250,000 Nm3/a	Electricity	51KWel	408,000 kWh/a
				Heat	37KWth	
c	Composting	(Electricity demand for compositing is not provided yet)				
	material (Straw, etc)		6,000 t/a	Compost (ca. 62%DM)		5,253 t/a
	Fermented residues	10,2%TS, 75% VS	9,681 t/a			

Figure 10: Input and output of the proposed Lintong pilot project (agraferm technologies AG)

	Investment		
a	**Biogas generation**		
		396,700 €	**European price of Agrafem**
b	**CHP unit**		
		105,500 €	**Offical offer of Lindenberg-Anlagen (Ref-No. VP /08)**
c	**Composting**		
		308,699 €	**Combined China and European price)**
	TOTAL	**810,899 €**	**(plus VAT tax, Fahrzeuge and land cost)**

Figure 11: Estimated investment of the proposed Lintong pilot project (Lindenberg)

With German technologies, the proposed Lintong pilot project was assigned with a necessary investment of approximately 7 million Yuan RMB. As Table 5 indicates, this project was highly (economically) sensitive towards the price declining of organic fertilizer and the price increasing of straw in the market. For example, instead of 5.49 years of investment return period, it could be extended up to 26 years if the organic fertilizer price would decline from 600 Yuan RMB per ton to 400 Yuan RMB per ton.

Different from Germany, where the energy price and the plant performance are the key economic drivers of the feasibility, in China the sales price for fertilizer to market (liquid and solid digestate) is one of the crucial economic parameters.

High investment, plus high economic sensitivity about the fluctuation of organic fertilizer price and straw price, hindered the farm owner to build the pilot project as been proposed. Although several technical scenarios and business models were developed by FH Trier Research Group, such as technology transfer from German companies to a Chinese engineering company, it was impossible to reduce the total investment costs lower than 2 million RMB as the farm owner expected. Finally, the farm owner built a biogas plant designed and constructed by a Chinese biogas company. The total investment was around 1.3 million Yuan RMB, covered by governmental subsidies.

Table 5: Economic sensitivity analysis of proposed pilot project Lintong

Change rate of electricity tariff	-20%	-10%	0%	+10%	+20%
Electricity tariff	0.480	0.540	0.600	0.660	0.720
Investment payback periods (y)	9.65	9.35	9.06	8.80	8.54
Change rate of Organic fertilizer price	-20%	-10%	0%	+10%	+20%
Organic fertilizer price	400	450	500	550	600
Investment payback periods (y)	26.08	13.45	9.06	6.83	5.49
Change rate of Straw price	-20%	-10%	0%	+10%	+20%

Straw price	240	270	300.00	330	360
Investment payback periods (y)	6.26	7.41	9.06	11.67	16.40
Change rate of Investment costs	-20%	-10%	0%	+10%	+20%
Investment costs (RMB)	5,838,473	6,568,282	7,298,091	8,027,900	8,757,709
Investment payback periods (y)	7.25	8.16	9.06	9.97	10.88

Reviewing the performance of the biogas plant

The total investment of the biogas plant included two 400 m^3 digesters suitable for 20t/d caw dung as input substrates and a biogas production of 800 m^3 per day. The plant had been only operated for about one month since its starting in the summer of 2011. The amount of generated biogas was only enough to supply several days of engine's operation for electricity production. It was then out of operation because there was less biogas generated. When FH Trier Research Group visited the plant in November 2011, the plant operator said that there was little biogas yield at that moment due to the cold weather condition. Heat supply to the digesters (or insulation) was not employed in order to reduce the initial investment. The biogas plant would be restarted by spring 2012 as the operator said.[4] Emptying the two digesters would be the first step to get it restarted. The digestate had been stored in a lagoon next to the biogas digesters. Environmental pollution remains unsolved, although a biogas plant standing there, seeing Figure 12.

[4] FH Trier Research Group has no further information if the plant is currently in operation.

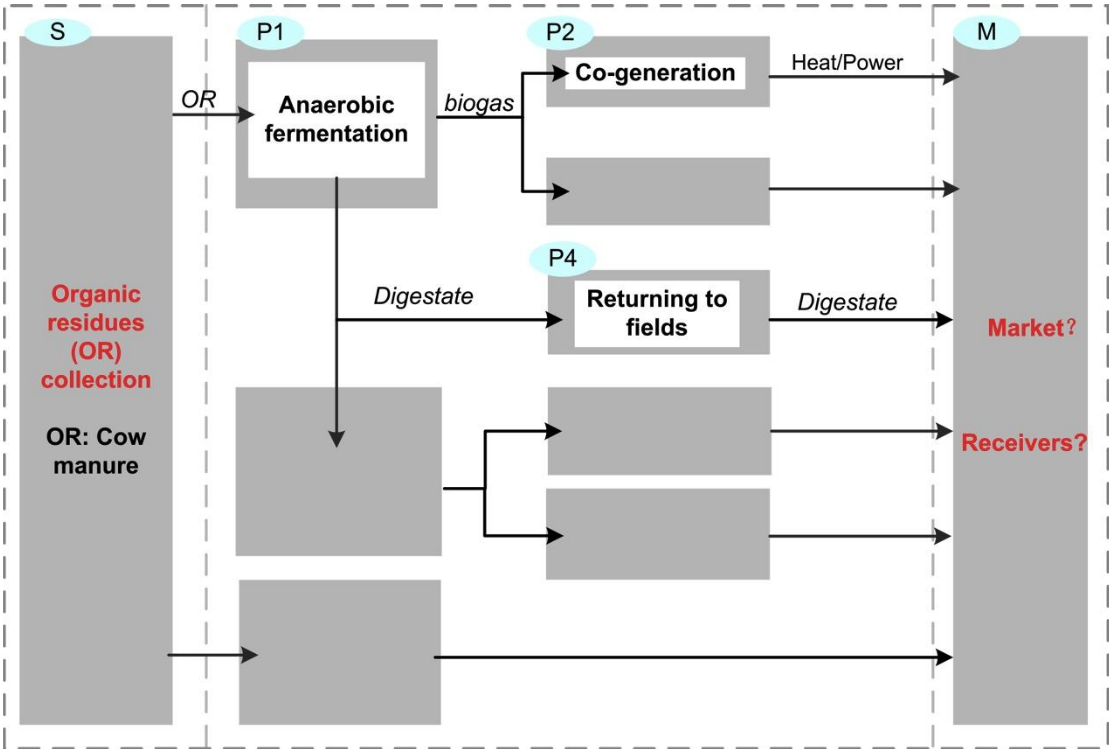
Figure 12: Biogas plant constructed with poor performance at the 1000 milk cow farm

Major concerns of the farm owner by the discussion during the on-site visit of FH Trier Research Group in November 2011:

1. How much biogas was exactly produced during the trial operation in summer 2011?
2. What could be the causes for the biogas plant to stop generating biogas? Was it the cold weather or too much settlings in the anaerobic tanks?

Cooperation level analysis:

Although the farm owner indeed wanted to build the biogas plant properly, she failed to reach her goals. The reasons are a lack in cooperation with other input substrate providers and the governmental subsidy policy. As her own input material allows only for an installation of around 50KWel, the co-generation was to small to feed the generated electricity into the grid. Furthermore, the subsidy is just based on the initial investment and on the performance of the plant. Hence, the farm owner had an incentive to minimize the construction costs in order to get the plant built with the available subsidies. Therefore, the planning and construction standards were relatively poor and the plant went out of operation after two months.



Pilot project	Status	Substrate	Investor	Performance	S	P1	P2	P4	M
Lintong	Constructed and in poor operation	Cow manure	Farm owner	Poor	+	-	-	-	-
Legend: ■ Not relevant "+" Positive "-" Negative									

Figure 13: Level of cooperation along the material flow system of Lintong pilot project

2.2.3 Excursus Rethinking Governmental Subsidies

Developing Yangling and Lintong pilot projects pointed out the fact that the present Chinese governmental subsidies for medium and large size biogas plants at intensive livestock farms is causing negative influences on developing economically and ecologically viable pilot projects of recycling organic residues from livestock farms.

The governmental subsides had played an important role in constructing medium and large biogas plants (MLBP) at intensive livestock farms in China. Between 2006 and 2010, the number of MLBP at intensive livestock farms was increased by around 670%, due to the support of the governmental subsides. [5] But many of the constructed biogas plants showed a poor performance like the one at the farm in Lintong. Furthermore, they are below the threshold limit of 500KWel and therefore not able to feed the electricity into the grid.

Table 6 shows the definition of MLBP according to the Chinese national standard.

Table 6: Definition of middle- and large scale biogas plants in China

(National Standard NY/T 667-2003*)

BGP size	Individual volume of fermenter (m^3)	Total volume of fermenters (m^3)	Biogas Production (m^3/d)*
Large	≧ 300	≧ 1,000	≧300
Middle	50 – 300	100 – 1,000	≧50
Daily lowest biogas yield at ≧25°C fermentation temperature			

*Ministry of Agriculture updated the classification of scale for biogas engineering in September 2011 (NY/T 667-2011), which defines super large, large, middle and small scale of biogas engineering as the daily yield of biogas (Q, m^3/d) by Q≧ 5000, 5000＞Q≥500, 500＞Q≥150 and 150＞Q≥5 respectively. Because the subsidies before September 2011 were managed based on NY/T 667-2003, we still used the version of NY/T667-2003 for discussion in the paper. For reaching the scale of an installed electricity capacity of 500KWel, the daily yield of biogas should be around 5000m^3/d.

[5] Ministry of Agriculture (MOA). 2010. *2010 China Agriculture Statistical Report*. P. 171-172.

The governmental subsidies for MLBP at intensive livestock farms are featured by three characteristics: The responsible government agency of the governmental subsidies is the Ministry of Agriculture (MOA); the subsidies only support biogas plants at intensive livestock farms; and the subsidies served as compensation of the construction cost of the MLBP. During the 11th Five Year Development Plan (2006-2010), MOA had supported around 4,000 new MLBP (MOA 2007). Between 2006 and 2009, MOA allocated 16 billion Yuan RMB to support MLBP and household-size biogas plants (Hao 2010).

According to the regulations of MOA (2007), the central and local government (provincial, municipal and lower levels) share the contributions to the MLBP subsidies. The subsidies from central government cover no more than 45% of the total investment of MLBP (usually between 25%-45%) and the local government fund cover not less than 5% of the total investment. The amount of the subsidies to support one MLBP is regulated by two principles: First, the governmental subsidies compensate around 50% of the construction cost and second, the total subsidies from central government cannot exceed 2 million Yuan RMB for one MLBP, which limits the initial investment options.

From 2006-2010, the governmental subsidies increased and supported the construction of 4000 new MLBP. Hence, officially, 39% of the medium and large scale of intensive livestock farms in China has established biogas plants (MOA 2007). However, the operation and performance of the MLBP are in average relatively poor resulting in low biogas output and availability, lack of process control and performance monitoring (Raninger 2012). Currently, the limited biogas production is used to generate electricity for on-site use or directly utilized as cooking fuel of households. Both alternatives are characterized by a low energy efficiency of biogas utilization and causing secondary pollution (Tang 2011; Xu 2010). Furthermore, there is a lack in utilizing the digestate as fertilizer (Lin 2011). Both aspects leading to less income generation and in reverse to a limitation in farmers ability to invest in "high technology" biogas equipment based on the current subsidy system. Hence, although the present economic and political system provides increasing subsidies to the construction of MLBP, with the purpose of limiting environmental protection and increasing clean energy production by livestock farms, often the reverse effects are achieved as illustrated in Figure 14.

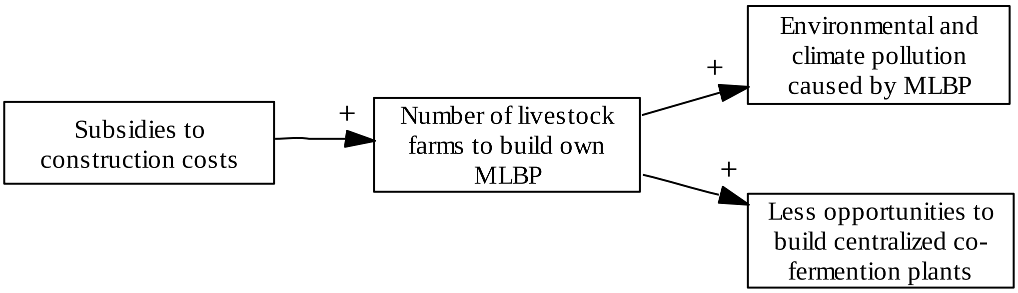


Figure 14: Negative effect of governmental subsidies for MLBP at intensive livestock farms

(Causal loop diagrams based on system dynamics are applied to determine the interaction among factors. An arrow going from A to B indicates that A influences B. A plus sign at an arrow end, "+", means increasing of A causes the increasing effects of B. Snowball effect could be identified when a feedback cycle exists in causal loop diagram.)

Although, the regulation on 500KW as minimum size for renewable energy electricity feed-in tariff encourages the development of more centralized co-fermentation biogas plant (CCBP) the subsidy scheme based on the investment (with a limited of 2 Mio RMB per plant) counteracted this opportunity. Large-scale CCBP, based on high quality German technologies, are outperforming in terms of energy production (biogas, heat, electricity) and provide a stable digestate usable for compound fertilizer. But these technologies require a high initial investment and needs a stable income sources for the payback period. As already mentioned the challenge of securing a stable and high input amount for plants bigger than 500KWel is one of the two challenges. The second major challenge is that based on the low feed-in tariff for electricity the digestate must be market. As the Chinese fertilizer prices are volatile and yet the awareness to utilize digestate from biogas plant as quality fertilizer is not fully developed this is considered to be a major risk for the investor.

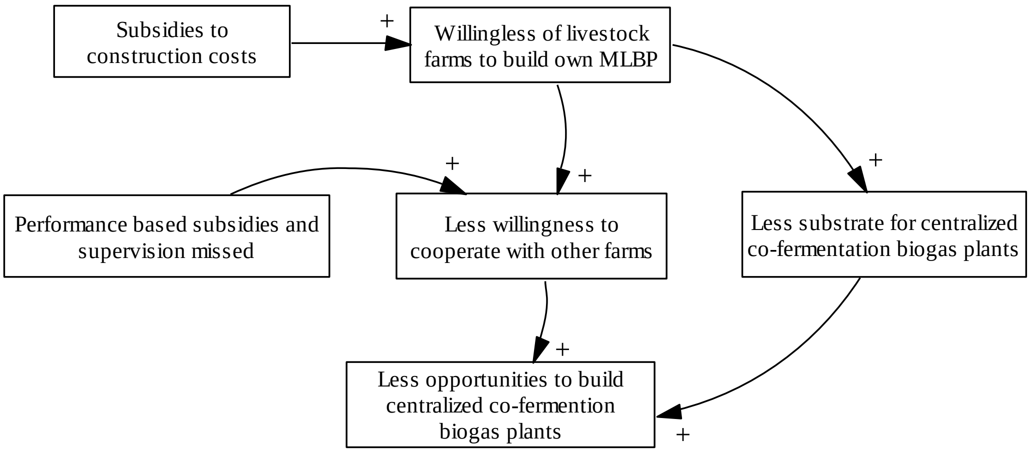


Figure 15: Present subsidies limit chances of establishing centralized co-fermentation biogas plants

Conclusion: Governmental subsidies are discouraging the development of centralized co-fermentation biogas plants

Environmental and climate pollution challenges

Present governmental subsidies for MLBP have initiated a rebound effect of polluting the environment instead of limiting the environmental pressure, shown in Figure 16.

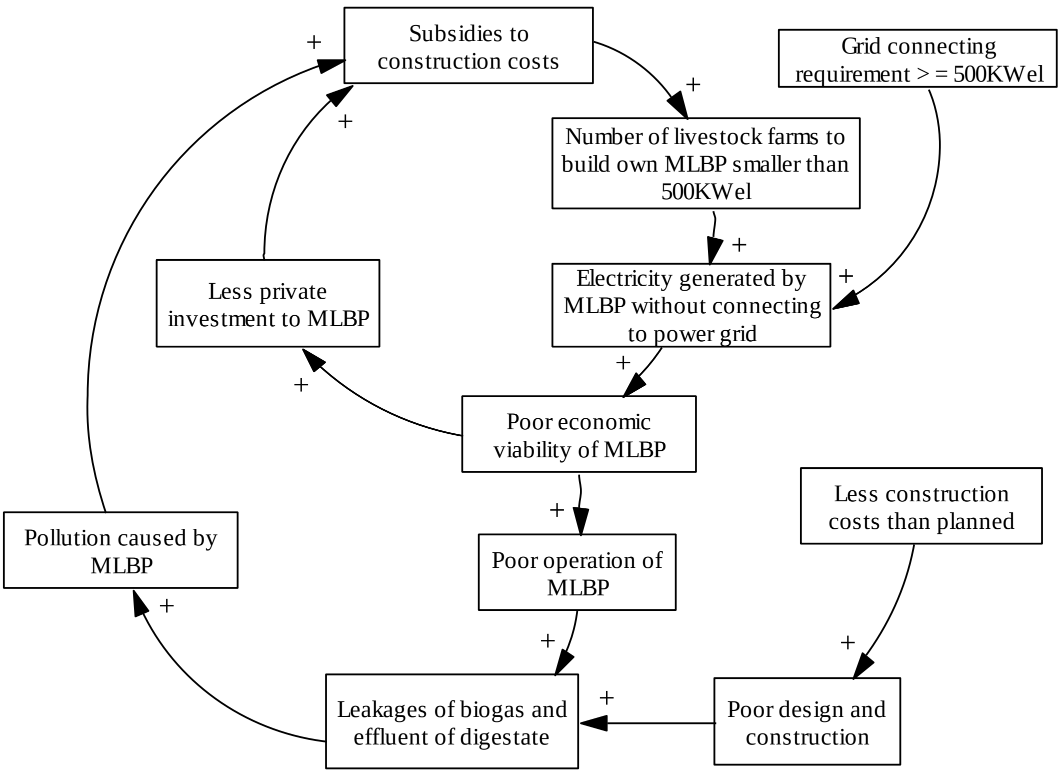


Figure 16: Present subsidies are hardly leading to a higher level of environmental protection.

Less construction costs than planned: The current governmental subsidies are construction oriented, based on the total construction budget. One drawback of the system is that the performance and operation of the MLBP is not related to the subsidies. Many livestock farms try to cut their own investment in MLBP to save costs. Although the owners of MLBP are supposed to provide around 50% of the total investment to build MLBP, they actually spend less than written in the respective feasibility study reports, because either the total investment can be artificially increased in those reports, or local fiscal subsidies cannot cover the matching funds as promised in the feasibility studies. Hence, the subsidies of the Central Government are often the main funding sources for the construction of MLBP. The insufficient investment (or saving attempts after the feasibility study period ends in order to limit the own contribution of the farmers) is often resulting in poor design and construction of MLBP.

Low economic viability: For most MLBP, the quantity of the generated electricity is not eligible to be connected with power grids. The regulation of 500KW as minimum size for national grid-connection has kept away most of the MLBP from the biomass feed-in tariffs system within the framework of the Renewable Energy Law. In 2004, over 99% of the Chinese pig farms had an annual output of less than 50,000 fattened pigs. Based on the data, most of the MLBP show an installed electricity capacity of around 100 to 350KW. Due to the grid-connection restriction, these MLBP will have to discontinuously generate electricity for their own use or to flare the biogas. Some MLBP sell biogas directly to nearby households. Biogas could be sold between 1~2 Yuan RMB per m^3. But the management costs are very high for livestock farms to collect the payment of biogas from nearby households.

By the end of 2007, a survey of 172 MLBP in Fujian province demonstrated that about 81% of the projects used less than 30% of the produced biogas and that the largest part of the biogas was emitted directly into the air or flared in emergency flames. (Xu, 2010)

Recommendations for optimizing governmental subsidies and other aspects for promoting the development of economically and ecologically viable projects of recycling organic residues are provided in Chapter 2.1.4.

2.2.4 Scientific and Technical Results from Developing a Pilot Project in Jimo

Sewage sludge is a big stream of organic residues in China, which increasingly requests the development of environmentally sound solutions. In 2010, the amount of sewage sludge was nearly 22 million tons in China with an annual increase of nearly 10%, of which 80% was landfilled or even dumped without stabilization resulting in GHG emissions and contamination of soil and water bodies. (China Water, 2011)

Hence, the pilot project in Jimo city focused on developing new concepts for the energetic utilization of sewage sludge from the municipal waste water plant (WWTP). Currently, landfilling is the major disposal method for sewage sludge and municipal solid waste (MSW) in Jimo. The landfill together with unsorted municipal solid waste from urban areas is located at the northern boundaries of the Lingshan Township, in about 20 km distance from the WWTP. The landfill is constructed and operated by Jimo Government. The material flow system of sewage sludge and MSW is shown at Figure 17.

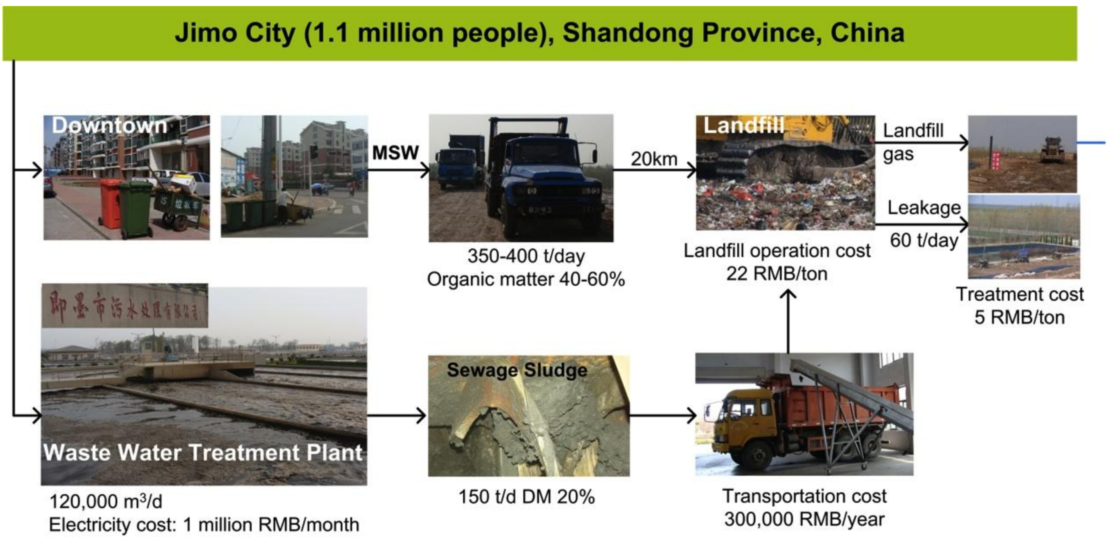


Figure 17: Material flow system of sewage sludge and MSW in Jimo

The goal of the pilot project concept was to create an (at least) energy-autarky concept for the Jimo WWTP by energetically utilizing sewage sludge and biodegradable MSW. In the concept, two processes were integrated to improve the total energy efficiency, recycling of organic residues from Jimo urban area and reducing GHG emissions of the landfill.

The two processes were hydrothermal carbonization (HTC) of sewage sludge and anaerobic digestion of organic MSW. FH Trier Research Group adapted the existing HTC technology to the local conditions and subsequently developed a possible combined HTC-Biogas scenario. The synergy of this combination is the full utilization of the excess heat of the biogas plant (from the co-generation unit) as process energy for the HTC process.

The main components of the overall plant configuration include five modules as shown at Figure 18:

- MSW separation module
- Biogas-CHP module with heat exchangers
- HTC module
- HTC coal drying module
- Composting module of digestates (leftovers from the fermentation process).

Firstly, the collected MSW is fed to the waste separation module to separate the recyclable and organic materials and recover valuable components such as paper, plastics and glass. The organic MSW is than fed into a fermentation unit for anaerobic digestion. The resulting biogas is conducted to a gas treatment unit where sulfur compounds, siloxanes and excessive humidity are removed and used in the downstream installed CHP unit. The digestate is composted in order to create a soil conditioner or even compound fertilizer for non-food-production usage.

Sewage sludge coming from the wastewater treatment process is fed into the HTC system. The thermal energy, which is required to obtain the HTC process conditions, is supplied by the CHP exhaust gas via a heat exchanger. After carbonization, the coal slurry is fed into the dewatering unit (filter press), where the volume of the material is reduced significantly by mechanical water removal. The dewatered coal then goes to the drying unit using excess heat from the CHP engine motor cooling circuit. Compared with raw sewage sludge, the dried HTC coal shows an excellent net calorific value and therefore can be considered as secondary/substitute fuel for a close-by coal power plant, which shares the same parent company with the WWTP. Hence, the project could in the downstream replace partly fossil fuels and achieve additional reductions of up to 74,000 t/a of climate relevant, fossil CO_2.

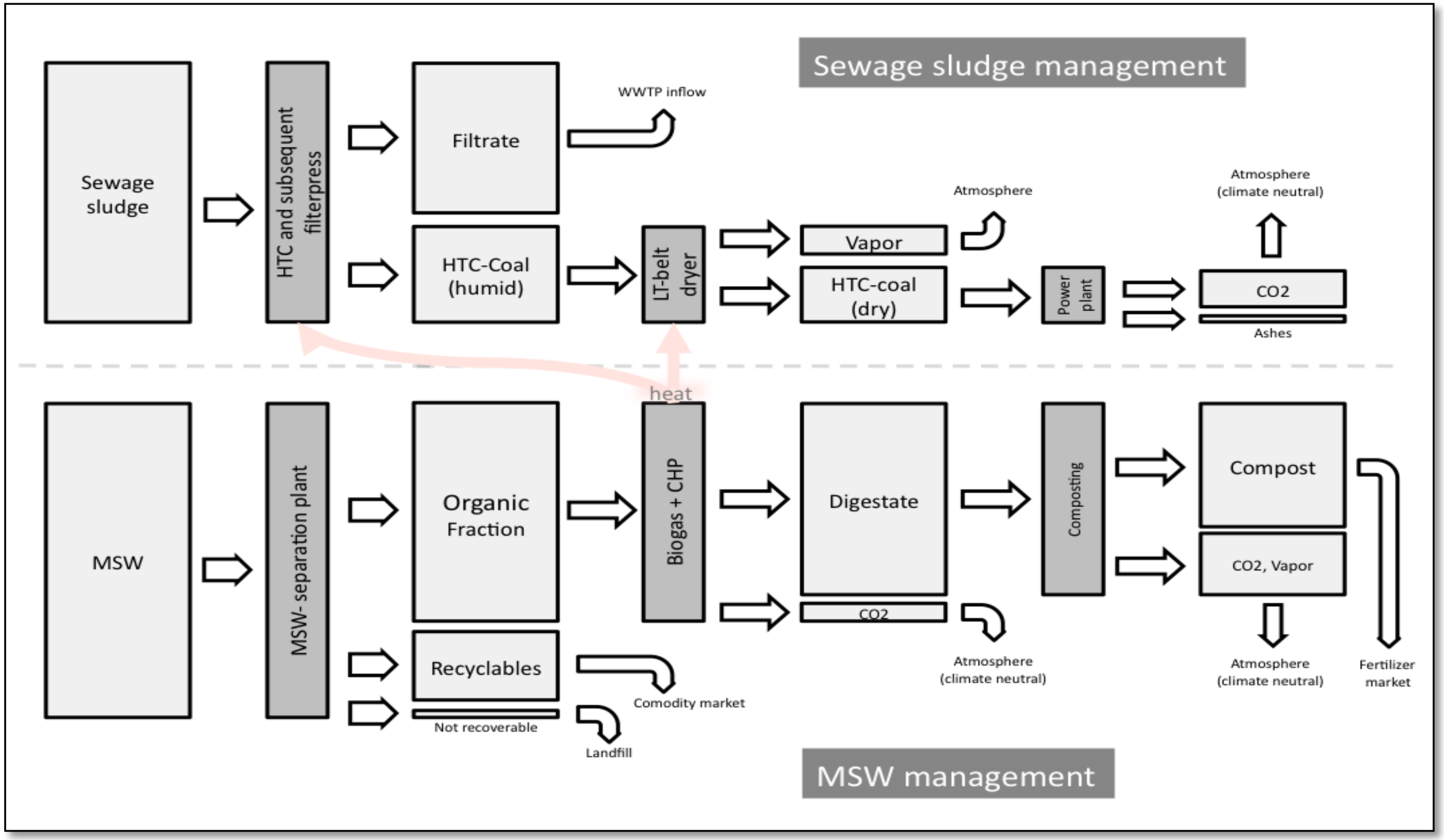


Figure 18: Concept for Jimo pilot project (TerraNova Energy GmbH)

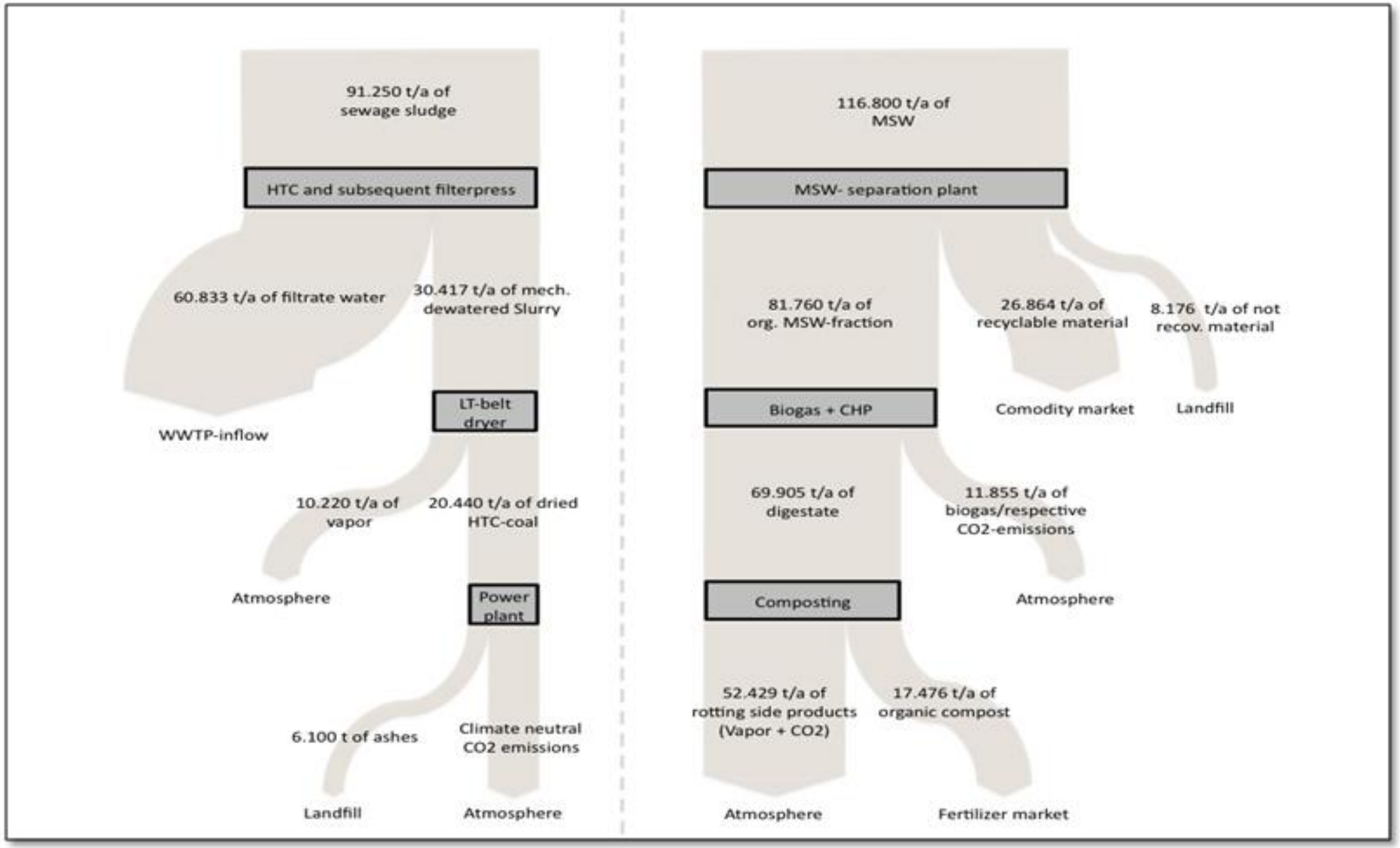


Figure 19: Mass balance of Jimo pilot project - Sewage Sludge (left) - MSW (right) (TerraNova Energy GmbH)

The HTC system consists of a group of ten HTC lines with a respective capacity of 10,000 t/a per line. For reasons of redundancy the actual required processing capacity of 91,250 t/a sewage sludge is supported by an extra capacity of 8,750 t/a.

The MSW separation plant processes, corresponding to the assumed data, 116,800 t/a of urban domestic waste, whereof 26,864 t are recyclables, which can be sold on the respective commodity market.

The organic fraction of the MSW (81,760 t/a) is fed into the biogas digestion unit, where according to the basic biogas data, approximately 8.2 million m^3 of biogas are generated per year. This gas consists of about 60% methane and 40% CO_2.

Through the biologic digestion about 1.45 kg/m^3 gas are leaching from the initial organic substance, so that in the end approximately 69,905 t/a of digestate are produced. This material is fed to the composting unit where approximately 75% of the original material is extracted by dewatering and rotting losses in the form of water, vapor and CO_2 (Baldauf, 2006). The produced soil conditioner can be sold locally.

Total investment of the proposed Jimo pilot project was estimated to about 38,244,000 EUR, and return of investment rates were about 7% to 16% for different scenarios, details shown at Table 7 and Table 8.

Table 7: Total investment of the proposed Jimo pilot project

HTC-plant (incl. Dewatering)	€	**13,000,000**
Coal-Sludge-Drying	€	**2,000,000**
CHP-Heatexchanger-System+additional burner	€	**1,200,000**
Biogasplant (incl. CHP)	€	**5,044,000**
MSW-separation-plant	€	**15,000,000**
Fermentation rest composting facility	€	**2,000,000**
TOTAL	€	**38,244,000**

Table 8: Economic sensitivity analysis of Jimo pilot project

Distance to landfill	km	20	30	40	20	20	40
Distance to power plant	km	15	15	15	15	15	15
Savings on deposition fee	€/t	6	6	6	12	18	18
HTC coal price	€/t	10	10	10	20	40	40
Return of Investment Rate	%	7.1%	7.8%	8.4%	10.8%	15.0%	16.3%

(The transport cost was estimated to 0.13 €/t/km according to the feedback of the Chinese partner.)

The proposed concept of Jimo pilot project shows tremendous advantages in sustainability compared with the disposal of organic residues at the local landfill. Today, in China MSW is disposed without separation, neglecting that valuable raw materials and energy can be recovered in a sustainable and value adding way. By means of the combined HTC-biogas concept, glass, plastics, paper/cardboards and other recyclable materials can be reintegrated profitably to the market. Therefore, the project ideally demonstrates how the current "end-of the pipe" approach can be transformed into a resource economy.

Furthermore, organic pollutants, like pharmaceuticals or heavy metals, will be safely removed from the water cycle. Furthermore, the HTC process ensures the safe sanitation of the sewage sludge to prevent the dissemination of disease causing bacteria or viruses.

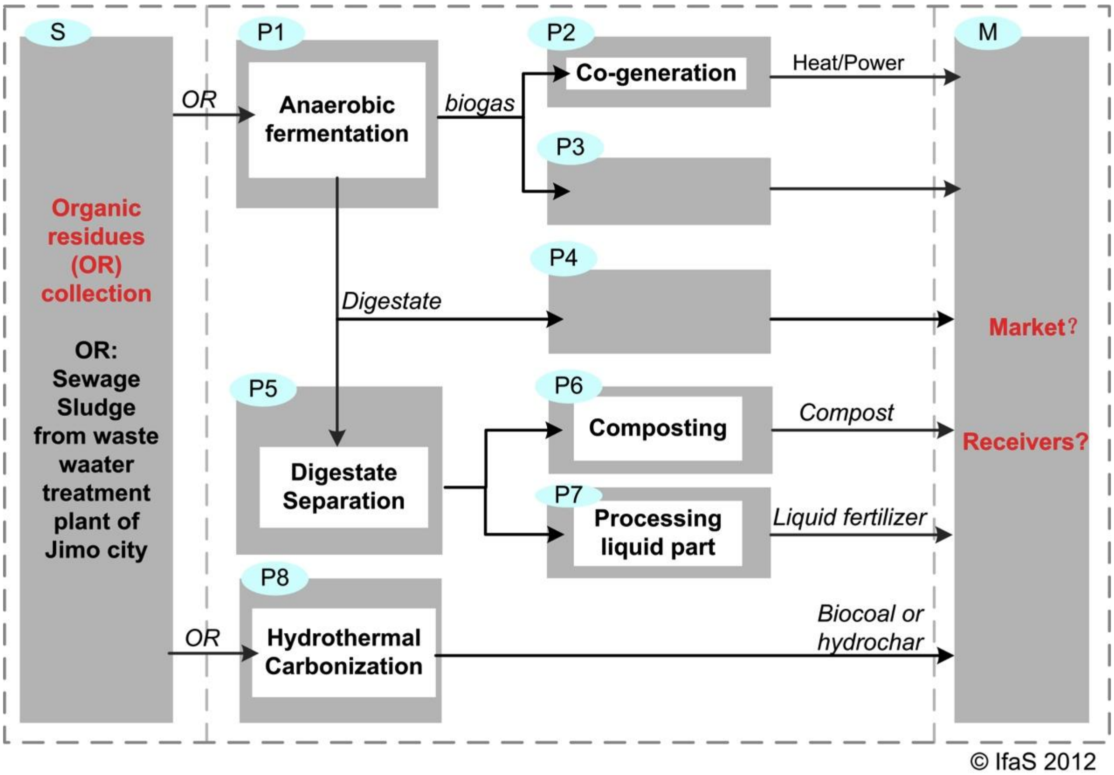
Other sustainability relevant factors are as follows: Reduction of transport need and related emissions, the decrease of landfill leachate, whose treatment generates high engineering overhead, tremendous costs and consumes large amounts of energy as well as the improvements for the regional and social value adding since, due to the new technology, new jobs can be provided.

Furthermore, the implementation could allow revenues from the sale of "CO_2-certificates" in terms of the Clean Development Mechanism, which would be generated by the emissions reductions related to the plant concept. Further considerations have to be taken into account during the final construction planning of such kind of plant.

Cooperation level analysis:

Although the presented scenario promotes an environmental friendly, climate protective and regional value adding approach to supersede the current disposal management system, the concept was not realized up to now. The first challenge was the leadership transition in Jimo city during the project implementing phase. Sewage sludge was a heavily concerned issue by the previous leadership team during the beginning phase of the Sino-German recycling project and innovative concepts were expected and would have been supported. But this goal of the proposed pilot project for establishing an energy independent WWTP, with a combined HTC-biogas process, became a less interesting topic for the new leadership of Jimo city.

In addition to the leadership transition, the brand new concept of combined HTC and biogas technologies was a challenge as well. More research and environmental education are necessary for introducing this new practice of waste management to the governmental officials. As Figure 19 shows, both input side and output side need more efforts to improve the overall level of cooperation.



Pilot project	Expected Investor	Status	S	P1	P2	P4	P5	P6	P7	P8	M
Jimo	Jimo government	Not constructed	-	+	+	+	+	+	+	+	-
Legend: ■ Not relevant "+" Positive "-" Negative											

Figure 20: Level of cooperation along the material flow system of Jimo pilot project

2.2.5 Scientific and Technical Results from Developing a Pilot Project in Lanzhou

Food waste is another big stream of organic residues in China. About 1200 t/d of commercial food waste in Beijing, for instance, are generated by restaurants and dining halls of hotels, schools and other entities (Table 9). Cases of using food waste to feed pigs, to illegally produce cooking oil and to return them to dining tables are reported and criticized. The improper utilization of food waste has become a big public focus due to the risks of causing health and environmental problems for recent years. Hence, in 2011, the Chinese government selected 33 cities to establish pilot projects of developing sustainable solutions for recycling food waste of restaurants. (Xinhua, 2011) Lanzhou is one of those 33 cities and it is a research site for the Sino-German Recycling project.

Table 9: Food waste as a big stream of organic residues in china

Cities	Beijing	Shanghai	Guangzhou	Xiamen
Commercial food waste (t/d)	1200	1000	1000	450~600
Inhabitants (mio.)	20	20	12	4

Data source: Ruan, S.B. 2011. "Research on status and development of food waste recycling in Nanning". In: Law and Economy, 284, August 2011.

Overview of the pilot project

Location:	Lanzhou city
Project goal:	producing waste oil, biogas for combined heat and compost from food waste
Designed capacity:	200 t/d food waste, installed electricity capacity 2.4 MW
Business model:	Building Operation and Transfer (BOT)
Investor and operator:	Gansu CN Bioenergy System Co.,Ltd
Total investment:	113 million Yuan RMB

The treatment process of for the food waste was designed by CN Bioenergy Systems Co., Ltd. based on the ideas of a two-step anaerobic process developed at the Brandenburg University of Technology (BTU). However, as the special characteristics of the Chinese food waste does not allow direct use of that process scheme some adaption has been made to apply a "similar two-step process".

After pre-treatment of the waste – mechanically with a shredder and thermally by heating up to 70°C – a first biological step, called hydrolysis, is used to convert the organic material in the food waste to biodegradable products which are easily degraded to biogas in the second biological step, the methanization. Both biological processes will be run as thermophile processes at 55°C.

The solid product from the hydrolysis is then composted in an already finished box composting system with forced and controlled aeration. The ideas, equipment and control system comes from a Germany based company, Umwelt Elektronik GmbH, a member of FH Trier Research Group. The designed treatment line is shown at Figure 21, the constructed parts of the pilot project are presented by Figure 22.

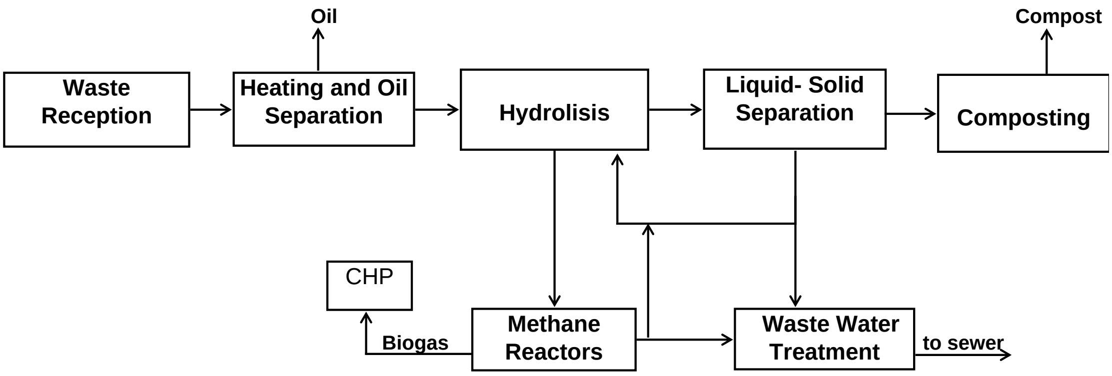


Figure 21: Designed treatment line of Lanzhou pilot project

Figure 22: Overview of Lanzhou pilot project

The very special substrate (leftovers from Chinese restaurants) and the adaptation of a laboratory level biogas technology to a real technical solution were the challenges for the CN Bioenergy plant in Lanzhou. Therefore, coordinated by IfaS, German SMEs of the FH Trier Research Group including Umwelt Elektronik GmbH, LEE s.a.r.l., gewitra mbH, areal GmbH and X-TERN International diagnosed Lanzhou pilot project and gave recommendations for various aspects as shown below.

The Food Waste

The food waste from the restaurants covers the whole spectrum of organic material. Proteins, carbohydrates, grease, oil and a high degree of contamination – up to 10% of textiles, glass, plastics, metals and porcelains characterize the waste. The waste is very wet – TS = Total Solids < 18%, mostly 15%. That means the waste has less biogas potential and the actual mass balance (after the start up) showed more liquid leaving the plant than in the design phase expected. The high contamination caused problems in the pre-treatment by blocking the shredder and the lift system for the waste transportations between the two treatment steps.

Another feature of the waste is its high salinity. Chloride concentrations of 4,000 mg/l or even higher can be expected. This will not influence too much the biological process but will cause a corrosion problem. Unprotected carbon steel and most stainless steel will very quickly show pit corrosion. This problem wasn't considered in the design. All material in the waste line is carbon steel.

The pre-treatment

There is no sorting out of inert or unwanted materials in front of the biological process. The negative effect of this inert material will be increased when the other treatment steps will be in operation as none of the following steps has mixing devices to avoid settling of heavy components and no measures to take floating materials out of the process.

There will be an additional treatment by heating up the waste to 70°C (pasteurization) and simultaneously remove oil and grease for fuel production. No details have been given or were reported about that process. Therefore, no comments can be made.

The Hydrolysis

The BTU concept had not been applied in large scale in Europe neither have percolation reactors being used in other hydrolysis reactors in Europe. Hence, the entire design risk was up to CN Bioenergy. Although several adaption measures had been applied within the inauguration of the plant it was found that the percolation process does not properly function with the local food waste as there is no structure in the material which allows a certain porosity and by that percolation of liquids through a porous media. The food waste hydrolysis in this case should have better been a completely mixed reactor with a solid-liquid separation to gain a liquid with low suspended solids concentration and a solid part which can be given back to the hydrolysis reactor to increase solid retention time or send for post treatment to the composting facility.

A specific problem for the hydrolysis reactors in Lanzhou might be the gas atmosphere above the open reactors. Even the hydrolysis is connected to the air treatment (odor removal) the formation of dangerous or even explosive gases has to be taken into account. That portion of the plant should be subject of a safety analysis in order to avoid problems.

Dewatering

The dewatering device already installed is a Bellmer Screw Press (German supplier). These screw presses are used for dewatering purposes in many anaerobic digestion plants in Europe. However, for a proper function these presses need a certain amount of fibers or other structure giving material in the substance, which needs to be dewatered. As this is not the case for the Lanzhou plant the result of the dewatering is very poor, shown at Figure 22.

As the plant is not complete and the whole biological part is still under construction the results gained with the Bellmer Screw Press are those with shredded food waste without any further treatment. The result is a "solid" fraction still very wet (TS <25%) and a "liquid" fraction with a high amount of suspended solids (SS > 5%). The result will not be better if further treatment, e.g. heating with grease and oil removal and hydrolysis will be added. These processes will not improve the dewatering behavior of the waste as they liquefy more than giving structure to the waste.

Other dewatering processes like centrifuges with or without polymer dosing or filter presses have to be tested based on recommendations given by the FH Trier Research Group. The dewatering is an essential step in the complete process. If the result is poor – low solid concentration in the solid fraction creates problems with the post treatment which is aerobic composting or high suspended solid concentration in the liquid fraction which will cause problems in the methane reactor of the actual design if that liquid is sent to the digester.

As the efficiency of such a waste treatment will be rated upon the products, which come out of the process – solid fertilizer and biogas – the dewatering process needs a careful design review in order to reach the target of the food waste treatment process. Dewatering or liquid-solid separation is one of the most essential parts of the Lanzhou food waste treatment.

Figure 22: Food waste treated at Lanzhou pilot project

Methanization

The "liquid" part from the hydrolysis and the liquid part of the dewatering process will be sent to the methanization.

There are three concrete tanks each with 1.000 m³ which will be the digesters where biogas is produced. Retention time by design will be two days at an organic load of 15 kg COD/m³day. This is a very challenging design, which normally is used for methane reactors using fixed bed technology to get high bacteria concentration.

The actual design for the Lanzhou project shows a digester without internal packing material. By choosing a special operation mode, CN Bioenergy wants to realize an "Anaerobic Sequence Batch Process" with a sludge blanket of high bacteria concentration.

The digester is fed from the bottom in some batches per day. With the feeding a certain mixing will be allowed. That means biomass or sludge from the bottom is dispersed in the liquid. After the feeding a settling phase starts. The biomass/ sludge can settle and a zone in the upper part of the digester will clarify. After that settling phase the extraction phase starts. The liquid is extracted in the upper part of the digester leaving (hopefully) most of the biomass in the digester. By such an operation mode they try to increase the bacteria concentration in a sludge blanket in the lower part of the reactor.

It is difficult to judge that process. However, the high design load of 15 kg COD/m³day is a challenge and only can be reached with very high concentration of active biomass. That biomass only can be accumulated if the feed has very low suspended solid concentration. First of all, the short retention time asks for already hydrolyzed components. Solid material cannot be decomposed in high efficiency reactors. Secondly, the more suspended solids are fed the more sludge extraction is necessary and by that removal of valuable biomass. The quality of the solid-liquid separation is again an important factor for the overall efficiency of the process.

The digesters could be changed if necessary to get packing material in and by that increase bacteria concentration because of the large surface of the packing material where bacteria can grow.

But the digesters also could be changed (if necessary or advised) to act as completely mixed digesters with a sludge concentration of 6 – 8% TS within a one-step anaerobic digestion process.

Composting

The composting unit at Lanzhou site is already in operation.

Composting is an aerobic process. That means, to allow the bacteria to do their work we have to supply enough oxygen. This oxygen is supplied by a pressure-aeration of the compost pile. The process in Lanzhou is provided (at least in essential parts) by Umwelt Elektronik GmbH from Germany.

Aeration of a compost pile means that the complete pile is accessible for the air. This is only possible if a high porosity in the pile can be achieved. This has to be done by mixing the dewatered solid fraction of the digestion process with structure material like straw, wood chips or other material providing structure and porosity.

This has not been done with some of the material, which was stored on site. Pure food waste after dewatering (TS < 25%) without any structure material could not really be aerated in the boxes as there is no porosity allowing the air to penetrate in the organic material. All results shown on site have been very poor and will not allow the use as fertilizer of high quality. Structure material has to be found in the region at affordable costs in order to allow composting and the production of a quality product. A research program for finding suitable structure material which eventually can be reused several batches before it is decomposed or even inert material which allows compensating moisture and giving porosity is strongly recommended. Using a part of made compost as structural material had been tested by the FH Trier Research Group and a positive result being reported by CN Bioenergy.

Waste water

Experience shows that the waste water from these biogas plants need very intense treatment as nitrogen and organic pollution is extremely high. A concept of "Oasis 21", developed by the German areal GmbH, was suggested, shown as Figure 23. It consists of three parts with re-utilization of liquid parts, re-utilization of solid parts and agro-forestry.

The liquid part will be treated in the existing wastewater treatment plant. Due to a high concentration of effluent, it will be further treated with reserve osmosis (RO), which has been proven to be an effective technology for the desalination of water. RO uses a semi-permeable membrane that contains tiny pores through which water flows. The small pores of this membrane are restrictive to salts and other natural minerals. These pores are also restrictive to disease causing pathogens. Hence, reverse osmosis is highly effective in removing the contaminants and pathogens.

The permeate, effluent of RO will be used for irrigation in agro-forestry, which will be constructed in the immediate vicinity of the project site, and/or as potable water on-site. The concentration of RO that contains mostly salt, nitrogen und potassium will be brought to the humus substrate production plant.

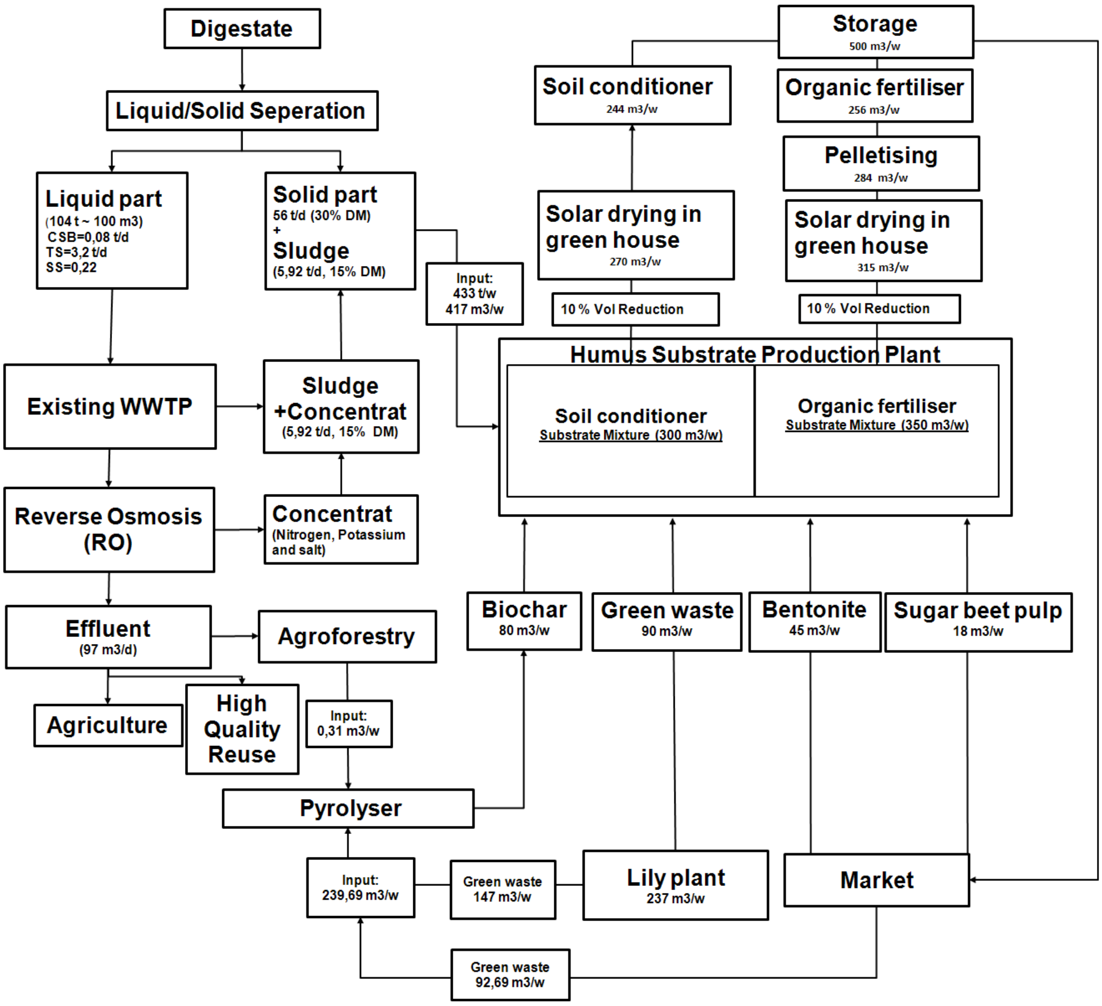


Figure 23: The concept of Oasis 21 for Lanzhou project (areal GmbH)

Summary (Lanzhou pilot project)

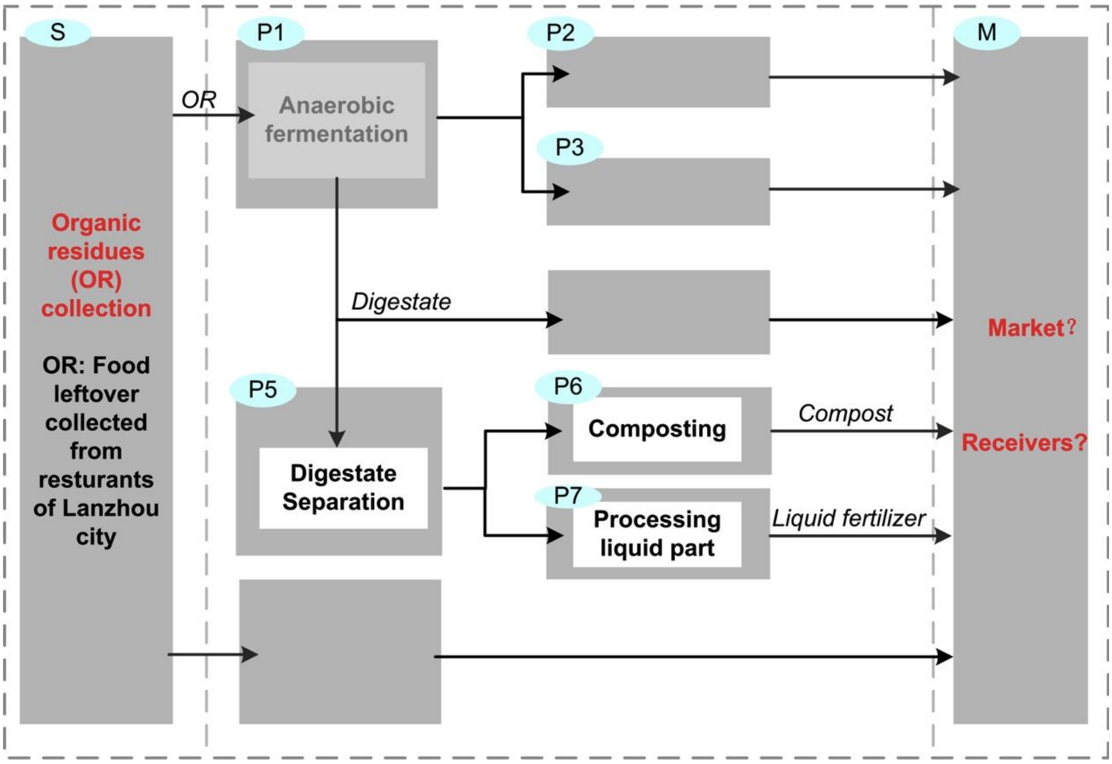
CN Bioenergy is challenged with the task to implement a new technology (which had just been applied on a laboratory scale so far) in a very difficult field of application. Food waste with many unwanted components has to be processed to get valuable products like fertilizer and biogas. There are three major points for CN Bioenergy:

- Finding the right technical solution for a hydrolysis process which is the main step providing the feeding for the methane reactor
- Finding the right technology for the solid-liquid separation
- Improving or enabling the composting to get an end product, which can be sold by finding structure material which is affordable.

Beside these major points, there are many aspects of biogas technology, which should be considered as important for a successful and safe operation of the Lanzhou plant. Corrosion related issues – right materials for the different waste streams – are one of the aspects. Another is safety in the biogas plant. The right zoning, where to use explosion proof equipment and where to detect dangerous gases should be a steady theme if we are involved in biogas plants.

Cooperation level analysis:

In addition to the technical challenges, the financial challenge is crucial for CN Bioenergy to operate and complete the plant, as the local government did not pay the treatment fees to CN Bioenergy as fixed by the BOD contract, because the local government was still in the process of setting up a system for the restaurants as food waste generators to pay the treatment costs. The system of polluters paying principle still requires efforts for improving environmental awareness of the public and establishing the respective legal conditions.



Pilot projects	Status	Investor	S	P5	P6	P7	M
Lanzhou	Constructed and in poor operation	Private company	+	-	-	-	-
Legend: ■ Not relevant "+" Positive "-" Negative							

Figure 24: Level of cooperation along the material flow system of Lanzhou site

2.2.6 Scientific Technical Results from the Case Study of Shandong Minhe Biogas Plant

Overview of Shandong Minhe Biogas Plant (Phase I, Figure 25, 26):

Substrate: The daily input had reached 510 t, with the TS value of 6-7%. In average, 260 t chicken manure (80% water content) and 500 t waste water (no other animal manures included) are the daily substrate added into the sand settling pond before moving to eight digesters. The TS value is expected to be gradually increased up to 8-9%.

Biogas and electricity generation: Installed electricity capacity is 3 MW. The biogas production is 25,000 to 27,000 m^3 per day; Electricity is produced around 56,000 kWh per day. Electricity is sold to power grid gaining the subsidy tariff according to China's Renewable Energy Law.

CERs: The project had got a half year payment for its Certified Emission Reductions. The auditing report of issuing CERs to another one and half years has been finished in August 2012.

Digestate: Around 600 t/d digestate is generated. TS value is around 4%. Digestate is not used to dilute chicken manure in order to avoid the accumulation of ammonia nitrogen in the digesters. Digestate is stored at an open-air storage pond and then transport to vineyards and other agricultural fields nearby. A digestate management network has been established to cooperate with Shandong Minhe biogas plant. In order to increase the added value of the digestate, Minhe biogas plant has invested a treatment line with membrane technology for processing digestate with a capacity of treating 300 t/d. It aims to transfer digestate into concentrated liquid fertilizer, solid digestate and water. Water could be reused as flushing water to clean chicken farms. This treatment line started its testing operation in August 2012.

Investor and operator: Shandong Minhe Livestock Co. Ltd., Penglai, Shandong Province, P.R. of China

Main technology suppliers: Hangzhou Energy and Environmental Engineering Co. Ltd. (HEEE), a Chinese company, provided the design and construction of anaerobic digestion part and the control system. GE Janbach supplied the biogas engines.

Shandong Minhe Biogas Plant (Phase II) has finished it design by HEEE and its construction will be started soon. Biogas generated by Phase II will be upgraded into bio-methane and then compressed as auto fuel. Taxies and buses quite often use the compressed natural gas (CNG) as fuel in China. The fuel cost of using CNG is at least one third cheaper than the cost of using gasoline for taxies and buses in China. CNG price is between 3 to 4.5 Yuan RMB/ m^3 at the CNG station. (EIA, 2009) The tariff of electricity generated from biogas is between 0.55 to 0.75 Yuan RMB/KWh. (NDRC, 2006) Many potential investors believe biogas for bio-methane would have better economic and ecological effects than biogas for electricity and heat in China.

Figure 25: Shandong Minhe Biogas Plant

Figure 26: On-site visit of Shandong Minhe Biogas Plant (Jan. 2011)

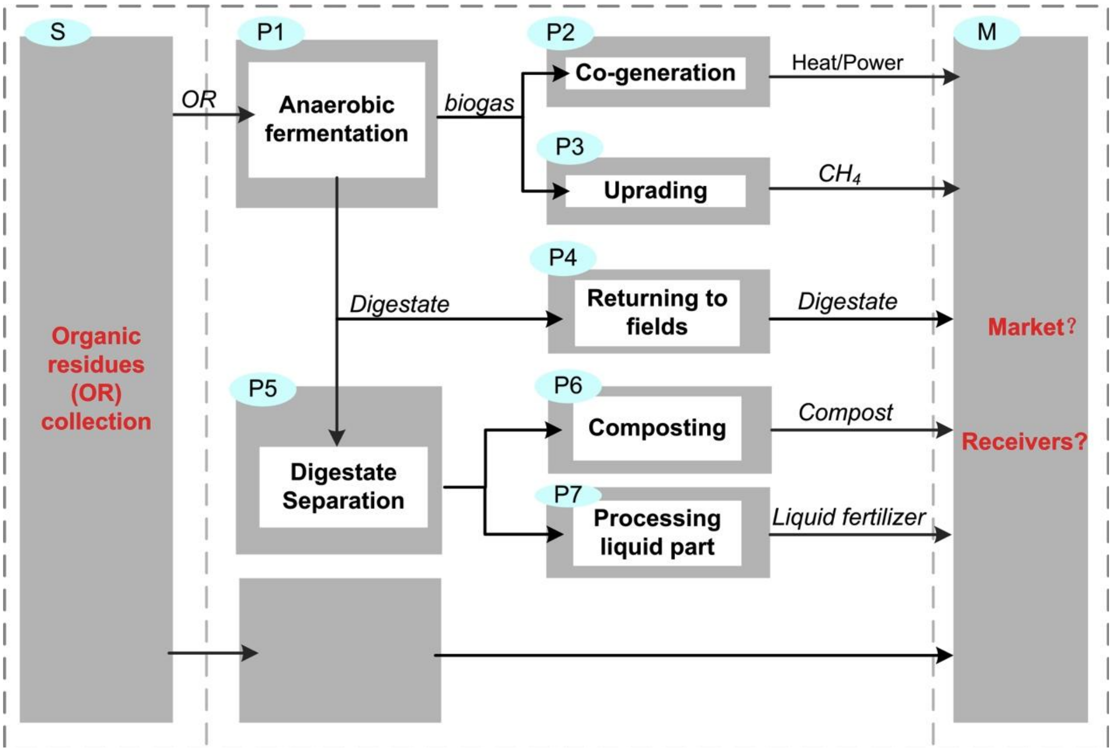
Cooperation level analysis:

Shandong Minhe Biogas Plant is currently the biggest and the most successful biogas plant in China. Based on the in-depth case study, it showed the good coordination along the material flow steps has been the foundation for such an achievement. As shown at Figure 27, the good coordination includes the following features:

Substrate (S): A stable supply of substrate is guaranteed because the chicken manure is the own organic residues of the project investor and operator, namely Shandong Minhe Livestock Co. Ltd., Penglai, Shandong Province, P.R. of China.

Technology processes (P1 to P7): Suitable technology suppliers were selected and the integration of the different processes optimized and operated by the engineering team of the Shandong Minhe Livestock Co. Ltd.

Market and receivers of outputs (M): Two key factors had got the chairman of Shandong Minhe Livestock Co. Ltd finally decided to invest Minhe biogas plant by the company itself, instead of cooperating with other investors. The first factor was the confirmation of local power grid that electricity generated from biogas plant would be allowed for connecting to power grid and the second one is the confirmation that the project could be registered as a CDM project and selling CERs as additional income.



Pilot project	Status	Investor and operator	S	P1	P2	P3	P4	P5	P6	P7	M
Case study: Minhe biogas plant	Constructed and in efficient operation	Shandong Minhe Group	+	+	+	+	+	+	+	+	+
Legend: ■ Not relevant "+" Positive "-" Negative "+/-" bidirectional											

Figure 27: Analysis of the level of cooperation along the material flow system of Shandong Minhe Biogas Plant

2.3 Policy Recommendations

Based on developing four pilot projects and a case study with Shandong Minhe Biogas Plant FH Trier Research Group concludes that an economically and ecologically viable project for recycling organic residues requires a high level of cooperation among:

- Input (e.g. long-term supply agreements), hereinafter "head" side,
- Output (e.g off-take agreements for energy, digestate and GHG reduction), hereinafter "tail" side,
- Money flow (e.g secured financial sources and attractive financial returns),
- Suitable technologies combined with an experienced management team (qualified design/construction contractor who can bond/insure their work).

The four pilot projects lack a sufficient level of cooperation among those four pillars. Hence, improving the level of cooperation for recycling of organic residues in China urgently requires the optimization of the "head" (S) and "tail" (M) sides. The "head" side means a stable supply of substrates for the various conversion processes. The "tail" side is rational regulations on the market and prices of electricity, heat, bio-methane, hydrothermal char, and digestate. If the "head" and "tail" sides are well coordinated, the optimization of various conversion processes (middle part) would be the business of companies via market rules, and of course their business activities should be supervised via related emission control regulations.

For optimizing the "tail" side, as shown in Figure 28, optimizing the "head" (S) and "tail" (M) sides is an urgent task for supporting the development of economically and ecologically viable projects of recycling organic residues.

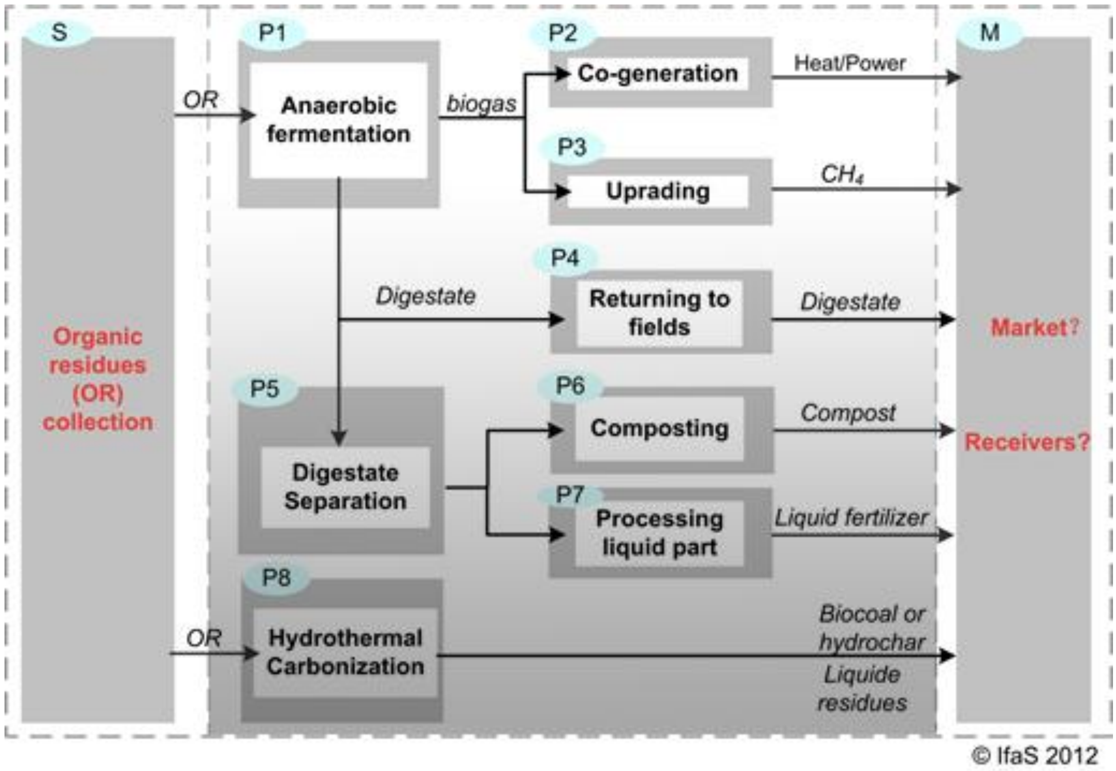


Figure 28: Improving the level of cooperation along the material flow system for the recycling of organic residues in China urgently requires the optimization at the "head" (S) and "tail" (M) sides

The following four aspects should be concerned crucial for improving the "head" and "tail" sides for recycling organic residues in China:

- Setting up the **source-separated collecting system** of different organic residues like food waste from restaurants and households,
- Establishing **performance based governmental subsidies** for pilot projects and subsidies encouraging co-fermentation as well,
- Gradually establishing the "**polluters paying principle**" for solving the financial challenges that governments may stop paying companies who are the investors and operators of BOD based recycling projects,
- Encouraging **various options of utilization and processing of digestate** and meanwhile strengthening the supervision of digestate utilization.

The governmental subsidies are crucial in shaping the biogas industry development. Based on the previous experiences, the strategy of the future biogas subsidy policy should take into account the following principles:

- The subsidies design should target at stimulating the market based competitiveness of the biogas industry and promote private investment to the industry.
- The subsidies should be designed as a comprehensive system to take the biogas industry (different scale, different developers, etc.) as a whole and promote the overall industry development and the technology renovations.
- A comprehensive subsidy system needs cooperation among different government agencies, such as the Ministry of Agriculture, the National Development and Reform and Committee, and the Ministry of Environmental Protection.

Some more detailed suggestions are provided as follows:

a. Change the construction oriented governmental subsidies to a product/performance oriented subsidy system

The construction oriented governmental subsidies encourage the establishment of small-scale biogas plants on single farm sites rather than having large industrial-sized biogas plants with economy-of-scale effects. Often the initial investments are overestimated, the construction costs are – within the construction phase – reduced in order to minimize the farmers´ own financial contribution. This behavior in most cases lead to very low-performance of the biogas plants and create rather environmental pollutions as rebound effects. The only solution is a performance based subsidy system like the German Renewable Energies Law or other subsidies targeting at the quality level of the fertilizer produced.

b. Lower the electricity feed-in tariff limitation

The grid companies' regulations on a minimum of 500KW installed electricity capacity for being allowed to feed electricity to the grid excludes most of the Middle and Large Scale Biogas Plants (MLBP) at livestock farms from this income source. The regulation results in the direct emission of biogas into the air, receiving little incomes from producing energy and even ending the operation of MLBP due to poor profitability. If changing the construction oriented governmental subsidies to product/ performance oriented governmental subsides, the electricity feed-in tariff limitation should also be changed or even canceled. Otherwise the product/ performance oriented governmental subsidies will hardly benefit most of the intensive livestock farms.

c. Governmental subsidies should encourage co-fermentation

Current governmental subsidies are arranged for supporting mono-fermentation. For instance, subsidies from the Ministry of Agriculture only support intensive livestock farms to use their own animal manures. The National Development and Reform Committee issued special subsidies in 2011 for the recycling of food waste from restaurants. Additionally, a limited number of subsides are available for pilot projects of sewage sludge. Up to now, there exist no governmental subsidies encouraging the development of recycling projects with co-fermentation or other conversion processes of recycling different substrates in one system. This border limits technically and financially the development of recycling organic residues in general. If China wants to achieve the 3GW biomass power generation target by 2020 fixed by the 12^{th} Five-year Plan, the governmental subsidies need to support co-fermentation.

This research believes that economically viable and ecologically sound recycling projects could be achieved in China through improving the coordination along the material flow steps of recycling organic residues, especially the "head" and "tail" sides of the system. To achieve this state, coordination among different governmental departments is a crucial step to go. This is a strategic direction that China should develop because economically and ecologically recycling of organic residues would help China to reduce pollution, generate renewable energy, improve nutrient cycling, create jobs and increase regional added value in the Chinese countryside and rural areas.

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