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Functional analysis of technological innovation system with inclusion of sectoral and spatial perspectives: The case of the biogas industry in Russia

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ABSTRACT

This study aims to conduct a functional analysis of the technological innovation system with the inclusion of sectoral and spatial perspectives. This involves the impact analysis of a variety of sectors' integration into the biogas value chain and a more explicit review of spatial and institutional contexts of the transition process. By applying mixed methods research, this approach is illustrated by examining the development of the biogas industry in Russia. As a result, the adjusted framework enables us to understand how technological innovation develops, diffuses, and uses in specific segments and places. Such an advanced insight of the analyzed case also helps to give accurate recommendations for policymakers, researchers, and practitioners, who seek to initiate or expand the diffusion of biogas technologies in Russia.

1. Introduction

Technological innovation has often been perceived as an essential part of any solution to tackle grand sustainability challenges such as climate change, lack of clean water, waste management, etc. (Kuhlmann and Rip, 2018; Malhotra et al., 2019). The technological innovation system framework is one of the key approaches for analysing the innovation dynamics of (new) technologies (Carlsson et al., 2002). Being a methodological tool, the TIS can be influenced by internal and external factors (Bergek et al., 2015). A key step in conceptualizing the TIS framework is to articulate its focus and boundaries, i.e. its delineation. However, this step creates many issues for TIS scholars, by which the framework has been criticized for a lack of attention to the relation of innovation processes with the system's environment (Bergek et al., 2015; Binz et al., 2014; Binz and Truffer, 2017;Coenen et al., 2012; Markard et al., 2015). Nowadays, the potential for sustainability transitions is highly regulated by transnational relationships and actors/forces that are located around the world (Truffer et al., 2015). System boundaries are becoming blurred and porous, and innovation processes are becoming more complex in the spatial dimension that, in turn, raises the question of whether a territorial (national, regional, local) system is still a valid perspective (Binz and Truffer, 2017). Another criticism concerns the sectoral neglect in TIS analysis since the overall development of industry/technology varies across different parts of the value chain, which can differ in terms of knowledge bases, supporting sectors, and market structures (Hipp and Binz, 2020). At the same time, such criticism can be a misinterpretation since the TIS functional approach has always acknowledged external factors (Markard et al., 2015; Ulmanen and Bergek, 2021).

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Table 1
Indicators of system functions (Bergek et al., 2008b, Bergek et al., 2008a; Binz et al., 2012; Hekkert et al., 2007; Hekkert and Negro, 2009; Suurs, 2009;Vasseur et al., 2013).

System functions		Indicators
(F1)	Entrepreneurial Activities	Commercial projects; contractors; demonstrations; experiments
(F2)	Knowledge Development	Assessment and feasibility studies; learning activities; R&D and technological projects; demonstration and pilot projects; laboratory experiments; patents; reports and scientific publications
(F3)	Knowledge Diffusion	Conferences; platforms; workshops; partnerships; meetings; joint projects and alliances
(F4)	Guidance of the Search	Hard institutions: policy instruments/targets and goals; formal regulations, directives, laws, and standards Soft institutions: informal interfaces; promises; expectations; press articles that raise expectations, beliefs, and visions
(F5)	Market Formation	Pricing policies; CO_2 taxes; tax exemptions; feed-in rates; quotas; regulation/stimulation programs
(F6)	Resource mobilization	Human resources: qualified specialists Financial resources: subsidies and investments through entrepreneurial and governmental programs Physical resources: the availability of natural resources Generic infrastructure: educational systems, refueling infrastructure
(F7)	Creation of Legitimacy	Interest groups, lobby activities, media, promotion of technology by organisations and governments in the forms of awards, prizes, brochures, competitions

Moreover, TIS has strong connections to other innovation approaches such as national, regional, and sectoral innovation systems (Andersson et al., 2018) and combines certain features of each innovation system perspective. This aspect deserves more attention in TIS analysis and thus the research aims to shed some light on this issue.

The biogas[3] industry is chosen as an empirical case, in which value chain segments belong to a variety of sectors such as agriculture, energy (electricity and heating), waste management, and transportation. These sectors are needed to pay more attention as they are highly embedded in environmental pressure and emissions of greenhouse gasses. A biogas value chain can contribute to the reduction of environmental impacts from these sectors, i.e. from the recycling of organic waste up to the substitution of fossil fuels and chemical fertilizers. In addition, the biogas case will help to observe differences in sectoral characteristics, analyze how interrelated sectors affect each other to better understand their roles in the wider implementation of focused technologies. The article receives Russia as a focal geographical dimension because this case can make a valuable contribution to the sustainability transition research, as just a few studies have focused on countries that belong to the 'economies in transition', and more research of innovation processes in developing emerging economies is highly needed (Binz et al., 2020).

The study aims to analyze the dynamics of the biogas TIS in Russia by applying the system functions approach. This includes the impact analysis of a variety of sectors' integration into the biogas value chain and a more accurate review of the spatial and institutional contexts of the transition process. In particular, the objective of the proposed adapted framework is to provide better insights into policy measures that might be implemented to improve biogas diffusion in Russia from the innovation system perspective. To the best of the author's knowledge, this is the first attempt to apply the TIS theoretical framework in the context of the biogas industry in Russia.

The article starts by introducing the TIS theoretical framework and reviewing the literature on its sectoral and spatial extension (Section 2). Section 3 presents the research design including the research case, system delineation, and methodology of the article. Section 4 provides a detailed TIS system functional analysis of the Russian biogas industry. Section 5 concludes with the theoretical contribution and identifies policy implications of the research.

2. Theoretical framework: extension of the classical TIS approach

The technological innovation systems approach, which is based on evolutionary theorizing and systems theory (Markard, 2018), is taken for the theoretical departure of the study. A large number of TIS studies have focused on environmental technologies, by which TIS has become an important building block of sustainability transitions research (Markard et al., 2012). System functions are used as performance indicators to analyze TIS operations, which helps to understand the dynamics of technological change (Suurs and Hekkert, 2009). In this study, the classification of system functions is based on the research of Hekkert et al. (2007), and their typical indicators are presented in Table 1.

The classic definition of TIS is "network(s) of agents interacting in a specific economic/industrial area under a particular institutional infrastructure or set of infrastructures and involved in the generation, diffusion, and utilization of technology" (Carlsson and Stankiewicz, 1991, p.93). The definition shows that technological systems are not spatially limited and can be international, national, or regional. In the same way, technology itself can cut across various sectors (Coenen and Díaz López, 2010). Bergek et al. (2015) were among the first who called for the identification of context structures that address the complexity in TIS analysis. The authors distinguish two types of the interplay between a TIS and context such as 'external links' and 'structural couplings' (see Fig. 1). External

[3] Biogas is a combustible mixture of gases, consisting of mainly methane and carbon dioxide. It can be produced through anaerobic digestion (AD) or fermentation of a variety of biomass resources. The use of biogas energy is considered CO_2 neutral since the CO_2 released during the biogas combustion is the same CO_2 that the plants have assimilated during photosynthesis to create organic substances. In this way, the burning of biogas is simply a recycling of CO_2 in the biosphere (Jørgensen, 2009).

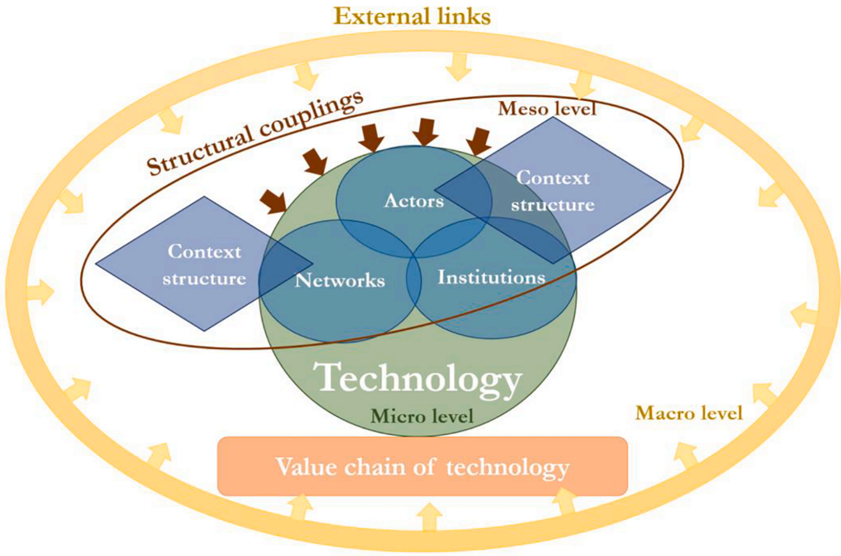

Fig. 1. Interaction between a TIS and context factors (based on Bergek et al., 2015).

links refer to factors that influence a TIS but are placed outside of a focal TIS and thus do not share any structural elements. These factors are operated on the macro level. Structural couplings occur when a focal TIS shares one or more structural elements with a specific context structure. These factors present a meso level, while analysis of structural elements inside of a focal TIS shows a micro level of analysis. Analysis of the relation between a TIS and context structures can help to get a more dynamic understanding of innovations system changes. In the next subsections, the overview of the literature, which analyses different dimensions of the TIS framework, will be discussed more in detail.

2.1. *A focal TIS and sectoral context*

According to the literature review on the extension of TIS analysis, the sectoral context typically comprises several levels of hierarchy. The first level includes sectoral analysis through a TIS value chain, seeing technology as a 'bundle of value chains' (e.g. Gustavo et al., 2019; Malhotra et al., 2019; Stephan et al., 2017; Welie et al., 2019). For instance, Stephan et al. (2017) show how different sectors (electronics, chemical, and automobile sectors) take significant parts in the value chain of lithium-ion batteries focusing on two TIS system functions, knowledge development (F2) and knowledge diffusion (F3). Malhotra et al., 2019 examine the importance of inter-sectoral learning across three energy-related TISs – solar photovoltaic systems, wind turbines, and lithium-ion batteries. Based on the notion of structural overlaps, Mäkitie et al. (2018) proposed an extended version of the TIS framework and found the positive influence of the oil and gas sector on the offshore wind power sector in Norway. Such perspective allows exploring value chain segments of technology by dividing it into several categories[4] and studying specific parts of the value chain or the interaction between, for example, upstream and downstream sectors.

The second level comprises an analysis of a focal TIS with competing and/or complementary TIS/sectors (e.g. Magnusson and Berggren, 2018; Wicki and Hansen, 2017). Such framework is based on the notion of structural overlaps/couplings between a TIS and established sectors (two-way interaction, in which systems influence on each other) and external links (one-way influence from a context element on a TIS) (Bergek et al., 2015; Mäkitie et al., 2018). Structural overlaps or couplings do not respect national borders and could operate within their geographical context (Schot and Kanger, 2018). They affect the following structural components: 1) actors, 2) networks, 3) institutions, and 4) technology.

To summarize, the overall development of industry/technology varies across different parts of the value chain as they can differ in terms of knowledge bases, supporting sectors, and market structures (Hipp and Binz, 2020). Many TISs are related to different sectors since modern technologies (especially radical) usually cover different technological components and subsystems.[5] Thus, analysis of the dynamics and interplay of different sectors active in a particular TIS would help policymakers to create more appropriate policy measures to foster TIS development and diffusion.

[4] Categorisation is not rigid. For instance, it can be divided into seven categories such as 1) production equipment supply, 2) material supply, 3) core design and manufacturing, 4) peripheral components supply, 5) project development (or system integration), 6) logistics and installation services, and 7) end use (Malhotra et al., 2019) or merely on a) upstream, b) core, c) downstream and d) operation and maintenance (Hipp and Binz, 2020).

[5] Stephan et al. (2017) call such technologies "multi-component technologies" (MCTs).

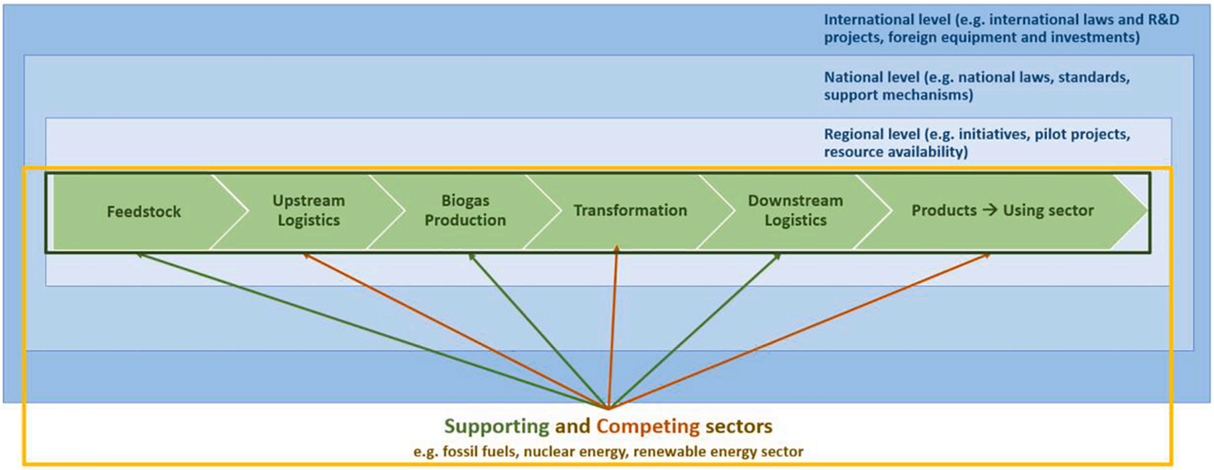

Fig. 2. The proposed delineation of sectoral and geographical contexts.

2.2. A focal TIS and geographical context

The criticism on the spatial dimension of TIS analysis has arisen from a larger research agenda on the 'geography of sustainability transitions' (Binz et al., 2014; Coenen, 2015; Coenen et al., 2012), which has been involved in transition theorizing quite recently. It refers to the need for greater attention to the spatiality, scale, and context-specific factors that shape transitions (Binz et al., 2020). Innovation processes are becoming more complex in the spatial dimension since a value chain of technology might be located within one or more countries. In the same way, the technology itself does not stop developing and diffusing where the national border ends. In some cases, TISs have even more international than national characteristics (Vasseur et al., 2013).

Although geographical delimitation does not follow from the TIS definition (Bergek et al., 2015), the TIS concept is originally criticized the innovation systems with territorial inclusions (Carlsson and Stankiewicz, 1991). Multi-scalar conception is the most probable setup for the TIS approach. Most of the research distinguishes two regional sub-systems such as a national TIS and a foreign TIS or international TIS (Andersson et al., 2018; Gustavo et al., 2019; Huang et al., 2016). Analyzing the potential interaction between different countries, the authors also emphasize the usefulness of studying several national TISs (Vasseur et al., 2013; Wieczorek et al., 2015a). As a result, cooperation between countries in terms of technology development and policy instruments may partly complement each other's deficiencies and speed up technological transitions. Wieczorek et al. (2015b) and Huang et al. (2016) show how external factors critically influenced the rapid development of the technological innovation system. An additional example is a global PV industry, a 'product' of different national TIS, that comprises critical parts of the industry such as downstream (e.g. Australian market), midstream (e.g. Chinese producers), and upstream (e.g. German technological developers) (Markard et al., 2015). Some studies also argue for regional delineation since specific regions can disclose the important dynamics for global and/or national sustainability transition (e.g. Leitch et al., 2019; Sixt et al., 2018). Thus, studies applied the TIS perspective to separate subsystems (national or regional) with linkages through international TISs.

2.3. The delineation of sectoral and geographical contexts

This article aims to show how different sectoral and geographical views affect the biogas industry in Russia. Similar to most structural-functional analyses (Coenen et al., 2012), the focal innovation system of this study is nationally delineated and focused on the Russian biogas industry to enable in-depth analysis of the system. Such a study can be labelled as a 'national TIS' snapshot of a wider 'global TIS' (Binz et al., 2014). Besides international and national levels, the study also highlights the regional level since generation based on biogas technologies is often local, small, and parts of purely municipal energy and heat supply. Thus, their implementation depends on incentive schemes not only at the national level but also at the level of regions and individual municipalities. Thus, the TIS analysis aims to apply multiscalar conception and distinguish international, national, and regional levels. Analysis of sectoral context includes several levels of hierarchy. The first level is sectoral analysis through a TIS value chain, and the second one comprises an analysis of focal TIS with competing and complementary sectors. Fig. 2 schematically illustrates the proposed delineation of sectoral and geographical contexts. Such a model will be tested through a thorough analysis of the biogas industry in Russia.

It is worth noting that geographical and sectoral configurations do not analysed separately and are embedded in the TIS functional analysis. It is also acknowledged that the criticism of sectoral and geographical neglect can be a misinterpretation since the TIS functional approach has always recognised external factors (Markard et al., 2015; Ulmanen and Bergek, 2021). Moreover, TIS has strong connections to other innovation approaches such as national, regional, and sectoral innovation systems (Andersson et al., 2018) and combines certain features of each innovation system perspective. In the TIS functional analysis (Section 4), the specific events of sectoral and geographical contexts will be marked as follows: for the sectoral context: 1) a TIS value chain as [S:VC], and a) competing

Table 3
Overview of data collection used in the study.

Data collection method	Collected Data	Primary proxies of TIS system functions
Semi-structured interviews	Nine extended personal interviews with experts, the CEO of Russian biogas companies, chief engineers, program managers, and other relevant actors.	(F1) Entrepreneurial Activities (F6) Resource mobilization
Participant observation	The author carried out observations during the conferences dedicated to the Russian renewable energy industry. Approximately 20 h of participant observation; Extensive informal communication; Field notes, i.e. audio notes, PowerPoint presentations, handouts.	(F4) Guidance of the Search. (F7) Creation of Legitimacy
Patent data	The final database results in 964 patents	(F2) Knowledge development (F3) Knowledge diffusion
Literature review	eLIBRARY.RU database. The total volume of scholarly literature reached 2027 publications.	(F2) Knowledge development
Additional methods	Official reports, publications, presentations, and newsletters; Policy and legal documents; Publications by industry associations and non-governmental organizations, Newspaper articles and specialized journals Reports and analyses (incl. annual reports) Press releases, information on websites Online interactive seminars, interviews, workshops, and conferences	(F4) Guidance of the Search. (F5) Market Formation (F6) Resource mobilization

and complementary sectors [S:CS]; and for the geographical context: 1) international level [G:IL], national level [G:NL] and regional level [G:RL].

3. Research design

In regards to the conducted literature review, analysis of sectoral context includes several levels of hierarchy. The first level is sectoral analysis through a TIS value chain, and the second one comprises an analysis of a focal TIS with competing and complementary sectors. Similar to most structural-functional analyses (Coenen et al., 2012), the focal innovation system of this study is nationally delineated and focused on the Russian biogas industry to enable in-depth analysis of the system. Such a study can be labelled as a 'national TIS' snapshot of a wider 'global TIS' (Binz et al., 2014). At the same time, geographical and sectoral configurations do not analysed separately and are embedded in the classical TIS analysis.

3.1. Research case: biogas technologies

The biogas industry includes several value chain segments that belong to a variety of sectors such as agriculture, energy (electricity and heating), waste management, and transportation. The biogas technological variety is high. Multiple resources for biogas production (e.g. manure, organic waste, sewage sludge, and wood) can be used for the generation of different types of energy (electricity, heat, and gas fuel) in various sectors (e.g. transportation, agriculture, energy (heat and grid-connected electricity supply), building sector, waste management) (Wirth and Markard, 2011). Thus, different actors are involved in the implementation of biogas technologies. Farmers, biogas plant operators, utility companies, suppliers of technical equipment, various associations, financial institutions, end consumers, suppliers of resources for biogas production (e.g. restaurants, food producers, households, hotels, waste-disposal companies), gas distribution companies all take part of the broader network of actors in the innovation system (Markard et al., 2009). The biogas innovation system is influenced and dependent by the development of these sectors, including their policy areas, institutional settings, rules, power structure, private agreements, and ways of thinking (Golembiewski and Sick, 2015; Markard et al., 2009), which should be taken into account. Therefore, the full analysis of the biogas value chain and its interaction with other sectors will help to create appropriate policy measures to foster the biogas uptake in Russia that, in turn, will contribute to incorporating sectoral dimensions and observing their relations.

3.2. Russia as a focal geographical dimension

The choice of Russia is made for several reasons. First, Russia pursues an insufficient climate policy (World Biogas Association, 2019) and is the world's fourth-largest polluter (Aris, 2019). Anthropogenic GHG emissions in Russia for the same year amounted to 2 billion tons of CO_2 or 3.7% of global GHG emissions, including land use, land-use change, and forestry (LULUCF) (Yulkin, 2018). The largest share of anthropogenic GHG emissions comes from the burning of fossil fuels for energy generation.

Second, bioenergy is the most promising type of renewable energy in Russia, with a huge potential for utilizing urban treatment facilities, agricultural, industrial, and food waste. The country is one of the world's leaders in the production and export of agricultural products (FAO, 2019) and has one of the world's largest gas transportation systems, which can be used for biomethane injection and transportation. According to estimations, one Russian region alone – Belgorod Oblast – can provide up to 400 million m^3 of biomethane per year produced from livestock. The total potential of biomethane production in Russia exceeds 40 billion m^3 per year (Samorodov and Yulkin, 2015). The total biogas production from agricultural organic waste reaches 66–70 billion m^3 (Larive International, 2013;

Reutov et al., 2014; The Bioenergy International, 2016) and sewage utilization is approximately 4 million m^3 of biogas per day (Namsaraev et al., 2018). For comparison, the volume of domestic consumption of natural gas in Russia amounted to 235.8 billion m^3 in 2019 (Gazprom, 2020). However, the current level of organic waste and sewage sludge processing is very low. A major part of the waste is collected into open pools and/or spread onto fields as some kind of natural fertilizer that leads to contamination of soil and drinking water.

Third, the diversification of the Russian economy is low. The Russian economy is highly dependent on revenues from the export of fossil fuels. The global transition to low-carbon development leaves less and less space in the market for fossil fuels and carbon-intensive products that form the basis of the Russian economy and exports. This fact is aggravated by the high share of exports in the production of these resources. In 2017, 69.2% of the country's produced oil, 44.5% of the extracted coal, and more than 30% of the extracted natural gas were exported (Yulkin, 2018). Soon, there may not be enough demand for these resources at all. If nothing is changed in terms of the diversification of the economy, it may result in serious economic losses for Russia. The country needs to mix its energy sector with carbon-free energy sources.

3.3. Data collection and methodology

A mixed-method design was implemented to investigate the research aim (see Table 3). A variety of documentary sources such as official statistics, policy, and legal documents, publications by industry associations and non-governmental organizations, newspaper articles, and specialized journals were collected, analyzed, and codified. Such information can help to trace the structural evolution of an innovation system, identify its main events and key actors (Bento and Fontes, 2015). In addition, semi-structured interviews with the representatives of Russian biogas companies have been conducted. Questions were addressed regarding the history of companies, their realized biogas projects both in Russia and abroad, the existence of international partnerships, problems faced by companies in terms of implementation of biogas projects in Russia, and their possible solutions to achieve rapid growth of biogas technologies. This was also supplemented by the discussions with the representatives and stakeholders in workshops of the Conferences. News articles about biogas companies in Russia, online companies' statements, interviews, videos were also collected.

The analysis of patent activity and scientific literature in Russia were also provided. Russian patent data was obtained through the search system of the Federal Service for Industrial Property in Russia, commonly known as Rospatent. The relevant patents were searched by using the keywords 'biogas', 'biomethane', 'landfill gas', and 'upgraded biogas' with priority dates from 01.01.1992 to 31.12.2019. After processing the patents, the final database results in 964 patents. Each document was evaluated for its relevance to the research theme taking into account the initial set of international patent classification (IPC) classes listed in the IPC Green Inventory of the World Intellectual Property Organization (World Intellectual Property Organization, 2020). Scientific literature was extracted through the eLIBRARY.RU database, which is the largest electronic library of scientific publications in Russia (https://www.elibrary.ru). The searching keyword was 'biogas', 'biomethane', 'landfill gas', and 'upgraded biogas' with the same priority dates from 01.01.1992 to 31.12.2019. The keywords were searched in the topic area, i.e. the abstracts, titles, and keywords, and only in publications with document type 'article'. Each publication was evaluated through its title and abstract to check its relevance to the analyzed field. The total volume of scholarly literature reached 2027 publications. Evolutions in patent activity and scientific publications can help to analyze the emergence of the domestic TIS (Gosens and Lu, 2013) and the counts of patents and publications can be used as proxies for knowledge development (F2) and diffusion (F3) (Bergek et al., 2008b; Hekkert et al., 2007).

4. Biogas industry in Russia – TIS functional analysis

(F1) *Entrepreneurial Activities*. In the 1990s, the Russian bioindustry was almost lost and only individual enterprises with extremely worn-out capacities remained (TP Bioenergy, 2019). In 1999, Russia made the first steps to create a political and regulatory framework for the development of renewable energy [G:NL]. However, there was no big interest in their development due to the abundance of fossil fuels. Since 2009, the construction of biogas facilities began to grow. Most known biogas plants in Russia are listed in Appendix A, Table A1, which shows the big involvement of foreign companies [G:IL] in the construction of biogas facilities in Russia as almost all biogas installations were implemented with the help of foreign organisations, particularly from Germany and Austria [G:IL]. The first industrial biogas stations in Russia – Luchki (2012) and Baitsury (2012) in the Belgorod region [G:RL]– were implemented by the Russian companies AltEnergo [G:NL] and Regional center of biotechnology [G:NL] where the equipment was supplied by the Big Dutchman Agro Co for both projects [G:IL]. The energy produced from the biogas plants is sold to the grid with a premium of about 5%. The main goal of the projects is to solve environmental problems arising from the rapid development of agriculture in the region.

The best-known wastewater treatment plant in Russia with two cogeneration plants, the Kuryanov sewage treatment plant (2009) and the Lyubertsy sewage treatment plant (2012) were launched by Mosvodokanal [G:NL]. These plants treat the sewage sludge of 12.33 million Moscow inhabitants. The Austrian concern EVN [G:IL] won the tender and carried out the project design in cooperation with the MosvodokanalNIIproject Institute and specialists of Mosvodokanal. At that time, there was no production of such biogas units in Russia. Some engines ran on this type of fuel with the constant addition of diesel fuel but their use was impractical from the economic, technical, and environmental points of view (Mosvodokanal, 2009).

Some biogas companies in Russia were established as subsidiaries of foreign companies. For example, the company Agrobiotech Ltd. is a Russian branch of LANDCO SA (Luxemburg), which specializes in projects in Russia and the production of components for biogas plants (Agrobiotech, 2020) [G:IL]. Agrobiotech Ltd. is an engineering company, which manufactures equipment for biogas plants. The company does not have any implemented projects in Russia yet but it supplies the biogas equipment for European projects [G:IL]. Bioenergy LLC also did not get demand for their biogas equipment in Russia: "We thought that we could offer Russian

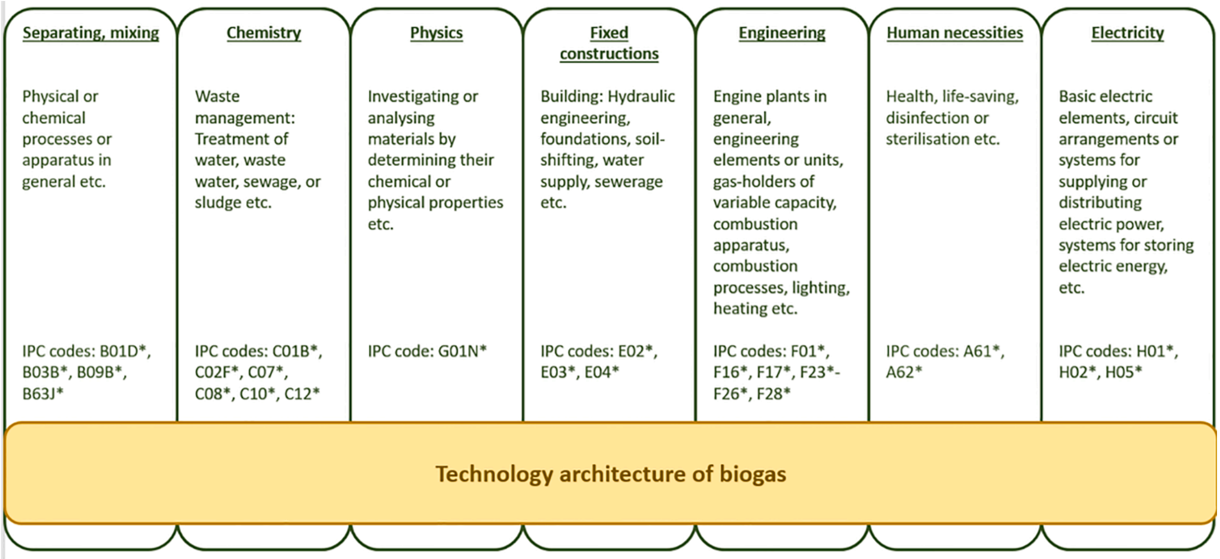

Fig. 3. Technology architecture[11] of biogas (inspired by Stephan et al., 2017) [S:VC],.

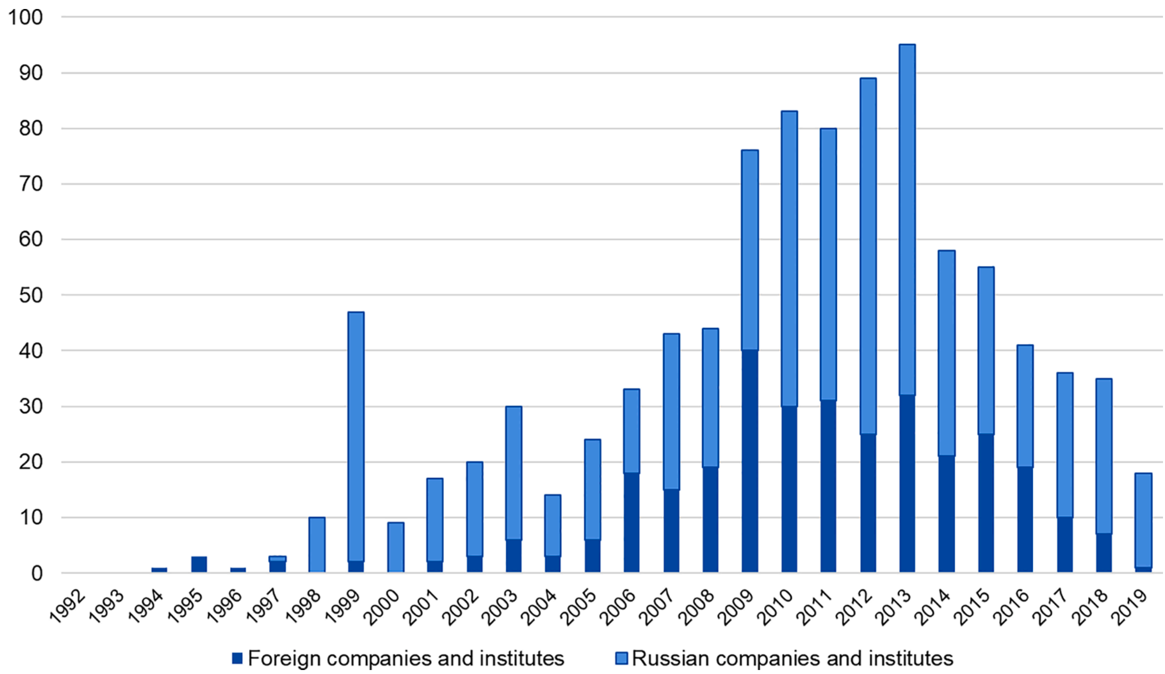

Fig. 4. Patent activity in Russia by year [G:IL].

enterprises a comprehensive solution that allows them to get fertilizers and electricity instead of waste, get rid of waste and make a profit on it" (Skolkovo Foundation, 2019). However, Russian companies prefer to receive a document confirming the safety of their waste and store waste on adjacent land. Instead, the biogas technology 'WiseSoil' was purchased by companies from the United States and several European countries. To enter the European market and increase consumer confidence, the company opens a subsidiary company in Lithuania and creates a consortium with two foreign firms (Skolkovo Foundation, 2019) [G:IL].

Another interesting example is the Russian company EVOBIOS LLC [G:NL], which constructed a biogas plant in JSC Breeding plant Pervomaysky in Leningrad Oblast (2019) with special conditions for the biocomplex. The company has signed a long-term contract with the farm for the disposal of organic waste and the purchase of electricity and fertilizers (Evobios, 2019). EVOBIOS LLC carried out the cost of equipment. Part of the electricity produced by the biocomplex is used for its consumption, and another part – for the need of the EVOBIOS LLC.

Table 4
The number of patents registered in Russia with patent holders, by year.[21]

Year	Number of patents			
	Foreign companies [G:IL]		Research institutes (RU) [G: NL]	Private companies/individuals (RU) [G: NL]
2019	1	DK	9	8
2018	7	CN, CH	13	15
2017	10	CN, DE, NL, US, NO, FR, BE, FI	8	18
2016	19	GB, LT, DE, SE, FR, AT, NL, FI, SG, CH, ZA, US, IL	8	14
2015	25	DE, NL, CH, CN, FR, SE, FI, US, IT, TR, IL	20	10
2014	21	DE, US, IT, NL, IL, AT, CZ, CN, FR, PL, SE	19	18
2013	32	DE, FI, FR, AT, LU, KZ, CH, HU, US, NL, SE, UA, BE, CA, IT, ES	31	32
2012	25	NL, US, DK, FI, DE, CN, HU, IT, CH, KR, SE, CA, EE, NO, IN, AU, GB, UA	33	31
2011	31	AT, US, DE, SG, GB, FI, NL, CA, CL, IT	18	31
2010	30	DK, US, CA, FR, DE, IT, AT, NL, AU, CH, AZ, GB, SE, FI	34	19
2009	40	US, ES, DE, SE, UA, FI, EE, BY, GB, CA, PT, NO, BE, MC, JP, CN	19	17
2008	19	US, DE, KR, UA, CZ, BE, NZ, FR, NO	14	11
2007	15	DE, IT, BE, SE, FR, US, GB	9	19
2006	18	DE, JP, AT, DK, SE, FI, US, LU, UA, GB	4	11
2005	6	US, AU, JP, NL	4	14
2004	3	DE, FI, CH	7	4
2003	6	US, IT, DE, CZ, UA	6	17
2002	3	GB, FR, PL	3	14
2001	2	DK, UA	3	12
2000	0	–	1	8
1999	2	DE, UA	4	41
1998	0	–	1	9
1997	2	NL	1	0
1996	1	NL	0	0
1995	3	US, GR, NL	0	0
1994	1	US	0	0
1993	0	–	0	0
1992	0	–	0	0

Russian companies have begun to enter the market of neighboring countries. For example, EVOBIOS LLC has implemented the grant project in the Republic of Uzbekistan [G:IL]. In November 2019, the company also announced the opening of its representative office in China [G:IL]. In 2017, the specialists of SelhozBioGas LLC were invited to a pig farm in Yerevan (Armenia) to assess the possibility of launching the purchased Chinese equipment [G:IL]. The company manufactured some missing pieces of equipment, developed and assembled an automation and control system (SelhozBioGas, 2019).

(F2) *Knowledge Development.* Fig. 3 shows the biogas technology architecture, which consists of multiple components related to different fields. Before starting the mass production of biogas plants, many Russian companies were engaged in research and development, carrying out microbiological experiments, conducting field tests, creating special equipment, manufacturing individual components of the biocomplex, etc. Since the 1990s, several organizations and research institutes were involved in the development of biogas technologies. For instance, the Federal Scientific Agroengineering Center VIM implemented the biogas project in the Lukhovitsky district of Moscow Oblast (see Table A1) [G:NL]. A variety of research organizations manufactured and supplied biogas installations to farmers for the utilization of agricultural waste and the production of biogas and liquid organic fertilizers. For example, the Siberian Institute of applied research (SIPRIS LLC, Omsk) created a working value of bioreactor 2.5–75 m^3 and the LMW Wind-energy Company – reactors 2.5–20 M^3 [G:NL]. Nowadays, the Foundation of Skolkovo Innovation Center supports three technopark residents that specialize in biogas technologies such as 1) Bioenergy LLC creates the technology for AD plants; 2) OKTO LLC develops the climate-independent technology for the production of organic fertilizers in biogas plants for the disposal of organic waste with hazard classes III and IV; and 3) Ecosystem Small innovative enterprise scientific and technical center LLC develops innovative technologies for processing a wide range of organic waste, provides environmental audit and support services for enterprises [G:NL].

An analysis of biogas patents in Russia shows the greatest activity for the years 2009–2013 (see Fig. 4). This fact can be linked to the overall interest in renewable energy in the world and Russia, and the establishment of the elaborated political and regulatory framework for the use of renewable energy (2007). Many biogas companies were established during that time and the main technological platform (TP) Bioenergy was created (2010) [G:NL]. The patent analysis also shows the big involvement of foreign companies that registered patents in Russia (see Table 4) [G:IL]. The highest activity is recorded in 2009–2015. As for Russian actors, most of the research is performed by companies/individuals rather than research institutes. From the commercial point of view, this is a good indicator since companies commercialize technologies and introduce them to the market. At the same time, the number of publications shows the growing interest in biogas technologies in Russia (see Fig. 5). The publication record contains a mixed set of academic, commercial, and public actors and some data on cooperation between them. Overall, if an analysis of biogas patents in

[1] Technology architecture consists of the fields' titles defined by the classification of the World Intellectual Property Organisation.

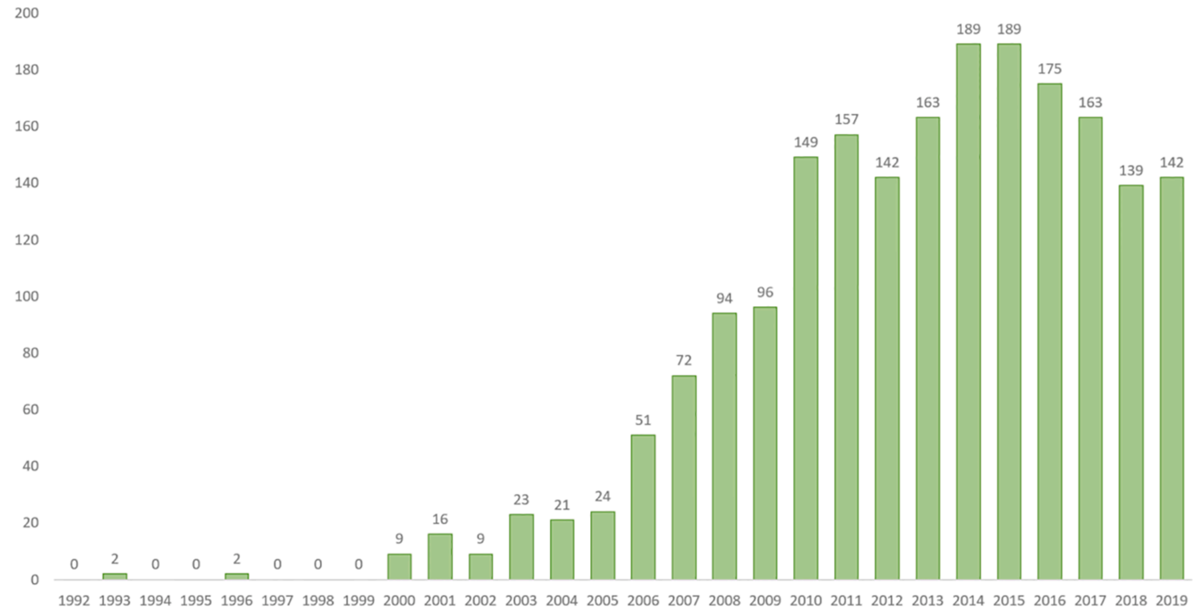

Fig. 5. The number of publications on biogas technology in Russia, by year.

Russia shows their gradual decline, the interest in biogas technologies from an academic point of view is still on a high level.

(F3) *Knowledge Diffusion.* One of the main networks in terms of bioenergy in Russia is the technological platform Bioenergy. In close cooperation with leading Russian and foreign experts [G:IL], the TP Bioenergy Council prepared the "Roadmap for the development of bioenergy in the Russian Federation for the period 2019–2030″, in which biogas production is characterized as technologies with high relevance, significant scientific background, and a high degree of readiness for commercialization (from 0 to 3 years) (TP Bioenergy, 2019). According to the Roadmap's forecast, biogas is related to the first phase with the short-term perspective (until 2022) that implies the readiness for the widespread commercialization of existing technologies.

Within the Russian knowledge network, an increasing amount of collaborations is taking place between research institutes and entrepreneurs, both on the national and the international level [G:IL]. German companies and scientific organizations provide significant assistance in terms of R&D development of the biogas industry in Russia. For example, the Russian-German project "Cooperation of bioregions in Russia and Germany" (2009–2012) aimed to create the scientific basis for production and construction of bioenergy plants in such Russian regions as the Kaluga Oblast, Orel region, Nizhny Novgorod regions, and the Republic of Tatarstan (Tren and Pfaiffer, 2013) [G:IL]. The German partners carried the methodology analysis, gave methodological support and practical recommendations on data collection for Russian researchers (Tihonravov, 2011) [G:IL].

Nowadays, the Belgorod region is the most progressive Russian region in terms of biogas production, to which international networking has also contributed [G:RL]. The Belgorod Institute of Alternative Energy cooperates with German companies MT-Energie GmbH, EnviTec Biogas AG, Weltec Biopower GmbH, and Italian Agrotechnica s.r.l. and Rota Guido s.r.l. (Belgorod institute of alternative energy, 2019) [G:IL]. In November 2012, Belgorod Institute of Alternative Energy and the German company MT-Energie has signed an agreement on the construction of three more pilot biogas stations in the region of 2.4 MW [G:IL]. In total, MT-Energie plans to build more than ten processing facilities in the Belgorod region (Vinogradov and Leonov, 2016).

Gazprom (Russia), Gasunie (Netherlands), Eurotechnika, and BioGazEnergoStroy (Russia) formed the international consortium by signing a "Memorandum of Understanding for a joint project for the development of 'green' gas in Russia" (2011) [G:IL]. The main purpose of the project is to develop 'green' gas in Russia and make the benefits of the gas available to the European Union (Gazprom, 2011). The Memorandum was preceded by the project development within the framework of scientific and technical cooperation between Gazprom and Gasunie (Karasevich et al., 2014). However, there is no updated information about the results of such cooperation.

Regarding national collaborations, many Russian biogas companies highlight that the success of their activity is the result of teamwork and interaction with research institutes, universities, and laboratories [G:NL]. As an example, the participants of the Biotechnological cluster of the Kirov region founded the biogas company SelhozBioGas LLC in 2011. The company cooperates with

[2] AT – Austria, AU – Australia, AZ – Azerbaijan, BE – Belgium, BY – Belarus, CA – Canada, CH – Switzerland, CL – Chile, CN – China, CZ – Czech Republic, DE – Germany, DK – Denmark, EE – Estonia, ES – Spain, FI – Finland, FR – France, GB – United Kingdom, GR – Greece, HU – Hungary, IL – Israel, IN – India, IT – Italy, JP – Japan, KR – Korea, KZ – Kazakhstan, LT – Lithuania, LU – Luxembourg, MC – Monaco, NL – Netherlands, NO – Norway, NZ – New Zealand, PL – Poland, PT – Portugal, RU – Russia, SE – Sweden, SG – Singapore, TR – Turkey, UA – Ukraine, US – USA, ZA – South Africa.

various research institutes that help to conduct laboratory research, design works, manufacture of equipment, and implement several biogas projects in such regions as Kirov Oblast (2013), Astrakhan Oblast (2017), and Volgograd Oblast (2019) (SelhozBioGas, 2019). Biogas companies are interested in working with universities as they can create an educational base for training specialists in the field of biotechnologies.

(F4) *Guidance of the Search.* Russian involvement in international cooperation in the climate change area remains passive and is explained as a way to solve various foreign policy or foreign economic problems (Makarov et al., 2018). In the 1990s, the climate agenda served as a tool for country's integration into the international community and one of the cooperation areas with the United States; in the 2000s, it was used to obtain concessions from foreign partners, and later on – to attract investment for joint projects within the Kyoto Protocol (Makarov, 2016; Mitrova and Melnikov, 2019) [G:IL].

Concerning the Paris Agreement (2015),[6] Russia set preliminary goals to reduce GHG emissions up to 70–75% by 2030 in comparison to 1990 emissions if the maximum absorption capacity of forests is taken into account (UNFCCC, 2015) [G:IL]. Concerning GHG emissions reduction, the Paris Agreement itself probably does not imply any serious costs for Russia. However, the world's transition towards low-carbon development, which is stated in the Paris Agreement, is rather challenging for the Russian economy since it is highly dependent on revenues from the production and export of fossil fuels and other carbon-intensive industries (e.g. metallurgy, chemical, and petrochemical industries) (Makarov et al., 2018). These industries form a significant share of GDP, exports, budget revenues, and employment, which makes Russia vulnerable to several serious risks (ibid). These issues have changed the viewpoint of the Russian elites about renewable energy because now they perceive that there is an urgent need for the country to mix its energy sector with carbon-free energy sources.

State support is one of the key tools for stimulating the development of renewable energy technologies [G:NL]. In 1999, Russia started to propose a legislative framework for the development of renewable energy. However, it was not successful. The State Duma proposed the "Federal Law on the State Policy in the Sphere of Unconventional Renewable Energy Sources" (1999) that aimed to stimulate the economically efficient development of renewable energy. This policy initiative was dismissed; some others – did not receive enough support and were left underfinanced (Pristupa and Mol, 2015). Renewable energy source development was not a priority at that time (Pristupa et al., 2010).

In November 2007, a legal framework (Federal Law No.250-FZ) for the development of renewable energy sources was introduced into the main Federal Electricity Law, No. 35-FZ "On the Electric Power Industry" (2003) [G:NL]. This event appeared to be the main step in the creation of legislation and a regulatory system for renewable energy in Russia. The Law set the framework for the use of renewable energy, and the directions for the legislation development. It also introduced the definition of renewable energy: "solar energy, wind energy, water energy (including wastewater energy), except for the use of such energy at hydroelectric power stations, tidal energy, wave energy of water objects, including reservoirs, rivers, seas, oceans, geothermal energy using natural underground heat carriers, the low-potential thermal energy of the earth, air, water with the use of special heat carriers, biomass, which includes plants specifically grown for energy, including trees, as well as production and consumption waste, except for waste obtained in the process of using hydrocarbon raw materials and fuels, biogas, gas released from production and consumption of waste in landfills, gas generated at coal minings" (Russian Government, 2003). Since 2008, the reduction of GHG emissions in terms of energy efficiency was one of the main priorities. The stated goal to reduce the energy intensity of GDP by 40% between 2007 and 2020 was later mitigated up to 44% for the period from 2005 to 2030 (Makarov et al., 2018). However, due to budget limitations, subsidies to the regions, which constituted the main channel for the financing of the energy efficiency program, were canceled in 2015 (ibid).

In 2009, the major documents in the energy field in Russia the State Programme on "Energy Efficiency and Energy Development" and "The Energy Strategy of Russia up to 2030″ were launched with the official targets intended to increase renewable energy share (except hydropower stations with a capacity of more than 25 MW) in total electricity generation up to 1.5% by 2010, 4.5% by 2020 and an outlook towards 8% in 2030 (Pristupa and Mol, 2015) [G:NL]. It was also aimed to construct biogas facilities up to 330 MW by 2020 (Namsaraev et al., 2018). Biogas has also been considered innovative energy- and resource-saving environmental technologies. The priority development of biogas technologies was stated by the President of Russia, Dmitry Medvedev, in 2010 (Tihonravov, 2011). However, the target of 1.5% by 2010 was not achieved. A new version of the State Programme on "Energy Efficiency and Energy Development" (2014) [G:NL] decreased the share of renewables in total electricity generation from 4.5% to 2.5% by 2020 and did not provide any financial support for energy generation from biomass (Namsaraev et al., 2018; Russian Government, 2014). However, even this number was not achieved.

The draft of "Energy Strategy of Russia up to 2035″ was submitted to the government by the Ministry of Energy in 2015 but was only approved on 2 April 2020 (Ministry of Energy of the Russian Federation, 2020) [G:NL]. Renewable energy considers as one of the breakthrough technologies that can increase competition and significantly change the structure of international flows of products, technologies, and services in the energy sector. At the same time, it states that, until 2035, fossil fuels will continue to form the basis of the world energy market. The biogas industry only appeared in the statement "the use of local fuels (peat, forest and agricultural waste, and municipal solid waste) takes an insignificant place in the regional fuel and energy balances" without any future numerical indicators. To summarize, the targets for renewable energy development in Russia are rather flexible and can be changed over time (Pristupa and Mol, 2015). These goals and plans have, to a large extent, a declaratory nature rather than a push for action, keeping fossil fuels and the nuclear energy sector as the top priority for the Russian government (Lanshina et al., 2018).

Regarding bioenergy itself, the Russian government adopted the Comprehensive Program on Development of Biotechnology

[6] Russia has signed the Paris Agreement and approved its ratification on 23 September 2019.

through 2020 (BIO 2020) in April 2012, which was supported by the Roadmap for Biotechnology and Genetic Engineering Development approved on July 18, 2013 (Russian Government, 2012) [G:NL]. One of the Roadmap's targets was to achieve the 80% of energy recovery from poultry and crop farming, animal farming wastes, timber, and food processing waste in a total volume of agricultural, food, and timber waste. However, this goal was also not accomplished due to the lack of governmental support and investments in the bioenergy industry (Namsaraev et al., 2018).

The question regarding the most critical barriers to the implementation of biogas technologies in Russia was raised at the Conferences. In terms of energy, the existing legislation is rather appropriate [S:VC]. However, the most important problem is the lack of standards for waste management [S:VC]: "while the waste from the agro-industrial enterprises will be qualified as fertilizers, nobody will build modern facilities for waste disposal and, most importantly, nobody will pay money to investors for waste processing. In other words, we do not even need to create new legislation, we just need to remove this small loophole. And tomorrow there will be a lot of waste disposal stations" (representative of the Russian biogas company). Indeed, the "Sanitary rules for meat industry enterprises No. 3238–85 of 27.03.1985″, which is the main document in the work of the Federal Service for Veterinary and Phytosanitary Surveillance [S:VC] (Vinogradov and Leonov, 2016), do not promote any modern technologies in the field of waste management for agricultural producers and thus do not stimulate agricultural enterprises to embed biogas plants.

Generations based on biogas technologies are often local, small, and parts of purely municipal energy and heat supply. In the field of bioenergy, most opportunities do take place on the regional level and the measures, which are provided by the local governor, play an important role and sometimes even determine the feasibility of the project (Larive International, 2013). Some Russian regions (e.g. Dagestan Republic, Kaluga Oblast, the Krasnodar region, Lipetsk Oblast, Mari El Republic, Murmansk Oblast, Nizhny Novgorod, Saint Petersburg, Tatarstan Republic, Udmurt Republic, Vologda Oblast, Vladimir Oblast) promote biogas technologies in terms of regional initiatives and implementation of biogas projects (Karasevich et al., 2014) [G:RL]. Biogas stations Luchki and Baitsury are good examples of such successful collaboration. The Belgorod's municipality has established many regional initiatives that help to implement the biggest biogas plants in Russia [G:RL]. Due to the support, the company Regional center of biotechnology can sell energy from the biogas plant Baitsury to the grid with a 5% premium. Currently, the Belgorod region produces about 5% of the total electricity consumption of the region. Another example is the biogas plant installed by the agrofirm Promyshlennaya in Orenburg Oblast (2012) [G:RL]. This pilot biogas project was successfully implemented within the framework of public-private partnership. The financing was made by private investments of the enterprise owner and grant funds within the regional target program "Energy saving and energy efficiency improvement in the Orenburg region for the period 2010–2015″ (Infobio, 2013) [G:RL]. Overall, regional initiatives demonstrate that regions can play a major role and perform as 'laboratories' and sources of innovation (Boute, 2013). However, in terms of investments, municipalities can implement a rather limited number of biogas projects without state support. Additionally, there are no official targets that can oblige regions to support biogas.

(F5) *Market Formation.* Historically, the Russian energy sector functioned in a highly centralized way (Mitrova and Melnikov, 2019). In the Soviet Union, all energy industries had a strict hierarchical structuring and, even nowadays, the Russian energy sector is characterized by high corporate concentration and a lack of market mechanisms. The electricity market includes privately-owned and dominant state-owned companies, which control 70% of capacity in the power generation sector, own all high-voltage and almost all distribution grids in Russia (Mitrova and Melnikov, 2019).

The sanctions and international political environment led to high uncertainty and often unpredictability of external conditions and factors, which forced Russia to reconsider its future direction of activity towards the energy sector [G:IL]. In the crisis years 2015–2018, the Russian government undertook short-term policies instead of a long-term proactive strategy to adapt to market developments (Mitrova and Yermakov, 2019). International financial and technological sanctions revealed the critical dependence of Russian energy companies on the import of technologies, equipment, services, and software in a number of the most promising areas of energy development [S:CS]. Perhaps these circumstances caused the inclusion of mandatory levels of equipment localization in the support scheme for renewable energy technologies and the establishment of the import substitution programs. Overall, even renewables are not on the list of sanctions, the regularity, and effectiveness of meetings between Russian and European companies and business associations, with whom they have worked together on several issues related to the energy agenda, have started to decline [G:IL]. It has negative consequences for establishing and maintaining communication, as well as attracting investments in Russia. This fact deteriorates the existing transnational networks, institutions, and norms, which will further test the adaptability of established arrangements.

Until recently, it was not possible to sell electricity from biogas plants to the grid. The first step was made in the form of the introduction of a green tariff[7] [S:VC]. Such a mechanism was established on the wholesale electricity and capacity market (Decree of the Russian Government No. 449 of 28.05.2013) and later on the retail electricity market (Decree of the Russian Government No. 47 of 23 January 2015). However, since the support measures in the wholesale electricity market are designed exclusively for solar, wind, and small hydro generation, the construction of large generating capacities (more than 25 MW) based on biomass is not stimulated by the Russian government [S:CS]. On the retail market, Decree No. 47 sets the framework to provide electricity to grid companies at regulated rates within 5% of quotas for losses in the networks, which makes it possible to establish a network of biogas plants with a total capacity of about 870 MW on the Russian retail market (NORDICECONEWS, 2018). However, a large burden falls on regional executive authorities in terms of developing and approving a package of documents that regulate the conditions and procedure for

[7] The green tariff is a price established on the state level for electricity produced based on renewable energy sources, which allows obtaining a guaranteed return on investment in the construction of generating facilities using renewable energy based on the 15-year contract with fixed tariffs (Mitrova and Melnikov, 2019; The Bioenergy International, 2019).

conducting competitive selection. This issue often becomes an obstacle to the development of the retail segment of renewable energy (Russia Renewable Energy Association, 2020).

The first project that received the green tariff is landfill gas utilization at the landfill “Novyj Svet-Eko” in the Leningrad region, which was implemented by the Swedish company Vireo Energy AB[8] in 2016 (Golovina, 2017). The biogas plants ‘Luchki’ and ‘Baitsury’ in the Belgorod region also received green tariffs support. Many Russian regions have adopted green tariffs in the retail market including Astrakhan Oblast, Belgorod Oblast, Irkutsk Oblast, Orenburg Oblast, Kaluga Oblast, Krasnodar region, the Krasnoyarsk Krai, Moscow, the Republic of Adygea, and the Republic of Bashkortostan [G:RL].[9] Regarding the procedure of obtaining the green tariff, the representative from the Russian biogas company remarked that: “together with our partners, we went through the process of obtaining the green tariff and we won a tender, for example, in the Kaluga Oblast for a small facility with about 700 kW of capacity. It took about six months to initiate the regional regulatory framework on green tariffs, realize the tender and sign the investment agreement with the region [administration] before the project implementation. There is nothing terrible here. We see a fairly open and interested attitude from the regional authorities. However, there is a very common misconception that our projects lead to an increase in the load on consumers. It is not true because this is only 5% of the loss in the networks, i.e. it is less than 1% of the total volume of electricity transmission.” (“Biofuels and biomass” workshop, 2019).

The relationship between biogas and established energy sectors also needs to be discussed [S:CS]. The market for biogas in Russia is hampered by the abundance and low prices of fossil fuels. The share of investments in renewable energy does not exceed investments in energy from fossil fuels. Around 50% of oil fields have certain benefits and subsidies, and in some Russian regions, this number even reaches 80% [S:CS]. Certainly, there is no fair competition in the energy market in Russia. Upgraded biogas can be injected into the natural gas grid, and, theoretically, after receiving the appropriate certification, the owner of the biogas plant in Russia can sell gas to Europe. Besides the certification aspect, there is a monopolistic issue: to do so, the owner needs to get approval from the only operator of gas export – Gazprom – to transfer its volumes to European countries [S:CS]. This experience is not yet applicable. Furthermore, even though biogas and other renewable energy sources lobby for stronger renewable energy support, they compete with each other in terms of investments [S:CS]. Several companies are developing solar and wind energy in Russia. “In the bioenergy sector, there is no powerful ‘player’ as in the solar industry, who could take on the role of a powerful investor operator” (the interviewee). Smeets (2017) characterizes the success of certain renewable energy projects through the existence of “neopatrimonial networks between Russia’s emerging green energy companies and major oligarchic business groups.” In addition, some authors detect the connection between the development of renewable energy support and the creation of solar energy manufacturing base by key Russian industrial players (Boute and Zhikharev, 2019). The hydropower sector also has many benefits from renewable support policies in Russia [S:CS] (Eurasian Ventures, 2020). Bioenergy is mostly developing by a ‘bottom-up’ scheme without any state investment projects. This fact hinders a more rapid development of biogas technologies since almost all expenses for their construction are upfront.

Currently, there is no demand for the use of biomethane in Russia but its export is rather promising. For example, Scandinavian countries actively re-equip vehicle fleets for biomethane use. At the same time, it is impossible to build enough biogas plants there due to the insufficient amount of waste. The solution can be to export liquefied biomethane from Russia and transport it, for example, to Finland. Due to logistical reasons, the Leningrad region is the most attractive region to export, as it is the nearest region to Scandinavian countries with a sufficient amount of waste and a good transportation hub.

The current Russian market of organic fertilizers is estimated as emerging, locally concentrated, and extremely fragmented. Organic fertilizers are usually manufactured and used by companies that produce them. Russia has all the opportunities to become a world leader in the production of ecological products. In addition, there is a growing demand for such products, which is a good incentive. So far, Russian organic labeling is not recognized in the world. Therefore, domestic organic products will have to be additionally certified by national or international standards. In recent years, the idea of ecological farming has been actively promoted in Russia. Federal Law No. 280-FZ “On Organic Products and Amendments to Certain Legislative Acts of the Russian Federation” has entered into force on the 1st of January 2020. It is the first time when the law regulates the procedure from manufacturing, storage, and transportation to the labeling and marketing of organic products in Russia (Leishman, 2019).

(F6) Resource Mobilization. The sanctions imposed on Russia in 2014 restricted Russia’s access to international financial markets [G:IL]. Most Western financial markets were closed to Russian companies and banks (Tuzova and Qayum, 2016). The situation caused massive capital outflows and the decline of foreign direct investment (ibid). Due to sanctions and an unfavorable political environment, the Russian currency, the ruble, has been devaluated. The Russian equipment has become cheaper, and the companies use a significant number of Russian suppliers for the production of modules for European orders [G:NL]. In the same way, foreign equipment becomes much more expensive and unprofitable for its implementation in Russia [G:IL]. As the representative of the Russian biogas company also marked that the topic of biogas was relevant before the devaluation when the cost of foreign equipment in rubles was much lower. At that time (especially in 2011–2012), there was a sharp increase in electricity prices, by almost 15–20% per year: “…We thought that this story would continue, i.e. the ruble would be stable, but the price of electricity would increase reaching almost 10 rubles. Therefore, everyone has started to be interested in biogas energy as a source of autonomous energy supply. At that time there were many people at conferences, all exhibition stands were dedicated to biogas. However, that was until 2014…” To some extent, these events can explain the frequent change of renewable energy targets and low targets of decarbonization, as these efforts would require significant investments that are not available due to sanctions.

Decree of Government No. 961 of 23 September 2016 provides subsidies for the connection of renewable energy equipment to the

[8] From September 2017, the company Vireo Energy AB changed its name to Recovia AB.

[9] Information was taken from the presentation in the workshop ”Biofuels and biomass”, 2019

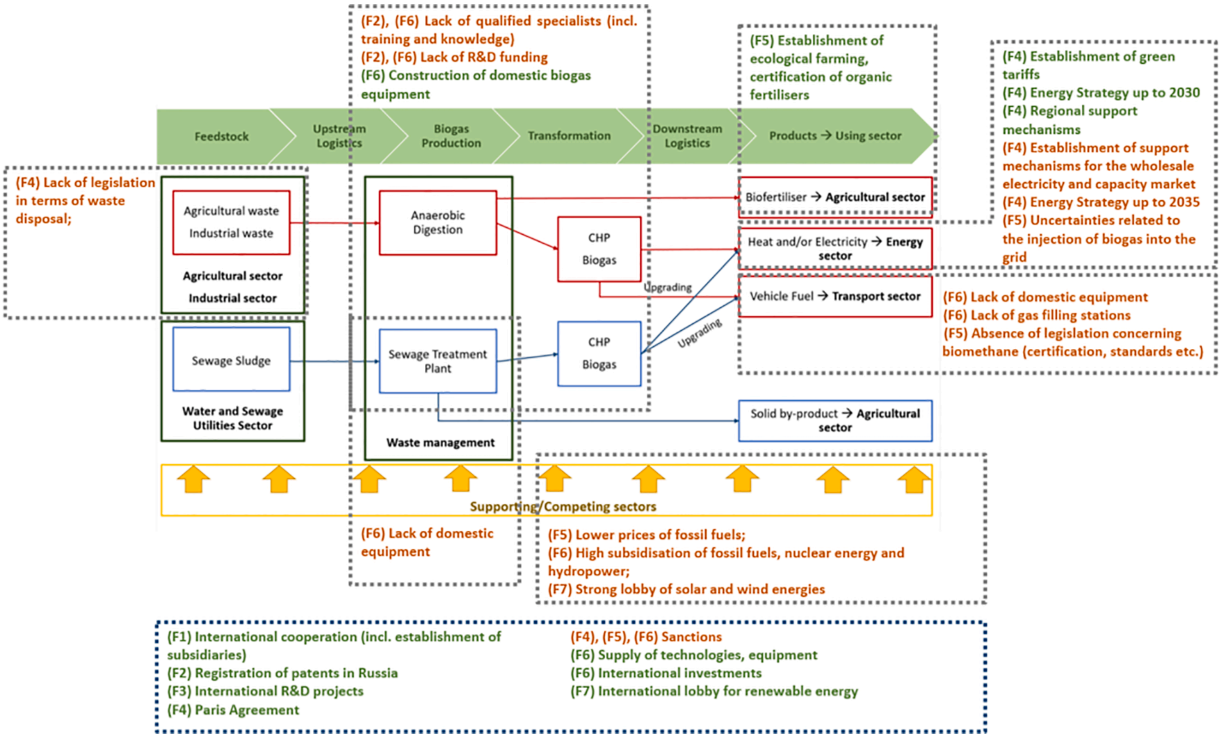

Fig. 6. The main functional factors that affect biogas TIS in Russia.Appendix A.

grid network [G:NL]. The total amount of subsidies should not exceed 70% of the cost to the grid network connection and no more than 15 million rubles (NORDICECONEWS, 2018; Russian Government, 2016). Regarding R&D funding, German companies and scientific organizations have assisted the development of biogas projects in Russia [G:IL]. As an example, the Russian-German project "Coop-eration of bioregions in Russia and Germany" (2009–2012) was supported and funded by the Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety of Germany (Tihonravov, 2011).

Nevertheless, there is a financing problem associated with biogas plants – neither a farmer nor an agricultural cooperative can provide sufficient financial resources for such projects [S:VC]. Despite this, the implementation of biogas plants is hindered by the reluctance or inability of potential customers to use traditional financing mechanisms or construct plants solely with their funds. This situation is caused by the objective reasons, i.e. a) a lack of soft loans for potential customers of biogas plants; b) the novelty of technology on the Russian market, and c) customers' doubts about the technological and economic expediency of biogas plants (Tihonravov, 2011). One solution might be to implement biogas projects where the environmental service company operates a biogas plant. In this way, this company concludes a long-term contract with enterprises that will supply and dispose of waste. This scheme allows to solve the problem of waste disposal and reduce energy costs without investments from the enterprise's side. Such scheme was performed by the company EVOBIOS for the biogas plant in JSC Breeding plant Pervomaysky in Leningrad Oblast (2019) [G:RL].

Biogas technologies are rather new, complex, and capital-intensive technologies for Russian agricultural enterprises. To operate the plant, Russian companies need knowledge, specialists, and investments, which they do not have. Mainly, biogas plants in Russia were constructed with the use of R&D, technologies, and specialists from abroad (see examples in Table A1). Despite the sufficient volume of research material, there is a serious lack of industrial production of large-scale biogas plants, equipment for the treatment of waste-water plants, and landfill gasses in Russia. The sanctions imposed against Russia markedly affect the foreign investment attractiveness and make it more expensive to buy foreign equipment for Russian companies. In this situation, it becomes more difficult for biogas plants with foreign equipment to be profitable.

(F7) *Creation of Legitimacy*. There is a positive trend that Russian lobby groups recognize the changing energy paradigm towards renewable energy. At the same time, traditional energy companies do not want to lose their established business [S:CS]. Such com-panies enjoy the privileges from the government and perceive renewable energy development as a threat to the companies' activity and their share in the energy market. The biogas lobby activities appear to be weak. The main organization, which promotes bioenergy, is the technological platform Bioenergy that consists of a wide range of actors including ministries and departments, businesses, scientific organizations, universities, and social institutions. This organization reveals two barriers to the establishment of legitimacy in Russia. The first barrier is a lack of information. There is no widespread promotion on radio, television, and in the press about the possibilities and advantages of renewable energies, and there is no information about positive examples of their use (TP Bioenergy, 2019). The second one is the psychological barrier. Russia is rich in fossil energy resources and, historically, the Russian energy sector is used to function in a highly centralized way with the habit of power engineers managing large single capacities (ibid).

5. Discussion and conclusion

This study intended to include sectoral and geographical perspectives into the TIS functional analysis. This involved the impact analysis of a variety of sectors' integration into the biogas value chain and a more explicit review of the spatial and institutional contexts of the transition process. Fig. 6 gives examples of the main functional factors that affect biogas TIS in Russia and shows that the factors belong to various sectors and do not solely relate to biogas technologies (i.e. anaerobic digestion and sewage treatment plant). As a result, different factors that consider the spatial and sectoral configurations of focal TIS enabled us to understand how technological innovation develops, diffuses, and uses in specific segments and places.

From the sectoral perspective, the empirical analysis shows that certain sectors, which are either involved in or placed outside of the biogas TIS, influence biogas development. For example, sectors that are incorporated in the biogas value chain drive knowledge development and diffusion (F2 and F3) (see also other studies of Malhotra et al., 2019; Stephan et al., 2017). Guidance of the search (F4) and Market formation (F5) demonstrate how policies, instruments, and practices in one sector influenced the development in other sectors. Even though certain sectors are not involved in the value chain of biogas TIS, they compete and/or complement each other as was shown in the analysis of the relationship between biogas TIS and the established energy sectors. Certainly, there will be no biogas production without feedstock supply from agricultural, industrial, water, and utility sectors (F6). In the situation with biogas technologies in rural areas, agricultural and/or industrial enterprises (F1) interact with biotechnological companies that design and produce biogas equipment for the organic wastes to implement commercial projects, demonstrations, and/or experiments. Lobbying competition between actors from traditional energy companies hinders the biogas development in Russia (F7). Empirical analysis shows the big involvement of different sectors in the development of biogas technology in Russia.

From the spatial perspective, the study demonstrated a complex picture of innovation dynamics in the early development stages of the biogas industry in Russia. International actors actively promoted biogas technologies. The participation of foreign researchers in R&D projects contributed to the knowledge formation and diffusion in the early years, i.e. a factor that enabled a more rapid transfer of technology (F2, F3). Foreign manufacturers and engineers (F1) were engaged in the construction and maintenance of biogas plants in Russia (see Table A1 and Fig. A1). International agreements (e.g. the Kyoto Protocol, the Paris Agreement), associations (e.g. World Intellectual Property Organization, WTO), financial institutions (e.g. International Bank for Reconstruction and Development, European Bank for Reconstruction and Development) all play a significant role in the emergence and formation of the renewable energy sector in Russia (F4, F5, F6). Geographical perspective helps to reveal a complete picture of structural elements and their geographical distribution.

Additionally, this study has applied the TIS theoretical framework in the context of a country with a transition economy, which, to the author's knowledge, is the first attempt to analyze the biogas industry in Russia using the TIS approach. It also shows that the TIS framework is a promising analytical tool for analyzing the innovation processes in countries with economies in transition. The study also contributes to the innovation system literature by applying mixed methods research since very little research integrates quantitative and qualitative data collection and analysis.

The study also demonstrates important aspects and recommendations for Russian policymakers. The main measures, which the government should implement, are legislation regarding waste disposal that can penalize the enterprises for the illegal waste disposal into fields and landfills. As the representative of the Russian biogas companies mentioned that "small agricultural enterprises simply do not have enough money [for the construction of biogas plants] as they have many other debt obligations. However, large agricultural holdings, which are mostly monopolists, do not care about the environment since no standard of waste management could facilitate them to recycle it." This statement leads to another important measure – the introduction of soft loans for biogas producers. Other recommendations concern the establishment of federal support programs, which will assist in the financing of biogas projects. Federal programs should also facilitate the construction of pilot biogas projects that will demonstrate more effective use of waste as an energy source and thus create a positive image of biogas technologies. Additionally, there is a shortage of qualified engineers focused on biogas technologies, and thus new faculties that will educate specialists for the biogas industry should be established. Last but not the least, lack of information decreases social awareness about the importance of waste separation and utilization. Media, public and/or professional organizations (in forms of publications of popular brochures, special issues in scientific and technical journals, newspapers, etc.) should provide more educational information on current environmental problems, positive features of biogas technologies in terms of improved waste management and its multi-functionality, etc.

Russia is an energy-rich country, whether it is fossil fuels or renewable sources. Russian authorities should pay more attention to the promising biogas industry as it can be considered as an important factor for the modernization of the Russian economy, which can help to improve social and environmental conditions, accelerate technological development, solve organic waste disposal, create innovative industries and new jobs in rural areas, reduce energy dependence and migration from rural areas, and develop small and medium-sized businesses.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Table A1
Most known biogas plants in Russia.

Year	Biogas plant, Location	The total capacity/ Digester size	Substrate	Russian companies/research centers	International relation	Reference
2002	Agricultural farm Krasnaya pojma (Lukhovitsky district, Moscow Oblast)	65 m^3	Cattle manure	Federal Scientific Agroengineering Center VIM	None	(Efendiev, 2013)
2009	MosMedynAgroprom (Village of Doshino, Kaluga Oblast)	2.4 MW	Cattle manure	Construction of the technological part of the project and operation: company Biopotok. Construction of the energy part of the project and operation: corporation BioGazEnergoStroy	The equipment for processing of organic waste and biogas production and gas-piston plants are made in Europe (~GE Jenbacher engine J208)	(BioGazEnergoStroy, 2011; Pantskhava, 2016)
2009	Kuryanov sewage treatment plant (Moscow)	128,000 m^3 of biogas per day	Sewage sludge	Project design: the JSC MosvodokanalNIIproject Institute and specialists of Mosvodokanal	Investor: Austrian concern EVN Equipment: Four GE Jenbacher gas-piston internal combustion engines	(Kevbrina, 2013; Khramenkov et al., 2010; Namsaraev et al., 2018)
2011	Mortadel (Vladimir Oblast)	150–160 kWh per day	Pig manure	Construction: LLC Mortadel-Stroy	Equipment, technology and supervision: company Euroindustries	(PigUA.info, 2011)
2011	State farm Roshchinsky (Bashkortostan Republic)		Waste from slaughterhouses and pig farms	n/a	Equipment supplier: AEV Energie (Germany, Regensburg)	(Infobio, 2011; Tihonravov, 2011)
2011	Perm region	70 m^3 of biogas per day	Pig manure	EnergoRezhim LLC	None	(EnergoRezhim, 2011)
2011	JSC Sharkansky RTP (village Sharkan, Udmurt Republic)	300 m^3 of biogas per day	Any organic waste: grass, silage, and slaughterhouse waste	EnergoRezhim LLC	None	(EnergoRezhim, 2011)
2012	Lyubertsy sewage treatment plant (Moscow)	145,000 m^3 of biogas per day	Sewage sludge	Project design: the JSC MosvodokanalNIIproject Institute and specialists of Mosvodokanal	Investor: Austrian company EVN	(Kevbrina, 2013; Khramenkov et al., 2010; Namsaraev et al., 2018)
2012	Agrofirm Promyshlennaya (Orenburg Oblast)	Capacity processing of 2–2.5 tons per day	Any organic waste: cattle, horse, pig, poultry manure, vegetable waste, beer pellets, biological waste etc.	Kompleksnye sistemy utilizacii (Integrated recycling systems)	n/a	(Kompleksnye sistemy utilizacii, 2012)
2012	Luchki (Belgorod Oblast)	2.4 MW	Meat processing waste, pig drains, corn silage and other raw material	Implementation of the project: company AltEnergo	Equipment: Big Dutchman Agro	(AltEnergo, 2019)
2012	Baitsury (Borisov district, Belgorod Oblast)	1 MW	Pig manure	Project design: LLC Promagrostroy Construction: Regional center of biotechnologies	Equipment: B Big Dutchman Agro (Germany)	(Tihonravov, 2011)
2013	Village of Vasilievo-Shamshevo (Rostov Oblast)	Capacity processing of 50 tons per day	Chicken manure	BioenergyResource-3 LLC and EnergoRezhim LLC	None	(EnergoRezhim, 2011)
2013	Breeding farm Istobenskiy (Orichevsky district, Kirov Oblast)	Up to 50 m^3 per day	Cattle manure	SelhozBioGas LLC	None	(SelhozBioGas, 2019)
2016	Istra district (Moscow Oblast)	Reduction of the use of natural gas by almost 300,000 m^3	Industrial wastewater	n/a	Coca-Cola HBC Russia	(Coca-Cola HBC Russia, 2017) (Coca-Cola HBC Russia, 2018)
2017	Astrakhan Oblast	Capacity processing of 10 tons per day	Animal and plant residues	SelhozBioGas LLC	None	(SelhozBioGas, 2019)

(continued on next page)

Table A1 (*continued*)

Year	Biogas plant, Location	The total capacity/ Digester size	Substrate	Russian companies/research centers	International relation	Reference
2017	Village Bogdanikha (Ivanovo Oblast)		Sewage sludge	Under federal program of the International Bank for Reconstruction and Development in Reform and modernization of Housing & Utilities in the Russian Federation	General contractor: TAHAL Consulting Engineers Ltd (Israel) Supplier of four cogenerators: company MaxMotors (official distributor and service provider of GE Gas Engines (Austria) in Russia) Design documentation development: SWECO (Sweden)	(Sidorova, 2016)
2017	Samarkand region, Republic of Uzbekistan	60 M^3	Organic waste	EVOBIOS LLC	Customer: Agency for restructurization of agricultural enterprises (Uzbekistan)	(Evobios, 2017)
2017	Yerevan, Armenia	n/a	Pig manure	Manufacturing and installation of some missing pieces of equipment: SelhozBioGas LLC	Customer: Pig farm in Yerevan (Armenia)	(SelhozBioGas, 2019)
2019	Ufa, Bashkortostan Republic	Capacity processing of 2 tons per day, 50–60 m^3 of biogas per day	Different types of organic waste: manure, poultry manure, whey, expired food products.	Cooperation between Russian companies: SelhozBioGas LLC and Kompleksnye sistemy utilizacii (Integrated recycling systems)	None	(SelhozBioGas, 2019)
2019	Nekhaevsky district, Volgograd Oblast	Capacity processing of 10 tons per day	Pig manure of different humidity and various plant residues.	SelhozBioGas LLC	None	(SelhozBioGas, 2019)
2019	JSC Breeding plant “Pervomaysky” (Pervomayskoye settlement, Leningrad Oblast)	240 kW / h	Cattle manure	EVOBIOS LLC	None	(Evobios, 2019)

Fig. A1. Map of Russia with locations of analysed TIS actors related the most known biogas plants in Russia.

Table A2
The timeline of main regulations in renewable energy sector of Russia.

Year	Description
2007	Introduction of the Federal Law No.250-FZ for the development of renewable energy sources into the main Federal Electricity Law, No. 35-FZ "On the Electric Power Industry" (2003). The Law set the framework for the use of renewable energy, and the directions for the legislation development.
2009	Establishment of The State Programme on "Energy Efficiency and Energy Development" (first version with the target of 4.5% of renewable energy share in total electricity generation.
2009	Establishment of the Energy Strategy up to 2030 with the official targets intended to increase renewable energy share;
2012	Adoption of the Comprehensive Program on Development of Biotechnology through 2020 (BIO 2020)
2013	Approval of the Roadmap for Biotechnology and Genetic Engineering Development
2013	Establishment of the Decree of the Russian Government No. 449 of 28.05.2013 for the wholesale electricity and capacity market
2014	Revision of The State Programme on "Energy Efficiency and Energy Development" decreased the share of renewables in total electricity generation from 4.5% to 2.5% by 2020 and did not provide any financial support for energy generation from biomass
2015	Establishment of the Decree of the Russian Government No. 47 of 23.01.2015 for the retail electricity market
2016	Russia signed the Paris agreement
2019	Russia approved the Paris agreement
2020	Establishment of the "Energy Strategy of Russia up to 2035″, which do not set any future numerical indicators for the development of renewable energy in Russia;

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Appendix A

Table A2

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