Technological Innovation System in Agribusiness: Motors and Evolution

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Abstract. This research aimed to analyze the evolution and interaction over time of the functions of a technological innovation system (TIS) based on the concept of an innovation motor. A case study of the innovative system associated with the production of cage-free pullets for laying eggs in Pelotas/RS was developed. The results corroborate the adequacy of functions and motors as an appropriate theoretical approach in agribusiness. The motors proposed by the TIS approach evolve sequentially and are associated with the mechanisms of cumulative causation. The results of the case study identified two new functions: analysis of the chain as a whole and coordination of the actors involved in the system, as well as the presence of tipping points at the beginning of each motor. The main limitation is the absence of a greater detailing of the market motor in discussions on the evolution of the motors and functions of the TIS Cage-Free Pelotas. Practical implications include innovation motors as a new guiding approach for participatory innovation initiatives in rural areas. Originality is the application of the approach in agribusiness, the proposition of two new functions for the analysis of motors, and the inclusion of the concept of tipping points as an activation trigger in the evolution between motors.

Keywords: Technological Innovation System; Agribusiness; Sustainability; Innovation Motors; Tipping Points.

1 Introduction

Criticisms that the linear method of technological development is flawed, coupled with the demand for sustainable agriculture, have encouraged scientists to better consider the complex context in which the technologies have been applied (Lamers; Schut; Klerkx & van Asten, 2017). These conclusions are reached because when analyzing research organizations, it is evident that it is difficult to implement new technologies developed with a focus on sustainability (Planko; Cramer; Chappin & Hekkert, 2016).

The theoretical approach called technological innovation systems (TIS) has received considerable attention in recent years as a reference for the study of emerging technologies, such as technologies focused on sustainability (Kukk; Moors & Hekkert, 2015). The TIS approach has been considered adequate to explore how organizations can encourage the creation of supply chains and increase the chances of successful implementation, succeeded by new technology available to society (Bergek, A.; Jacobsson, S.; Carlsson, B.; Lindmark, S. & Rickne, A, 2008).

Several studies have been conducted, for example, on technologies associated with biotechnology, precision agriculture (Eastwood; Klerkx & Nettle, 2017; Hall, 2005; Klerkx; Van Mierlo & Leeuwis, 2012), and sustainable agricultural systems (Lamers *et al*., 2017).

A technological innovation system (TIS) can be defined as a "set of actors and institutions in networks that interact in a technological field and/or new product" (Markard; Raven & Truffer, 2012). A TIS can also be defined as an analytical construct incorporating subsystems of the innovation system until it is disconnected to guide decision-makers (Bergek et al., 2008).

The concepts of TIS are based on the idea that the determinants of innovation and technological change do not lie only in research organizations but are also located in the broader innovation system that supports and restricts the activities of these organizations (Bergek et al., 2008). Thus, a TIS is generally analyzed in terms of seven functions. System functions are considered classes of processes that contribute to the development, diffusion, and use of technological innovations (Hekkert; Suurs; Negro; Kuhlmann & Smits, 2007). Technological innovation systems are the most important processes in building an innovation system; namely: F1 - entrepreneurial experimentation; F2: knowledge development; F3: dissemination of knowledge; F4: research orientation; F5: market formation; F6: resource mobilization; and F7: creation of legitimacy. The list of seven system functions was established based on a review of many years of literature on system innovation (Hekkert et al., 2007). However, more recently, a set of three other functions has been considered fundamental in the evolution of a technological innovation system: coordination (Markard; Geels & Raven, 2020; Planko et al., 2016), sociocultural changes (Planko et al., 2016; Markard et al., 2020), and the analysis of the system as a whole (Markard et al., 2020).

When the approach to technological innovation systems is analyzed, one criticism of the approach is that it is static and pays little attention to the evolution of system functions (Lachman, 2013; Planko et al., 2016). In addition, little attention has been paid to how the interaction between functions occurs, which is included and excluded along the innovation trajectory (Lamers et al., 2017).

The concept of an innovation motor (Suurs & Hekkert, 2012; Suurs, 2009) overcomes criticisms of the TIS approach by emphasizing the evolution of functions and their relationships over time. The concept of an innovation motor is a set of hypotheses on how and which functions influence each other at different stages of the evolution of a technological innovation system, forming a typology called innovation motors (Suurs & Hekkert, 2012; Suurs, 2009).

The concept of an innovation motor, however, has not been widely understood and developed in the innovation systems literature (Köhler; Raven & Walrave, 2020), with the exception of the work of (Walrave & Raven, 2016). This gap represents an opportunity, given the need to better understand the dynamics of a TIS, especially the evolution of functions and their interactions that support the evolution of TIS, as the understanding of the relationships between functions over time is still limited (Köhler et al., 2020), especially in rural environments, which has not been found in previous studies.

Considering the need to advance the understanding of the dynamics of a technological innovation system, the following research question was established: How do the functions and interactions between them evolve in a system of technological innovation in agribusiness? Therefore, it was established as a general objective to analyze the evolution and interaction of the functions over time, from the concept of an innovation motor in the rural environment, and with a focus on sustainability. To answer the proposed research question, a case study of an innovative system associated with the production of cage-free pullets for egg laying was developed. This technology has been developed worldwide and in the region of Pelotas-RS by Embrapa Clima Temperado-Pelotas/RS with a view to concerns about animal welfare and sustainability.

2 Technological Innovation Systems

2.1 Key Functions of Technological Innovation Systems

The functions of innovation systems are considered classes of processes that contribute to the development, diffusion, and use of technological innovation (Hekkert et al., 2007). These are dynamic processes that occur between the structural components (actors, networks, and institutions) of the system. Each function contributes to building a favorable system around the new technology (Musiolik & Markard, 2011). The seven functions traditionally discussed in the literature are discussed below.

Function 1: Entrepreneurial experiments. Entrepreneurs are key in a TIS because they convert potential new ideas into business opportunities (Hekkert et al., 2007; Planko; Cramer; Hekkert & Chappin, 2017). These entrepreneurs can be new businesses or established firms that want to diversify into new technologies. By testing new technologies in the market, social learning processes can be activated. This makes it possible to gather new information on the reactions of consumers, governments, competitors, and suppliers (Hekkert et al., 2007; Planko et al., 2017).

Function 2: Knowledge development. Learning activities, such as research, development, and learning in a practical context, are fundamental to any innovation process. Knowledge cannot only be acquired about new technology but also about markets, networks, and users (Bergek et al., 2008; Hekkert et al., 2007; Planko et al., 2017).
Function 3: Disseminating Knowledge. Conferences, workshops, and alliances encourage knowledge exchanges. This is important not only for the exchange of specific R&D knowledge but also for the exchange of knowledge between the government, business, and the market (Hekkert & Negro, 2009; Planko et al., 2017).
Function 4: Research orientation. This key process summarizes all activities and events that convince actors to enter or invest in a TIS. A positive expectation regarding technology development is the main aspect here. This expectation may be based on changes in attitudes, entry prices, regulations, and policies (Bergek et al., 2008; Hekkert et al., 2007; Planko et al., 2017).
Function 5: Market formation. We can say that the new sustainability technologies have difficulty competing with dominant technologies. It is necessary to create temporarily protected market niches for technology to develop and gain a market share. Such niches can have favorable tax regimes, guaranteed consumption quotas, environmental regulations, and public contracting policies (Bergek et al., 2008; Hekkert et al., 2007; Planko et al., 2017).
Function 6: Resource mobilization. This key process pertains to the resources required for a TIS to function properly. Financial and human resources must be mobilized to enable the construction of an innovation system, and complementary resources must be developed, such as complementary products, services, and network infrastructure (Bergek et al., 2008; Hekkert et al., 2007; Planko et al., 2017).
Function 7: Creating legitimacy. Sustainability-focused innovations often struggle to overcome the inertia caused by the current production system, which is often reluctant to change. Therefore, coalitions and lobbying in defense of the new technology with a view to winning resources and favorable tax regimes and putting new technology on the policy agenda (Hekkert et al., 2007; Planko et al., 2017).

2.2 New Key Functions Associated with TIS

Three new key functions for developing a technological innovation system have been suggested: coordination (Markard et al., 2020; Planko et al., 2016), sociocultural changes (Planko et al., 2016; Markard et al., 2016; 2020), and the analysis of the system as a whole (Markard et al., 2020). The three new function proposals are discussed below.
Coordination Function (F8): the effort coordination function is seen as a function that contributes to the acceleration of the construction of a TIS because the diffusion of innovations usually requires alignments between several policies (Markard et al., 2020;

Planko et al., 2016). However, a set of activities is considered important in this effort to coordinate a TIS. (Planko et al., 2016) highlighted seven other activities. The first two were creating a shared vision and setting common goals among the TIS participants. The third activity involves the standardization of products and services. Standardization is important for reducing production costs and building a reliable system, enabling buyers and consumers to choose among available brands (Planko et al., 2016). The fourth activity is the creation of open innovation platforms within the TIS with the aim of increasing the speed of innovation of complementary products (Planko et al., 2016). Finally, the last three activities are system orchestration, which refers to the management and alignment of the efforts of individual participants, and requires the activity of defining the functions of TIS participants in order to create the resources required to compete with the regime. Finally, the last activity is the creation of transparency, which is important because it can avoid overlapping functions and resources by optimizing the TIS (Planko et al., 2016).

Function of Sociocultural Change (F9): Innovations, especially those focused on sustainability, need to be well rooted in society (Markard et al., 2020; Planko et al., 2016). This means that entrepreneurs need to strive for desired changes to take place in consumer decision-making. Therefore, these entrepreneurs need to change their ingrained values and norms in favor of new technology. A set of activities is associated with sociocultural change. In relation to the entrepreneurs' businesses, they themselves must induce a more collaborative action among their employees; induce changes in consumer values; and work in the educational system with a view to training professionals with skills to work in the new technology (Planko et al., 2016). Markard et al. (2020) highlight that policymakers can change consumer behavior by providing more information about new technology, creating performance standards for products, reducing fees, and creating subsidies that aim to encourage the adoption of new sustainable technology.

Changes in the function of the system as a whole (F10): Markard et al. (2020) highlighted this function by stating that innovations focused on sustainability fail to align the system as a whole. For this to occur, two critical issues need to be overcome: (i) the need to foster complementary interactions between multiple innovations and (ii) the need to promote changes in the system's architecture. In agribusiness, the need for a global vision is not new and can be seen in the production chain concept. According to Batalha and Silva (2008, p. 32), the definition of a production chain starts with the identification of a final product "[...] after this identification, it is necessary to chain, from downstream to upstream, the various operations technical, commercial and logistical requirements for its production". Through the application of the production chain concept, one can see the complexity of the production process, which implies aligning and innovating the various links of the production chain as a whole, with a view to the success of the chain that one wants to promote.

2.3 Innovation Motors

Suurs (2009) highlights that the discussion on innovation motors originates in studies on organizational change, more specifically in the notion of motors employed by (Poole; Van de Ven; Dooley & Holmes, 2000). Suurs and Hekkert (2012) and Suurs, Hekkert, and Smits (2009) studied the notion of innovation motors in technological innovation systems and identified four types of combinations of functions. Each of these four motors is described as follows.

The first motor is driven by science and technology (Suurs & Hekkert, 2012; Suurs, 2009). This motor refers to a pattern in the innovation system in which the development of scientific knowledge and diffusion is central, supported by research projects and policies (Walrave & Raven, 2016). Motor function is initiated by a common activation trigger, which is a social and environmental problem (Suurs & Hekkert, 2012; Suurs, 2009). The production and dissemination of scientific knowledge shape the first experiments and some entrepreneurial activities, which may increase or decrease depending on whether the results confirm initial expectations (Walrave & Raven, 2016). This motor is dominated by knowledge development (F2), knowledge dissemination (F3), research guidance (F4), and resource mobilization (F6) functions. The role of entrepreneurial activities (F1) is also important in the motor engine that drives science and technology (Suurs & Hekkert, 2012; Suurs et al., 2009).

The second motor is called the entrepreneurial motor. This refers to a pattern of the innovation system in which the central dynamic is constituted by an increase in active entrepreneurs in the innovation system (Markard et al., 2020). Suurs and Hekkert (2012), Suurs (2009), and Walrave and Raven (2016) explain that in this motor, the start of a vicious circle of technological development is the entrepreneurs who lobby (F7) for better economic conditions, and thus make technological development possible. Suurs et al. (2009) explain that the entrepreneur's role is to translate knowledge into business opportunities and, eventually, innovations. Suurs and Hekkert (2012) clarify that, in some cases, this dynamic is strengthened by niche market activities (F5). These involve small markets that are usually not developed within TIS itself (Suurs & Hekkert, 2012; Walrave & Raven, 2016). The periphery of this motor comprises motor connections driven by science and technology (Suurs & Hekkert, 2012).

The third motor is called the system construction (Suurs & Hekkert, 2012; Suurs, 2009). This refers to a pattern of the innovation system characterized by an increase in system actors acting in networks, infrastructural development, and attempts to reconfigure institutions (Walrave & Raven, 2016). The network starts to attract broader social support, for example, for the institutionalization of new incentive policies or the construction of physical infrastructure. The motor comprises entrepreneurial motor relationships, but with more additions and emphasis on creating legitimacy (F7),

market formation (F5), and research orientation (F4). The valley of death in the TIS evolution process (Suurs & Hekkert, 2012; Walrave & Raven, 2016).
The fourth is the market motor (Suurs & Hekkert, 2012; Suurs, 2009). This refers to a pattern of the innovation system in which there is substantial market demand that is sufficient to keep all entrepreneurs associated with TIS (Walrave & Raven, 2016). TIS is already legitimized by social and political actors and is no longer explicitly questioned. In terms of functions, all functions are important, but creating legitimacy is less important (Suurs & Hekkert, 2012; Walrave & Raven, 2016).

3 Methodology

The research strategy was classified as a qualitative study of single-case analysis (Yin, 2017). A qualitative case study is characterized by the search to know in depth a certain situation that is supposed to be unique (Yin, 2017).
This case was defined as an innovation system associated with the cage-free chicken production process. The spatial domain was defined as the starting point for the city of Pelotas RS and the actors and institutions in other cities with interactions based on it. Having decided on the case and spatial domains, the next step was to identify the structural components of the system. These included not only companies but also rural producers and some of their suppliers, universities, and development institutes, as well as public bodies and organizations with common interests. The snowball technique was used to identify the actors in the sense that once one of the actors was identified, he was asked about other actors who could participate in the TIS. This procedure is supported by Bergek et al. (2008), who state that, given the large uncertainties involved when the analysis concerns an emerging TIS, a definitive focus may be difficult to choose and may have to change over time.
A script was used for data collection that guided the interviews, document analysis, and participant observation. The interview and document analysis scripts are based on the seven functions of Hekkert et al. (2007), with the addition of the three functions proposed by Planko et al. (2016) and Markard et al. (2020).
Four interviews were conducted with key people:
Responder 1 - Researcher II in Agroecology at the Brazilian Agricultural Research Corporation (EMBRAPA), focusing on colonial and organic poultry farming and agroecology.
Respondent 2 - Veterinary Doctor, Poultry Professor of Technical Education at the Federal University of Pelotas/IFSUL.
Respondent 3 - Regional Manager of the Technical Assistance and Rural Extension Company - Emater/Ascar.
Respondent 4 - Extensionist at Emater since 2012–Lecturer in the colonial aviculture course.

The documents considered in the data collection comprised a thesis, five official government documents, three minutes of a network meeting involving TIS members, a law, and 11 news articles from local newspapers and media. In addition, participant observation was carried out in 12 activities involving the analyzed TIS. Data were collected for 2019 and 2020.

For the analysis of the collected data, the procedural method or sequence analysis (Abbott, 1995) suggested by Suurs and Hekkert (2012) was used. The procedural method conceptualizes development and change processes as sequences of events and explains the products of a process as the result of an order of events (Abbott, 1995). Events are central elements of what subjects do or happen to them (Abbott, 1995). Hekkert et al. (2007) recommend that all mapped events be allocated to functions via a schema. This allowed the researcher to verify the validity of these functions. Forty-one events were identified and classified along the TIS trajectory (1999-2020).

To conduct the study, we followed the research judgment criteria proposed by Yin (2017). Regarding the quality of the results, multiple data sources were used, such as interviews, documents, legislation, and participant observation (Yin, 2017). Regarding internal validity, the observed results were compared with the existing theory regarding the functions initially, the innovation motors, and the confidentiality of the collected data (Yin, 2017). External validity is determined by comparing the results obtained and interpreted during the research with the co-author of the research, who we believe has more comprehensive knowledge about the case studied and is an expert in the theoretical approach of technological innovation systems (Yin, 2017). The reliability of this research is supported by the data analysis script composed of theoretical categories (10 functions of the dynamics of a TIS) reviewed in Sections 2.1 and 2.2 (Yin, 2017).

4 Results and discussions

4.1 Description of the Evolution of the Motors and Functions of the TIS Cage-Free Pelotas

In this section, the evolution of innovative functions and motors is described based on the events identified and classified according to the ten functions reviewed in Sections 2.2 and 2.3. Three motors are identified. The TIS Cage-Free Pelotas (Phase I) began with the creation of the Science and Technology motor in 1999, and subsequently by the Entrepreneurship Motors (Phase II in 2017) and by the System Construction motor (Phase III in 2019, Figure 1). Each of these motors is described as follows.

Phase I, the creation of the Science and Technology Motor Company, was characterized by the presence of the first tipping point (TP1), which was a social demand to create income for a local community of rural producers in extreme poverty.

Based on this demand, EMBRAPA created a research project (F4) to develop technology for the creation and management of free birds for these vulnerable families. From the project onwards, knowledge development (F2) began with the installation of demonstration units to validate the previously designed creation model. The results of the demonstration units indicated the need for reorienting research (F4), including research on the preparation of low-cost poultry feed, as well as for the automation of processes within the poultry house, which culminated in knowledge development activities (F2). The installation of demonstration units and new research projects contributed to the creation of a producer-training course (dissemination of knowledge, F3). The entrepreneurial experimentation function (F1) was also present at this stage, with the formalization of the first production establishment in compliance with sanitary, environmental, and fiscal rules for this type of production.
Phase II of the creation of the Entrepreneurship Motor began with a second tipping point that was characterized by the need for local rural producers to generate more income in their businesses, especially those producers who had idle breeding facilities (poultry houses) due to the stoppage of the activities of the local cooperative, which was produced in the traditional system (TP2), fostering several initiatives of entrepreneurial experimentation (F1) in the technology of production of cage-free poultry eggs. Subsequently, these entrepreneurs began to lobby the local government agency with a view to creating legitimacy (F7) of the new technology, placing their ventures on the local government's agenda with a view to solving their identified problems and resources that favor production. In response to the lobbying carried out by the producers, the local government agency started a series of analysis and negotiation actions with the aim of structuring the chain as a whole (F10), such as an agreement for a local slaughterhouse to dispose off poultry, the promotion of one of the producers to carry out the step of rearing the pullets, and the installation of a feed mill.
Phase III, the creation of the system construction motor, also started with a tipping point (TP3), which was interpreted as the local government's need for strategies for the development of the cage-free egg production chain. Based on this search, it was decided to create a network involving producers and public and private organizations led by the local government, with a view to coordinating actions (F8) with a focus on promoting technology. Once the network was created, two new functions began to be developed with TIS participants: market formation (F5) and resource mobilization (F6). Market creation actions involved holding meetings with local traders to attract new customers and meetings with managers of public organizations with the objective of creating specific demands on the part of these organizations. Resource mobilization actions involve the inclusion of new actors with different functions in the newly created network.

In addition to activities associated with market formation (F5) and resource mobilization (F6), the network also started to interact with the other two motors: entrepreneurship and science and technology.
The interaction with the network's entrepreneurship motor expanded the actions to create legitimacy (F7) through the dissemination of the creation of the network itself and the importance of the new technology for the production of cage-free pullet eggs, the creation of a law by the local government to encourage entrepreneurs, publicizing the activities in local and national newspapers, and creating a logo for the network created. The actions of structuring the chain as a whole (F10) involved the continuation of actions initiated in the entrepreneurship motor as well as the development of new options to encourage the creation of a feed mill. In the Entrepreneurial Experimentation actions (F1), new projects were designed for other rural producers to enter production with new technology.
In the interaction with the science and technology motor, the network influenced the research orientation (F4), with the proposition of reactivating the lowest-cost feed research project, this time together with current producers, in actions to develop knowledge (F2), as a line of research into production costs and knowledge dissemination actions (F3), as a way to encourage producers to split the long-term training course and short-term courses on alternative food and marketing strategies. Figure 1 summarizes the described evolution of the functions and motors identified in the TIS cage-free pelotas.

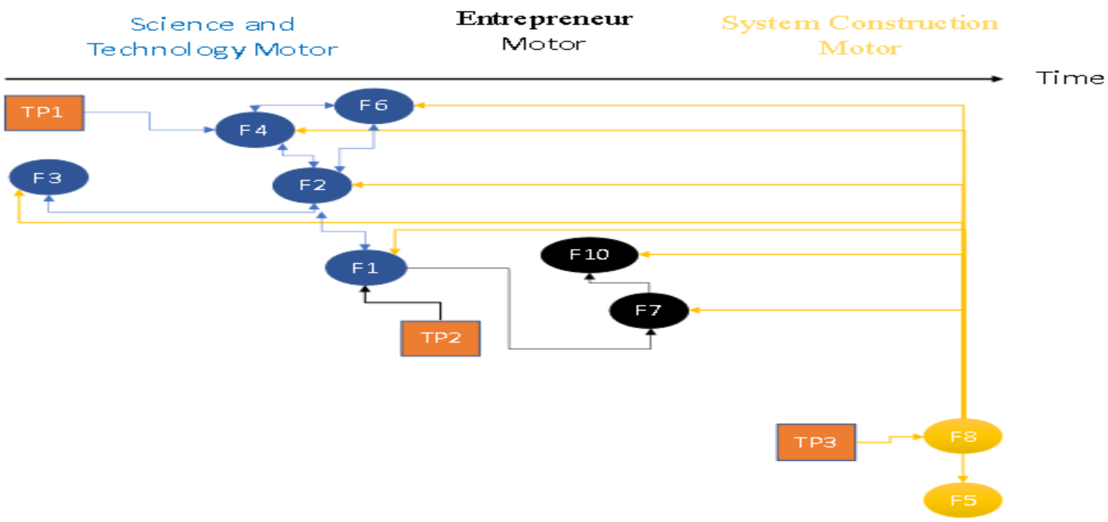

Fig. 1. Evolution of TIS Cage-Free Pelotas Functions and Motors

4.2 Discussion of the Evolution of Motors and Functions

The evolution of the TIS Cage-Free Pelotas motors and functions was organized in two stages:1) analysis of each of the motors individually: science and technology motor, entrepreneurship motor, system construction motor; and 2) motor sequence analysis.

When comparing the description of the Science and Technology Motor of the TIS Cage-Free Pelotas, it is verified that it corroborates the description of this type of motor proposed by (Suurs & Hekkert, 2012). It appears that the motor system is dominated by knowledge development functions (F2). Dissemination of knowledge (F3), research orientation (F4), and resource mobilization (F6) (Suurs & Hekkert, 2012). The Entrepreneurial Experimentation (F1) function was incipient, with only one formalized enterprise. The market formation function (F5) was considered absent because it was restricted to the production and marketing activities of the demonstration units. Likewise, the legitimacy creation function (F7) was limited to a small set of actors' participants in this motor (Suurs & Hekkert, 2012). In addition, the new functions identified in the literature on coordination (F8), sociocultural changes (F9), and evaluation of the chain as a whole (F10) were also absent.

When comparing the description of the Entrepreneurship Motor of the TIS Cage-Free Pelotas, the results partially corroborate the proposition of Suurs and Hekkert (2012), as important differences and similarities were identified. Suurs and Hekkert (2012) define the entrepreneurship motor as similar to the science and technology motor with the addition of entrepreneurial experimentation (F1) and legitimacy creation (F7) functions. Regarding similarities, the TIS Cage-Free Pelotas in the Entrepreneurship Motor phase was characterized by many entrepreneurial experimentation initiatives (F1) associated with legitimacy creation initiatives (F7), which was also highlighted by Suurs and Hekkert (2012). Regarding the differences, the TIS Cage-Free Pelotas was characterized by the presence of the chain analysis function as a whole (F10) as a result of the lobby promoted by entrepreneurs in order to solve local problems, more specifically associated with solving the bottlenecks identified in the production chain with a view to the productive feasibility of its projects, such as a place for disposal of poultry after the end of the production cycle and feed at lower costs. The presence of the new function chain analysis as a whole (F10) corroborates the proposal by Markard *et al.* (2020) as another important function, especially in agribusiness and new technologies that transform into new businesses. In agribusiness, one can see how complex the production process is because of the multiple steps that must be articulated throughout the manufacture of any product until it reaches its final consumer.

Regarding the TIS Cage-Free Pelotas System Construction Motor, the results partially corroborate the proposition of Suurs and Hekkert (2012), as important differences and similarities were also identified here. Suurs and Hekkert (2012) defined the system construction motor as a motor in which all functions are involved, which is an important addition in relation to the two previous motors in the market formation function (F5). The similarity is that the market formation function (F5) appears as one of the functions of TIS, and this motor involves a relationship with all other functions (Suurs & Hekkert, 2012). The difference is related to the coordination function (F8), which was proposed as a key function in this motor and corroborates the proposal (Markard *et al*., 2020; Planko *et al.,* 2016). Planko *et al*. (2016) justify the need for the coordination function as they consider that many actors are involved in the building system, each with its own agenda and strategic plan; however, the system as a whole benefits most if resources are combined and if efforts are aligned. Without coordination, individual efforts can be useless (Planko *et al*., 2016).

Regarding the analysis of the sequence of the TIS Cage-Free Pelotas motors, the results partially corroborate the proposition of Suurs and Hekkert (2012), as similarities and differences were identified.

Regarding similarity, a sequence in the creation of innovative motors can be seen: science and technology motor => entrepreneurship motor => system construction motor. This result is consistent with the conclusions of Suur (2009). Suurs (2009) explains that the sequence of motors is in line with the concept of cumulative causation and that the structural conditions under which a vicious circle emerges are affected by its previous dynamics. More specifically, he explains that with each motor change, the previous structural configuration will reinforce the activities that constitute the next (motor) cycle, which can be seen in the trajectory of the TIS cage-free pelotas.

Regarding the difference, it can be seen that there is a tipping point (TP) at the beginning of each motor and not only in the science and technology motor. For the creation of the Science and Technology Motor, Suurs (2009) cited social demands for new technology as an example. However, Suurs (2009, 2012) does not emphasize these tipping points in the trajectory of TIS, nor does it provide a definition of the term. In the literature, tipping points have been defined as discontinuities in the development of a system trajectory that fundamentally changes its structure and dynamics (Mey & Lilliestam, 2020). In other words, (Mey & Lilliestam, 2020) defined a tipping point as the point that separates state A from state B of a system. We observed this phenomenon in all changes in the type of motor, as we see a conjunction composed of an entrepreneurial type of social intervention combined with a perceived context, such as an economic crisis that is internal or external to the system (Mey & Lilliestam, 2020). Our findings are also supported by the recognition of the presence of the tipping point phenomenon during the stages of the innovation process in other evolutionary studies from different areas of research, such as biophysical systems, environment-human interaction, and social systems (Mey & Lilliestam, 2020) and even in the area of innovation, but under different names (Bergek et al., 2015; Dias & Ramirez, 2020; Dias, 2011). Suurs (2009) also recognizes the possibility of tipping points in other phases by recognizing that it is important to understand that there is a possibility that TIS will not evolve into any other vicious circle if external factors are not present.

Finally, from the explanations of the sequence of motors related to cumulative causation and tipping points, it is inferred as possible explanations for the absence of the market motor in the TIS Cage-Free Pelotas. Finally, it is worth commenting on the absence of the sociocultural change function (F9), proposed by (Planko *et al*., 2016; Markard *et al.,* 2020), in none of the three motors described in the TIS Cage-Free Pelotas. As it involves changes in the mental groups of consumers and organizations (Suurs & Hekkert, 2012), this must be an important function in the market motor; for this reason, it cannot be verified.

5 Final Considerations

This study aimed to analyze the evolution of functions and the interactions between them over time in a technological innovation system (TIS) within agribusiness. Throughout the evolution of the TIS cage-free pelotas, the framework associated with the functions and motors is suitable for the analysis of the evolution of the TIS, given that the presence of three motors was found:

Initially (Phase I), by the creation of the Science and Technology motor, started in 1999, and subsequently by the Entrepreneurship Motors (Phase II), started in 2017; and by the motor construction motor system (Phase III), started in 2019, and by the absence of the motor market (see Figure 1 in Section 4.1).

As the main theoretical contributions, the literature on the analysis of the evolution of technological innovation systems in the research stands out.

The adequacy of functions and motors (Hekkert et al., 2007; Suurs, 2009; Suurs & Hekkert, 2012) is an appropriate instrument for the analysis of technological innovation systems in agribusiness.

The Entrepreneurship Motor was characterized by the presence of the chain analysis function as a whole (F10) as a result of the lobbying promoted by entrepreneurs to solve local problems, more specifically associated with the solution of the bottlenecks identified in the production chain with a view to the productive feasibility of its projects.

The system construction motor and the presence of the coordination function (F8) as a key function in this motor corroborated the proposal (Planko et al., 2016; Markard et al., 2020), and this is a key function for the analysis of TIS.

The motors proposed by Suurs (2009) and Suurs and Hekkert (2012) evolve sequentially in association with the mechanisms of cumulative causation.

The influence of the tipping points at the start of each of the identified motors was verified (Mey & Lilliestam, 2020).

As an empirical contribution to the rural environment, knowledge about the evolution of functions and the interactions between them over time can contribute to the solution of one of the main problems associated with participatory innovation initiatives in rural areas, as these focus exclusively on the rural community level. It is known that these groups often find it difficult to overcome structural barriers to innovation that require interventions from higher levels of the system, such as poor access to extension services, land, credit, high input quality, and markets (Lamers et al., 2017).

For future research, it is worth highlighting the need to improve and test the results found here for other technological innovation systems in agribusiness. It is also suggested to better understand the roles of different actors, especially key actors that are difficult to replace, feedback circles, and cumulative effects. Finally, the main limitation of the research may be the absence of a market motor, but it is justified by the current stage of development of the researched TIS; however, it is noteworthy that it is difficult to identify a priori the stage of the TIS in the research process.

References

Abbott, A. (1995). Sequence Analysis: New Methods For Old Ideas. Annual review of sociology, 21(1), pp. 93-113.

Batalha, M. O.; Silva, A. L. D. (2008). Gestão Agroindustrial. São Paulo: Atlas.

Bergek, A.; Jacobsson, S.; Carlsson, B.; Lindmark, S.; Rickne, A. (2008). Analyzing The Functional Dynamics Of Technological Innovation Systems: A Scheme Of Analysis. Research Policy, 37(3), pp. 407-429. DOI:10.1016/j.respol.2007.12.003

Bergek, A.; Hekkert, M.; Jacobsson, S.; Markard, J.; Sandén, B.; Truffer, B. (2015). Technological Innovation Systems In Contexts: Conceptualizing Contextual Structures And Interaction Dynamics. Environmental Innovation and Societal Transitions, 16, pp. 51-64. DOIi:https://doi.org/10.1016/j.eist.2015.07.003

Dias, M. F. P. (2011). Dinâmica De Configuração De Regras Para Inovação: Um Olhar Complexo E Interteórico Numa Organização De Pesquisa Agrícola Do Agronegócio Orizícola Do Rio Grande Do Sul. Tese de doutorado. Universidade Federal do Rio Grande do Sul, Porto Alegre, RS. Available at: http://hdl.handle.net/10183/30465. Access on: November 17, 2021

Dias, M.; Ramirez, M. (2020). Niche Evolution, External Circumstances, And Network Transformation: From Butiá Technical Niche To Butiá Socio-Technical Niche. Revista Brasileira de Inovação, 19, pp. 1-26. DOI: https://doi.org/10.20396/rbi.v19i0.8657550.

Eastwood, C.; Klerkx, L.; Nettle, R. (2017). Dynamics And Distribution Of Public And Private Research And Extension Roles For Technological Innovation And Diffusion: Case Studies Of The Implementation And Adaptation Of Precision Farming Technologies. Journal of Rural Studies, 49, pp. 1-12.

Hall, A. (2005). Capacity Development For Agricultural Biotechnology In Developing Countries: An Innovation Systems View Of What It Is And How To Develop It. Journal of international development, 17(5), pp. 611-630.

Hekkert, M. P.; Negro, S. O. (2009). Functions Of Innovation Systems As A Framework To Understand Sustainable Technological Change: Empirical Evidence For Earlier Claims. Technological Forecasting and Social Change, 76(4), pp. 584-594.

Hekkert, M. P.; Suurs, R. A. A.; Negro, S. O.; Kuhlmann, S.; Smits, R. E. H. M. (2007). Functions Of Innovation Systems: A New Approach For Analysing Technological Change. Technological Forecasting and Social Change, 74(4), pp. 413-432. DOI:http://dx.doi.org/10.1016/j.techfore.2006.03.002

Klerkx, L.; Van Mierlo, B; Leeuwis, C. (2012). Evolution Of Systems Approaches To Agricultural Innovation: Concepts, Analysis And Interventions. Farming Systems Research into the 21st century: The new dynamic, pp. 457-483. D0I:10.1007/978-94-007-4503-2_20

Köhler, J.; Raven, R.; Walrave, B. (2020). Advancing the analysis of technological innovation systems dynamics: Introduction to the special issue. Technological Forecasting and Social Change, 158, 120040. DOI:https://doi.org/10.1016/j.techfore.2020.120040

Kukk, P., Moors, E. H. M., and Hekkert, M. P. (2015). The Complexities In System Building Strategies — The Case Of Personalized Cancer Medicines In England. Technological Forecasting and Social Change, 98, PP. 47-59. DOI:https://doi.org/10.1016/j.techfore.2015.05.019

Lachman, D. A. (2013). A Survey And Review Of Approaches To Study Transitions. Energy Policy, 58, pp. 269-276. DOI:10.1016/j.enpol.2013.03.013

Lamers, D.; Schut, M.; Klerkx, L.; van Asten, P. (2017). Compositional Dynamics Of Multilevel Innovation Platforms In Agricultural Research For Development. Science and Public Policy, 44(6), pp. 739-752. DOI:10.1093/scipol/scx009

Markard, J., Raven, R., and Truffer, B. (2012). Sustainability Transitions: An Emerging Field Of Research And Its Prospects. Research Policy, 41(6), pp. 955-967. DOI:10.1016/j.respol.2012.02.013

Markard, J.; Geels, F. W.; and Raven, R. (2020). Challenges In The Acceleration Of Sustainability Transitions. Environmental Research Letters, 15(8). DOI:https://doi .org/10.3929/ethz-b-000439169

Mey, F. & Lilliestam, J. (2020). Deliverable 3.1: Policy And Governance Perspectives On Tipping Points-A Literature Review And Analytical Framework. Available at: <https://www.iass-potsdam.de/en/output/publications/2020/deliverable-31-policy-and-governance-perspectives-tipping-points>. Access on 17 nov. 2021.

Musiolik, J. & Markard, J. (2011). Creating And Shaping Innovation Systems: Formal Networks In The Innovation System For Stationary Fuel Cells In Germany. Energy Policy, 39(4), pp. 1909-1922.

Planko, J.; Cramer, J. M.; Chappin, M. M.; Hekkert, M. P. (2016). Strategic collective system building to commercialize sustainability innovations. Journal of cleaner production, 112, pp. 2328-2341.

Planko, J.; Cramer, J.; Hekkert, M. P.; Chappin, M. M. H. (2017). Combining The Technological Innovation Systems Framework With The Entrepreneurs' Perspective On Innovation. Technology Analysis and Strategic Management, 29(6), pp. 614-625. DOI:10.1080/09537325.2016.1220515.

Poole, M. S.; Van de Ven, A. H.; Dooley, K.; Holmes, M. E. (2000). Organizational Change And Innovation Processes: Theory And Methods For Research. Oxford: Oxford University Press.

Suurs, R. A. A. (2009). Motors Of Sustainable Innovation: Towards A Theory On The Dynamics Of Technological Innovation Systems. Ulrtecht: Utrecht University.

Suurs, R. A.; Hekkert, M. P.; Smits, R. E. (2009). Understanding The Build-Up Of A Technological Innovation System Around Hydrogen And Fuel Cell Technologies. International Journal of Hydrogen Energy, 34(24), pp. 9639-9654.

Suurs, R.; Hekkert, M. (2012). Governing the Energy Transition. [S.l.]: Routledge. pp. 163-190. Available at: https://www.taylorfrancis.com/chapters/edit/10.4324/9780203126523-14/motors-sustainable-innovation-understanding-transitions-technological-innovation-system-perspective-roald-suurs-marko-hekkert-roald-suurs-marko-hekkert. Acess on 16 june 2021.

Walrave, B.; Raven, R. (2016). Modelling The Dynamics Of Technological Innovation Systems. Research Policy, 45(9), pp.1833-1844.

Yin, R. K. (2017). Case Study Research And Applications: Design And Methods. Sage