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Change management models induced by disruptive energy technology development

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

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First, I would like to thank my supervisor, Dr. habil. Zoltán Csedő for his exceptional professional support and guidance during my PhD studies and research. I was able to participate in several research programs and writing publications with my supervisor, which are the milestones of my scientific development. These publications, however, are not only milestones, but the main pillars of my dissertation, as well: change management as the central area and its relations to strategy, innovation, knowledge, and technology, moreover, my practical experiences about energy technology development led me to the research question which is – in my opinion – theoretically and practically important.

I would like to thank the Institute of Management and the Department of Management and Organization for the supportive professional and intellectual environment, which provided not only inspiration, but stable foundations for researching my topic, the novel aspects of change management and innovation. Regarding these stable foundations, I would like to highlight two former dissertations from the numerous outstanding scientific works of the Institute and the Department. The dissertation of Dr. habil. Zoltán Csedő, Associate Professor, Head of Department about *organizational change and change management*, and the dissertation of Dr. Miklós Dobák Professor Emeritus about *innovation and the organization of large corporations* were very inspiring for me. I thank for their personal support, as well.

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1 INTRODUCTION

The energy sector is going through a global transformation. The main trends of the transformation are the pursuit for sustainability (Ergüden & Çatlioglu, 2016), the prevalence of renewable technologies (Bollino & Madlener, 2016), the spread of decentralized solutions (Adil & Ko, 2016), the increased use of digital devices (Alagoz & Kaygusuz, 2016) and the focus on energy efficiency and security (Costa-Campi, et al., 2014). Based on the foundations of the contingency theory (Burns & Stalker, 1961), this changing environment means pressure for companies in the energy sector for adaptation and renewal. Renewal needs innovation, but the innovation-focused change management is difficult because of strategic (March, 1991; Duncan, 1976; Burgelman, 1991), structural (Dobák, 2002; Bartlett & Goshal, 2002; Csedő, 2006), capability-based (Grant, 1996; Teece, et al., 1997), and managerial (Beer & Nohria, 2000; Dobák, 2002) dilemmas (Csedő & Zavarkó, 2019b). This complexity is increased by two further factors. First, even though disruptive technologies with their novel value creation can change the dynamics of an industry, yet they are less attractive for (large) companies for investments because of their prior inferior performance compared to well-known technologies (Christensen, et al., 2015). Second, in the global energy sector, renewal is impeded by several internal and external factors:

a) strict external regulation, which is mainly due to the energy supplying activity (previously) critical on the nation-state level and occasionally due to state ownership (Nisar, et al., 2016; Cullmann, et al., 2016);
b) large organization size and bureaucracy, which causes difficulties in the decision-making concerning innovation (Costa-Campi, et al., 2014)
c) the dominance of current technology and resources, which makes it difficult to focus on new technologies (OECD, 2011; Markard & Truffer, 2006; Salies, 2010).

As both external and internal factors are hindering the achievement of goals concerning innovation and technological development, thus endangering long-term effectiveness, there is a need for competency development, organizational change, and change management (Csedő, et al., 2018). In other words: disruptive technology development can face serious obstacles, even in cases when it would be clearly required for environmental adaptation. Consequently, it is important to create or extend organization and management models for the top managers of energy companies that can support change management for disruptive technology developments.

Before the start of my PhD studies, I was able to see the renewal challenges of energy companies as a management consultant: those organizational obstacles which stood in the way of the realization of a new corporate and innovational strategy. The theoretical framework was created based on the literature review and the discussions with my supervisor. This framework is focusing on organizational change and change management while analyzing it from innovation management and knowledge management perspectives which are the main pillars of my scientific research of renewal. The nature of the interrelations among these cornerstones is widely accepted within the literature (for example one input factor of innovation is knowledge). At the same time, my personal belief is that changing environments should lead not only to new organizational behavior patterns but to new or extended theoretical models, as well, which study these new patterns or build on them.

If we analyze changes in the energy sector one step closer to the concrete opportunities and challenges, we can find new technologies that can be key solutions to the future energy sector according to the scholars and professionals, as well. One of these is the power-to-gas (P2G) technology, through which the surplus electricity (produced by renewables in the peak period) can be converted into a gas product, which can be efficiently transported through the natural gas grid or stored for later use (Götz, et al., 2016; Csedő, 2019). Therefore, the power-to-gas technology offers a solution to one of the main challenges of the energy sector, the storage of renewable energy produced during the peak period. On the one hand, overproduction without storage is a market problem regarding the high-volume integration of renewables, because it pushes down energy prices. On the other hand, it is a technical problem as well, because the network overload and the necessity for grid-balancing lead to the growth of operational and maintenance tasks for the network operators (Csedő, 2019; Schiebahn, et al., 2015). During my PhD research, I also participated in the R&D&I activities of the Hungarian P2G technology development by the framework of action research, and I build my PhD dissertation on this, as well.

Based on my personal interests, motivation, and the topic's environmental, social, and economic context I formulated the following research question:

What organizational changes are induced by a disruptive energy technology development (power-to-gas technology development), and what models can be used to lead these changes for the widespread, commercial-scale implementation of the technology?

The question implicitly contains some pursuit for "understanding" which indicates the qualitative methodology of my PhD research. At the same time, the research question has a dominantly practical and functionalist position, because its goal is the improvement of the already existing "system". The structure of the research question is also the result of a conscious choice because my goal is to support the achievement of the functionalist aims through a partly interpretative approach (this will be discussed in more detail in the Research Framework section). It is important to highlight that my aim through my PhD research which followed a qualitative methodology was the expansion of already existing theories regarding the topic of organizational change and change management through the synthesis of my new empirical research results obtained in the energy sector and previous literature.

My novel or revised models were not tested on a large sample; thus, my conclusions are not generally applicable in a positivist sense. Through my methodological choices (the use of grounded theory data analysis, conduction an extended case study), however, I strived for the creation of a substantive theory valid in a limited social environment (Glaser & Strauss, 1967).

The main theoretical, practical, and methodological pillars of my research are illustrated in Figure 1.

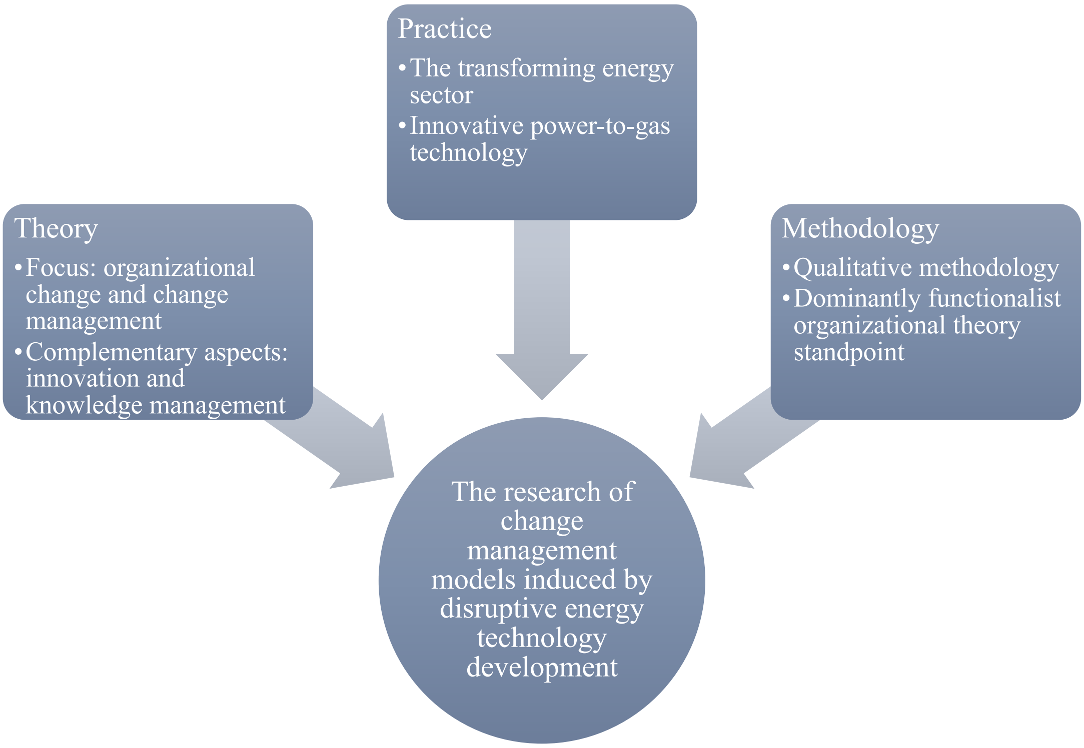

Figure 1. The theoretical, practical, and methodological pillars of my research

Source: own construction

Based on action research, my PhD research served theoretical and practical purposes as well, because my motivation is to contribute to the exploitation of the potential in power-to-gas technology and thus to the sustainability of the national and regional energy sector. This purpose is important regarding the practical significance of the P2G technology and its development level, as well. First, the development and implementation opportunities of the power-to-gas technology, which is suitable both for the use of renewable energies and the pursuit for decarbonization, aroused the interest of larger and smaller international actors as well (Bailera, et al., 2017). Second, although in the last couple of years the international scholarship has been assessing more intensively the potential effects on the energy sector and the research and development results of the innovative power-to-gas technology (Blanco & Faaij, 2018; Zavarkó, et al., 2018), in practice the extensive, industry-wide implementation of the promising methanation technology has yet to happen (Ghaib & Ben-Fares, 2018).

Furthermore, I also go beyond the P2G-specific research in a few points with my management-focused PhD research. First, this is related to the “disruptive” attribute that can be seen in the title of my dissertation. P2G technology seems to be disruptive “at first sight”, as

a) power-to-gas technology is the most cost-efficient long-term energy storage solution, which will truly be relevant with the further spread of renewables (Thema, et al., 2019)
b) can connect the electricity system with the natural gas grid (Götz, et al., 2016)
c) makes possible a high volume and long-term energy storage and thus it facilitates a higher integration of renewable energy sources into the energy system (Schiebahn, et al., 2015)
d) recycles carbon dioxide through the methanation process and thus decarbonizes the energy system (Bailera, et al., 2017).

Nevertheless, its potentially disruptive impact has not been assessed in the international literature, yet, so my dissertation examines this aspect as well owing to its practical relevance. Considering the theoretical foundations of disruptiveness, and based on empirical qualitative and quantitative data, I discuss that P2G is a value innovation in the present and can be a disruptive technology of the future if (1) the costs of Carbon Capture technologies fall, (2) incentives for decarbonization and (3) renewable energy production increase, and (4) the regulatory environment is supportive enough.

Moreover, according to the overview of Blanco and Faaij (2018) power-to-gas research deals with specific energy costs, process planning, time series analysis, business models, technological overviews, cost optimization, life-cycle analysis, and project overviews. However, it does not focus on the management challenges of the development and implementation of the power-to-gas technology. Therefore, my research topic, the scientific assessment of the implications of power-to-gas technology development from the aspects of change management and innovation management is not yet covered in the literature and thus my upcoming results will provide both theoretical and practical contributions.

Beyond assessing disruption potential, I show the importance of inter-organizational innovation networks and technological know-how flows, which are also overlooked in the international P2G literature. The main practical contribution of my PhD research, that it emphasizes the importance of networking, digital knowledge and innovation management, technological know-how flows among collaborative organizations, and the consciously guided and aligned organizational changes for the success of P2G technology development.

Finally, my PhD research aimed to analyze former change management theories from the aspect of organization theory, and also to systemize and (re)interpret them based on the empirical results gained in the energy sector. Since the general renewal challenges and the particular managerial challenges of the disruptive technology development lead (led) to the open innovation (Chesbrough, 2003), the main theoretical contribution of my PhD research that it offers a new perspective for analyzing the relationships of disruptive technology development, open innovation, and change management. As a novel concept regarding the international literature, as well, I differentiate the one-dimensional and the multi-dimensional change management, moreover, the closed and the open organizational change.

The structure of my dissertation is the following:

- My PhD studies was focused on organizational and management theory. Accordingly, in *Section 2 (Theoretical framework)*, I clarify the theoretical focus of the research, my foundations in organizational theory and how these affect the methodology and the research of change management.
- *Section 3 (The presentation of the sectoral context of the research based on the literature)* outlined the practical relevance and actuality of my PhD research and identifies those research gaps in the international literature, which I aim fill in party or fully, based on my theoretical framework.
- *Section 4 (Research framework)* describes the research strategy and the research model that was created based on the foundations in organizational theory, theoretical framework, and the lessons of the sectoral analysis. I present in this section the research sub-questions and related presumptions which were formulated based on the theoretical framework, the sector-specific literature, and the empirical research. Moreover, methodological choices and their applications are also discussed.
- Research results are presented in detail in *Section 5 (Results).*

- I summarize the answers for the research sub-questions and the main research question in *Section 6 (Conclusion),* I formulate my theses considering the presumptions. Furthermore, I analyze the novelty of the theses and discuss the limitations and future research directions as well.

2 THEORETICAL FRAMEWORK

In this section I will present the most relevant theoretical foundations and definitions for my research, and the most recent scholarly results regarding the topic. I interpret the scholarly observations from the perspective of my research question as well, I elaborate my interpretations and I formulate conclusions based on the synthesis of the literature. I create a theoretical framework based on the critical analysis of the scholarship, which guided my PhD research and contextualizes my research results.

2.1 Theoretical focus

Based on the research conducted during my PhD studies together with my supervisor and our related publications, it can be said that the fundamental theorem of our research is that the changes in the environment and within the organization must be in accordance to ensure long-term effectiveness. The theoretical focus of my PhD research is also the organizational changes, their conscious management, i.e., change management, which I analyze from the perspectives of innovation and knowledge management by building on the main theories of the resource-based view of the firm.

My research mainly focuses on the leadership-oriented and strategic parts of change management. In line with the phrases „Change Leadership" and „Change Management" used by Gill (2002) and the differences between the „general" leadership and management roles (Kotter, 1995; Kotter, 1990), in my research leadership- and strategy-focused change management is considered as a task which belongs to the top management of the organization. Its goal is to lead and implement the bigger changes to ensure long-term effectiveness, while the more operative part of the change management is the realization of smaller changes through well-defined processes and tools. Therefore, my high-level change management view differs from operative change management, and especially from crisis management, which does not appear in my research.

2.2 Foundations in organizational theory

The aim of the observations and conclusions presented in this chapter is to present my assumptions and considerations behind my PhD research.

Therefore, I will elaborate on my organizational theory perspectives because paradigm reflexivity is important during a research process (Végh & Primecz, 2016). To this end, I build on the research assumptions and paradigms regarding social science and the nature of society defined by Burrell and Morgan (1979) and the most important scholarly observations of interpretative science and organizational theory. Before exploring my organizational theory perspectives, I briefly explain my research motivation and theoretical connections that are of utmost importance in my research.

My PhD research served practical purposes as well, my motivation is to contribute to the exploitation of the power-to-gas technology's potential and the achievement of sustainability goals through concepts that are extended and revised. All of this is relevant in practice because (energy) companies need to operate efficiently in their current business areas (exploitation) and search for new business areas and innovate (exploration) in the present and at the same time) (Duncan, 1976; March, 1991). Exploitation requires stability; however, exploration and innovation generate change in the organization (Csedő, 2006), therefore change management and innovation management are linked through renewal (Csedő, et al., 2018). Moreover, knowledge is a central component of innovation (Fejes, 2015), and of continuous renewal (Grant, 1996) like organizational learning is of change (Bakacsi, 2004). Thus, the management of knowledge is also essential regarding the topic of innovation and change. (Csedő, et al., 2018)

My PhD research had a positivist foundation because its goal was the exploration of general theoretical definitions and interrelations. Moreover, the research was tied to functionalist organizational theory because its aim was to create concepts that support more efficient and effective technology development. However, my empirical research was built on qualitative methodology, which falls closer to the interpretative paradigm (Burrell & Morgan, 1979). Therefore, besides positivist science and functionalist organizational theory, in this chapter, I summarize the scholarly statements of interpretative science and organizational theory as well. This means that I do not discuss critical theoretical approaches. The two other paradigms defined by Burrell and Morgan (radical structuralism and radical humanism) and postmodern theories are not relevant for me, because these approaches serve fundamentally different social goals than the interpretative and the functionalist approach[1].

2.2.1 Assumptions about social science and the nature of society

By identifying research assumptions regarding social science and the nature of society, Burrell and Morgan (1979) created a matrix based on these two dimensions. In the matrix, they defined four incommensurable paradigms that are not overlapping and cannot communicate with each other. The endpoints of one organizing dimension are subjectivist and objectivist research positions, which are based on the combination of assumptions that are ontological[2], epistemological[3], about human nature[4], and methodological[5]. The endpoints of the other dimension are order (or regulation)[6] and the sociology of radical change[7]. The four paradigms defined by the two dimensions are: functionalist paradigm, interpretative (interpretive) paradigm, radical structuralist paradigm, and radical humanist paradigm. In this instance, I deal only with the functionalist and interpretative paradigms because these are in accordance with the fundamental goal of my research, the understanding of management activities and their support through the renewal process. In contrast to that, the radical structuralist and humanist paradigms criticize the capitalist

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[1] Radical structuralism assumes the existence of suppressive structures while radical humanism assumes the existence of suppressive thought patterns, and postmodern theories refuse meta-narratives.

[2] Concepts about existence, the main question of which here is whether the studied reality is "outside" in relation to the consciousness of the individual, or a product of the consciousness of the individual.

[3] Epistemology, the main question of which here is whether tangible and transferable knowledge of reality can be acquired, or whether the knowledge itself is much more subjective in nature and therefore reality can only be understood through experience.

[4] Examining the relationship between the human and his environment, the main question of which here is whether the environment determines the human response, or whether the human is the creator of their own environment and thus has free will in their decisions.

[5] The way of collecting knowledge about reality, the main question here is whether social science can be placed methodologically on a similar fundaments as natural science or not.

[6] It aims to understand and develop the dominant social system (capitalism).

[7] It aims to reveal the oppressive thought patterns of the dominant social system and to radically change the social system.

social structure. Thus, the assessment of the topic from the perspective of these paradigms would not result in added value to the understanding and development (which happens in parallel) of the already existing system.

The most important components of the assumptions formulated by Burell and Morgan and summarized by me are presented in Table 1:

Assumptions about social science	Ontology	Nominalism	Reality has no “real” structure independent from the individual. Names and labels are artificial creations that structure reality.
		Realism	There is an external reality independent from the individual, which has a relatively immutable and tangible structure.
	Epist-emology	Anti-positivism	Reality can be understood only in a specific context and from a specific perspective, not through general regularities or causal relations.
		Positivism	Reality can be explained through causal relations and general regularities thus phenomena can be predicted.
	Human nature	Voluntarism	Human behavior is determined by autonomous human will.
		Determinism	Human behavior is determined by the environment, specific situation.
	Methodology	Ideographic	A phenomenon can be understood in a natural context through direct data collection, in the field, with qualitative tools.
		Nomothetic	A phenomenon can be understood by following a systematic research technique, through the testing of the hypothesis by quantitative tools.
Assumptions about the nature of society (about sociology)		Regulation	Status quo, social order, consensus, integration and cohesion, solidarity, the satisfaction of needs, actuality.
		Radical change	Radical change, structural conflict, dominance, contradiction, emancipation, scarcity, opportunity.

Table 1. The most important components of the assumptions

Source: own construction based on Burrell and Morgan (1979)

2.2.2 Positivist science and functionalist organizational theory

The functionalist paradigm is connected to positivist science because these two are based on the same assumptions. From an epistemological perspective, the functionalist paradigm is characterized by positivism, from an ontological perspective it is realist, from a methodological perspective its approach is nomothetic; and it belongs to the sociology of order (Burrell & Morgan, 1979). According to Donaldson (2003), positivist science becomes truly dominant together with the functionalist approach which modifies the function of the existing system towards the improvement of the satisfaction of needs.

The aim of the positivist, functionalist approach is to understand order, stability, and balance and to maintain these through efficient and effective regulation (Burrell & Morgan, 1979); to describe these through general theories that increase knowledge (Donaldson, 2003). Moreover, the goal of positivist and functionalist works is to predict and control phenomena (Chia, 2003). The paradigm's works study the characteristics of systems, processes, and – no radical – changes (Morgan & Smircich, 1980) in order to support development within the system (Cunliffe, 2011).

The metaphysical roots of these approaches reach back to the philosophical school of Parmenides, according to which reality has a constant and relatively immutable, tangible structure that is independent of us (Chia, 2003). In reality, as a concrete structure, the individual is not shaping its environment, it is merely a respondent or adaptive element (Morgan & Smircich, 1980). This means that behavior is determined by the environment (Cunliffe, 2011). The assumptions regarding stability and the external structure independent from us are the basis of modern science because the stable structure comes with the opportunity to break it down into its components and study them separately. The emphasis is on being and not on becoming, i.e., the process overview is not dominant, any observed change is the rearrangement of the components within a stable structure and not a transformation. The acceptance of these assumptions makes to relevant to create general theories, and thus the value of knowledge comes from its generalizability (Chia, 2003). Positivist science explains how the world works while keeping in mind valuelessness (Donaldson, 2003), thinks about the already existing society in universal terms (Cunliffe, 2011), and uses scientific and engineering analogs (Burrell & Morgan, 1979). From this perspective, organizations (like humans) are controlled by the environment, and the change of the environment presents itself as an adaptation challenge based on contingency theory, as a survival challenge based on selection theory, for which the answer is organizational change. This change is initiated by a managerial decision aspiring an optimal solution, efficiency, and effectiveness (Donaldson, 2003).

2.2.3 Interpretative science and organizational theory

The interpretative paradigm of Burrell and Morgan (1979) also belongs to the sociology of order; however, it is, from an ontological perspective, nominalist; from an epistemological view, anti-positivist; regarding human nature, voluntarist. and built on ideographic methodological assumptions. The goal of the interpretative approach is to understand the depths of reality, the subjectively and socially constructed and continuously changing reality (Burrell & Morgan, 1979), and thus to reveal the background of the phenomena, the individual and collective meanings (Hatch & Yanow, 2003). Moreover, the aim of interpretative research is to unfold different interpretations, beliefs (Kelemen & Rumens, 2008), to explore the possible narratives (Cunliffe, 2011), to understand symbolic discourses and the process of constructing reality (Morgan & Smircich, 1980).

In contrast to the metaphysical roots of the functionalist approach, according to the interpretative view, the world is continuously changing. There are no constant structures that are independent of individual and collective consciousness (Chia, 2003), reality is a social construct created through interaction (Kelemen & Rumens, 2008). From an extremist standpoint, reality is only the projection of the mind of the individual, who is the creator and interpreter of symbols (Morgan & Smircich, 1980). This also means that the social world cannot be understood in the same way as the natural or physical world, and the creation of general theories and regularities is not possible (Hatch & Yanow, 2003). Consequently, all knowledge is context-specific since different people construct reality in different ways (Hatch & Yanow, 2003). Through interaction, humans produce shared meanings in the subjectively experienced time and space (Cunliffe, 2011). From this perspective, organizations are no longer black boxes with inputs and outputs, but cultures, sets of shared meanings (Kelemen & Rumens, 2008), continuously changing social constructs (Cunliffe, 2011).

It is important to emphasize here that opposed to the functionalist approach in which the external environment generates change to which an organization has to adapt, from an interpretative perspective organizational change can be caused by a change in the social definitions of reality, such as new organizational self-definition or external environmental interpretation (Gelei, 2006). This two-way relationship (environment-organization) becomes even more complex through organizational change, because „in an uncertain situation the ambiguity of the organizational reality may be emphasized" (Bokor, 2000, p. 49)[8]. Moreover, this ambiguity is not static during organizational change either, but it changes continuously through the process of organizational learning because according to the interpretative approach „organizational learning is the formation process of the shared world of meanings"[9] (Gelei, 2002, p. 104).

2.2.4 The effects of organizational theory assumptions on the research methodology

It is clear that the functionalist and interpretative paradigms are built on opposing assumptions, therefore it seems necessary to briefly discuss my own research position.

1. Firstly, I accept the theorem of Gioia and Pitre (1990) which argues that the multiparadigm approach allows for a more complete theory-building regarding complex organizational phenomena compared to research conducted within one paradigm.
2. Secondly, contradictory theoretical assumptions (Burrell & Morgan, 1979) can appear sequentially but not simultaneously in one research.

In this case, the interpretative, qualitative approach supported the wider functionalist goals and answering a functionalist question. In order to dissolve the contradictions, I chose my methodological tools accordingly (extended case study method, coding technique of grounded theory).

[8] p. 43 in the English version of the reference

[9] Translation from Hungarian

2.2.5 The effects of organizational theoretical assumptions on the research of change management

Management and organization science literature can be characterized by an extensive agreement regarding the notion that in a fast-changing environment the organizational ability to renew and adapt is a critical requirement for effective operation and the survival of the organization (Lawrence & Lorsch, 1967; Duncan, 1976; Teece, 1986; March, 1991; Grant, 1996). This statement is even more relevant in the age of fast technological developments (Teece, 2016; Davenport & Westerman, 2018; Hortoványi & Vilmányi, 2018). The scholarship of the past years also sheds light on the fact that innovation and organizational change management are integral components of organizational renewal (Dobák, et al., 2012; Hortoványi & Balaton, 2016; Csedő, et al., 2018), which is also supported by knowledge management and organizational learning (Fejes, 2015; Galeitzke, et al., 2017; Hortoványi, 2016).

Besides the correlations outlined above, we could discuss several other areas of management related to organizational renewal (for example project management, process management) (McDermott, 2002; Jørgensen & Ulhøi, 2010; Bagno, et al., 2017), but in organizational renewal, these are clearly interconnected by the significance of innovation. The scientific research of innovation and innovation management is not a new issue: the adaptation- and renewal-centric literature has been actively concerned with innovation since the 1960s'. Innovation is assessed in several aspects from the analysis of structural solutions (Burns & Stalker, 1961), through strategic decision making based on the analysis of the external environment (Porter, 1980), then by emphasizing organizational capabilities (Teece, et al., 1997), up until the current concept of digital innovation management (Nambisan, et al., 2017). However, I believe that the re-examination of change management, or more broadly the models of organizational renewal is crucial from time to time because of the importance of path dependency (Csedő & Zavarkó, 2019a).

According to path dependency theory (Wilsford, 1994), the past defines the future, the decisions made in the past affect the decisions made in the present. In this case, the concept of path dependency does not primarily refer to the path dependency of organizations, but rather to our thought process regarding organizational renewal. In this context, the descriptions of Sydow et al (2009) concerning organizational path dependency and of Sherrer (2005) regarding economic and institutional path dependency suggests that the initial decisions generate self-affirmative processes (such as the conception of a theoretical model and getting empirical proof), which then push new decisions (research or organizational practices) in the same direction. Besides, the initially invested resources and the 'cost' of learning (which is needed to master the solution) can equally lead to a critical turning point when the attention of thinkers and decision-makers is bound to the issues, patterns, and actions of a dominant direction (for example a paradigm) while giving little thought to alternatives. Although there are available options, their place is shrinking and heading towards the closing point. Here the process gets to a closed path (such as a dominant theoretical framework) from which it is extremely difficult to detach because the rational decision-maker will leave the path only when the loss of efficiency caused by the suboptimal solution is greater than the cost of creating something new (Scherrer, 2005). I believe that it is difficult to objectively define efficiency and its loss not only in the case of a technology (Noble, 1984), or political institution (Scherrer, 2005) but also in the case of management and leadership models. This approach can be paralleled with the views of Thomas Kuhn, according to which a paradigm (or a theoretical framework) can be so coherent and convincing for those thinking within it, that it restricts the development of alternative concepts (Bird, 2000). (Csedő & Zavarkó, 2019a)

It is important to see, however, that the path dependency theory does not mean historical determinism, because the former allows the abandonment of the current path, i.e., in this instance, we can talk about "historical contingency" instead (Wilsford, 1994, p. 275). In my case, this means that it is worth looking back at which approaches regarding organizational renewal define our way of thinking today, moreover, it is required to examine former models because simply following the patterns in a new environment (for example in a digitalized society, economy) can lead to suboptimal solutions (Wilsford, 1994).

Based on the above, and in line with my fundamental position regarding organizational theory, the following question can be asked: How can organizational change management be interpreted based on the assumptions made explicit of the functionalist and the interpretative approach?

Together with my project supervisor, I assessed the possible interpretations regarding the theoretical models of change management from the perspectives of interpretative and positivist science, interpretative and functionalist organizational theory (Csedő & Zavarkó, 2019a)[10] based on the assumptions of Burrell and Morgan's paradigms (and their simplification). Naturally, the results could not have been comprehensive: (1) it was our goal to identify interpretations that could come logically from the assumptions, but (2) it was not our goal to identify every possible interpretation, because that exceeds the capacities of a research group and the magnitude of a study. Through the research, we were not looking for entirely functionalist or interpretative observations, but for observations that (could) imply them (Table 2.).

Therefore, we were not looking for theoretical inconsistencies in the models, but for possible interpretations which could be forward-looking for the future research of the assessed notions.

The possible functionalist premises of change and change management:

a) Realism: If reality is a relatively stable, constant structure, then change has to be triggered or something/someone triggers it, thus change management is a unique or cyclical task. (Angyal, 2009, p. 6)
b) Positivism: If phenomena can be generally described and predicted, then the characteristics of change can also be predicted. The possible and needed change management strategies can be specified equally for every organization. (Kotter, 1995, p. 60)
c) Determinism: If the behavior or behavioral change can be explained through situational factors, then change management has to focus on the modification of the environment, the situation. (Beer & Nohria, 2000, p. 136)

[10] What follows are the results of this research, therefore I will use the plural form when describing our research.

d) Nomothetic methodology: If phenomena, and thus the characteristics of change can be identified through action-reaction assessment, there is no need to observe the individual behavior's background. The success of change management can be measured through the evaluation of system-level components. (Beer & Nohria, 2000, p. 136)

The possible interpretative premises of change and change management:

a) Nominalism: If there is no permanence and change is continuous, change does not have to be triggered, and thus, the management and leadership of change is a continuous task. (Kanter, 1983, p. 64)
b) Anti-positivism: If phenomena cannot be predicted, then the characteristics of change cannot be predicted either, and they can be understood only retrospectively in the given organizational-environmental context. (Van De Ven & Poole, 1995, p. 522) *Change management strategies to be followed can be defined only within the given organizational context. Change management is the support of individuals through the – uncontrollable – change.*
c) Voluntarism: If behavior and thus behavioral change cannot be (entirely) explained through situational factors, the individual can affect change. (Angyal, 2009, pp. 2, 15) *Change management has to focus on the cognition of the individual (and collective) wills, knowledge, interpretations related to change.*
a) Ideographic methodology: If the phenomena, and thus the characteristics of change can be identified in a certain context, through direct data collection, on the field, while thoroughly assessing the background that influences individual (and collective) behavior, then the success of change management can be determined through personal presence and the identification of motivations. (Kotter, 1995, p. 62)

Author, date, page number	**Highlighted definition/model**	**Examples for components that suggest functionalist assumptions**	**Examples for components that suggest interpretative assumptions**
Kanter, 1983, p.64	Continuous internal organizational change is the answer to external environmental change.	Supposes a tangible, external reality. (Realism)	Discusses continuous change within the organization. (Nominalism)
Van de Ven & Poole, 1995, p. 511, 532	Change is a too complex phenomenon to be analyzed through a single theory, but it can be better understood through the linking of theoretical models.	Creates its own framework to clarify the models. (Positivism)	Rejects the only explanatory organizational change and development theory. (Anti-positivism)
Kotter, 1995, p. 59,66	Change management model (process steps), dealing with resistance as one of the tasks.	Explains the success of change management through a general model (Positivism)	In a given organizational situation there can be individuals with different attitudes (supporters and resistants) if the given situation is interpreted differently by the individuals. (Nominalism)
Beer & Nohria, 2000, p.136	In the integrated change management model, system-level factors (type E change) and individual factors, such as motivations and culture (type O change) have to be dealt with simultaneously.	Supposes that the employee will adapt its behavior in accordance with the changed organizational systems. (Determinism)	For the exploration of motivations and the culture, personal presence is needed. (Ideographic methodology)
Angyal, 2009, p. 2, 11, 15	Seemingly uncontrollable changes (such as crises) can be predicted and even managed based on the knowledge about other scientific fields, experiences, or the nature of the processes.	The uncontrollable changes can be predicted and managed by following certain theories. (Positivism)	If changes can be managed (occasionally) by the leader, then the situation does not unilaterally define behavior. (Voluntarism)

Table 2. The interpretation of theoretical models from a functionalist and interpretative perspective

Source: Csedő – Zavarkó, 2019a

Based on the sociology of order, our functionalist foundation (according to which the goal is the further development of the already existing system), and the assumptions outlined above, the following unified definitions can be given about change management:

a) Functionalist approach: Change management is the realization of organizational change necessary from time to time in order to adapt the organizational operation to the environment through the modification of organizational systems and environmental factors.
b) Interpretative-functionalist approach: Change management is the support of individuals and groups through continuous organizational and environmental change to understand deeper the factors behind the change and the characteristics of change (motivations, shared meanings) through personal leadership and to modify these factors in accordance with the given organizational goals. (Our definition becomes functionalist through the "modification")

It is important to point out that by searching for and identifying opposing assumptions, the goal was not to criticize the consistency of the theoretical models. On the contrary: in our study, we wanted to point out, that in the theoretical models that shaped our thinking, assumptions that can be contradictory from the perspective of certain paradigms (could) have played important roles because these result in satisfactory solutions for (1) understanding of the complex organizational reality and (2) guidance for better managerial performance. (Csedő & Zavarkó, 2019a)

This observation is supported not only by the analysis of change management models but the similar results of the analysis of knowledge and innovation management models, which are complementary viewpoints in my research. These findings can be found in Appendix 2.

2.3 The strategic background of the relationship between change and innovation

2.3.1 Resource-based theories as the basis of the research

My research, built on the foundations of contingency-theory (Lawrence & Lorsch, 1967; Pugh, et al., 1969), approaches the topic of renewal, innovation and knowledge management, and the associated organizational change through the lens of the environmental adaptation challenge and strategic ambidexterity (Duncan, 1976; March, 1991). The key factors in innovation, interpreted as a tool of renewal (Csedő, et al., 2018;

Zavarkó, et al., 2017), are knowledge, creativity, and entrepreneurial mindset (Hortoványi, 2010; Fejes, 2015), while in change this is learning (Bakacsi, 2004). Consequently, the individual and organizational capabilities, their development, and knowledge, as the source of sustainable competitive advantage in continuous environmental adaptation (Szabó, 2008) guide our attention toward a resource-based approach.

Resource-based strategic management theories emerged in contrast to the externally focused Porterian approaches (market environment, the industry structure's evaluation, and the positioning within it). They mainly rest on the consideration that because of the swift changes within the environment, organizational resources provide a more secure base for strategic planning and the acquirement of sustainable competitive advantage than strategic actions following the analysis of market and industry factors (Mészáros, 2010; Grant, 1996). The other fundamental statement of resource-based theories that innovation as an output created through the combination of organizational resources, also impacts the market environment, so it is not only the environment that affects the organization (Teece, 2007). According to the resource-based view, the source of real sustainable competitive advantage is the possession of resources that are rare, valuable, imperfectly imitable, non-substitutable, and which are embedded in the organizational operation (Barney, 1991). It is important to note that external and internal assessment must work complementarily (Balaton, et al., 2009), the difference is in the „from the outside inward" and „from the inside outward" understanding (Fejes, 2015). (Csedő, et al., 2018; Csedő, et al., 2019)

2.3.1.1 The framework and interpretation of dynamic capabilities

In my interpretation, adaptation, innovation, and change are also connected within the framework of dynamic capabilities (Teece, 2016; Teece, et al., 1997), which is an outstanding theory of the resource-based strategic approach. The framework of dynamic capabilities rests on the assumption that, in order to keep up with the rapid environmental changes, organizations need capabilities through which new business opportunities can be sensed (sensing), business models that are able to seize opportunities can be created and the necessary resources can be mobilized (seizing), and the organization will be able to transform its operations accordingly (transforming). (Teece, et al., 1997; Teece, 2016)

Interpreting Teece's work from the perspective of my research topic (Table 3), the strategic significance of dynamic capabilities is justified by the fact that (large) companies have to compete within rapidly changing environment and with growing start-ups as external challenges, while their time for adaptation is getting shorter. The strategic goal is the rapid environmental adaptation, which is possible through the recognition of opportunities (sensing) and the development of new business models. Innovation is needed for the business model. Dynamic capabilities are the prerequisites of innovation because these are suitable not only for the recognition of market opportunities but for the mobilization, development, and novel orchestrating (seizing) of the copyable and ordinary resources as well, that are useful for efficient operation. In practice, this could mean the selection of segments and technologies or the development and introduction of new products. However, for the realization of innovation and competitive advantage in a changing environment, organizational change is also needed. New processes, organic structure, and an organizational culture that supports change could mean the key for success, which requires entrepreneurial competencies during the identification of the change's direction, and leadership competencies during the transformation (Teece, et al., 1997; Teece, 2016). (Csedő, et al., 2019a)

	Goal		**Tool / Task**
Strategy	Rapid environmental adaptation, ambidexterity, shaping the business environment	➡ ↙	The identification of new business opportunities and the development of new business models
Innovation	New kind of value creation based on technological and market opportunities	➡ ↙	The development of ordinary capabilities, the novel combination, and coordination of resources
Change	New goals, processes, overcoming organizational inertia, flexible structural solutions, supportive culture	➡	The fulfillment of entrepreneurial and leadership roles

Table 3. The strategic, innovation, and change aspects of dynamic capabilities

Source: Csedő, Zavarkó & Sára, 2019a

Nowadays, due to the external environment, the organizations' new market opportunities are related to digitalization (sensing), and in order to exploit them there is a need for new digital solutions, capability development, mobilization, and their novel coordination (seizing), but for efficient accomplishment, a change in the processes based on new technologies and change management are necessary (transforming). Dynamic capabilities aid in responding to rapid technological changes "consistent with customer needs and technological opportunities" (Teece, 2007, p. 1343). In the age of rapid technology development cycles, the significance of dynamic capabilities has grown further, thus their organizational realization is worth a more profound examination based on Teece (2007):

a) The identification or creation of business opportunities cannot have to be a consequence only of individual creativity. Sensing requires organizational processes and analytic systems which support (1) internal research and development (R&D) and the selection of new technologies, (2) reaching external technologies and knowledge, (3) cooperation with other companies in the spirit of "open innovation" (Chesbrough, 2003), (4) the better understanding of consumer needs and the selection of relevant segments.
b) Seizing an opportunity "almost always requires investments in development and commercialization activity" (Teece, 2007, p. 1326), but the decision making often hampered in mature companies because of path dependency and the dominance of the exploitative activity (Szabó, 2014; March, 1991; Hortoványi, 2010; Burgelman, 1991). To avoid this, Teece (2007) highlights the overview of decision-making protocols and incentives, and also the role of leadership, which aids the formation of new business models and the cooperation between organizations.
c) As the external environment is constantly changing, the resources need to be reorganized continuously or from time to time with the help of dynamic capabilities. The realization of this can be supported by decentralization, adequate corporate governance (incentive system, control, entrepreneurial leadership), the co-specialization of different resources, continuous knowledge management, and organizational learning (Grant, 1996; Nonaka & Takeuchi, 1995; Teece, 2007, 2016). (Csedő, et al., 2019; Csedő & Zavarkó, 2019b)

2.3.1.2 Knowledge-based theory and its interpretation

Besides Teece's framework of dynamic capabilities, Grant's (1996) knowledge-based approach is also outstanding amongst the resource-based theories. The knowledge-based approach is built on the presumption that the organization's most crucial resource in a turbulent environment is specific, tacit knowledge of the employees because they cannot be copied by competitors, and thus, it can be the source of competitive advantage. In order to exploit the potential of competitive advantage in tacit knowledge, the most important task is their efficient and flexible integration into the organizational operation. (Grant, 1996)

By interpreting Grant's work in accordance with my research topic (Figure 2), through knowledge management I identify the interrelations among strategic, innovation, and organizational change elements in the knowledge-based approach. The strategic significance of the knowledge-based approach results from the uncertain market structure caused by innovations and intense competition, which, in the current technological environment, is truly relevant. The goal of the approach is to build foundations through which organizational responsiveness increases and competitive advantage can be obtained on dynamic markets. For this continuous change and the integration of the employees' task- and company-specific tacit knowledge is needed, because, these resources, competencies become unusable more slowly and are less accessible for the competitors than explicit knowledge.

Innovations are needed for continuous renewal, one of its types is based on new knowledge, while the other is based on the combination of already existing knowledge (architectural innovation). Innovations can be achieved either by (1) creating new knowledge through the combination of existing capabilities in a novel way or by (2) creating new capabilities through the combination of existing knowledge in a novel way.

Because the organization's goal is the continuous renewal, periodically they must change in internal operational mechanisms as well. In order to realize the combination tasks, efficient (which denotes the employee's easy accessibility to the necessary knowledge element) and flexible (which denotes the flexible combination of knowledge content that is available and useable by an organizational capability) knowledge integration, modularly built structure, instructions and behavior patterns are needed. Their formation or transformation within a large company requires top management intervention, change management (Grant, 1996). (Csedő, et al., 2019; Csedő & Zavarkó, 2019b)

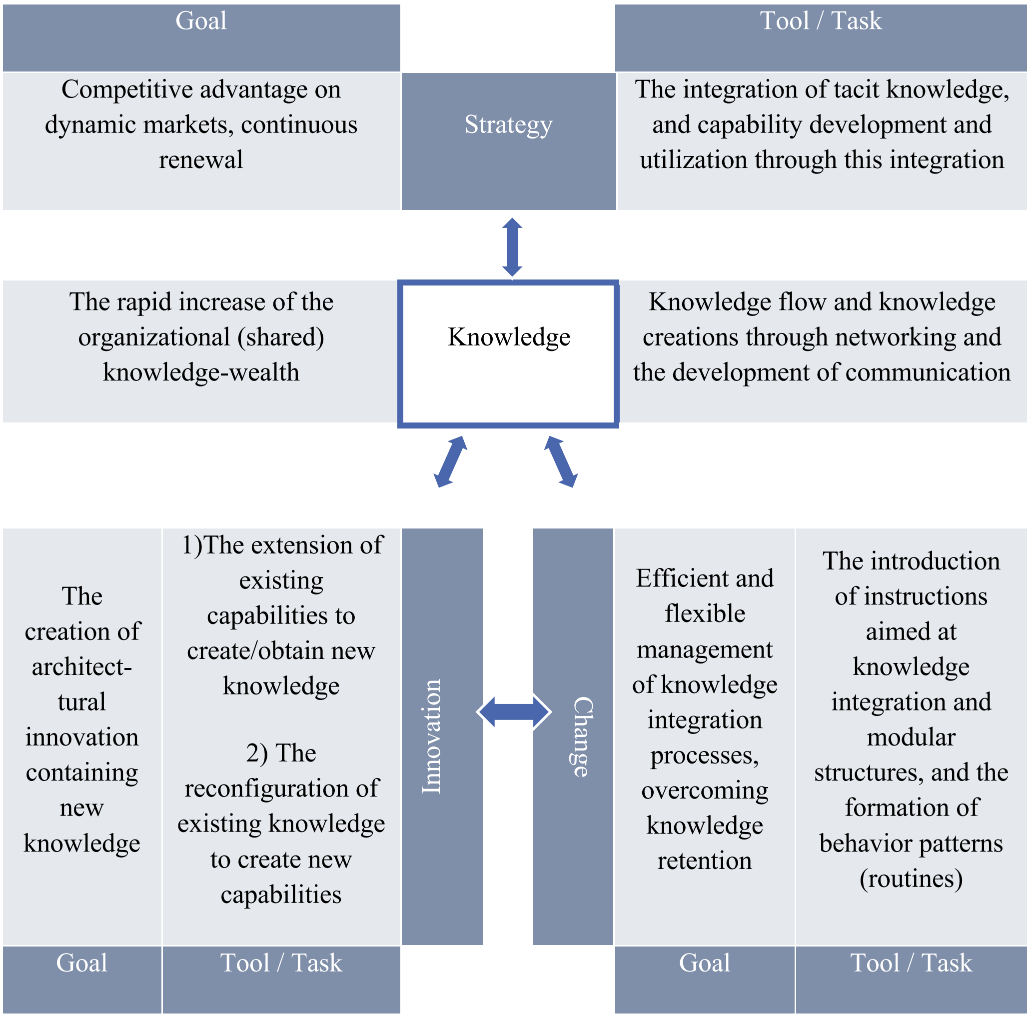

Figure 2. The interrelations between strategy, knowledge, innovation, and change

Source: Csedő, Zavarkó & Sára, 2019b

2.3.2 Change and knowledge management through the lens of strategic ambidexterity

2.3.2.1 Strategy, innovation, and change

(Large) corporations can achieve long-term effectiveness by overcoming internal and external challenges. As an internal challenge, the need for coordination and regulation, by which the organization can expand further, also grows with the growth of organizational size. At the same time, when the limits of its growth are reached, the organization is facing a renewal crisis, which it can handle with collaboration with external partners only temporarily, as the impulses coming from the outside become exhausted. As a result, the organization (1) begins to decline, (2) will stagnate, or (3) returns to its original activity (Greiner, 1972; Balaton, et al., 2009).

An external challenge is that environmental changes make changes necessary in the organizations' strategy, structure, and behavior to maintain or increase its performance (Burns & Stalker, 1961; Lawrence & Lorsch, 1967; Pugh, et al., 1969; Teece, 1986). At the same time, the more an organization is adapting to the current external factors, the more its future adaptation capability decreases (Burgelman, 1991). Moreover, the tension of allocating the scarce resources between exploration and exploitation means also a challenge for large companies to simultaneously operate effectively in the present, within their current business areas, and to look for new business areas while focusing on the future (Duncan, 1976; March, 1991). Regarding certain markets, the resource distribution dilemma affects innovation as well since by choosing to terminate or develop certain industries, markets, the organization also determines the innovation directions and investments. Innovation can be interpreted on both sides of ambidexterity: while the disruptive, market-creating (Christensen, et al., 2015) and radical (Hámori & Szabó, 2012) innovations are important typically for long-term effectiveness, the incremental, step-by-step development often aim for efficiency gains (Chikán, 2008; Hámori & Szabó, 2012). The efficiency-effectiveness and stability-change dilemma appear in a different way on the level of innovation because the maximum utilization of current solutions and the development of new ones need to be balanced as well (Sára, et al., 2014). This balance can be supported by forming the innovation growth strategies in a manner that is timely and appropriate for the given corporate context: in certain periods, high efforts must be made by companies to create and introduce innovation, but, since such radical innovations generate significant change within the organization, stable, calmer periods, focusing on the development of innovational capabilities, are also needed (Dobák, et al., 2012).

Strategic ambidexterity could be the answer to the adaptation challenge, regarding which the two most thoroughly discussed topics in the literature are structural and contextual ambidexterity (Taródy, 2016). Through structural ambidexterity (Tushman & O'Reilly, 1996) the organization realizes the explorative and exploitative activities in different organizational units. In contrast, contextual ambidexterity means (Gibson & Birkinshaw, 2004) that the two activities are feasible on an individual level through a behavior that reconciles the two activities. For the leaders of large companies, structural separation or contextual development can both be the subject of change management (Csedő, et al., 2018). Based on Kotter (2012) this process of change management could mean the development of a dual organization in which, alongside the traditional hierarchy, a network operates to support innovation.

Therefore, based on the literature, there can be connections between innovation and organizational change. Organizational change is needed because, just as the strategy has to fit the external environment and internal capabilities, the innovational strategy also has to fit internal capabilities. Since the external environment and/or the organizational strategy designates the innovational goals, the internal capabilities need to be modified, developed. This indicates the necessity of organizational changes and change management. For the innovational activities, the favorable internal environment created by organizational changes could even result in disruptive innovations that affect the external environment (Teece, 2007; Christensen, et al., 2015).

Additionally, change management is critical because employees are averse and resistant towards the change associated with renewal (which could mean significant structural or even cultural transformations and learning new behavioral patterns as well). Because of the organizational resistance, learning and following new behavioral patterns might fail. Sull (1999) introduced the term active inertia for the phenomenon when the organization follows existing patterns despite drastic environmental changes. This is a serious competitiveness (renewal) problem since, – based on contingency theory – even if the formal strategy and structure fit the environment if the culture is not appropriate, performance will be low (Antal & Dobák, 2004). In other words: the decisions concerning innovation are vainly right; if the implementation of innovation is limited, the renewal crisis persists, and the organization begins to decline (Szabó, 2014).

In summary, sometimes, to achieve the innovation goals that derive from the strategy, substantial organizational characteristics need to be changed, and the organizational resistance associated with change must also be addressed. From all this it can be deduced, that change management is an important tool for the implementation of corporate innovation. In a different approach, not only the implementation (as a process) but also the realization of innovation (as an output) can generate change within the organization (e.g., the processes are transformed due to a new manufacturing technology) (Hammer, 2004), the acceptance of which needs to be supported as well. (Csedő, et al., 2018)

2.3.2.2 Exploration, exploitation, and knowledge management

Since organizational learning is a central element of ambidexterity (March, 1991), knowledge management tasks also come to the forefront. Based on the scholarly results, regarding the contextual and behavioral learning aspects of ambidexterity, the leaders' knowledge and learning is a dominant component, which is also demonstrated by the appearance of the leadership-based ambidexterity (Raisch & Birkinshaw, 2008). Research highlights the necessity of the leadership team's heterogeneous knowledge in favor of ambidexterity (Oehmichen, et al., 2017; Koryak, et al., 2017), which occasionally can be supported by the new external knowledge of leaders returning from another company (Lee & Roberts, 2015). The formation of knowledge flows, overarching functional units, which serve the heterogeneity of the leadership's knowledge base, and thus the development of ambidexterity, could be a part of contextual development (Venugopal, et al., 2017). Regarding the leadership aspect of ambidexterity, in addition to heterogeneous knowledge, the exploratory behavior that supports innovation, search for knowledge is emphasized more in literature than the exploitative one. This is in line with Kotter's (1990) distinction of management and leadership roles, according to which the manager's responsibility is present stability, while the leader's is renewal, for which innovation is a prerequisite. Adegbile et al (2017) identified the leaders' strategic foresight ability as the main factor of innovational output. Based on the results of Li et al (2013) the focus of the leadership team should be less on the already known areas, and more on the unknown areas that are as different from the current ones as possible, in which a lower intensity but constant knowledge and opportunity search need to be conducted to increase new product introductions. At the same time, all this requires future-oriented and curious leaders (Hortoványi & Balaton, 2016). Besides the top management, middle management also has a key role regarding innovational and renewal projects (Tabrizi, 2014), thus, the aforementioned behavioral patterns occasionally have to take the place of the managerial characteristics.

Based on the above, innovation output is affected by the quantity of new knowledge and its search method on the management level, nonetheless, it is not different on the employee level either. Garriga et al (2013) pointed out that, depending on the innovation goals, different knowledge searching behavior is needed because, the search for external knowledge is a much more suitable tool for the implementation of incremental innovation – supporting exploitative activity and the increase of efficiency (Hámori & Szabó, 2012) – than in the case of radical innovation, which is based on the unique idea of an innovator. Garriga et al (2013) also determined that the low number of constraints regarding internal resource use (i.e., the high volume of organizational resources needed for the realization of innovational goals) increase the depth of the search for knowledge, while high constraints increase its width. The selection of the knowledge search's method is critical because, as Hortoványi (2016) pointed out, that the innovation output is higher for corporations that constantly and consciously learn from external sources; to achieve this the creation of organizational routines that absorb external knowledge is needed (Hortoványi & Balaton, 2016).

Regarding structural ambidexterity, the focus is not the reconciliation of the activities on an individual level, but rather those organizational solutions, which serve the separate implementation of the explorative and exploitative activity, and which, according to the novel scholarly research, are mainly related to organizational and inter-organizational networks. Wang et al (2014) assessed the dual embeddedness of innovation: (1) a knowledge element network and a (2) social network exist within the organization simultaneously, that are separated from each other. Based on their research, the structural characteristics of these networks, (1a) structural holes indicating an unexploited opportunity for combination with other knowledge elements, and (1b) structural holes indicating social separation, and (2a) the degree of centralization of the connection to the central knowledge element, and (2b) to main persons, determine the researchers' (individuals) operative innovational focus, and thus the choice between the explorative and exploitative activities as well. The authors stated that, alongside a strong internal social network, the structural holes in the knowledge network decrease the explorative search for knowledge outside of the company (because there are internal combination options to exploit easily). In contrast to that, the structural holes in the social network increase explorative research because the researcher has fewer internal social relations.

In conclusion, strengthening internal networks occasionally supports exploitative activity.

The development of internal networks can hinder the explorative activity based on the research of Funk (2014) as well. The author assessed the geographical location of the company from the perspective of reaching external knowledge and internal structure. He determined that, in the case of companies that have few opportunities to obtain external knowledge due to their geographical location, the organizational innovation output is higher if the employees are less connected to each other. The reason behind this is that the combination of the limited (internal) knowledge base along with strong social relations and the overly homogenous perspective can often lead to the acceptance of suboptimal solutions. A better alternative is the increased seclusion, the search for individual solutions associated with the discovery of new knowledge, and the preservation of diversity.

By summarizing the learning and knowledge management aspects of contextual and structural ambidexterity, it can be clearly argued that heterogeneous top management knowledge and exploratory knowledge search are key for renewal. However, renewal is not always supported by strong internal employee networking, but by the intensive knowledge flow at the top management level. By interpreting the scholarly results, the following conclusions, observations can be placed within the learning and knowledge management aspects of strategic ambidexterity (Table 4). (Csedő, et al., 2019)

	Exploration	**Exploitation**	**Related literature**
Organizational result	Renewal, entry to new business areas	Increase of efficiency in current business areas	March, 1991
Time horizon	Future	Present	
Innovation	Radical (or disruptive)	Incremental	Garriga et al., 2013; Hámori – Szabó, 2012
Number of problem solvers	Few	Many	Garriga et al., 2013; Funk, 2014
The method of the solution search	Strategic foresight, curiosity, unique idea	Extensive cooperation	Hortoványi – Balaton, 2016; Adegbile et al., 2017
Focus of the knowledge search	Unknown business areas (external)	Known business areas (external and internal)	Li et al., 2013; Garriga et al., 2013;
Knowledge base	Heterogenous	Homogeneous	Oehmichen et al., 2017; Koryak et al., 2018
Structural holes in the employee knowledge network	Few	Many	Wang et al., 2014; Funk, 2014
Structural holes in the employee network	Many	Few	
Structural holes in the top management network	Few	Many	Venugopal et al., 2017
Connection to external knowledge sources	Many	Few	Lee - Roberts, 2015; Hortoványi, 2016

Table 4. Knowledge management aspects of ambidexterity

Source: Csedő, Zavarkó & Sára, 2019b

2.3.3 Innovation and innovation management

2.3.3.1 The relevance and content of innovation management

The meaning of innovation is defined extensively, from different approaches in the literature. Schumpeter (1934; 1939) defined innovation as novel combinations of production factors and organized innovations into five basic types. The scholarship of recent years highlights the role of change through innovation (Csedő, et al., 2018). The literature also distinguishes between different types of innovation; thus, we can talk about a product, technological, organizational, process, and strategic innovation (Chikán, 2008; Csizmadia, 2015), which are connected from several perspectives: for example, new technological opportunities make process innovation possible.

From an organizational approach, the significance of innovation stands out in reaching long-term effectiveness as well (Hortoványi, 2016; Hortoványi & Balaton, 2016). By reacting to changes in the external environment, innovation means the satisfaction of consumer needs on a higher level (Chikán, 2008), while Fejes (2015), after assessing and summarizing the different definitions of the literature, identified progress and development as the central content of innovation. Based on these, in my interpretation innovation is the answer to adaptation challenges, i.e., innovation can be the tool for renewal regardless of its subject and nature. The reason behind this is for example, that an incremental process innovation, even though it typically aims the increase of internal efficiency and thus, is not strongly connected to the environmental adaptation tied to effectiveness, like a product innovation would be; regarding its content, it can support customer focus due to the faster operations. In conclusion, it is not necessary to place restrictions on the content of innovation when we interpret it as a tool for organizational renewal. Consequently, innovation management means the management of (a part of) organizational renewal. This definition makes clear the necessity of change management tasks in connection with innovation management, similarly to the necessity of the knowledge management, project management, and process management tasks resulting from the nature of innovation (McDermott, 2002; Jørgensen & Ulhøi, 2010; Sára, et al., 2014; Fejes, 2015). From all of this we can see that innovation management is an interdisciplinary activity within the field of management science, and its content – similarly to the multicolored definitions of innovation – is defined from several different perspectives (Bagno, et al., 2017). According to the definition closest to my interpretation, innovation management is a managerial activity, which mainly centered around guiding organizational change aimed at increasing competitiveness (Sára, et al., 2013), and the content of which can be defined according to three main perspectives based on the recent literature:

1. The content of innovation management can be described through the identification of innovation management practices (IMPs), which Tidd and Thuriaux-Alemán

(2016) listed in the following activity categories, based on their literature review: (1) innovational strategy creation, (2) the assessment of the external market environment (ex.: benchmarking), (3) idea management, (4) product portfolio management, (5) technological portfolio management, (6) development and implementation, (7) learning after the introduction, (8) resource and competency management.

2. Due to environmental changes, the definition of innovation management's content can be placed on new foundations. Nambisan et al (2017) approach innovation management from the perspective of the fundamental industry and organizational changes resulting from technological development and digitalization. Digital innovation management is needed because the challenges have changed: (1) the structural, temporal, and spatial boundaries of the innovation process have loosened, (2) the range of actors taking part in the innovation has become a lot wider, (3) the system of innovation activities, processes and outputs have become more complex. In conclusion, (1) the quick, dynamic pairing of problems and solutions (market needs and technologies), (2) the formation of a shared definition about innovation among the participants of the process, (3) the analysis and development of the technological infrastructure, and (4) the orchestration of these need to be placed in the focus of innovation management.

3. The content of innovation management can be defined through theoretical models which are organized by Bagno et al (2017) based on the following categories: (1) linear models (e.g.: the direction of functional tasks performed sequentially: market research, product development, testing, fine-tuning, introduction); (2) funnel models (downsizing the wide-ranging opportunities of the idea generation stage into one or two projects by the time it reaches the development stage); (3) interaction-focused models (innovation and its management are determined by the effects environmental and organizational factors on each other); (4) capability-focused models (primary focus on organizational resource and organizational renewal).

The enumeration of the aforementioned models also indicates a chronological order between them. While the linear models were created mainly at the beginning of the 90s', the capability-focused models are from after 2005. The connection between the capability-focused innovation management models and the resource-based view is clear, this supports the relevance of my theoretical framework that will be presented later.

In my opinion, the content of innovation management can be specified through the pairing of the characteristics of innovation (Fejes, 2015) and management functions. Following the management functions presented by Dobák and Antal (2004), innovation management can be described as managerial activities which include

a) the designation of innovational directions, the creation of innovational strategy (planning),
b) the development of innovation processes, systems, the novel combination of available resources, capabilities and the acquisition of missing resources, capabilities (organization),
c) the formation of an organizational culture and behavior that supports innovation (personal leadership),
d) the control of innovational capabilities and outputs (control);

examining the inputs and outputs - after reviewing the literature – it can be said that the basis of innovation management is the discovery, expansion, and utilization of knowledge accumulated within the company (knowledge management) which provides a competitive advantage, and its result is the creation of a new organizational, technological, market solution through which the value created for customers and owners grows. (Csedő, et al., 2018)

2.3.3.2 Digital innovation and knowledge management

Digitalization can play an important role in the adaptational, transformational processes of large corporations (Lerch & Gotsch, 2015) and, IT-supported knowledge management makes possible the development and exploitation of the operational efficiency and the innovational capabilities through synergies and the information processing capability (Nonaka, et al., 2014; Kettinger, et al., 2015).

In addition to strategic, HR-related, and organizational issues, the issues of technological support also get attention in connection with the knowledge mapping, evaluating, transferring, using, and developing processes of knowledge management, which has been one of the catalysts for corporate knowledge management since the 1990s (Fehér, 2007). Knowledge management systems are information systems that support the creation, codification, storage, retrieval, and application of knowledge; thus, they facilitate the organizational knowledge management processes (Alavi & Leidner, 2001). The role of knowledge management systems is critical because the creation of collaborative networks is one of the tools of developing and sustaining competitiveness in a changing environment. Within the network, cooperative learning between the individuals is important (Hortoványi & Szabó, 2006), and knowledge management systems are suitable for this purpose (Cao, et al., 2017). Thus, these systems now go beyond database-like, document library-focused knowledge management systems. Besides the network-based and interaction-supporting concept, the process-based approach, which focuses on the support of knowledge-intensive processes, is also dominant today, similarly to the digitalization aspects of innovation (Fehér, 2007; Sarnikar & Deokar, 2017). Galeitzke et al (2017) interconnect the management of technology, knowledge, and innovation on a conceptual level through the SECI model of Nonaka and Takeuchi (1995). According to their model, technology management is responsible for the acquisition and distribution of the tacit and explicit knowledge in the socialization and externalization phase, while innovation management is responsible for the development and storage of knowledge through combination and internalization.

In accordance with our contingency theoretical foundations, the effect of a knowledge management system on work performance does not depend on the system (system function) only. There is a positive relationship between the thorough understanding and use of the system and work performance, which in turn is influenced by the routine of the task, the knowledge absorption capability of the user, the system, and the leadership during implementation as well (Zhang, 2017). However, conscious and deep system usage is not axiomatic, even in systems with exceptional complexity and extended functionality, the employees are mostly just using a couple of functions (Zhang, et al., 2011). The usage of knowledge management systems (and thus performance improvement) is also influenced by social processes such as the way how superiors, colleagues, or subordinates use the system (Wang, et al., 2013) and the social interactions between them (Zhang & Venkatesh, 2017). In knowledge management, social interactions primarily denote knowledge sharing, which is affected by the basic functionality of the system and its further development. Dong et al. (2016) pointed out that the willingness for knowledge sharing is increased by the continuous development of the knowledge management system, focusing on the enhancement of user experience. All this requires not only the improvement of the user interface, but also the further development of logics and databases that manage data and information, or the development and implementation of new solutions (Hancock, 2017). Regarding this issue, Zhang and Venkatesh (2017) identified the potential software functions based on the literature overview; and defined the most important ones for the employees based on their qualitative, then quantitative research (Table 5). (Csedő, et al., 2019)

Highlighted functions	Posting knowledge, questions, or ideas; Commenting; Searching; Assessment of knowledge content
Peripheral functions	Taking notes; Credibility assessment; Launching a debate; Email visualization; Creating and subsequently improving partial knowledge; Marking content and their parts as critical; Skills and knowledge list of employees; Management of individual user types; Marking a profile as a favorite; Notifications; Creating a bookmark from tags or keywords; Thematic content display; Video playback

Table 5. The functions of digital knowledge management solutions

Source: Zhang and Venkatesh, 2017

At the same time, some research shows contradictory results regarding individual performance improvement (Zhang – Venkatesh, 2017), therefore, determining the functionality of knowledge management systems to be applied in practice, induces further research. (Csedő, et al., 2019b)

2.3.4 Technology development, innovation, disruption

Since my PhD research focuses on organizational changes generated by a „disruptive technology development", it is important to clarify my interpretation of this term, as well.

First, it is important to analyze the notions of "disruptive technology" and "sustaining technology" introduced by Christensen and Bowen (1995). In 20 years, the disruptive theory has had a serious impact on management research and practice, which is indicated already by the fact that the notion itself is wider than originally: in 2015 Christensen et al discuss even disruptive innovations. However, the authors point out that the prevalence of the theory comes with unexpected drawbacks because

> *"many researchers, writers, and consultants use "disruptive innovation" to describe any situation in which an industry is shaken up and previously successful incumbents stumble."*
> *(Christensen, et al., 2015, p. 2)*

According to the authors, the precise use of the terminology is important because different types of innovation (for example non-disruptive) require different strategic approaches. Consequently, I build my terminology on the most authentic sources, the original article written by Christensen and Bower (1995), and the above-quoted Christensen – Raynor – McDonald (2015) article, which refines the original theory.

2.3.4.1 Disruptive technologies and innovations

Based on Christensen and Bower (1995) we can distinguish between two technologies. "Sustaining" new technologies are similar to previous, mainstream solutions and imply continuous (incremental) small developments in order to satisfy consumer needs. Within companies, the investment in sustaining technologies is preceded by thorough market research regarding current consumer needs, and the new technology gives an answer to these. In contrast, disruptive technologies are completely new technologies, they create value through a different configuration ("attribute package") than conventional solutions, and in the beginning, they do not meet mainstream consumer needs. Although, through the disruptive technology the smaller company can offer the product or service cheaper, the mainstream consumer will wait until the smaller company competing with the disruptive technology brings the quality of the product/service (output) to the level of the large company performing sustaining technology development, then they will switch to the cheaper alternative – thereby realizing disruption, the technology transforms the market (Figure 3). Therefore, disruption is not a moment, but a process[11]. (Bower & Christensen, 1995; Christensen, et al., 2015)

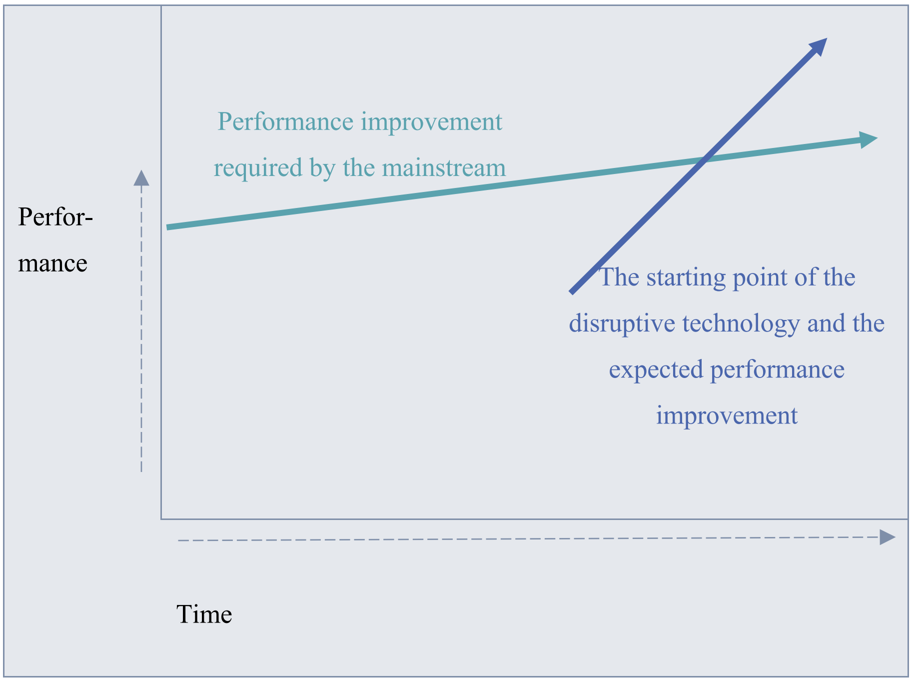

Figure 3. Identification of a disruptive technology

Source: Bower - Christensen, 1995

Large companies usually cannot react to disruptive technologies in time, because, in the beginning, they are financially less attractive based on their current market research and analysis practices. It is important that in fact, they are not able to be attractive based on market research, since, compared to the needs of current consumers, the initial performance falls behind current solutions. It could even be that the market itself, which could be served by the disruptive technology, does not exist yet. Therefore, disruptive solutions can appear in two areas:

a) segments with low profitability which are ignored by large companies since their focus are only on highly profitable segments

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[11] The authors also point out that "disruptive innovation" is a misleading term because, it does not denote the process view. In my opinion "disruptive technology" does not express this either enough, thus "disruptive technology *development*" appears in the title of my PhD research.

a) on a new market created by the disruptive innovation, i.e., the disruptive company "transforms" non-consumers into consumers. (Christensen, et al., 2015)

2.3.4.2 Interpreting disruptive innovation according to the strategic background

If the topic is analyzed looking "inside" the organization, we can see that a disruptive technology can affect organizations in several ways. If we try to understand disruptive technology development, as an activity, regarding

1) technological innovation, the support of processes could be in the center. Based on the definition of the OECD (1997), technological process innovation is a new or significantly developed production (value-creating) method that entails changes regarding tools, human capital, and work methods, and which results in new or improved products or in more efficient production.
2) the concept of business modeling (Osterwalder & Pigneur, 2010), we can even talk about business model innovation. The reason for this is that, based on Amit and Zott (2012), business model innovation is a process that aims for the organization of the company's new activities or for the modification of the system, and in which new technology could be a key resource. According to some perspectives, the change of the revenue and cost factors is also a key component (Horváth et al., 2018).
3) organizational change, we can see that the technology can be a substantial organizational characteristic, and thus the change of the technology can in itself mean organizational change. If simultaneously we are talking about innovation as well, then it could require or generate additional organizational changes (Dobák, 2002; Csedő, et al., 2018).
4) the resource-based view, we need to remember the framework of dynamic capabilities. In this, the adaptation to technological changes, innovation, and internal transformation are interconnected (Teece, et al., 1997; Teece, 2016; Teece, 2007).
5) ambidexterity (Duncan, 1976; Gibson & Birkinshaw, 2004), sustaining innovations could be connected to exploitative activities, while disruptive innovations to explorative activities. Christensen and Bower themselves are considering ambidexterity in their article from 1995 even though, they do not use this term. In their perspective, a business activity built on a disruptive technology

cannot be realized in one unit with current business activities, which undoubtedly suggests the necessity for creating the structural ambidexterity articulated by Tushman and O'Reilly (1996). (Csedő, et al., 2019a)

2.3.5 Strategic collaborations

2.3.5.1 Adaptation and innovation in collaboration with other organizations

Based on contingency theory, if the environment is changing, the organization has to modify its strategy, structure, behavior in order to maintain or improve its performance (Burns & Stalker, 1961; Lawrence & Lorsch, 1967; Pugh, et al., 1969; Teece, 1986). At the same time, they have to operate efficiently in their current business areas, while simultaneously they have to explore new business areas and innovate (Duncan, 1976; March, 1991). However, organizations tend to follow explorative routines because of path dependency (Sydow, et al., 2009; Burgelman, 1991), and the realization of strategic ambidexterity is not simple either since the exploration and the exploitation are competing for the same resources and require opposing practices (Gibson & Birkinshaw, 2004). Nonetheless, renewal can be encouraged through external partnerships (Greiner, 1972), which leads us to the open innovation paradigm. According to the open innovation paradigm, it will result in higher innovational performance if the innovation processes do not remain within the company, but instead external actors, such as consumers or suppliers, even from a different industry, become involved in the innovational activities (Chesbrough, 2003). This approach is in accordance with Teece's (1986) statement according to which, providing complementary resources is critical in order to profit from technological innovations, but these should not necessarily be owned by the creator of the technological innovation. Consequently, we can talk about a network-based innovational approach, as well, in which multiple organizations cooperate to realize innovation by building on common knowledge sharing, technology transfer, and learning (Millar, et al., 1997). (Csedő & Zavarkó, 2020)

2.3.5.2 *Change inside and outside the organization*

As we have seen multiple times already, innovation and change are closely connected (Teece, 2007; Hammer, 2004), and my change management approach is mainly built on the resource-based view (Barney, 1991; Grant, 1996; Teece, et al., 1997). An important observation of the resource-based school is that the dynamic reconfiguration of the organization's capabilities, and the strategic actions and innovation resulting from this, affect the external environment, shape the competition. If, to all this, we add the contents of the previous chapter, then the organizational capabilities can be combined with the capabilities of cooperating organizations as well. As a result, disruptive innovations (Christensen, et al., 2015) can emerge, that can bring change to an entire industry. The following figure summarizes the significance of change inside and outside the organization: inter-organizational (innovation) networks aid the adaptation of the organization to environmental changes, but, at the same time, create the opportunity for changing the industry and the competitive environment, as well (Figure 4). (Csedő & Zavarkó, 2020)

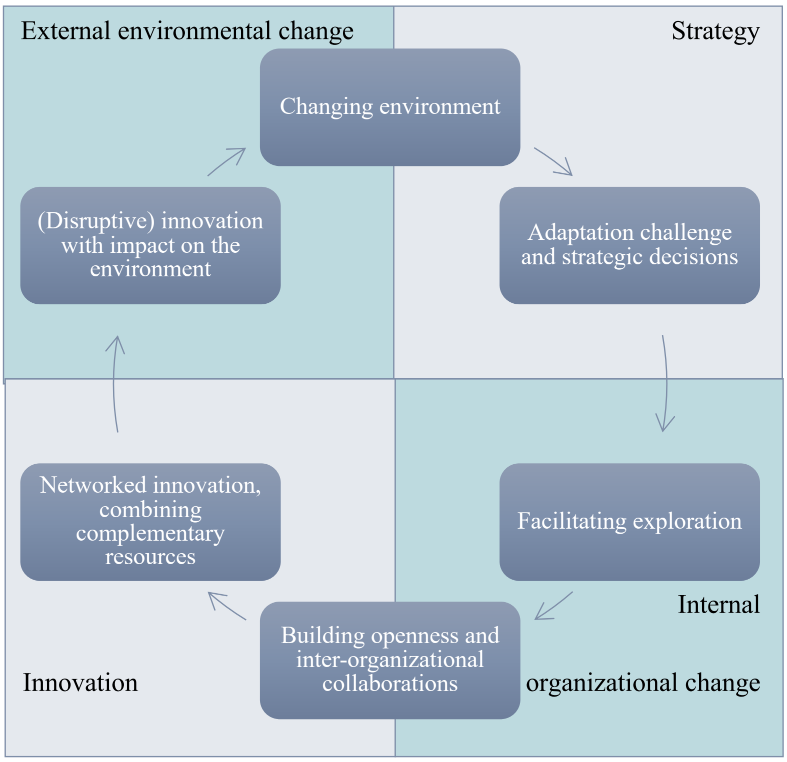

Figure 4. Innovation and change within and outside the organization

Source: own construction

2.4 Change management

On one hand, the change management approach of the research is built on the strategic nexus outlined in the previous chapter. On the other hand, I build on the idea, explained in the introduction, that the integration of maybe opposing positions from the view of science theory, could contribute to the better understanding and managing of complex organizational phenomena. In line with this, when discussing organizational change and change management, the integration can be important not only on a scientific level but concerning the counterpoints found in the change management literature as well (for example realizing change with top-down and bottom-up approach).

2.4.1 The phenomenon of organizational change

2.4.1.1 The need for organizational change and its management

Decades ago, several studies have proved that organizations that adapt to their environment, can survive (e.g., Burns and Stalker, 1961; Lawrence and Lorsch, 1967; Teece, 2007). However, adaptation to a changing environment is not a simple task since every organization is striving for some kind of stability, thus, change management has to be realized against organizational inertia (Dobák, 2002). Therefore, adaptation to the environment, which has three types, requires organizational change (Table 6).

Adaptation type	Description
Reactive	Change following changes in the external environment
Preactive	Making changes before changes in the environment
Proactive	Attempt to change the system of environmental conditions

Table 6. Types of adaptation

Source: based on Dobák, 2002

Several kinds of change could happen simultaneously in the organization (Dobák, 2002). Since Burnes (2014) points out that “change management is not a distinct discipline with rigid and clearly defined boundaries" (Burnes, 2014, p. 8), it is important to explicitly articulate our own definition before discussing change management more profoundly. According to our current interpretation, change management means leading those organizational changes that are needed for *environmental adaptation* and *organizational renewal*. It is important to emphasize that change management is necessary not only because of changing external factors since internal factors can generate change within the organization as well. Consequently: Change management is a managerial activity that has as its goal the identification, preparation, planning, implementation, and maintenance of the changes needed for environmental adaptation and organizational renewal. Due to the internal factors, in our definition of change management, organizational renewal denoting internal factors as well, appears alongside environmental adaptation. (Csedő & Zavarkó, 2019b)

2.4.1.2 The content of organizational change and guided change

Based on Dobák (2002), regarding organizational change, we can talk about changes observed in the substantial characteristics of the organization, which can be interpreted in the given environmental and organizational situation. These can change simultaneously with different intensities, moreover, they can have a considerable effect on each other. The significant characteristics can be the following:

1) Strategy
2) Structure
3) Culture
4) Behavior
5) Technology
6) Operational processes
7) Outputs
8) Power relations.

The focus of my research is consciously directed organizational change, which, based on Dobák (2002), can contain the following:

1) at least one of the substantial characteristics changes;

2) the extent of change can be perceived as significant in the given environmental and organizational context (the types of organizational change will be discussed in more detail in the next section);
3) the management guides or influences change, its direction, and process.

2.4.1.3 Organizational change from the inside and from the outside

Based on interpreting the organization as an open system – according to which the organization is in a constant relationship with the external environment (Dobák, 2002) – , organizational change can be caused by external and internal factors alike. The external forces that make change necessary can be defined with the toolkit of strategic management (for example PESTEL, Porter's five forces analysis). Such change generating factors can be the following:

b) Global trends (for example digitalization, pursuit of sustainability)
c) Progression on the industry's life cycle
d) Change in the competition within the industry (either because of the change of macro trends, industry actors, strategic actions, or the regulating environment)
e) Progression of the product's life cycle
f) New inventions and innovations. (Cummings and Worley, 2001; Balaton et al., 2009)

The strategy-level factors, in accordance with the external environment, can also generate organizational changes, these can be the following:

a) Growth, in a quantitative (for example the number of employees) and qualitative (for example R&D&I, new product development) sense;
b) Acquisitions and mergers;
c) Change in the top management team;
d) New vision or mission (Cummings and Worley, 2001; Balaton et al., 2009).

By analyzing organizational change from the inside, based on Dobák (2002), we can differentiate incremental and radical change (Table 7).

Incremental change	Aspects	Radical change
One or more substantial organizational characteristics change	**The range of change**	Several or all the substantial characteristics change
A slight modification of the changing organizational characteristic	**The extent of change**	Extensive change of the organizational characteristic(s)
Changes limited to a given organizational unit	**The scope of change**	Change in the whole organization
Changes affecting one or some hierarchical level of the organization	**The level of change**	Changes affecting every hierarchical levels of the organization
Less spectacular changes, implemented step-by-step	**The mode of change**	Changes through larger, spectacular jumps
Changes occur relatively slowly	**The speed of change**	Changes occur relatively quickly
Promoting the external adaptation of the organization and / or further developing the internal integration of organizational subsystems, structures, and processes	**The fundamental goal of change**	Promoting the external adaptation of the organization and / or creating new configurations of organizational subsystems, structures, and processes
Managed by lower-level managers or top management	**The management of change**	Directed by the top management

Table 7. Incremental and radical change

Source: Dobák, 2002

Burnes (2014) analyses the speed of change separately from the extent of change, based on which the possible subject of change can be defined differently (Figure 5):

Figure 5. The speed and subject of organizational change

Source: Burnes, 2014

The figure highlights that while the transformation of behavior and organizational culture is possible only with slow change, during rapid change the management can only transform the systems (structure and processes). (Csedő & Zavarkó, 2019b)

When change is assessed based on the connection to the external environment, the model of Burke and Litwin (1989) can be emphasized, in which transactional and transformational variables are distinguished by the exploration of causal relationships. At first, environmental changes affect transformational variables, which affect transactional variables, and this process in the end defines organizational performance (Csedő, 2006). According to Burke and Litwin, the transformational variables, that have a direct connection with the external environment, are the following:

1) strategy
2) leadership
3) culture.

Transformational changes significantly affect the whole organization, and fundamentally change its characteristics. Based on Burke and Litwin (1989), therefore, we can argue that the primary factor behind the organizational change is external environmental change. (Csedő & Zavarkó, 2019b)

2.4.2 The context of organizational change - renewal dilemmas

According to our change management approach (Csedő & Zavarkó, 2019b), there are several “forces” impacting organizational renewal, the organizational change related to innovation, and the change management concept can be built on the identification of these “forces” behind the organizational change. Since these forces often come from opposing directions and/or point in opposing directions, we can identify renewal and equilibrium dilemmas. These are presented in Figure 6.

Figure 6. The context of organizational change

Source: *Csedő & Zavarkó, 2019b*

The equilibrium and renewal dilemmas behind change management are the following:

1) Strategic viewpoint:
   Due to external environmental change, internal change is needed, however, adaptation to a high degree could become a disadvantage in the case of another environmental change (Burgelman, 1991)[12]. Thus, organizational changes through which balance can be created or sustained between exploitation and exploration (Duncan, 1976) must be implemented.
1) Structural viewpoint:
   The structure resulting from organizational changes must simultaneously fit the criteria of stability and flexibility (Dobák, 2002), differentiation and integration (Lawrence and Lorsch, 1967), (global) efficiency, and (local) responsiveness (Bartlett and Ghoshal, 2002).
2) Capability-based viewpoint:

[12] This is the so-called adaptation paradox.

Change management has to simultaneously deal with the utilization of existing organizational capabilities and their reconfiguration through dynamic capabilities, and the development of new capabilities and dynamic capabilities. (Teece et al., 1997; Teece, 2016; Grant, 1996)

3) Managerial viewpoint:
   An important challenge of change management is how to integrate the viewpoints of bottom-up organizational development and type O change into top-down organization planning (Dobák, 2002) and the type E change process (Beer – Nohria, 2000).

2.4.3 The overall process model of organizational change – in light of the renewal dilemmas

The process model integrating opposing forces described in the previous chapter is presented in the following figure. The original model is the work of Daft (1989), for this model, in turn, we reworked the version interpreted by Dobák (2002) and completed from the perspective of renewal dilemmas (Figure 7).

The central element of the model is that the identification of the necessity for change and the birth of the change idea are both conditions for initiating a change. The feedback also needs to be highlighted, which can concern the goal setting, not just the realization, and can generate additional changes or developments. The essence of the supplementation is that strategic, structural, and capability-based dilemmas could be in the background of organizational change, and successful change management integrates the top-down and bottom-up approaches. (Csedő & Zavarkó, 2019b)

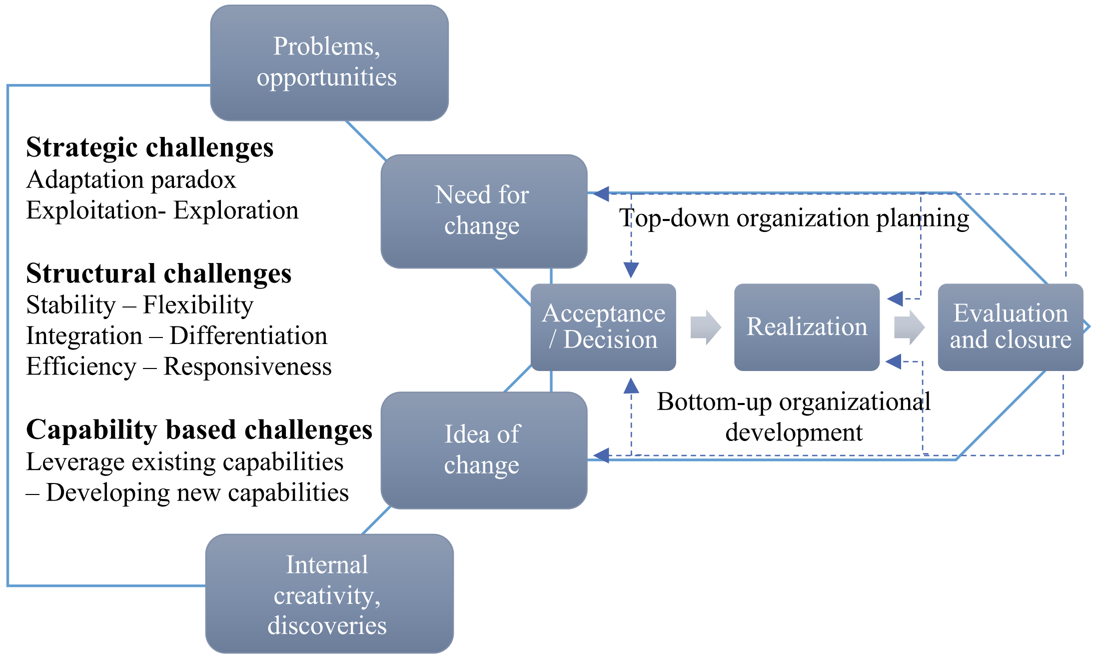

Figure 7. The comprehensive process model of organizational change

Source: *Csedő & Zavarkó, 2019b*

2.4.4 Phases of the change management process

In what follows, I firstly present previous outstanding process models, then I describe the integrated change management process that incorporates these and includes additional findings from the literature.

2.4.4.1 Former outstanding models

Based on Cummings and Worley (2001), sensitization is the condition for the initiation of internal change. The aim of sensitization is that the changes of the external environment reach the level that will be noticed by the management. If that level is too high, it is no longer possible to react to changes in time. Thus, efforts should be made to enable leaders to look at the company from an "external" perspective through their relationships (such as consultants) or the applied performance measurement methods (such as monitoring the performance of competitors).

The process steps following the emergence of the need for change are discussed in many ways in the literature, of which the models of Schlesinger et al. (1992), Lewin (1975), and Kotter (1996) are relevant from various perspectives (Figure 8).

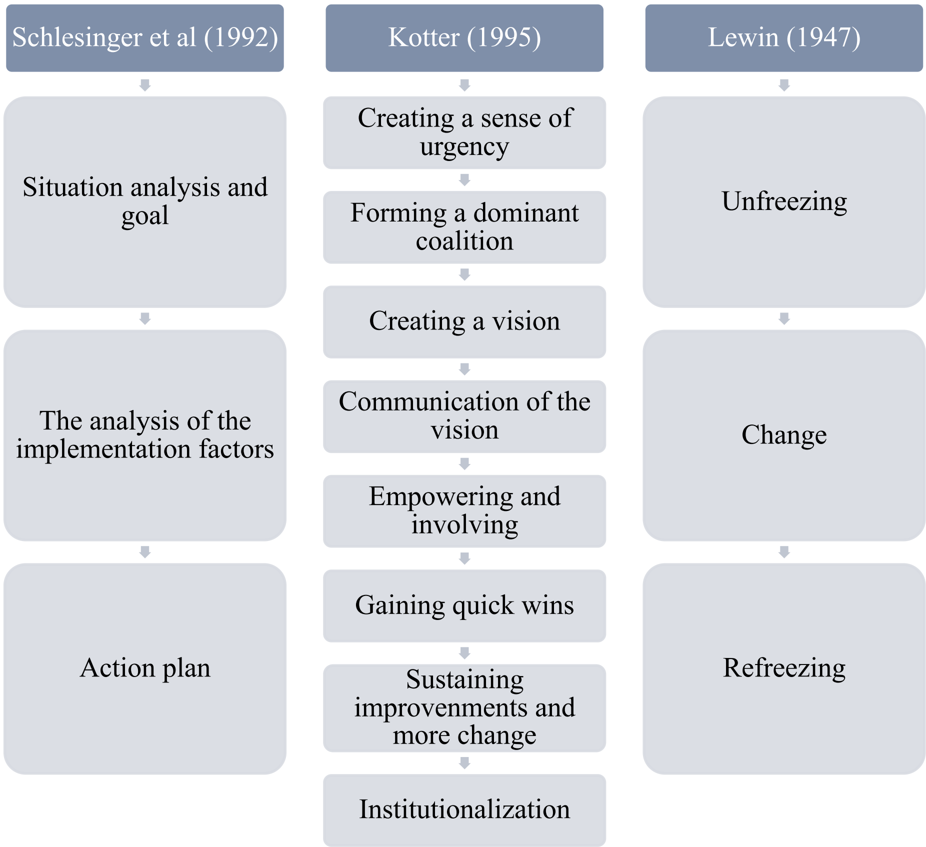

Figure 8. The process models of Schlesinger (1992), Kotter (1995) és Lewin (1947)

Source: *Csedő & Zavarkó, 2019b*

According to Schlesinger et al (1992), every change process must begin with situation analysis, through which the significance of the problem, its solutions' urgency, and the definition of the necessary change are clearly outlined. Lewin (1947) pointed out the importance of the so-called unfreezing phase preceding change, which focuses on a broad perception of the necessity of change, and the authenticity and sustainability of the old, routine-like organizational characteristics are questioned. The refreezing phase, which makes the implemented changes long-lasting, also has to be highlighted. The value of Kotter's (1995) model is the separation of the larger phases of the previous models and their combination with the leadership (vision and communication), the political (dominant coalition), and the bottom-up approaches (empowering and involvement). (Csedő & Zavarkó, 2019b)

2.4.4.2 The change management model integrating opposing approaches

In the following, I present an integrative model in greater detail, in which the main considerations of the three models mentioned above and further scholarly observations both appear. The process of change management consists of three main phases, each containing four broader activities (Figure 9).

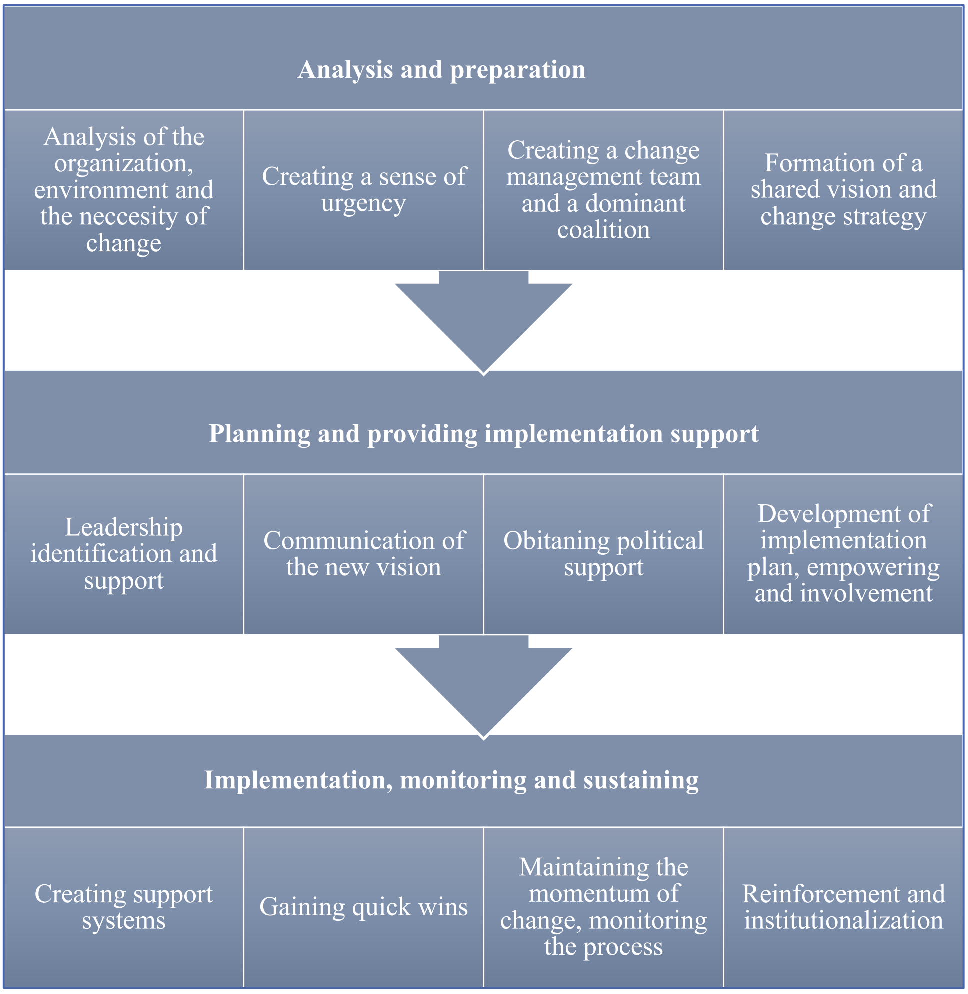

Figure 9. Integrated change management model

Source: *Csedő & Zavarkó, 2019* [13]

The literature is not consistent regarding how the process steps of change management are built on each other. An important feature of the integrated model is that the listing of the broader activities within the phases are more or less logically built on each other, but

[13] Based on Lewin, 1975; Schleslinger et al., 1992; Kotter, 1996; Cummings and Worley, 2001; Jick and Peiperl, 2003; Luecke, 2003; Burnes, 2014; Smith et al., 2014, Hayes, 2018

the model does not define a strict sequence between them. Certain activity pairs can be conducted in a reversed order or even simultaneously. For example, the formation of the change management team can precede the creation of a sense of urgency, especially regarding a larger organization in which a single charismatic leader cannot singlehandedly convey the message about the cruciality of change. This interchangeability is illustrated through the side-by-side listing of the activities. Also unique in the model is that it treats the implementation, monitoring, and sustaining not as distinct phases, but together. There are two reasons for this. On one hand, in the case of larger organizational changes and larger organizations, the progress of change can differ within the organization: while in some organizational units the system is already transformed and the new behavior must be institutionalized, it can happen that in other parts only the first projects are underway. On the other hand, if we integrate the considerations of the bottom-up organizational development and of the type O change into change management, we must notice that change is a learning process through which the organizational behavior is constantly adjusted. Thus, we cannot talk about sequences between the changing of the organizational behavior and the embedding of the routines. In contrast to that, however, the analysis and certain elements of the preparation (such as the creation of a shared vision), moreover, the planning and certain elements of the implementation support (such as involvement in the operative planning or the communication of the vision) have to be built on each other through the integration of the bottom-up approach as well (since without a shared vision, acting in accordance with it or communicating it is impossible). (Csedő & Zavarkó, 2019b)

2.4.4.3 Integrating opposing elements into the change management strategy

Chin and Benne (1985) worked out four strategies for the implementation of change:

1) *Normative-reeducative*,
2) *Rational-empirical,*
3) *Action-centric,*
4) *Determined by power relations.*

The top-down and bottom-up elements can be integrated into the first three types of change management strategies using the tools found in the change management literature (Table 8):

	The nature of change management (based on Dobák, 2002; Beer-Nohria 2000)	
Strategy (Chin – Benne, 1985)	**Top-down element**	**Bottom-up element**
Normative-reeducative	Leadership, showing example and communication (Kotter,1996; Smith, et al., 2014; Hayes, 2018)	Involvement and participation (Cummings and Worley, 2001)
Rational-empirical	Influence by change agents (Cummings and Worley, 2001)	Group problem solving and learning (Hughes, 2010; Argyris and Schön; 1978; Senge, 1999; Burnes, 2014)
Action centric	Resource allocation between projects (Turner, 2009; Jarocki, 2011)	Interaction between the project and the main organization (Csedő, 2006; Parker et al., 2012)
Determined by power relations	Reward or punishment (Nutt, 1986)	

Table 8. The integration of top-down and bottom-up elements in change management strategies

Source: *based on Csedő & Zavarkó, 2019b, complemented*

2.4.5 The integration of onefold change management and continuous organizational learning

Up until now, we modeled change as a onefold phenomenon and change management linearly, in this chapter, however, we will focus on the concept of continuous change. According to this, continuous, small-scale change (that is not yet the subject of change management) is present in the everyday operations of the organization (Dobák, 2002).

Small-scale organizational change is continuous because the external environment is not completely stable either and, the organization, as an open system, is in interaction with its continuously changing environment (Dobák, 2002). On the other hand, the organization as a whole can learn continuously since, the activity of the organization can be broken down into action-result relationships, and the (at least single loop) learning based on the experiences is a constant phenomenon.

From the numerous definitions of organizational learning, the following one is the closest to the environmental adaptation approach: "Organizational learning means the *process* of action improving actions through better knowledge and understanding." (Fiol & Lyles, 1985, p.803)

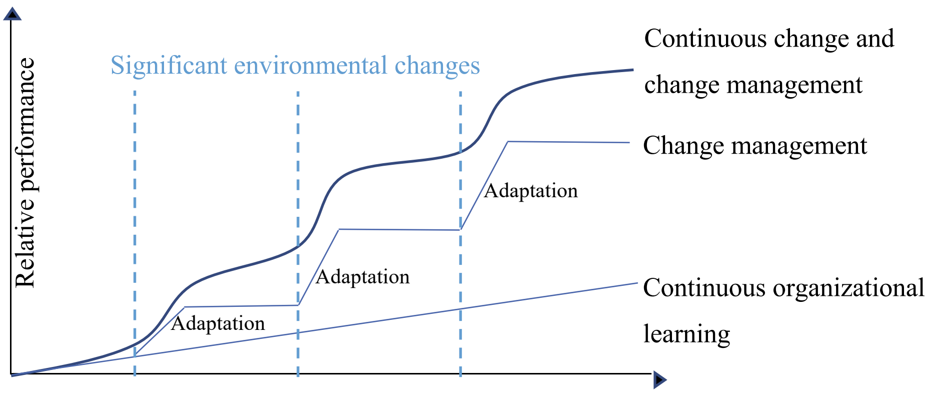

Figure 10. Onefold change management in parallel with continuous organizational learning

Source: *Csedő – Zavarkó, 2019b*

On the vertical axis of the diagram, we indicate "relative performance" and not absolute performance. This is an important distinction because the adaptation to environmental changes does not necessarily mean the increase of the absolute performance (such as profit); since it can happen that the adaptation is enough "only" for the maintenance of the performance. The increase of the relative performance indicates that the organization performs better compared to how it would if it would not learn consciously, and if it would not adapt to the new environment (Figure 10). If continuous change is paired with investment in organizational learning and the organizational mechanism are supporting multi-loop learning, then the performance can be maintained or increased in a changing environment. Since environmental change can reach a level that exceeds the possibilities of adaptation through continuous learning because of path dependency, the role of change management is the realization of adaptation to substantial environmental changes by a larger organizational change. Continuous organizational learning can even catalyze the results of change management. (Csedő & Zavarkó, 2019b)

2.5 Summary of the theoretical framework

Based on the literature review presented in the chapter, I created the following theoretical framework to contextualize my research and clarify its focus (Figure 11).

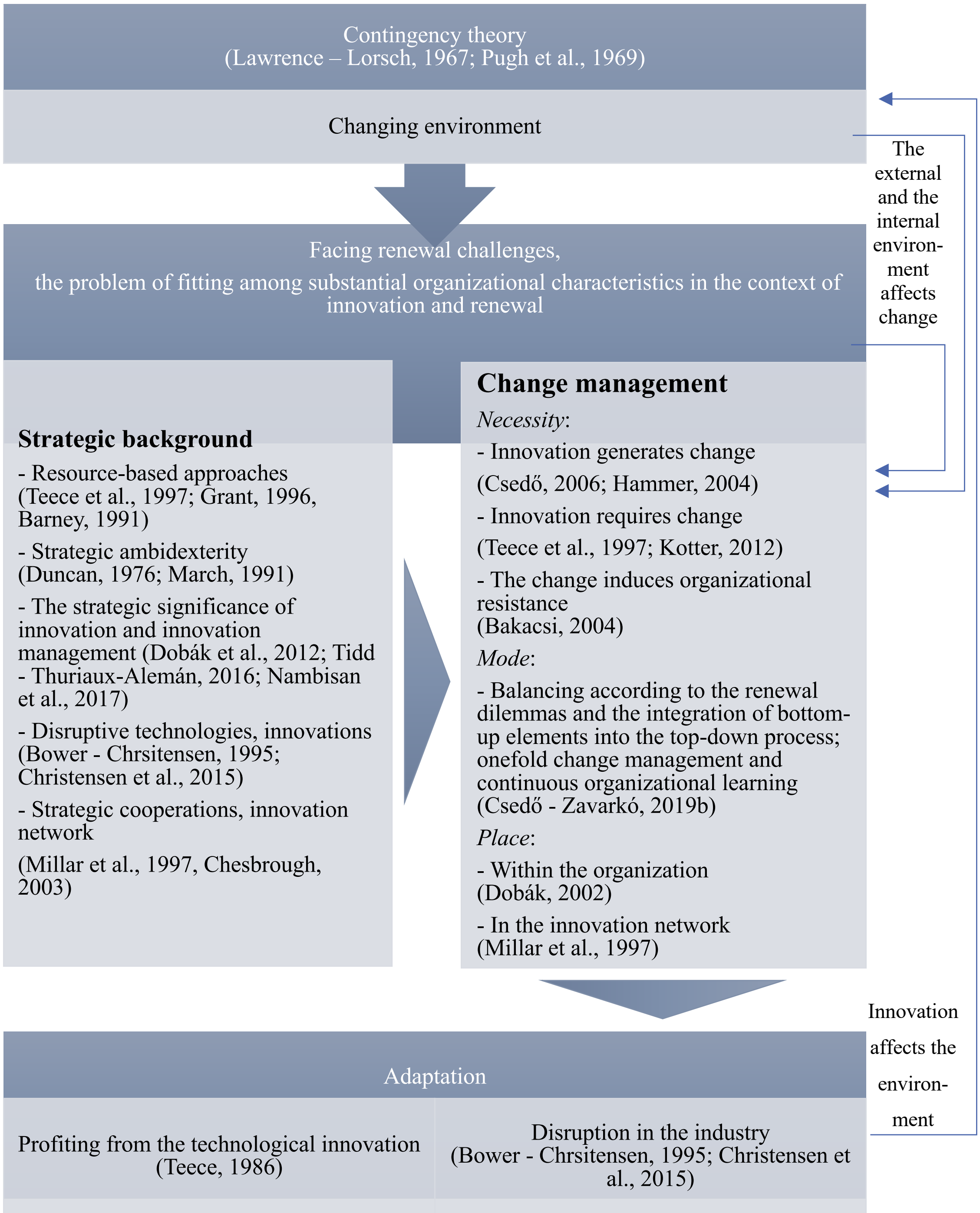

Figure 11. The theoretical framework of my PhD research

Source: *own construction*

The figure points out that my theoretical framework is built on contingency theory, thus, in a changing environment adaptation is necessary for organizations. For adaptation, strategic decisions must be made, behind which, according to my approach, the goal of ensuring strategic ambidexterity should be. Because of the quickly changing environment, strategic decisions must be made by building on internal resources (developing and recombining them). Moreover, I accept that disruptive technologies can fundamentally change the dynamics of competition in the industry.

After determining strategic directions, the top management (could) face that the substantial organizational characteristics do not fit the strategic goals, and the development, the reconfiguration of capabilities would be necessary for (technological) innovation. This makes organizational change and change management necessary. I accept, that not only the realization of innovation requires change, but the realization of innovation (such as the introduction of a new technology) also involves change and requires change management owing to organizational resistance. Change management must be realized by balancing strategic, structural, capability-based, and management-related renewal dilemmas. In my perspective, the development of technological capabilities, knowledge development, and cooperation with other organizations are all important tools of change management aimed at innovation. If innovational activities take place through collaboration, organizational change can happen in not just one organization. Since the aim of the process is to profit from technological innovation, for which the complementary resources of cooperating partners are often needed, innovation can result in change for them as well. Based on the presumptions of the resource-based school, the implemented technological innovation can impact the environment, and if the new solution is disruptive, it can fundamentally influence the dynamics of the industry.

3 THE PRESENTATION OF THE SECTORAL CONTEXT OF THE RESEARCH BASED ON THE LITERATURE

The environment of my PhD research can be broadly defined as the Hungarian energy sector, within this, the power-to-gas industry, more precisely, the power-to-methane segment (production of biomethane). In the power-to-methane segment, I focus on the novel and more innovative biological methanation technology (Figure 12).

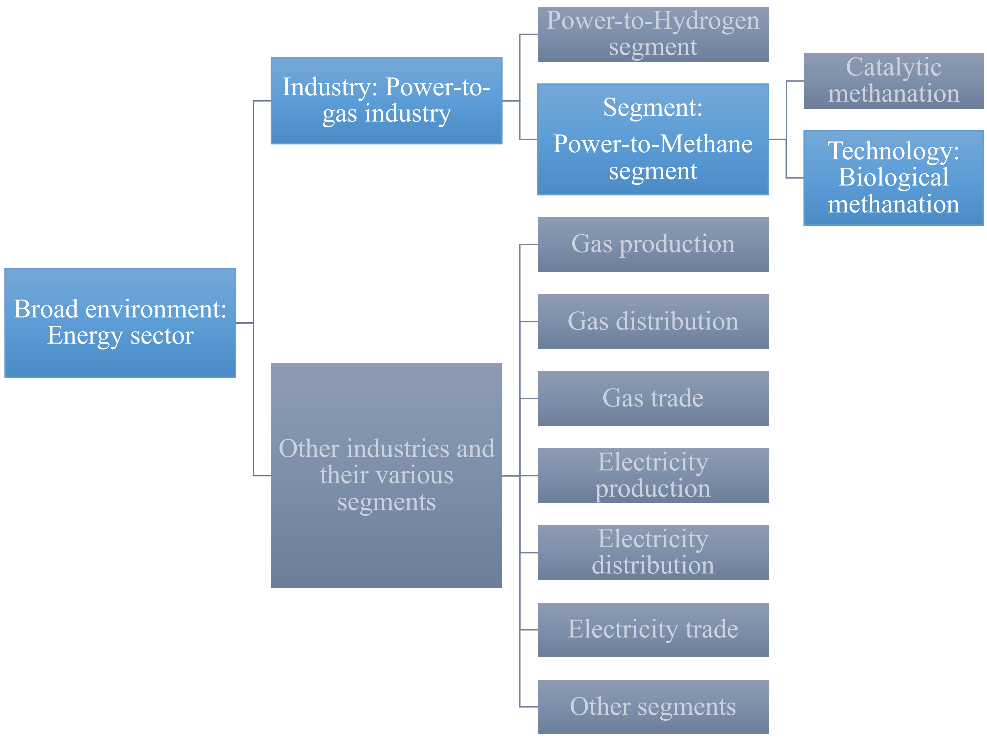

Figure 12. The environment and focus of my research

(in blue: relevant areas, in grey: not relevant areas)

Source: *own construction*

In what follows, based on the above structure, I present the main characteristics of my research environment, in accordance with the literature.

3.1 Energy sector

3.1.1 Global transformation

The energy sector is going through a global transformation, regarding which the main trends are the pursuit for sustainability (Ergüden & Çatlioglu, 2016), the prevalence of renewable technologies (Bollino & Madlener, 2016), the spread of decentralized solutions (Adil & Ko, 2016), the increased use of digital devices (Alagoz & Kaygusuz, 2016) and the focus on energy efficiency and security (Costa-Campi, et al., 2014). Schaeffer (2015) lists general macro-environmental factors (such as global financial crises, geopolitical tensions, climate change), and industry phenomena (such as the rising energy needs of developing countries, the sudden increase of the shale oil and shale gas extraction of the United States, the marginalization of nuclear energy, the constant change in the market price and importance of oil, the drastically declining cost of renewable energy technologies) as the driving forces of change. These changes, and the industry trends mentioned in the introduction cause a renewal urge, to which special management challenges are connected:

1. Reconciling sustainability with dual value creation: Høgevold and Svensson (2012) emphasize that the pursuit of organizational sustainability is not the alternative for growth and profit maximization, but rather an additional goal.
2. Compliance with state policies: Sustainability initiatives, agreements, and guidelines are crucial in shaping the market and development activities of energy companies. For example, the EU must significantly increase the PV installation rate to reach a carbon-neutral electricity supply by 2050 (Jäger-Waldau, 2019) and overcome the integration challenges of the renewable energy to the grid (Sarkar & Odyuo, 2019).
3. Challenges regarding the infrastructure: Industry change is a challenge for energy companies, regarding the physical infrastructure because the decentralized solutions are not entirely compatible with the existing physical systems; but also regarding the business aspect since there is a need for new business, ownership and operational models: such as the creation of (1) consumer systems, (2) smaller community systems, (3) mixed systems with the contribution of energy companies or (4) governmental systems (Adil - Ko, 2016). Luthra et al (2014) point out, that

> the growing need for energy and energy efficiency can be satisfied by energy companies through the optimalization of the operation of networks, and for all of these smart tools need to be used. In connection to this, Schaeffer (2015) pointed out, that the necessary and spreading new ICT solutions could require new control systems and strategies. (Csedő, et al., 2018)

In addition to general management issues, meeting these challenges is difficult because of the specific historical situation of the energy sector. Nisar et al (2016) examined the realization of those organizational structures which support the open innovation perspective, in the case of energy companies. The authors point out, that organizational openness (and thus, innovational capability) depends not only on internal organizational factors. In most developed countries, the energy sector is characterized by detailed and strict regulations, rigid institutional frameworks, and the impact of the external environment on the organization results in structures that are less supportive for openness, cooperation, and innovation (Nisar et al, 2016). The authors also suggest that the rigid regulatory and organizational environment results from the fact that historically, energy is considered a public good, and the control and insurance of the energy supply (used to be) a critical activity on the nation-state level. This phenomenon resulted in the previously dominant state involvement and ownership in the energy sector, which was followed by a significant wave of privatization in the 1990s and then a renewed increase in the share of state ownership today (Cullmann et al, 2016). Besides the strict external regulation, large energy companies are also characterized by internal rigidness. Based on the empirical research of Cohen (2010), Costa-Campi et al. (2014) concluded that the large size of the company can be an impeding factor regarding research and development, mostly due to the length and difficulties of decision making concerning the justification, purpose, and object of the investment; on top of that, this phenomenon is even more relevant in the energy sector, because the energy industry is typically highly concentrated (Costa-Campi et al, 2014). (Csedő, et al., 2018)

Finally, based on former research, the usage of traditional technologies and resources also hinders renewal. Anadon et al. (2011) and the OECD (2011) both concluded, that the dominance of existing, traditional technologies makes it more difficult to start innovation processes in new areas, and it hinders building consensus regarding the outcome expectations connected to innovational activities. Markard and Truffer (2006), and Salies

(2010) classify the existence and usage of fossil and nuclear energy technologies as the obstacle of radical innovation related to renewable energies. Organizational size, market concentration, and the dominance of the current technologies all strengthen organizational inertia and path dependency. (Csedő, et al., 2018)

3.1.2 The power-to-gas technology

In a simple interpretation, the concept of power-to-gas denotes the technologies that produce gas from electricity, however, the definitions in the literature differ in their details. The following definitions have been identified reviewing the international literature:

1. According to Schiebahn et al, the term power-to-gas means the production of chemical energy carriers, using electricity produced in the peak period. (Schiebahn, et al., 2015)
2. According to Götz et al, the essence of the power-to-gas process is the conversion of surplus electricity into gas that can be injected into the gas grid (Götz, et al., 2016).
3. According to Baleira et al, the power-to-gas system produces synthetic gas from electricity (Bailera, et al., 2017).
4. According to Ghaib and Ben-Fares, power-to-gas is an energy storage technology, which uses chemical processes. (Ghaib & Ben-Fares, 2018)
5. According to Blanco and Faaij, the power-to-gas technology means the conversion of electricity to hydrogen with the possibility of further combining it with carbon dioxide to produce methane. (Blanco & Faaij, 2018)

The main steps of the power-to-gas process are presented in Figure 13.

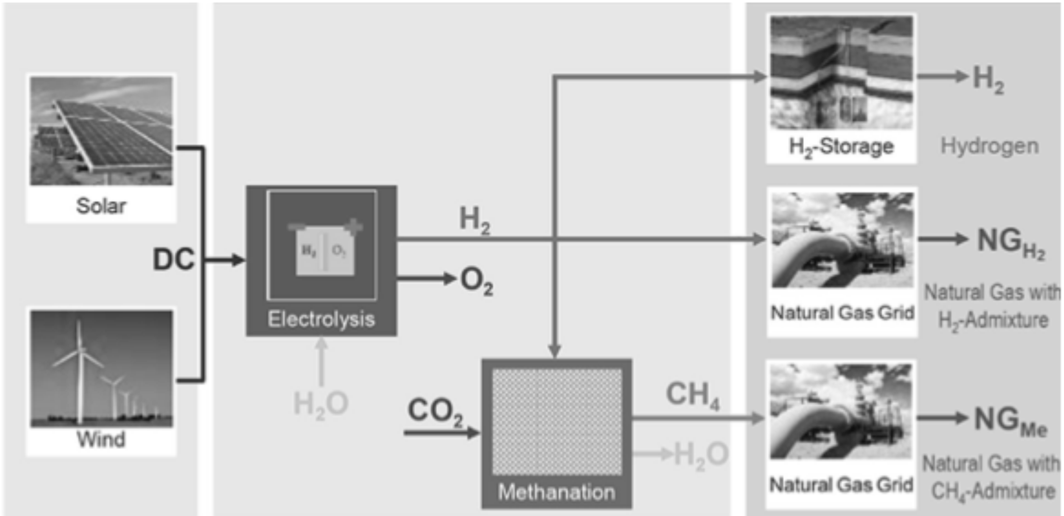

Figure 13. The concept of the power-to-gas process

Source: *Schiebahn, et al., 2015*

Schematic description of the power-to-gas process:

a) The surplus renewable energy is used for water electrolysis, and, as a result, hydrogen and oxygen are created.
b) The formula of the electrolysis: $4H_2O \rightarrow 4H_2 + 2O_2$+Heat
c) The oxygen is the byproduct of the electrolysis, while the hydrogen
    a. can be stored and used, for example, as fuel
    b. can be injected into the gas grid by its safety limits
    c. can be used in the methanation process to produce methane
d) Besides hydrogen, carbon dioxide is also necessary for producing methane
e) The formula of methanation: $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$
f) The byproduct of the methanation process is water, and methane that can be injected into the natural gas grid, as it is the main component of natural gas,
g) If the electricity and/or the carbon dioxide comes from a renewable source (such as biogas, of which approx. 40% is methane and 60% is carbon dioxide), then, in the case of the end product, we can talk about biomethane. (Ferry, 1998; Fontaine, et al., 2017; Schiebahn, et al., 2015; Sinóros-Szabó, et al., 2018)

3.1.3 The power-to-gas industry

3.1.3.1 The boundaries and technologies of the power-to-gas industry

The power-to-gas definition of Blanco and Faaij (2018) expresses well how the power-to-hydrogen (P2H) and the power-to-methane (P2M) processes are built on each other. This also fits the areas of use of produced hydrogen (Schiebahn, et al., 2015): direct utilization (e.g. as fuel), injection into the gas grid by its safety limits, combining with carbon dioxide to produce methane (Ikaheimo, et al., 2018; Galyas, 2018).

In the case of P2H and P2M, different technologies compete. Based on the literature review, three electrolysis technologies are applied and researched in the P2H segment. Besides the widely applied alkali electrolysis and the increasingly applied PEM electrolysis (Götz, et al., 2016; Bailera, et al., 2017; Ghaib & Ben-Fares, 2018), a new research area is the high-temperature (solid-oxide) electrolysis, which could integrate the H_2O/CO_2 co-electrolysis and methanation reactions (Luo, et al., 2018; Wang, et al., 2018). It is only in the development phase, in contrast to the commercialized alkali and PEM electrolysis (Ghaib & Ben-Fares, 2018). In the P2M segment, the catalytic (or Sabatier) and the biological methanation technologies are applied (Götz, et al., 2016). The Sabatier process utilizes nickel- and ruthenium-based catalysts (Schiebahn, et al., 2015), while the biological methanation happens by methanogen microorganisms as biocatalysts (Götz, et al., 2016). The potential performance (CO_2 conversion) in the case of the biological methanation is higher (more than 95%) than in the case of the Sabatier process (70-85%) (Blanco & Faaij, 2018). The product gas with high methane content can be injected two the gas grid, can be used for heating, fueling or industrial processes (Ghaib & Ben-Fares, 2018). Traditional biogas upgrading through which the carbon dioxide is separated from the product gas increasing its methane content, cannot be considered as a power-to-gas technology if – by definition – its characteristics include the capability to store electricity and the transformation (conversion) of carbon dioxide (Bailera, et al., 2017). The discussed literature observations are summarized in Figure 14.

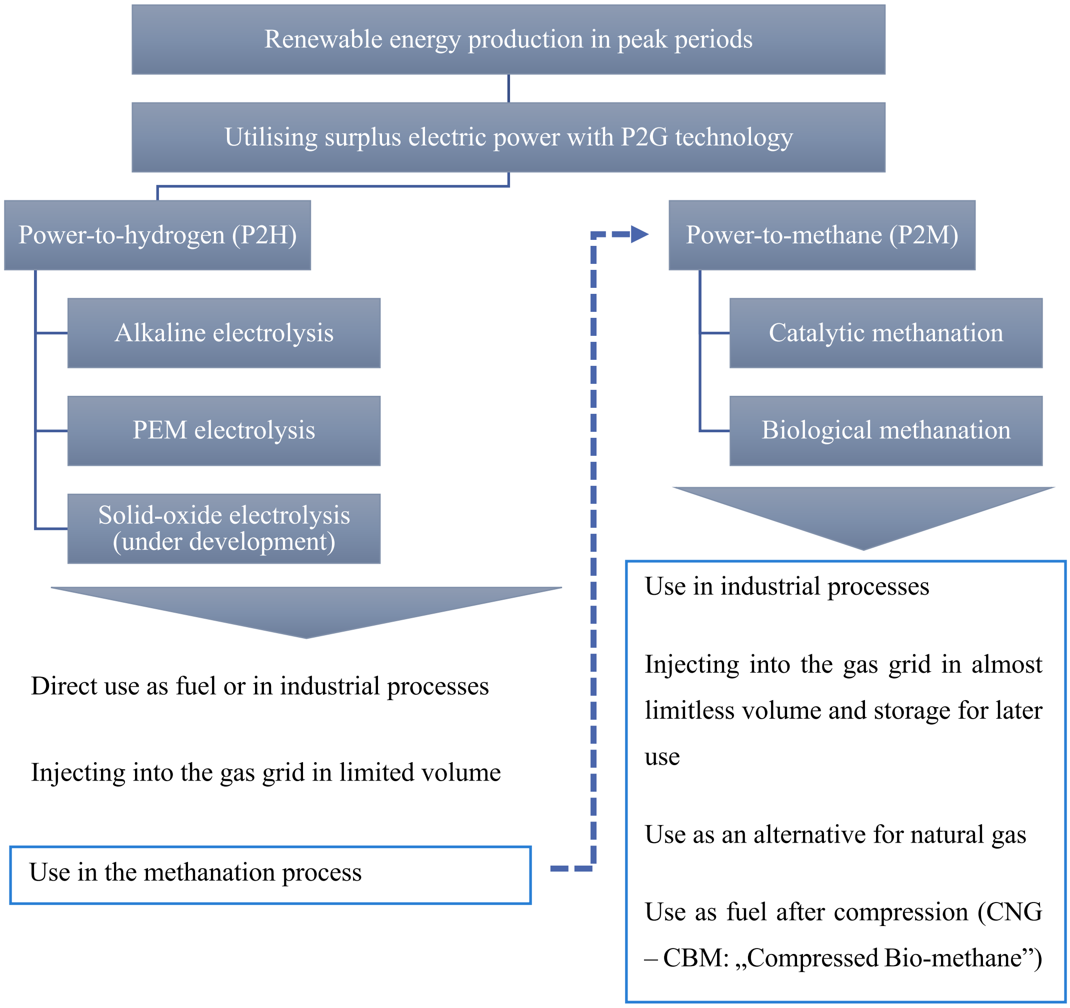

Figure 14. The added value and use of the power-to-gas technology based on the literature review

Source: *Zavarkó, 2019a*

3.1.3.2 International power-to-gas development projects and their lessons

In what follows, we focus on the projects of the P2M segment because, the methanation technology has greater energy storage potential given the current infrastructure (Blanco & Faaij, 2018). As presented before, catalytic, and biological methanation is used in the P2M segment. Based on Baleira et al (2017), the higher number of projects running with catalytic methanation (22 catalytic and 12 biological methanation projects), the development of the technology at the beginning of the 20th century, its more frequent use since the 70s' (Götz, et al., 2016) and the development of – sometimes patented – newer and more efficient biological methanation technology with selective micro-organisms (Sinóros-Szabó, et al., 2018), suggests that the latter is more innovative. It is important to mention, however, that both technologies are continuously researched (Zavarkó, et al., 2018).

In the following, those international P2M projects will be presented, based on the literature and public company data, that are outstanding (innovative) in the P2M segment based on their (1a) performance or (1b) technology, and (2) there is enough available information for viewpoints of the analysis: based on my theoretical framework, the focus is on technological solutions and the activities of those taking part in the project, as on the capabilities that are needed for R&D performance and grid-scale plant establishment, and that, in the time of open innovation (Chesbrough, 2003) can be ensured through strategic cooperations (Bakacsi, 2011). Table 9 shows the data of the assessed projects.

Project	Location	Electrolysis	Electrolyzer (kWe)	Methanation technology	Relevancy
ETOGAS – Audi e-gas plant	Werlte, Germany	Alkali	6000	catalytic	Outstanding plant size
Sunfire - HELMETH	Kalsruhe, Germany	High temperature	15	catalytic	Innovative electrolysis technology
MicrobEnergy – BioPower2Gas	Allendorf, Germany	PEM	300	biological	First commercial plant with bio-methanation
Electrochaea - BioCat	Avedøre, Denmark	Alkali	1000	biological	Patented micro-organism and largest bio-methanation plant
RAG - Underground Sun Storage	Pilsback, Austria	Alkali	500	biological	Regionally the closest competitor

Table 9. Outstanding international power-to-gas projects

Source: *Zavarkó, 2019a*

In the field of catalytic methanation, the e-gas project of Audi and the HELMETH project can be highlighted. Audi's plant is Wertle has been in operation since 2013, with its 6 MW output, it is the world's largest power-to-gas plant. The electric power needed for hydrogen production comes from a wind park at the North Sea, and the carbon dioxide is separated from the raw biogas produced at a neighboring biogas plant. The plant produces SNG through the power-to-gas process with 54% efficiency, which is then injected into Wertle's natural gas grid. The waste heat, produced as a byproduct, is recycled in the processes of the biogas plant and carbon dioxide separation. The establishment of the plant was preceded by several R&D phases, including testing the methanation of the raw biogas and the creation of a 250 kW test plant near Stuttgart. The project is primarily built on the technology development of ETOGAS, but several energy research institutions (ZSW, Fraunhofer IWES), EWE Biogas, and the owner of the biogas plant, and Audi, as the sponsor have taken part in the different phases of the project. (Ghaib & Ben-Fares, 2018; Bailera, et al., 2017; German Energy Agency, 2019) The lesson of the Audi e-gas project is that, for the creation of a plant, with an outstanding size in the industry, wide-ranging cooperation is needed, in which the research institution, the strategic investors and the key partners who grant the input factors, all have to make an appearance.

The HELMETH (High-Temperature Electrolysis and Methanation) project was realized between 2014 and 2017, partly with the funding of the European Union worth 2,5 million euros. It demonstrated a highly efficient power-to-gas process by combining the technologies of high temperature (solid-oxide) electrolysis and catalytic carbon dioxide methanation. This solution is still in the experimental phase and requires significant research and development, this is also shown by the 15 kW performance of the electrolyzer. The 76% efficient technology development, which has already been completed but which represents a step forward in the field, was led by the Kalsruhe Institute of Technology, but the Sunfire technology development company, the Polytechnic University of Turin, the European Research Institute of Catalysis, the National Technical University of Athens and the German Technical and Scientific Association for Gas and Water have also taken part (Bailera, et al., 2017; Ghaib & Ben-Fares, 2018; European Commission, 2018; Kalsruhe Institute of Technology, 2018). The lesson from the HELMETH projects is that, in order to achieve outstanding R&D&I, alongside the cooperation of universities, research institutes, non-profit organizations, and companies, the financial support of a governmental or international organization could also be necessary.

Regarding biological methanation, MicrobEnergy, which belongs to the Viessmann Group, created the first commercial plant with biomethanation in Allendorf. The BioPower2Gas plant has been operating and injecting SNG into the natural gas grid since 2015, for which the carbon dioxide is sourced from two biogas plants close to the Viessmann Group. The plant produces the hydrogen needed for the process with two 150 kW PEM electrolyzers. Besides the international Viessmann Group, which manufactures industrial, cooling, and heating equipment, the network operator EnergieNetz Mitte, the energy supplier EAM EnergiePlus, the engineering consulting company CUBE, Institute of Decentralized Energy Technologies (iDe), and the German Biomass Research Center (DBFZ) have taken part in the project. The Federal Ministry of Economic Affairs and Energy also contributed financially. The establishment of the commercial plant was preceded by four research and development phases: laboratory research, the biological methanation of pure sources (55 kW electrolyzer), raw biogas methanation (120 kW electrolyzer), and the methanation biogas that comes from wastewater (180 kW electrolyzer). It is important to also point out that, alongside the development of the power-to-gas technology, MicrobEnergy also strives for the integration of the technology into the energy sector, therefore, it developed the IoT system, which connects the different systems (Bailera, et al., 2017; Viessmann Werke GmbH & Co. KG, 2019; IdE gGmbH , 2019; Viessmann Werke GmbH & Co. KG, 2019). The lesson of the BioPower2Gas projects is that, the project participants also include an energy service provider and a network operator with extensive energy expertise, additionally, the development and implementation of the power-to-gas technology can be connected to the development of the supporting digital solutions.

The BioCat plant of Electrochaea GmbH in Avedøre, Denmark, with its 1 MW electrolyzer performance, is the largest commercial power-to-gas plant that uses biological methanation. The key of Electrochaea's process is the methanogen archaea strain, which is capable to convert carbon dioxide and hydrogen into methane with 98,6% efficiency. The source of carbon dioxide is raw biogas, and it can even be a traditional biogas upgrading system which supplies pure carbon dioxide. The locally produced, surplus wind energy is used in the process, moreover, the oxygen, produced as a byproduct, is also recycled in the nearby wastewater treatment process. The product gas goes into the distribution network, thus increasing the energy storage capabilities of the Danish energy system. The project involved the Danish electricity and gas system operator Energinet, the electrolyzer supplier Hydrogenics, the NEAS Energy energy asset manager, the HMN Gashandel A / S gas supplier, the Biofos A / S wastewater treatment plant (WWTP) operator, the Insero energy consulting and development company, and also Audi. Similar to the Microbenergy and Audi plants, previous R&D phases have taken place here, including a laboratory plant and a 250 kW plant. Strategic investors (energie 360 °, Caliza Holding) and venture capital funds (b-to-v, Munich Venture Partners, Sirius Venture Partners) also participate in the financing of the technology development led by Electrochaea GmbH (Bailera, et al., 2017; Electrochaea.dk ApS, 2019; Electrochaea GmbH, 2019; Electrochaea GmbH, 2019). The lesson of the BioCat project is that strategic and financial investors are needed in the development and implementation of the technology, and the input source can also be a wastewater cleaning plant, the proximity of which also allows the recycling of the oxygen by-product.

The closest to Hungary is the Underground Sun Storage project in Austria, which received state funding of 4.9 million EUR from the Austrian Climate and Energy Fund. The technology produces hydrogen and oxygen from renewable energy (primarily solar power) with a 500 kW electrolyzer. The hydrogen is stored 1000m underground in a reservoir, to which carbon dioxide is added from a biogenic source. Here, the naturally occurring microorganisms transform hydrogen and carbon dioxide into biomethane in a short time, which can be injected into the natural gas grid. The project is owned by RAG. RAG is a large Austrian energy company, which is concerned with the efficient storage and production of oil and natural gas. The project also involved the University of Loeben, the University of Natural Resources and Life Sciences in Vienna, the Austrian Center for Industrial Biotechnology, and the University of Linz. The Underground Sun Storage is primarily a development project which lasts until 2020 (RAG Austria AG, 2017; RAG Austria AG, 2018). The lesson of the Underground Sun Storage project is that, alongside governmental resources, a profit-oriented energy company is coordinating the projects, which is realized through the contribution of numerous universities and research centers. (Zavarkó, 2019a)

3.1.3.3 The maturity of the industry

Typically, an industry goes through four phases:

1) initial attempts, where the boundaries and norms of the industry are less clear;
2) growth and consolidation, where certain technologies spread, and certain actors become dominant;
3) maturity, where the entry barriers are high already and the opportunities for growth are slowly becoming exhausted;
4) decline, where the industry actors are forced to switch because of the decreasing profit level (Foster, 1986; Balaton, et al., 2009).

Based on the results of the literature review, the power-to-gas industry is developing quickly on an international level, the boundaries of the industry are clear, but technologies have not become the industry standard, and there are no extremely dominant actors yet (Figure 15). As of now, alongside a couple of commercial plants, there are several R&D projects running. Within the industry, the power-to-hydrogen and power-to-methane segments can be distinguished, these are built on each other, and within them, two to three technologies are competing. (Zavarkó, 2019a)

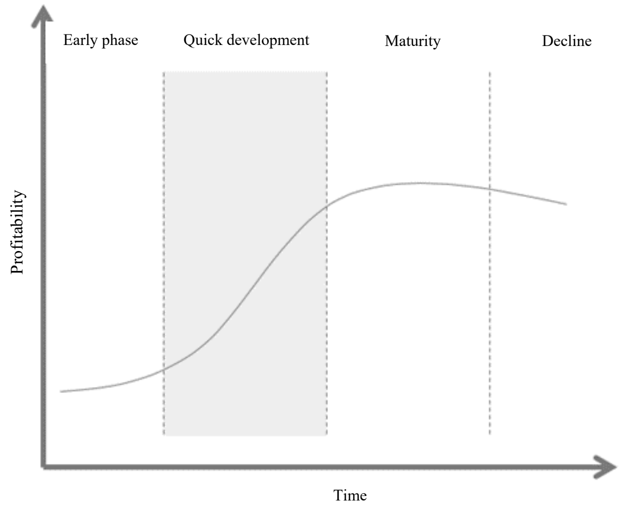

Figure 15. The place of the power-to-gas segment on the industry life-cycle
Source: *Zavarkó, 2019a*

3.1.3.4 Competencies and actors in power-to-gas projects

Every noteworthy power-to-gas project has been realized through the cooperation of several actors:

1) Technology developer startups
2) Large energy companies
3) Research centers and/or universities
4) Strategic investors
5) Financial investors

combined their resources to achieve high R&D performance or operational performance, and occasionally, governmental institutions have supported the innovational efforts. (Zavarkó, 2019b)

Based on the results, four competencies can be identified as the success factors of the power-to-gas technology development:

1) Innovative core technology

2) Financial support or investment
3) Broad industry knowledge, material resources
4) Scientific research, academic research.

These competencies were granted by different partners in the development projects (Table 10).

Project	Core technolo gy	Financial support / investment	Broad industry knowledge, material resources	Academic, scientific knowledge
Audi e-gas plant	Etogas	Audi	EWE Biogas, Audi	ZSW, Fraunhofer IWES
HELMETH	Sunfire	European Union (2,5 million EUR)	German Technical and Scientific Association for Gas and Water	Polytechnic University of Turin, European Research Institute of Catalysis, National Technical University of Athens
BioPower2 Gas	Microb-energy	Federal Ministry of Economics and Energy	Viessmann Group EAM EnergiePlus, EnergieNetz Mitte	iDe (Institue of Decentralized Energy Technologies), DBFZ (German Biomass Research Centre)
BioCat	Electro-chaea	energie 360°, Caliza Holding, b-to-v, Munich Venture Partners, Sirius Venture Partners	Energinet, Hydrogenics, NEAS Energy, HMN Gashandel A/S, Biofos A/S, Audi, Insero	University of Chicago
Undergrou nd Sun Storage	RAG	Austrian Climate and Energy Fund (4,9 million EUR)	Verbund, Axiom	University of Leoben, University of Natural Resources and Applied Life Sciences Vienna, Energy Institute at the Johannes Kepler University

Table 10. Actors of notable power-to-gas projects and the required competencies

Source: *Zavarkó, 2019b*

3.1.3.5 Research and development in the power-to-gas industry

Based on the literature review, one part of the research conducted in the power-to-gas industry focuses on improving the operative aspects of the technology, while the other side is concerned with system-level research (Zavarkó, et al., 2018).

On an operative level, development takes place in the following areas:

1) high-temperature electrolysis (Ghaib & Ben-Fares, 2018),
2) in-situ hydrogen injection during biogas upgrading (Lovato, et al., 2017),
3) performance of the catalyst (Bacariza, et al., 2018),
4) feeding biocatalysts (Sinóros-Szabó, et al., 2018),
5) adequate reactor building (Götz, et al., 2016) and other reactor characteristics (Inkeri, et al., 2018).

The system-level questions regarding power-to-gas technology are the following:

1) choosing the site for the power-to-gas plants (due to the high carbon dioxide need) and its sizing (Blanco & Faaij, 2018; Simonis & Newborough, 2017),
2) exploiting the network balancing potential (Zoss, et al., 2016)
3) implementation of the technology at wastewater treatment plants (Patterson, et al., 2017).

3.1.4 Description of the focal technology of the research

The characteristics of the focal power-to-gas technology are the following:

a) it contains a patented biocatalyst, a robust and extremely selective archaea strain (Methanothermobacter thermautotrophicus) discovered by Professor Laurens Mets at The University of Chicago.

b) this biological methanation solution is more effective than catalytic methanation because it achieves a conversion of ca. 98%[14], which is only 70-85% in case of thecatalytic methanation).
c) biological methanation is more flexible to volatile renewable energy production compared to competing technologies because the bacteria from a „sleeping” state become ready for methane production in seconds if proper nutrients and other input factors (such as temperature or mixing in the reactor) are provided.
d) biogas upgrading, through which the carbon dioxide is separated from the product gas increasing its methane content, cannot be considered as a power-to-gas technology if – by definition – its characteristics include the capability to store electricity and the transformation (conversion) of carbon dioxide.
(Mets, 2012; Martin, et al., 2013; Csedő, 2019; Blanco & Faaij, 2018; Sinóros-Szabó, et al., 2018; Zavarkó, 2019; Bailera, et al., 2017)

In Hungary and in the whole CEE region this biomethanation technology is developed and applied by Power-to-Gas Hungary Kft.

3.2 Determining the focus point of the empirical research based on the research gaps of the P2G literature

In what follows, I present the importance of researching two areas that are considered a research gap in the international P2G literature. These research gaps have fundamentally defined the industry-specific focus of my empirical research in order to contribute to the success of P2G technology development in line with my motivations.

[14] The creation of methane from carbon dioxide in the presence of hydrogen

3.2.1 The relevance of researching innovation management and networks in relation to P2G technology development

One of the main trends of the transforming energy sector is the increasing use of renewable energy technologies (Bollino & Madlener, 2016). Renewable energy technologies research (Johannsen, et al., 2020; Østergaard & Maestosi, 2019; Johannsen & Østergaard, 2019) is significantly focusing on research areas, such as energy supplies and cost-efficiency (Johannsen, et al., 2020; Østergaard & Maestosi, 2019; Johannsen & Østergaard, 2019), regional level integration and coordination (Bergaentzlé, et al., 2020; Dahlke, 2020), or system modelling and data analysis (Ben Amer, et al., 2019; Grundahl & Nielsen, 2019). Further important research areas that drive the transformation of the energy industry are: challenges related to the integration of renewables into the power system (Sarkar & Odyuo, 2019), technology investments and implementation (Singh, et al., 2019), theories and tools to overcome these challenges (Gohari & Larssæther, 2019; Lybæk & Kjær, 2015), with a special focus on organizational (Tricarico, 2018) and innovation management (Ianakiev, et al., 2017) perspective.

Nowadays, P2G technologies get increased attention from industry representatives, academia, and public sector not only on national level, but on global level, but organizational and innovation management aspects have not appeared yet. For the STORE&GO project, which is funded by the European Union's Horizon 2020 research and innovation program, is focusing on three variations of power-to-gas implementation in three different countries – but still on demo sites. Since 2016, 27 European partners are collaborating in the project (STORE&GO, 2020). This fact implies the critical role of inter-organizational innovation networks in case of power-to-gas technology development.

The scientific literature of energy storage elaborates the opportunities of P2G technologies for the transforming energy industry (Zoss, et al., 2016; Zhang, et al., 2017; Varone & Ferrari, 2015; Vandewalle, et al., 2015) and its different technological R&D aspects (Luo, et al., 2018; Wang, et al., 2018; Bacariza, et al., 2018; Inkeri, et al., 2018). Based on the overview of Blanco and Faaij (2018), P2G research focuses on levelized cost of energy, process design, time series, business models, technology review, cost optimization, life-cycle assessment, and projects surveys, but does not focus on the managerial challenges of the technology development and commercialization. The P2G technology has not been widely commercialized, yet (Ghaib & Ben-Fares, 2018). So, a research focusing on innovation management aspects of P2G technology development could add significant value to the commercialization of this technology on a wider scale, as well as could serve as a benchmark to other disruptive technologies for successful commercialization.

Quantitative research in this field highlights important operative (e.g., efficient reactor structure) or system level (e.g., impact on the energy sector) cause and effect relationships between key variables. In contrast, a qualitative research could enable deep insight into the P2G technology development in a given context (Hungary) and highlights factors (opportunities, barriers, interests, perceived benefits) that lead to the formation of an inter-organizational P2G innovation network. The empirical part of my research was realized with regard to these viewpoints. (Csedő & Zavarkó, 2020; Csedő, Sinóros-Szabó & Zavarkó, 2020; Pörzse, Csedő & Zavarkó, 2021)

3.2.2 Extending techno-economic analyses with strategic viewpoints

The promising role of the P2G technology in the energy sector has been argued comprehensively in the recent years (e.g. from the aspect of long-term energy storage (Blanco & Faaij, 2018), system analysis (Schiebahn, et al., 2015) or technological and economic factors (Götz, et al., 2016)). Furthermore, techno-economic assessments have already been conducted about P2G technologies with different methods and scopes recently. In terms of the return of the investment, for example, Ameli et al (Ameli, et al., 2017) analyzed the role of different capacities of battery storage and P2G systems in Great Britain with the Combined Gas and Electricity Networks (CGEN) model. Addressing electricity balancing challenges, they concluded that the capital costs must reach £ 0.5 m/MW for P2G to justify the investment. As a comparative approach, Collet et al (Collet, et al., 2017, 192) analyzed five different scenarios of biogas upgrading and P2G, pointing out that P2G technologies “are competitive with upgrading ones for an average electricity price equal to 38 € MW h^{-1} for direct methanation and separation by membranes” [p. 293]. In the case of production costs, Peters et al (Peters, et al., 2019) can be mentioned amongst others, who evaluated eight scenarios based on different combinations of H_2 and CO_2

sources and found methane costs in the range of 3.51 – 3.88 EUR/kg for P2G. Collet et al and Peters et al complemented their techno-economic analyses with ecological and environmental aspects, focusing on greenhouse gas (GHG) emissions, as well.

As detailed above, there are several approaches to perform a techno-economic assessment of the P2G and waste management technology (Eveloy & Gebreegziabher, 2018). Inspired by these research results, but with regard on the importance of management aspects (based on the previous section), analyzing disruptiveness can be also relevant.

As I pointed out before, P2G technologies are not only relevant on lab- or prototype-scale. For example, the largest P2M plant in the world (AUDI e-Gas project, 6 MW_{el}) started its operation in 2013 in Wertle (Germany) with catalytic methanation, while the largest biomethanation plant (BioCat project, 1 MW_{el}) is located in Avedøre (Denmark), operating since 2016 (Götz, et al., 2016). Another large biomethanation plant (700 kW_{el}) has also been commissioned within the STORE&GO Project in Solothurn (Switzerland), in 2019 (STORE&GO, 2021). The potential impact of P2M technology on the energy sector has already appeared in the power-to-gas (P2G) literature, which continuously broadens with novel technical and economic studies (Bailera, et al., 2017; Guilera, et al., 2018; Peters, et al., 2019). There is a consensus of the crucial role of the P2G technology for the future energy sector (European Commission, 2020; Bailera, et al., 2017).

Regarding that – based on the section 3.2.1. – innovation management is relevant in P2G research, a key term and a key phenomenon called “disruptive technology” and “disruption” is, in the intersection of these three key topics (1: future impact, 2: techno-economic aspects, 3: innovation), overlooked in the literature despite its importance. The disruptiveness of a technology is highly important from investment aspects, because disruptive technologies usually seem inferior from a certain performance aspect compared to other, better-known solutions, even though later, they can change the dynamics of a whole sector. In other words, investing in P2M on a company level and/or state level could affect organizational/sectoral competitiveness, as it should enable building new competencies through innovation (Cantwell, 2005), adaptation to new environmental changes (Feurer & Chaharbaghi, 1994), sustained and also sustainable growth (Schwab, 2019).

The disruptive technology theory is usually applied in business and innovation management research and is less frequently applied in technical contexts or for examining new energy technologies. In broader context, technology- and disruption-focused scholars currently pay attention to digital solutions, for example, Internet of Things (Almutairi & Aldossary, 2021) or disruptive effects of new solutions in specific sectors, such as digital transformation in the banking sector (Diener & Špaček, 2021), Industry 4.0. and Construction 4.0. (Lekan, et al., 2021), 3D technologies in the medical field (Servi, et al., 2021), blockchain technology in the education sector (Ullah, et al., 2021). Regarding the few similar disruption-focused studies in energy research, there has recently been published studies about disruptive technologies related to office energy management (Moreno Santamaria, et al., 2020), smart cities (Radu, 2020; Yigitcanlar, et al., 2020), blockchain and photovoltaic energy generation systems (Enescu, et al., 2020). For example, Ullah et al (2020) examined the adoption of blockchain technology for energy management in developing countries discussing the distributed ledger technology as disruptive. Zeng et al (2018) pointed out that conventional energy technologies are dominant in the energy sector, and found that low price, high consistency, and high improvement rate are key for the diffusion of renewable energy technologies. In contrast to this broad view, a narrower approach was followed by Müller and Kunderer (2019) when they predicted the potential disruption hazard of redox-flow batteries towards lithium-ion batteries with quantitative methodology. Based on these former research results, a study with a mezo-level approach could be valuable, that focuses on the attributes of P2M and does not determine ex-ante its disruptiveness, nor their competing technologies, but identifies them based on empirical data collection and analysis.

Based on the literature, P2M technology in a macro-economic context means an opportunity not only for seasonal energy storage but for decarbonization, as well, as it converts CO_2 into CH_4 in presence of H_2 (Schiebahn, et al., 2015). Moreover, P2M can provide e.g., sector coupling (Schäfer, et al., 2020), generate new business opportunities on a company-level (Breyer, et al., 2015), or also new challenges for the regulators (Csedő & Zavarkó, 2020). Thus, P2M seems to be disruptive at first sight. By definition, however, some other questions arise regarding the disruptiveness of the P2M technology. In addition, while a common example for disruptive solutions is the Netflix streaming service (Christensen, et al., 2015), one can see that interpreting disruptiveness in the case of P2M is more complex than in sectors where there are millions of potential customers.

Based on the theory and the example of Netflix, P2G can be disruptive (Table 11), but this is only a proposition for empirical research of its disruptiveness.

In sum, analyzing P2M as a disruptive technology with a techno-economic approach seem to be relevant, but it is worth going back to the fundamentals of the theory. (Csedő & Zavarkó, 2020; Csedő, Sinóros-Szabó & Zavarkó, 2020; Pörzse, Csedő & Zavarkó, 2021)

Aspect	Theory	Example based on Christensen et al. (2015) – Netflix (american online media provider)	Power-to-gas literature
Initial performance	The performance of disruptive innovations initially does not meet mainstream consumer expectations	In 1997, online ordering, DVD technology, was still new and immature, and was less preferred by most consumers over the more reliable video library system.	The efficiency of the power-to-gas process is lower compared to the efficiency of batteries
Start	Start by targeting a segment that is considered less profitable by a large part of the industry	Targeting the still low numbers of online shoppers and early users of DVD players in 1997 who aren't necessarily curious about the latest movies and accept the necessity of waiting several days for delivery	Instead of short-term energy storage, the focus is on high volume and long-term energy storage instead of short-term energy storage.
Change	Change in the environment, technologies	The internet makes streaming possible Netflix develops its online competencies	The increase of renewable energy sources, the necessity of integration, and network operation tasks create a need for commercial-scale and long-term energy storage The power-to-gas technology demonstrates its commercial functionality.
Disruption	Lower performance - partly due to environmental changes and partly due to the further development of the solution - becomes attractive to a wide range of people	From a basically online operation, Netflix was able to quickly transition to an online content service with a wide selection and an affordable price.	The power-to-gas technology, more precisely, the biological methanation solution, is able to flexibly adapt to energy production in the peak period, and by transforming the surplus electricity into gas, it makes it efficiently storable in the gas grid

Table 11. The disruptivity of power-to-gas based ont he paralel of the theory and practice

Source: own construction based on Christensen et al., 2015, complemented

4 RESEARCH FRAMEWORK

In this section, I present my research strategy and research model that grounded and guided the empirical data collection and analysis. Furthermore, I describe the applied methods and the steps undertaken to improve validity, reliability, and generalizability.

4.1 Research strategy

4.1.1 Factors influencing the research strategy

The most important factors determining my research strategy are the following:

1) Based on my organizational theory position, I aimed to support functionalist goals with partly interpretative tools.
2) Since my goal was to understand phenomena happing in the present (through answering "What kind…? And "How…? type questions), choosing a qualitative methodology was justified (Yin, 2003).
3) Although my research question is general, it is possible to answer it partially or fully with qualitative data analysis, case studies, and a grounded theory research strategy (Pataki, 2000). Therefore, I integrated, partly or entirely, the methods of qualitative content analysis, case studies, and grounded theory into my quantitative methodology.
4) Since my research had strong practical motivation (the exploitation of the power-to-gas technology's potential), and I aimed to create new knowledge, through connecting theory and practice, which generates change (in the energy sector), the method of action research had to integrate the components of my research strategy within the qualitative methodology into a coherent framework (Lewin, 1946; Reason, 2001; McNiff, 2013).
5) One of the key theoretical pillars of my research was the dynamic capabilities framework. It should be mentioned in relation to this, that the case study approach is favorable and case studies "are likely to yield powerful insights" (Teece, 2012, p. 1400).

6) In the power-to-gas industry, the technology development projects have been and are realized through the contribution of several actors (Bailera, et al., 2017), therefore, conducting peripheric case studies focusing on stakeholders was justified.

4.1.2 Methodological choices and their reasoning

Based on the recommendation of Mason (2006), I combined multiple qualitative methods, which will allow for a deeper understanding of the human experiences, the organizational reality that can be understood only to a limited extent from only one perspective. The pluralist approach supports the holistic understanding and description of a complex phenomenon as well (Frost, et al., 2010). Moreover, it is my belief as a researcher, approaching the research topic from multiple sides facilitates theoretical development.

The components of my research strategy (Figure 16):

1) I built my PhD research strategy on qualitative research methodology.
2) I conducted multiple case studies within the framework of action research.
3) While conducting the case studies, I
   a. gathered company documents
   b. conducted semi-structured individual and focus group interviews.
4) To process the data
   a. I used qualitative content analysis, for a prior inductive understanding,
   b. I made techno-economic analyses based on quantitative data, in line with my functionalist approach,
   c. I used the coding technique of grounded theory to be able to build or complete theories based on empirical data.
5) My research had a central case, where I conducted an *extended case study.* This is a type of case study with a deep analysis of the company and a retrospective approach (Burawoy, 1998; Danneels, 2010).
6) Besides the central case, I conducted peripheric case studies, which provided new viewpoints, and confirmed or fine-tuned the conclusions of the extended case study.

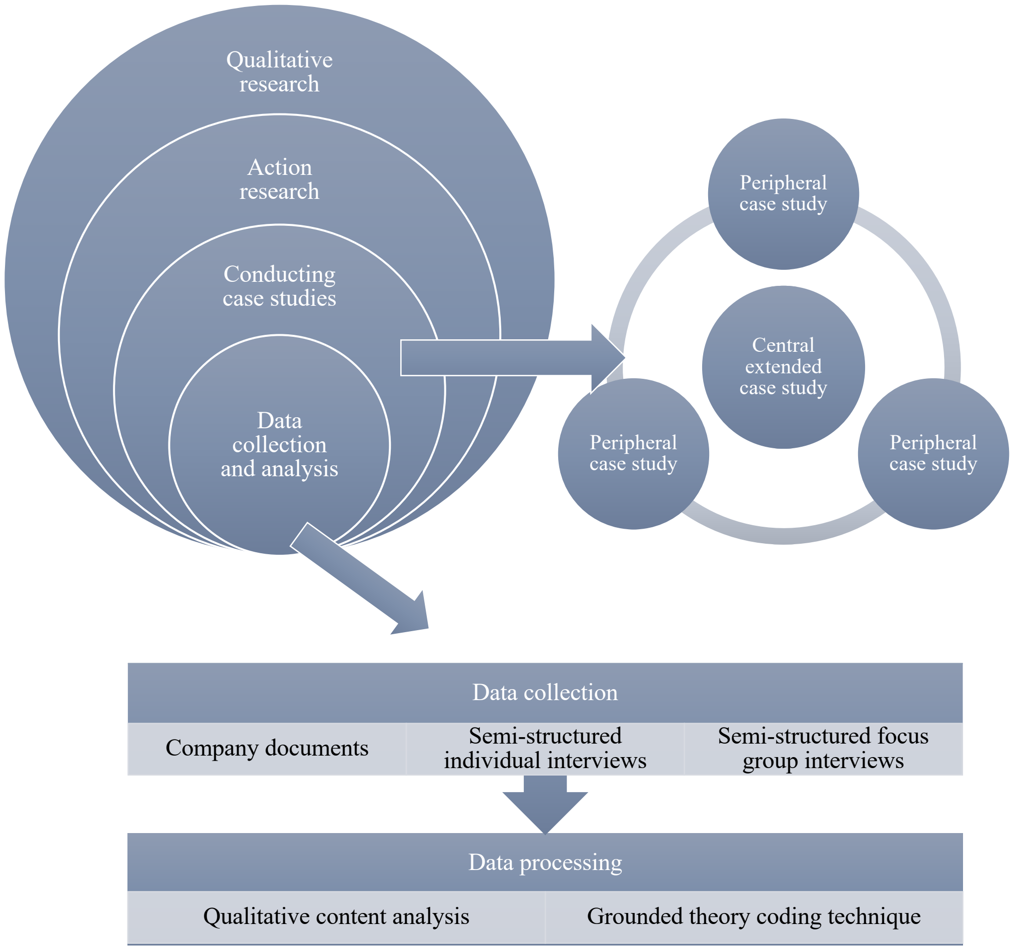

Figure 16. Research strategy

Source: *own construction*

The chosen methods are justified by organization theoretical considerations and previous research regarding the topic:

a) The methodological choices reflect the parallel presence of the functionalist and the interpretative in the research: the semi-structured interview, the theoretical background of the grounded theory coding technique and the extended case study aid the reconciliation of the opposing organizational theoretical presumptions (I will describe these in greater detail later). It is also important to point out that these methods build greatly on each other, for example, conducting an extended case study draws a lot from the tenets of grounded theory both from the theoretical (Burawoy, 1998) and practical side (Tripsas & Gavetti, 2000). [15]

b) Susman and Evered (1978) point out that action research can be applied to organizational research, and Blichfeldt and Andersen (2006) highlight that, according to numerous researchers, action research has to lean on the method of case study, which confirms to me that the two methods can be built on each other. At the same time, it is important to see the similarities and the differences between the two methods:
   - It is a similarity that, in both methods, the interconnection of the theory and the practice appears through field data collection, and it allows the researcher an in-depth insight into understanding a social context.
   - It is a difference that, the action researchers play an active part in defining the practical problem and the solutions, while this does not appear in the method of case studies. Moreover, experience suggests that sometimes action researchers carry out practical activities to the detriment of the thorough elaboration of the theoretical framework and the theoretical contribution. (Blichfeldt & Andersen, 2006)

I believe that building the action research and the case study on each other in my PhD research is justified by the similarities, and I adequately address the two risks mentioned in the differences

i. with the formerly presented theoretical framework,
ii. by applying the coding technique of grounded theory, which requires taking notes regarding data collection and data analysis through the research process and makes theoretical contribution possible.

[15] For example: iteration between data and theory, the criterion of reaching theoretical saturation (Glaser & Strauss, 1967)

c) In connection with my research topic, previous research also justifies my methodological choices, which have been published in peer-reviewed, high-quality international journals (Table 12).

Authors and dates	**Method**	**Topic**	**Title of journal**	**Scimago rank**
Lüscher and Lewis (2008)	Action research	Organizational change and the role of middle managers	Academy of Management Journal	Q1
Blair et al. (2019)	Action research	Energy: Improving electricity supply, support for decision-makers	Sustainability	Q2
Baker and Jayaraman (2012)	Action research	Energy: Production of nuclear fuel, information, and supply management	International Journal of Production Research	Q1
Tripsas and Gavetti (2000)	Extended case study	Organizational deadlock	Strategic Management Journal	Q1
Danneels (2010)	Extended case study	Dynamic capabilities and renewal	Strategic Management Journal	Q1
Bingham et al. (2015)	Extended case study	Dynamic capabilities and learning	Strategic Management Journal	Q1
Mishra and Bashkar (2011)	Grounded theory	Knowledge management processes, learning organization	Journal of Knowledge Management	Q1
Klingebiel and Joseph (2016)	Grounded theory	Innovational strategy	Strategic Management Journal	Q1
Ordanini et al. (2018)	Grounded theory	Technology and innovation	Journal of Service Management	Q1
Cassia et al. (2012)	Case study and grounded theory	Strategic innovation and product development	International Journal of Entrepreneurial Behaviour & Research	Q1
Carrero et al. (2000)	Case study and grounded theory	Radical innovation, learning, and adaptation	European Journal of Work and Organizational Psychology	Q1

Table 12. Some previous research, in a similar topic, justifying the methodological choices

Source: *own construction*

4.2 Research model

4.2.1 Action research

4.2.1.1 The goal of the action research

Action research is a participation-based and empirical process, which implies a continuous iteration between the social actions and the research, analysis of the actions. Thus, action research connects the theory and the practice, and it generates new knowledge and change to solve complex problems. (Lewin, 1946; Reason, 2001; McNiff, 2013)

As I pointed it out above, based on the literature, action research is a useful tool in management research (Lüscher & Lewis, 2008; Susman & Evered, 1978), and it can be applied in the energy sector as well Blair, et al., 2019; Baker & Jayaraman, 2012).

My action research is close to the concept of collaborative research (Heron, 1996) since, I connect theory and practice in the field of power-to-gas technology development primarily together with my supervisor, and secondarily with energy, engineering, and IT researchers and professionals. As an action researcher, I am fully engaged in the processes of the power-to-gas technology development and the organizational changes in the focus my own PhD research, the goal of which is the development of the previously described, theoretical, propositional knowledge through practice and gaining experience.

Taking into consideration the guidelines of McNiff (2013), I have to define

a) what am I doing?
   I deal with organizational change, change management, and innovation within the energy sector.

b) how am I doing it?
   I focus on the development of the power-to-gas technology.

c) why am I doing it?
   My goal is to contribute to sustainability efforts on a national, or even regional level.

My overall goal is to support the upscaling of power-to-gas technology to commercial-scale. Due to the complexity of this goal, I had to narrow the focus, therefore, through my PhD research I assess the management models of organizational change induced by the development of the disruptive power-to-gas technology.

4.2.1.2 The process of the action research

Since my research primarily focuses on organizational change and change management from the management sciences, I built my action research process on the three-stage model of Lüscher and Lewis's (2008) research also focused on organizational change and published in the Academy of Management Journal. In the case of my PhD research, the three stages of the action research are the following:

1. During the *preliminary fieldwork* phase, I studied the lessons of the literature about the transformation of the international energy sector, the international actors, projects, and Hungarian opportunities of the P2G industry, with document analysis and qualitative content analysis.

   The results of this research phase were published in 2018 and 2019.

2. During the *intervention* phase, the focus was on the development of the power-to-gas technology and the related organizational changes. The central extended case study of the technology development company, Power-to-Gas Hungary Kft was conducted in this phase. Peripheric cases were also explored in this stage, as well. For the preparation of the case studies
   a. semi-structured interviews were conducted
   b. public and confidential company documents were analyzed for the triangulation of the primary interview data
   c. iteration occurred between theory and data, preparing the third phase.

   This phase of the research was ongoing between 2018 and 2020, results were published in 2019, 2020, and 2021.

3. During the *theory-building* phase, I synthesized the empirical results with previous theories. To enhance validity, I presented the conclusions to additional

researchers and professionals from the fields of engineering, biotechnology, management, or IT and stakeholders who were involved in the action research. The conclusions were finalized based on their feedback.

This phase of the research started in 2020 and ended in 2021, which means that the intervention and the theory-building phase were parallel – in line with the methodology.

4.2.2 Case studies

4.2.2.1 Extended case study

I conducted an extended case study in the case of the central technology development company. Based on Burawoy (1998) and Daneels (2010), an extended case study can be characterized by the following considerations:

a) It focuses on getting to know a company in-depth, emphasizing the history of the company as well, not just analyzing the present.
b) The use of quantitative and qualitative data sources, as well as not only current but also archival company documents are analyzed.
c) During the interviews, emphasis is placed on looking back, reviewing the events chronologically and exploring their circumstances.
d) Data from a longer study period are analyzed and compared with the theory, from which theoretical constructs are derived. These are finalized by reinterpreting the data and comparing it with existing theories, by collecting new data, and creating new constructs when the points of the data and the theoretical framework show a solid fit.

Therefore, conducting an extended case study is about the in-depth, historical analysis of the company in which there is continuous change, interaction between (1) the theory and the analysis of the empirical data and (2) empirical data analysis and empirical data collection (Burawoy, 1998; Danneels, 2010). Compared to grounded theory, the requirement for continuous iteration and the theoretical-analytical notes to do so is a similarity between the two methods. It is a difference, however, that the extended case study builds the theory on the in-depth and retrospective exploration of a company, while in grounded theory there is no such requirement, rather construction based on empirical data is emphasized (a) based on Strauss and Corbin (1998) in an abductive way, through a well-structured process and compared with the theory; (b) based on Glaser (1992) only in an inductive way, freely and without utilizing the existing theories (categories from the former literature) (Mitev, 2012; Kucsera, 2008).

Based on the criteria of Miles and Huberman (1994), the central technology company is relevant based on the information intensity. This is justified by to factors:

a) Methodological relevancy: Conducting an extended case study is possible only if enough information is available.
b) Sectoral relevancy: Based on the international P2G projects, usually there is a central technology developer company, which is the "engine" of these projects.

As the extended case study method is applied within the framework of action research, this means, that I could not only get insights into the former activities of the company from interviews and documents, but I also participated in most of them.

4.2.2.2 Supplementary, peripheric case studies

Based on Miles and Huberman (1994) the following aspects seemed to be important to choose peripheric case studies:

a) The critical case and the theoretical choice are relevant due to my practical, functionalist position since the goal is not only to deeply understand a phenomenon but to expand on already existing theories and to explore logical connections as well. To define key practical viewpoints, I analyzed the power-to-gas literature.
b) In order to ensure triangulation and a multilateral approach, a combined, mixed case selection was warranted.

c) The aspect of homogeneity and typical cases appears in the case selection in the sense that the results of peripheric cases should be summarized, to support functionalist theory building.[16]

Based on the above, the results of the peripheric case studies are summarized and compared, and their conclusions are determined by comparing results to former theories and synthesizing with them.

From a practical viewpoint of the research question, which deals with the commercial-scale implementation of the P2G technology, I focused on the potential sites for P2G implementation during choosing peripheric case studies. Between 2018 and 2020, I contacted the following potential sites with my research fellows:

a) agricultural biogas plants (ABPs)
b) wastewater treatment plants with biogas plant (WWTPs)
c) bioethanol plants (BEPs)
d) industrial plants with CO_2 emission (e.g., power generation, petrochemicals, cement plant) (INPs).

The reason for contact these types of plants as in the case of ABPs, WWTPs, and BEPs, the CO_2 input for methanation can be provided with an easily and efficiently useable carbon source (the CO_2 content of the biogas and pure CO_2 can be sourced from the exhaust stream of the fermentation during bioethanol production (Laude, et al., 2011)), in the case of INPs CO_2 must be captured from flue gas with Carbon Capture (CC) technologies, for example, at a cement plant (Chauvy, et al., 2020).

Figure 17 presents the environment of the peripheric case studies based on the site-selection aspect. The figure illustrates the input connections of a P2M plant at different sites, showing how CO_2 can be sourced for the power-to-methane process.

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[16] It was not relevant to choose *politically important cases* because it was not my goal to draw this kind of attention; nor *randomness,* since my research did not aim at statistical validity; nor *convenience* (Miles & Huberman, 1994)*,* since I continued my research until the perception of theoretical saturation (Glaser & Strauss, 1967).

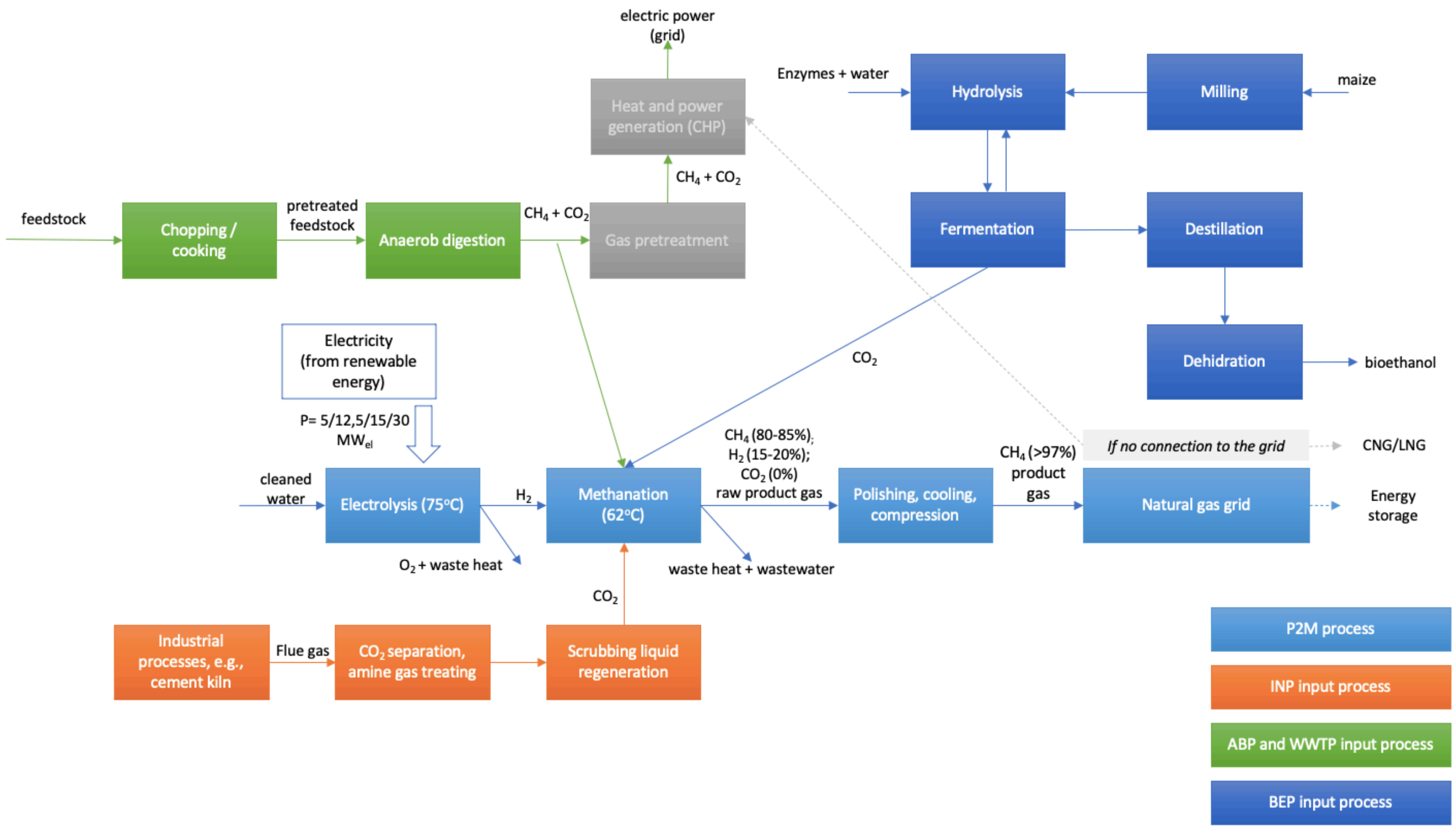

Figure 17. Power-to-methane process at different sites
Source: (Pörzse, et al., 2021)

4.2.2.3 Number and context of the case studies

In line with my fundamental position as a research, I combined the in-depth understanding of one company (P2G technology development) with the high-level analysis of 14 companies (potential sites for P2G) (Figure 18). While in case of the P2G technology developer company, I could study the topic from the aspects of management and organization, the 14 potential sites provided important data regarding the challenges and opportunities of P2G implementation, to which the central technology developer must react somehow. This means that I could examine the research area with "inside-out" logic with the extended case study, and with "outside-in" logic with the peripheric case studies.

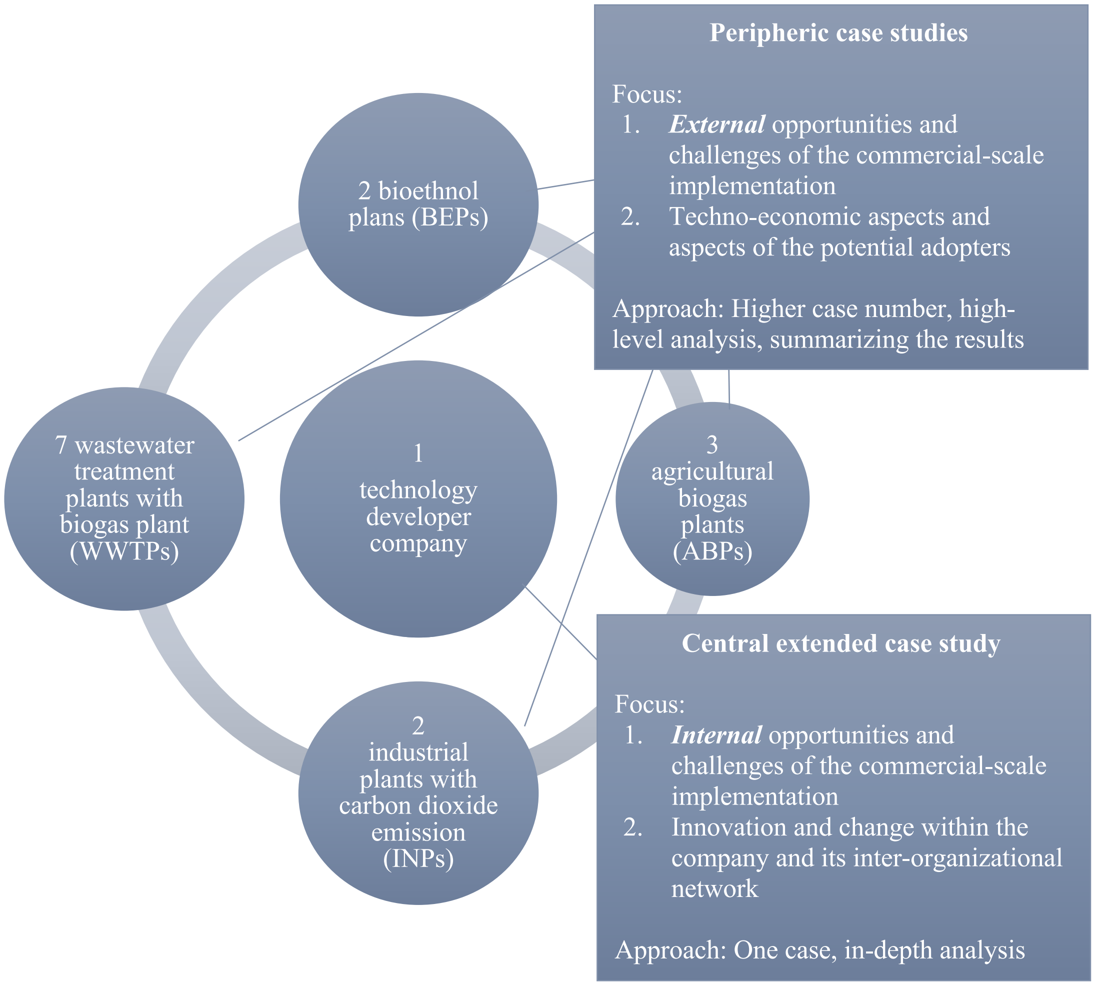

Figure 18. The logic behind case studies

Source: own construction

4.2.3 Emerging research sub-questions based on the iteration of data collection and theory

Richard (2005) points out that qualitative research cannot start without a plan either, thus, a conceptional question (for example to answer what I want to learn from the research) is needed (Agee, 2009). On the other hand, based on Creswell (2007), qualitative questions arise and change constantly. Combining these two aspects, I developed the question structure following Agee's (2009) recommendations:

1. A comprehensive research question, which was the research question described in the introduction. This guided my entire PhD research.
2. 'Dialogue' between the theory, the empirical research, and the research questions, i.e., the theoretical framework shapes the interview questions. This fits my data analysis methods (the coding process of the grounded theory described by Strauss and Corbin and conducting an extended case study).

Based on the research gaps of the power-to-gas literature and my theoretical framework,

1. I aimed a prior inductive understanding in two topics during the preliminary fieldwork phase which can orient the case studies;
2. three research sub-questions oriented the case studies (Q1-3) during the intervention phase, which were useful to answer the main research question (Q4) (Table 13).

Through the research, it was an important goal to empirically analyze the central topic and the main research question from several perspectives of the theoretical framework and the P2G-specific literature along the research sub-questions, thus supporting theory building.

<table>
<tr><th colspan="2" rowspan="2"></th><th colspan="2">P2G-specific research questions</th><th rowspan="2">The phases of action research</th></tr>
<tr><th>Complementing techno-economic analyzes with strategic aspects</th><th>Assessing management aspects</th></tr>
<tr><td rowspan="4">The main components of the theoretical framework</td><td>Environmental change and resource-based theories</td><td>Topic 1: Relevant external characteristics and changes in Hungary from the aspect of the focal technological innovation</td><td>Topic 2: Resources and other organizational characteristics of smaller and larger energy companies in the sector</td><td>Preliminary fieldwork: Empirical research prior to case studies</td></tr>
<tr><td>Technology development, innovation, disruption</td><td>Q1: What changes are needed for the widespread, commercial-scale application and the disruption of the technological innovation?</td><td></td><td>Intervention: Peripheral case studies</td></tr>
<tr><td rowspan="2">Innovation and innovation management

Knowledge management through the lens of strategic ambidexterity

Strategic co-operations</td><td></td><td>Q2: What innovation management tasks must be conducted to reach the widespread and commercial-scale implementation of the potentially disruptive technology in the relation system of explorative and exploitative activities?</td><td rowspan="2">Intervention: Extended case study</td></tr>
<tr><td></td><td>Q3: What organizational changes are induced by the focal innovative technology development within the stakeholder organizations?</td></tr>
<tr><td>Theoretical focus</td><td>Change management</td><td colspan="2">Q4: What organizational changes are induced by a disruptive energy technology development (power-to-gas technology development), and what models can be used to lead these changes for the widespread, commercial-scale implementation of the technology?</td><td>Theory building</td></tr>
</table>

Table 13. The emergence of research sub-questions through the research

Source: own construction

Naturally, while conducting the case studies, more specific questions arose regarding the sub-questions, these will be presented in the following chapters.

4.2.4 Presumptions for the research questions

In accordance with the qualitative methodology and action research, I did not define hypotheses, but theoretical, propositional knowledge (hereinafter: presumptions) for the research sub-questions and the main research question. This is because in case of action research, it is important to support practice with existing theories, but also to develop new theories that are built on practical experience. (These new theories or conclusions will be the theses of my dissertation.) (Coghlan & Brydon-Miller, 2014)

In the following, I briefly present these presumptions (P1-4) to the research questions (Q1-4), based on the literature findings presented in Chapters 2 and 3.

The preparation of the case studies was guided by (1) the prior results, (2) assessing every aspect of the main research question, (3) the P2G-specific research gaps identified in the literature. Thus, the peripheral case studies focused on not only the technical and economic aspects but also on the aspects concerning the strategy and disruptiveness of the wide-ranging, commercial-level application, in accordance with the following research sub-question:

Q1: What changes are needed for the widespread, commercial-scale application and the disruption of the technological innovation?

The research sub-question is answered by preparing and summarizing 14 peripheral case studies, and the following assumption was determined:

P1: The focal technology may become disruptive based on the literature results (Christensen, et al., 2015). The widespread and commercial-scale implementation of a potentially disruptive technology requires organizational changes at the companies that apply the focal technology. This is because technology is a substantial organizational characteristic in the examined organizational context (Dobák, 2002), which changes (must change) due to the implementation and this affects the other substantial organizational characteristics as well.

After an "outside-in" approach to peripheral case studies, the extended case study of the technology developer startup is completed with an "inside-out" approach, which includes two research sub-questions. One of the questions of the extended case study was the following:

Q2: What innovation management tasks must be conducted to reach the widespread and commercial-scale implementation of the potentially disruptive technology in the relation system of explorative and exploitative activities?

In line with my research framework, the presumption to the research sub-question is built on the importance of explorative and exploitative learning, moreover, digital innovation and knowledge management.

P2: In order to seize opportunities and address challenges, innovation management tasks, especially idea management, development, learning, and resource and competency management may be required (Tidd & Thuriaux-Alemán, 2016), the efficiency of which can be enhanced by digital innovation management (Nambisan, et al., 2017) and open innovation (Chesbrough, 2003), knowledge and technology transfer (Millar, et al., 1997) between startups and large organizations with complementary resources (innovative core technology – extended infrastructure and resource basis). The determinants of learning and resource and competency management are knowledge management mechanisms that enhance exploitation and / or exploration (March, 1991; Grant, 1996), and these can be supported by digital solutions that enable codification, systematization, sharing, and utilization of knowledge (Alavi & Leidner, 2001; Zhang & Venkatesh, 2017).

The third research sub-question was focused on the organizational changes:

Q3: What organizational changes are induced by the focal innovative technology development within the stakeholder organizations?

Based on the literature, the realization of the innovation (as a process) and the realized innovation (as an output) can also generate organizational changes, and the adaptation can be supported with partnerships with other organizations.

P3: Among the organizations involved, there will be some that need organizational change for innovation purposes (Teece, et al., 1997; Kotter, 2012), while - through partially open innovation processes (Chesbrough, 2003) - the achieved innovation goal will generate organizational changes in other organizations (Csedő, 2006; Hammer, 2004).

Along the three research sub-questions presented, I approach my research topic from several sides:

1) environmental change and strategic alignment;
2) resource-based examination;
3) examination of technical, economic, strategic issues and disruptiveness;
4) technology-specific innovational opportunities and challenges;
5) innovation management tasks;
6) organizational changes.

The aim of the multilateral approach is to ensure that the answer (theory) to the main research question is sufficiently nuanced and that the context in which the substantive theory is valid can be determined (Glaser & Strauss, 1967).

Main research question (Q4): What organizational changes are induced by a disruptive energy technology development (power-to-gas technology development), and what models can be used to lead these changes for the widespread, commercial-scale implementation of the technology?

Based on the assessment of change management theories and their interpretation, I define the following presumption, which can be supplemented based on the case studies and using the coding technique of grounded theory:

> P4: Disruptive energy technology development (power-to-gas technology development) can lead to incremental and/or radical organizational changes. The changes induced by technology development can be managed according to the following models: (1) top-down organizational planning and type "E" change, (2) bottom-up organizational development and type "O" change, (3) combined model (one top-down down and a bottom-up element each) or (4) an integrated model (integration of bottom-up elements into the dominantly top-down process). (Dobák, 2002; Beer & Nohria, 2000; Csedő & Zavarkó, 2019b)

4.3 Methods of the empirical research prior to the case studies

The purpose of the empirical studies prior to the case studies was to understand the following topics:

- Relevant external characteristics and changes in Hungary from the aspect of the focal technological innovation
- Resources and other organizational characteristics of smaller and larger energy companies in the sector.

4.3.1 Preliminary document analysis

I used document analysis for getting to know the environment and as a part of triangulation (Bowen, 2009), meaning that I analyzed the organizational phenomenon through document analysis alongside other methods (Denzin, 1970) in order to increase the credibility of my research (Eisner, 1991). The preliminary document analysis was focused on the European and the Hungarian energy sector, their trends, goals, and characteristics. During this, I searched for data that can determine the innovation potential of P2G in Hungary.

As a researcher utilizing document analysis, I had to be aware of the pros and cons of document analysis. Although document analysis is a time- and cost-efficient solution, it is an easily accessible, stable, and precise data source, and allows the understanding of several areas or phenomena, its drawback is that it often does not contain enough details. The document might cease to be available and if the content of a document has been produced in accordance with corporate policies and interests, it can lead to biased conclusions in an organizational environment (Bowen, 2009). Consequently, I needed other data sources in the intervention phase, as well.

4.3.2 Qualitative content analysis of documents

The goal of the qualitative content analysis to explore what innovation management-related resources and organizational characteristics appear at a smaller technology developer startup and a large energy company. This is relevant because the theoretical framework suggests that their collaboration can be important to achieve innovation goals.

Building on the empirical data, the qualitative content analysis can lead such conclusions which can orient further empirical research.

I identified three other innovative startups besides Power-to-Gas Hungary, which participate in the technology development of biological methanation: Electrochaea, Microbenergy, and Krajete. However, this was only one side of the research, because, based on the scientific literature review, power-to-gas technology development and implementation can be effectively realized through cooperation initiatives between smaller and larger energy companies. So, I chose five large energy companies to analyze deeper, which are significant market players in those regional energy sectors in which power-to-gas startups operate and are interested in renewable technologies and biomethanation based on their strategy and previous activities. I conducted a qualitative content analysis on more than 250 pages of publicly reachable corporate documents and communication (annual reports, strategies, websites, online communication, and articles) of the listed firms. I followed the method described by Zhang and Wildemuth (2009) during the analysis:

1) Preparing the data: I analyzed publicly reachable written documents, so after the collection and selection, further preparation was not needed.

2) Defining the unit of the analysis: The aim was to identify words, expressions, and sentences that imply the context (e.g., goals, activities, resources) of innovation management because innovation management is the main topic of the research.
3) Developing coding scheme: Inductive coding logic was followed, which means that I defined categories and codes based on the data. Nevertheless, the categories and codes were later fine-tuned according to the theoretical background.
4) First-round coding: We coded the documents of one smaller power-to-gas technology developer company.
5) Testing the coding scheme and fine-tuning: After that, I tested this categorization and coding scheme on the documents of one larger energy company and of another smaller power-to-gas technology developer company. I found new emerging categories and codes, moreover, there were some inconsistencies in the coding scheme, that is why we revised and fine-tuned it.
6) Coding all the documents: Using this coding scheme we coded all the documents and recoded the previous ones.
7) Assessing coding consistency: Among the codes, there were numerous similarities and overlaps, consequently, I needed to terminate redundancy.
8) Draw conclusions from the coded data: During the coding process, I identified clear connections between the two main categories and the codes, and that is why we also separated clearly the codes of smaller and larger companies. The findings were finalized and summarized in two tables presented in the Results section.

I used qualitative content analysis with the aim of identifying the meanings, interpretations, even narratives, produced in the given organizational context, regarding the key notions in the focus of my research. I am convinced that the most thorough understanding of the meanings supports the understanding of the phenomena, including the exploration of the connections. (Zavarkó, et al., 2018)

4.4 Conducting extended case study at the technology developer company and its methods

4.4.1 Presentation of the company

The main characteristics of the company serving as the environment for the extended case study are as follows:

a) Power-to-Gas Hungary Kft. is a startup company established in 2016.
b) In 2018, the company created its own P2G (P2M) prototype in cooperation with the German biotechnology company Electrochaea.
c) The prototype works with polymer electrolyte membrane electrolysis (PEMEL) and biological methanation technology.
d) The biological methanation is carried out by a patented biocatalyst, which is a robust, highly selective archaea strain (Methanothermobacter thermautotrophicus). This archaea strain was discovered at the University of Chicago by Professor Laurens Mets (Mets, 2012).
e) The structure of the prototype is the same as the world's largest biological methanization P2G plant (1 MW_{el}) to date, which was also developed by the German biotechnology company, Electrochaea. This plant started operations in 2016 in Avedøre (Denmark). In addition, a 700 kW_{el} plant established in 2019 in Solothurn (Switzerland), at one of the sites of the STORE & GO project funded by the European Union also uses this technology,
f) Power-to-Gas Hungary Kft. participates in planning industrial-scale P2G plants throughout Central and Eastern Europe
g) The company has been operating its prototype since 2018, with which it also carries out scientific and industrial R&D&I activities. (Csedő, 2020)

Further activities of the company are described in the Results section based on the research aspects.

4.4.2 Presentation of the technology

The prototype of Power-to-Gas Hungary Kft. is a scaled-down operational unit with mass and energy flows in proportion to the commercial process of P2G, and also contains functions to carry out research and development (R&D) in the field of P2G. The commercial-scale P2G plants can produce a gas mixture that meets the requirements of natural gas standards. The applied process consists of three main steps. (Csedő, et al., 2020)

(1) In the power-to-hydrogen (electrolysis) step, the plant would use surplus electricity from the electric grid (Mazza, et al., 2018) and produce hydrogen (with oxygen as a byproduct), in line with the chemical reaction below:

$$4H_2O \rightarrow 4H_2 + 2O_2 + Heat$$

Hydrogen is going to be used in the next P2G step (methanation). The oxygen byproduct can also be also used, for example at WWTPs, where the efficiency of the aeration system can be increased by injection of oxygen into it (Schäfer, et al., 2020).

(2) In the methanation step, the CO_2 content of the biogas (typically 30–50%) or CO_2 from flue gas is converted to methane, carried out by basic reactions and mediated by the biocatalyst employing a unique set of enzymes (Ferry, 1998):

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

If biogas is used for the process, methane and carbon dioxide gas components are not separated in this process, and the biogas is injected to the continuous stirred-tank reactor along with hydrogen, unlike biogas upgrading (Lovato, et al., 2017). Mass-flow rates are set to maintain the stoichiometric ratio of H_2 and CO_2 (increased, 4.1:1 in practice, because of the 23 times lower dissolution of H_2 than CO_2 in water).

(3) In the injection step, the product gas, in which the guaranteed purity of methane is more than 97%, is injected into the natural gas grid, but before this a polishing process (segregation of hydrogen gas compound, removal of water vapor, cooling) is needed. (Csedő, et al., 2020)

4.4.3 Data collection and analysis

To prepare the extended case study, I conducted semi-structured interviews and performed document analysis.

The interviews and the document analysis were guided by the following, previously introduced, research sub-questions:

> What innovation management tasks must be conducted to reach the widespread and commercial-scale implementation of the potentially disruptive technology in the relation system of explorative and exploitative activities?
> What organizational changes are induced by the focal innovative technology development within the stakeholder organizations?

More specific questions have been raised continuously during the action research.

4.4.3.1 Conducting semi-structured interviews and their analysis

For me, conducting semi-structured interviews is an important tool for understanding the challenges and the opportunities. Barriball and While (1994) point out that semi-structured interviews

a) grant more information than questionnaires
b) are suitable for identifying values, beliefs, motivations, and attitudes
c) give an opportunity for evaluating the credibility of the answers (by observing the nonverbal clues of the interviewee)
d) are really exploring the opinions of the individual since they cannot ask guidance from others in answering the question asked in the given moment.

Semi-structured interviews also have potential dangers, to which the researcher must pay attention. For example, the researcher may deduct from the data something other than what the respondent wants to suggest or reveal. Consequently, it is crucial to ask back or for details in a subtle manner, to examine the background information, through which additional valuable information can be obtained, and the real organizational problem can be observed, and the potential contradictions in the answers can be identified. (Barriball & While, 1994)

As action research frames my PhD research, I could contact not only the employees of the technology developer company, but many potential or current partners, and other stakeholders (e.g., a supplier), with my research fellows:

1) large energy companies
2) technology companies operating in other fields (e.g., information technology)
3) financial institutions
4) universities, research centers and other nonprofit institutions.

This is in line with the consideration presented it in chapter 3.2.1 that collaborations and networks can be important in innovation processes, which was can be justified by the literature and the industry practice, as well, and it appeared in my theoretical framework as well. Based on the above, the extended case study did not only mean exploring the activities and changes of a single organization but analyzing the development of connections to other organizations was also possible.

When choosing the subjects of the interviews with external stakeholders, the most important criterion was the theoretical sampling, the high-level decision-making authorization, leading a business or functional unit, or research area. Consequently, the top managements of the stakeholder organizations were interviewed. The length of the interviews was usually 1 hour. Audio-recording the interviews was not possible, so I made notes about what had been said. As this 1 hour was not always enough to explore a topic fully, I followed the practices seen in the literature, and occasionally I clarified the questions with interviewees in email, while asking the help of my research fellows (Daneels, 2010; Bingham et al., 2015).

In line with the extended case study method, I analyzed the data in iteration with the theory, which affected the further data collections as well. The logic of the data analysis of the extended case study is presented in Figure 19:

Figure 19. Data analysis of the extended case study

Source: Danneels, 2010

In the case of semi-structured interviews, having multiple interviewers can help maintain the challenging balance between flexibility and consistency (May, 1989), which was provided in my case, as I had research fellows and my publications have been co-authored, and I involved external researchers in the data collection, data analysis and the discussion of the results, as well.

4.4.3.2 Document analysis

Regarding the document analysis, I primarily strived to obtain and analyze confidential company documents, but publicly reachable documents were also relevant, as the document analysis was applied as the part of triangulation, as a supplementary data source. This meant the analysis of more than 300 pages of confidential and publicly reachable documents, which supplemented the primary interview data and oriented the iteration with the theory. I could analyze the following types of documents:

a) Documents for initiating, preparing innovation, technology development projects
b) Feasibility studies
c) Project reports
d) Technology descriptions
e) Notes about technological problems and opportunities for the solution
f) Meeting memos. (Csedő & Zavarkó, 2020)

4.5 Conducting peripheric case studies at potential sites and its methods

The peripheral case studies were guided by the following research sub-question:

> What changes are needed for the widespread, commercial-scale application and the disruption of the technological innovation?

4.5.1 Data collection

In this phase, I collected data from potential sites to identify

a) sites where the infrastructural, input, and output conditions are adequate for the establishment of a commercial-scale biomethane plant,
b) the assessment criteria of site managers as potential users for P2M, and competing solutions (if there are any).
c) site-specific factors, the development of which could increase the feasibility of a commercial-scale P2M unit.

The data collection began after the *preliminary fieldwork* phase and lasted from 2018 to 2020.

4.5.1.1 Semi-structured, focus group interviews

Based on infrastructural opportunities and availability of the top management, conducting semi-structured interviews with my research fellows was possible at 14 potential sites including interviews with managers and on-site consultations with expert-level site-operators.

The data collection process contained the following steps:

a) Prior evaluation of the P2G technology relevancy with the Chief Technology Officer or the Technical Director;
b) An in-depth presentation of the P2G technology and identification of the commercial opportunities with the Chief Executive Officer or the top management team;
c) Collecting reachable techno-economic data and documentation;

d) On-site techno-economic data collection and consultation with expert-level employees. (Csedő, et al., 2020)

Involving the lower-level employees appeared in former research with similar topic and method, as well, as a complementary viewpoint to the top management statements in strategic questions (Mishra & Baskhar, 2011; Klingebiel & Joseph, 2016; Tripsas & Gavetti, 2000; Bingham et al., 2015, Ordanini et al., 2018), but in my case, it was also relevant because of the concrete technical characteristics.

In some cases, more than one top manager or expert were interviewed at once. In these cases, I paid attention to the methodological considerations of focus group interviews, based on Kitzinger (1995) and Vicsek (2006), especially:

a) Those actors were involved, who are the stakeholders of the projects (e.g., financial director, technical director, site manager)
b) When I made an interview together with one of my research fellows, I tried to play a facilitator role to support the discussion about those technical questions which are related to economic and management aspects and are fundamental for the implementation.
c) A guideline was created with the main questions for the site-specific characteristics, which structured the conversation and allowed for comparison between the group interviews.

The interviews and the on-site tours were usually 1-1 hour long.

The present the cases of wastewater treatment plants (WWTPs) separately as well in the Results section because of their higher number in the sample (7), to show the standardization opportunities of the P2G implementation.

4.5.1.2 Data requesting forms

Besides the interviews, I sent data requesting forms to the potential sites, which were focusing on the technical analysis of the technology implementation.

4.5.2 The content of the interviews and the forms

The data collection structure of the peripheral case studies is presented in Table 14. For reasons of confidentiality, respondents provided specific financial data only in the form of trends or by highlighting opportunities and challenges.

Data	Technical, technological, infrastructural	Economic, commercial, investment related
General (Chief Executive Officer / Executive and Director level)	• Technology and infrastructure development plans and their motivations • Other emerging technologies such as options and their expected value creation	• Openness towards technological innovation and collaboration • The value-creating potential of P2G regarding these plans
	• Power supply network, from existing or planned photovoltaic capacities • Water supply • CO_2 input • Prospective location of the P2M unit and local infrastructure connection points (e.g. for biogas plant or wastewater treatment plant) • Connection to the natural gas system • Potential of utilizing by-products (waste heat, oxygen)	• Financial situation • Current biogas utilization in the case of biogas plants • Current or planned infrastructure developments, potential synergies with P2G technology
Specific (director and expert level)	• Connection to the power network (e.g. electrical voltage) • Connection to the natural gas network (e.g. distance from the plant) • Water and wastewater (e.g. treatment technology) • Technological and infrastructural links (e.g. current or planned use of waste heat) • Potential for expansion (e.g. geographical environment, transport links) • Site-specific issues (Detailed in Appendix 3)	• Free capital to be mobilized for investments • Current contracts that determine energy costs • Currently generated income or costs saved by using biogas in the case of biogas plants

Table 14. The structure of data collection for peripheral case studies

Source: Based on Csedő, et al., 2020

4.5.3 Data analysis

While qualitative data were emphasized in the extended case studies, quantitative techno-economic analyzes came to the fore in the peripheral case studies. This is also in line with my basic position in organizational theory and research strategy, based on which I assess the examined organization and its relationships in-depth, but I also examine quantitative factors in a larger sample in connection with the specific implementation. As part of this, technical and economic analyzes and scenario analyzes were carried out, the most relevant parts of which can be found in the Appendix.

Like the qualitative data collected during the extended case study, I also analyzed the qualitative data collected during the peripheral case study by iterating and comparing it with the theory, I formulated conclusions based on this and thus I present them in the Results chapter as well.

4.6 Theory building with the coding technique of the grounded theory

I chose the triple coding system of grounded theory as a method of data analysis for theory building. The qualitative content analysis prior to the case studies is similar to grounded theory because they are both based on field research, allow the use of multiple data sources, require systematic data analysis, and focus on identifying categories and topics during coding. The main difference is that the goal of qualitative content analysis is to deeply understand the meaning of the material, the background of notions, word choice, while grounded theory aims at theory building from empirical data (Glaser & Strauss, 1967; Cho & Lee, 2014).

One reason for choosing the coding technique of grounded theory is that grounded theory can successfully be applied in management research (Locke, 2001), and in relation to innovation (Lowe, 1995), and managerial intervention, change management (Partington, 2000). Although Partington (2000), Douglas (2003), and also Mitev (2012) point out that grounded theory is not yet a widespread tool in management research, in agreement with the authors cited, I support the integration of grounded theory considerations into research on organizational phenomena as a tool for theory-building based on qualitative research. The answers to the research questions are based on the description of grounded theory applicable to business-related research presented by Douglas (2003). I use a systematic method with grounded theory coding technique, the emphasis of which is the continuous comparison of data and categories (Glaser & Strauss, 1967). The key to this is that I take theoretical notes, not only during data collection, but also during data analysis, which allow the ideas, categories, and concepts to be compared again and several times with the data (Mitev, 2012).

The process described by Douglas (2003) and followed by me – of the markedly divided grounded theory approaches – is closer to the approach of Strauss and Corbin (1998): following coding stages (open, axial, and selective coding), allowing the use of previous literature concepts (Mitev, 2012). Open coding means the identification of codes from data, in the case of axial coding these codes are grouped, while selective coding filters and reinterprets the codes according to the central code (concept, theory) (Douglas, 2003). Following this coding process is necessary because in using the coding techniques of grounded theory – based on my research position – I aimed to take into consideration the already existing theories, therefore, the phases prescribed by Strauss and Corbin (1998) could be the appropriate methodological basis, while the process of Glaser (1992), focused only on data, could not (Mitev, 2012). Since the grounded theory is a data analysis rather than a data collection strategy (Mitev, 2012), when defining categories and constructing theory, I built not only on the interviews but on the results of the document analysis as well, thus strengthening empirical theory building (Glaser - Strauss, 1967).

The data analysis was not strictly separated from data collection, and initial results had an impact on the questions of further interviews until theoretical saturation is achieved. A part of this is that note-taking is continuous not only during data collection, but during data analysis as well, which contained numerous rudimentary theoretical concepts, literature connections to support theory building. It is important that I also point out that by following the coding method of grounded theory, I could produce a substantive theory valid in a limited social context, not a more abstract, formal, general theory (Glaser – Strauss, 1967). My aim was to explore interrelations that are valid according to the grounded theory coding method, accepting the statement that a theory can be built on systematic qualitative research (Mitev, 2012). Consequently, in a positivist sense, the new theory is not valid because it is not tested and proved (by me) by statistical methods, but this may be a research direction.

In accordance with the works of Strauss and Corbin (1998), and Douglas (2003), the following process of the coding technique of grounded theory was applied:

1. Open coding
    a. First phase
        i. I selected in vivo codes from my notes and answers to the questions which were related to management in a broader sense, as technical data were frequent because of the action research and the research topic. Examples: “technology”, “innovation”, “risk”, “analysis”, “energy storage”, “investment costs”, biomethane”, “development”, “financial background”, “regulation”
        ii. I defined 1-2 main messages based on the interviews, the essence of the interview, even its hidden content. Example: “The uncertainty in the regulatory environment makes financial planning difficult.”
    b. Second phase
        i. Then the data was recoded, through which I defined only one new code, occasionally “open label” code, examining also the code recorded in the previous section. Example: “regulatory environment”
        ii. After this, I redefined the lesson based on the comparison of the previous and the new codes, but I defined messages regarding the main topic of the research. These help to orient the next phase of coding. Example: “The supporting regulatory environment can be key to exploit the innovation”
2. Axial coding
    a. In this coding process, I listed all the codes under each other and then defined another code of a more comprehensive nature next to the codes. Examples: the “collaboration” word for the “joint development”, “partner”, “reconciliation” words
    b. I filtered out codes that were very different from the others and could not be classified into any comprehensive category from the perspective of my research question. By filtering out irrelevant codes, the theoretical focus is enhanced.

    c. Finally, I determined a couple of categories based on the comprehensive codes, and I also listed these comprehensive codes into the categories in a tabular form. Examples: "change inside the organization", "change outside the organization", "innovation network", "open innovation"
3. Selective coding and theory-building
    a. I compared the results of the open and axial coding with the results of the literature and with the previous models.
    b. This was an iteration process in which I utilized the notes taken during data collection and data analysis, not just the codes and categories.
    c. The aim was to create a summative model that synthesizes previous theoretical models and new empirical results. (These are the main conclusions of my dissertation.)
4. Validating and fine-tuning the model
    a. An important step regarding the validity and reliability of the model was to validate the conclusions with the participants.
    b. In this step, I considered the reviewer feedbacks for our published papers, and I asked my research fellows and professionals from engineering, biotechnology, management, and IT areas about the correctness of the conclusions, and I fine-tuned the conclusions according to their feedbacks.

4.7 Summary

4.7.1 Methodological framework

My considerations regarding the research methodology are based on the fact that multiparadigm research is useful for understanding complex phenomena, which in this case appears as follows:

1. In my research I built on previous research results, that are valid in a positivist sense and synthesize them with my own empirical results obtained by following a qualitative methodology.
2. I wanted to achieve functionalist research goals in a sequential way, partly with an interpretive approach.

The most important elements of my research methodology are summarized in Table 15.

<table>
<tr><th></th><th colspan="2">Relevant organizational theoretical approaches</th></tr>
<tr><th></th><th>Interpretative</th><th>Interpretative</th></tr>
<tr><td>Research question</td><td colspan="2">What organizational changes are induced by a disruptive energy technology development (power-to-gas technology development), and what models can be used to lead these changes for widespread, commercial application of the technology?</td></tr>
<tr><td rowspan="2">Research strategy</td><td colspan="2">Conducting a central extended case study and several peripheric case studies as parts of the action research</td></tr>
<tr><td>Prior inductive understanding in two topics</td><td>Answering three research sub-questions</td></tr>
<tr><td>Data sources</td><td colspan="2">Company documents, Semi-structured individual and focus group interviews</td></tr>
<tr><td rowspan="2">Data analysis</td><td rowspan="2">Preceding method:
Qualitative content analysis</td><td>Preliminary method: Techno-economic analyses based on quantitative data</td></tr>
<tr><td>Main method:
The coding technique of the extended case study and the grounded theory</td></tr>
<tr><td>Scientific measures</td><td colspan="2">Validity, reliability, and generalizability in a qualitative sense
Building a substantive theory</td></tr>
</table>

Table 15. Methodological framework

Source: own construction

4.7.2 Interviews, specific data, studying empirical and other models for theory building

The sources of the collected data, arranged according to the phases of action research, are shown in Figure 20. In addition to document analysis and data request forms, 32, approx. 1-hour long interviews were conducted, most of which I attended with my fellow researchers.

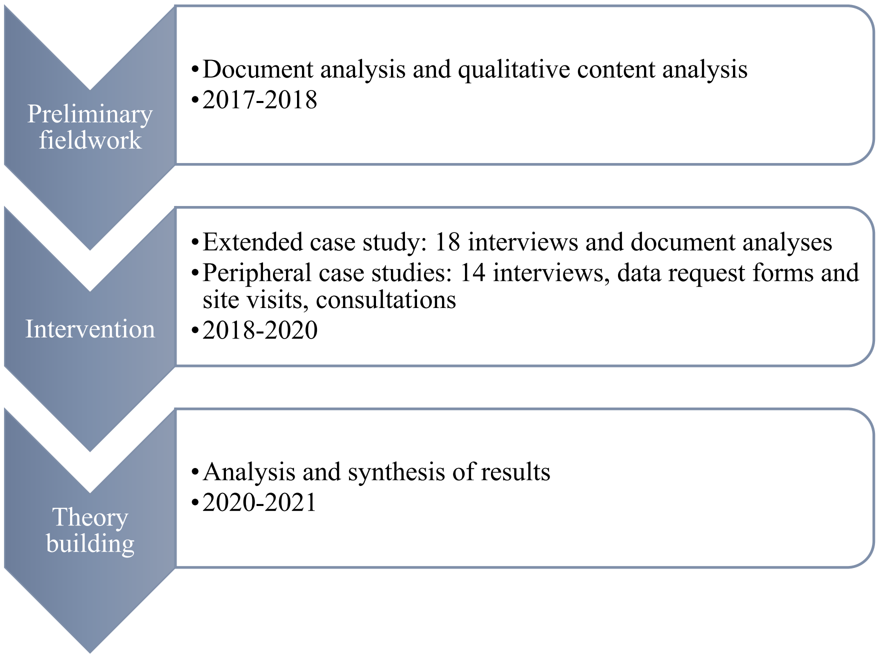

Figure 20. Summary of completed interviews and other data sources

Source: own construction

I continued to collect data until I reached theoretical saturation (Glaser & Strauss, 1967). The number of interviews is also in line with the literature samples, as research using the extended case study method and published on a similar topic in recognized international journals, e.g., Daneels (2010) conducted 17, Bingham et al. (2015) 31, Tripsas and Gavetti (2000) 20 interviews.

It is important that the technical-economic assessments are based on specific data, including the more than 30,000 measurement results generated by the prototype of Power-to-Gas Hungary Kft., and to determine the presumptions, I used the results of the recent literature, the details of which can be found in the Appendix.

Finally, it is worth noting that although the central theme of my PhD research was the relationship between change management and innovation, to build a more reliable, precise model, I extended my study (1) to the assessment of disruption and the study of the model of disruptive innovation from a management perspective, (2) and I used this with technical-economic calculations based on empirical data in the context of power-to-gas technology development.

4.7.3 Validity, reliability, and generalizability

According to Kvale (1996), the aspects of validity, reliability, and generalizability can be used to judge the acceptability of research from a scientific point of view. At the same time, as I presented it previously, in the case of a qualitative research methodology that falls closer to the interpretive paradigm of organizational theory, these positivist evaluation aspects are not appropriate. In the evaluation of qualitative research, the focus is not on verifying the end point, but on verifying the process of the research (Kvale, 1996; Csedő, 2006; Mitev, 2006). In the qualitative approach, therefore, a reinterpretation of these evaluation criteria is required, which

a) in the case of validity, means the thorough exploration of the context, phenomenon, meanings,
b) in the case of reliability, means the drawing of similar conclusions by other researchers,
c) in the case of generalizability, means the applicability of the theoretical models in a different context. (Gelei, 2002; Mitev, 2006)

In line with the above, I took the following steps to improve the validity, reliability, and generalizability of my research:

a) Validity
    a. I used triangulation for both data collection and data analysis tools.
    b. I considered practices and suggestions of former research published in high-quality international journals.
    c. A collected empirical data until I reached theoretical saturation.
b) Reliability

   a. My research and publications have been co-authored in order to increase the reliability of the conclusions.
   b. I asked for the assistance of my research fellows and supervisor in data collection, data analysis, and during the discussion of the results.

c) Generalizability
   a. Regarding the issue of generalizability, with my qualitative research approach, I only aimed for internal and analytical generalizability.
   b. This requires the careful, in-depth exploration and description of the context, identification of alternative explanations, creating my own research presumptions, and making the limiting factors of the research explicit (Miles & Huberman, 1994). This was aided by the applied methods that: while I used qualitative content analysis for preliminary understanding, the empirical data were also compared with previous literature results and theoretical models by conducting an extended case study and following the coding technique of grounded theory.

Besides the validity, reliability, and generalizability, Miles and Huberman (1994) also deal with the criteria of objectivity and usability. In a qualitative research, objectivity implies making methods, data, the process of conclusion making, personal presumptions, and possible other interpretation explicit, while usability means publishing the results and encouraging new research (Miles & Huberman, 1994; Csedő, 2006). Considering these, the theoretical framework showed my personal presumptions, interpretations about the interrelations of the focal concepts and phenomena. Moreover, I present the limitations and the future research directions at the end of the dissertation.

5 RESULTS

In the following, in line with the requirements of the chosen methodology, I present the results with literature references, as a result of iterating the empirical data with theory and previous literature findings.

The presentation of the results fits the order of the research sub-questions and the phases of the action research.

A significant part of these chapters contains the results of articles already published in international journals and written with my supervisor and fellow researchers (Csedő & Zavarkó, 2020; Csedő, Sinóros-Szabó & Zavarkó, 2020; Zavarkó, Csedő & Sinóros-Szabó, 2018; Pörzse, Csedő & Zavarkó, 2021).

When describing the results, the term "P2G" refers to the technology of Power-to-Gas Hungary Kft., and I will only distinguish between methane production (P2M) and hydrogen production (P2H) if this is justified, and I will also indicate this separately in a footnote.

5.1 Analyzing strategic and innovation opportunities based on the external environment

5.1.1 Analyzing innovation potential and strategic fit

The development of P2G technologies is in line with local industry trends and existing infrastructure. According to the new National Energy Strategy 2030, the installed capacity of electricity generating units from photovoltaic sources will exceed 6.000 MW by 2030 from ~1.000 MW of 2018 (ITM, 2020). Considering the volatility of the dominant ratio of the photovoltaic panels in this 6.000 MW (around 85%), and the planned increase of nuclear capacities, the development of commercial-scale energy storage technologies is a high priority. Even if the storage capacity of the accumulators could reach 100 MW (Keck, et al., 2019), it is an extremely small volume compared to the 6,33 billion m3 storage capacity of the Hungarian national gas grid (ITM, 2020).

In terms of CO2 sources, the theoretical P2G potential in Hungary is around 1 GW_{el}, only based on the CO2 output of anaerobic digestion plants (CO2 in raw biogas) and bioethanol plants (CO2 as a by-product) (Sinóros-Szabó, 2019). If one takes into account that Hungary imports ca. 80% of the natural gas (ITM, 2020), P2G technologies might have great importance in Hungary for commercial-scale energy storage, and also for reducing the dependence on natural gas import. (Csedő & Zavarkó, 2020)

5.1.2 Analyzing the companies of the industry from the resource-based view

Based on the energy sector-specific literature, large energy companies face innovation and renewal challenges, while the theoretical framework suggests that the renewal can be supported by external partners. This indicates the collaboration between large energy companies and P2G technology developer companies. Based on the qualitative content analysis, smaller P2G technology developer companies and large energy companies have complementary activities and capabilities.

Regarding complementarities, we found that the activities of the startups are obviously narrower, focusing on the operative development and pilot implementation of the power-to-gas technology. In their documents, they usually emphasize that they "have developed" "disruptive solutions", they "solve one of the most pressing challenges", or they "specialize in process control", conduct "scientific research", "build" or "optimize" something innovative with "experts from the fields of chemistry, biology, (bio) process engineering and engineering" resulting in the "leading method for biological methanation".

These citations indicate their focused research and development activities and the introduction of the background of their small teams highlights heterogeneity and knowledge intensity. However, they do not write about serious resources and infrastructure in contrast to large energy companies. Established, large companies highlight their vast financial resources, "complex portfolio", investment activities "in future profitable growth", or "in better future of energy". They mention their extensive infrastructure, "considerable market share" and role in "supporting economic growth", with delivering "competitive solutions" and "attentive support of customers" to "increase market and shareholder value". In sum, established, large energy companies focus their public documents and communication on their complex activities, several types of valuable resources and impact on the economic and societal environment.

Regarding the organizational characteristics, it is found – in line with the literature (e.g. Greiner, 1972, Teece, 2016) – that power-to-gas technology developer startups and large energy companies operate with different structural solutions, behavior, control mechanisms, and need for external resources. The novelty of the findings is the terms, which indicate these differences.

Power-to-gas technology developer startups often write about "research projects", "development teams", "engineering teams" and "project groups" as a part of "a dynamic early-stage company", while large energy companies have "boards" and "directorates" which "set our strategic course" and "define our policies". They also have "committees", numerous "departments" with functional labels which "cover the whole energy sector", but only "playing by EU regulations" and in an "efficient and responsible" way.

These findings indicate horizontal connections with flexibility in case of startups and hierarchical connections with top-down planning and regulations in case of large energy companies. This also determines the strict control in case of large energy companies and the profit-orientation with "optimization, cost-effectiveness" to create "an attractive dividend for our (their) shareholders".

In contrast, power-to-gas startups focus on the results of the technology development, such as "demonstrated the efficiency, productivity, robustness, and responsiveness", "patented biocatalyst", "proprietary process", "patent applications". However, while large energy companies rarely write about their "strategic partnerships with external startups", the startups often mention that they work "in partnership with" other actors or in a "network of industrial and university partners" and that they "received funding" from investors.

Based on these findings we created the following categories, subcategories, and codes, which were finalized based on the literature background. They characterize the possible cooperation and imply underlying dependencies and dynamics in the power-to-gas technology development and implementation aiming at technological innovation or a whole business model innovation. Findings are presented in Table 16 and 17. (Zavarkó, et al., 2018)

	Codes	
Subcategories	**Smaller P2G technology developer companies (Startups)**	**Larger energy companies (Incumbents)**
Activities	Technology-focused research and development Technology testing and optimizing Pilot implementation Cooperation with other institutions	Complex and wide range of activities (e.g. energy generation, supply, infrastructure development, satisfying end-customers' needs, investments, digitalization)
Human resources	Low number of employees and heterogeneous background (entrepreneurs, business development experts, researchers in natural science, researchers in management, engineers)	High number of employees and immense experience in specific functional areas
Knowledge	Specialized knowledge in renewables and natural science; holistic management knowledge	Wide and deep knowledge related to the traditional energy system; deep and separated functional management knowledge
Material resources and infrastructure	Few: Laboratory and related tools, pilot plants	Many: Financial resources, investment capabilities, large infrastructure, industry-leader experience, and dominance, production level
Main external connections	Universities, research institutes, industrial firms	State, financial investors, startups

Table 16. Category 1 – Complementary capabilities and activities (relative statements)

Source: *Zavarkó, et al., 2018*

	Codes	
Subcategories	**Smaller P2G technology developer companies (Startups)**	**Larger energy companies (Incumbents)**
Strategic goal	Disruptive innovation Competitive advantage Patents, licensable technology New approaches and solutions Scientific results and publications	Profitable growth Creating shareholder value Sustainable and responsible operation Supporting national and regional energy, economic and societal policies Stable and efficient operation International business development
Structure	Project- or team-based	Hierarchical, clearly structured, and regulated
Behavior	Flexible and dynamic	Inflexible, top-down planned, strictly controlled
Control	Goal-oriented (efficiency of the technology, project results)	Behavior-oriented and profit-oriented
Need for external knowledge and resources	High (capital, infrastructure, wide market knowledge)	Low (new ideas and innovative solutions)

Table 17. Category 2 – Differences in organizational characteristics (relative statements)

Source: *Zavarkó, et al., 2018*

Based on the qualitative content analysis, there are complementary capabilities and activities which could support the commercial-scale implementation of the P2G technology. Besides, almost completely opposing organizational characteristics can be found: the flexible, team-oriented, and dynamic structure and behavior of the startups are antagonistic to the top-down managed, strongly regulated operation of large energy companies. However, it also must be seen, that not only the resource base, the structure and the behavior differ, but there are important differences regarding strategic goals as well: while technology developer startups mainly determined strategic goals regarding the own organization, large energy companies aim to serve broader, social goals. This can be considered as an underlying reason for striving for risk aversion and a high degree of stability.

5.2 Peripheric case studies: Analyzing the required changes for the widespread, commercial-scale implementation and disruptiveness of the technological innovation

With the peripheral case studies, I aimed to answer the following research sub-question:

Q1: What changes are needed for the widespread, commercial-scale application and the disruption of the technological innovation?

Through the action research, this relatively broad sub-question has led to two further, more specific questions, which also help to answer the main research question:

1) on the one hand, *standardization* can be an important strategic, technical and economic aspect of P2G in a wide range of commercial-scale applications;
2) on the other hand, by analyzing possible *disruption* as a strategic concept from a techno-economical perspective, conclusions about organizational change and change management can be given an appropriate context.

5.2.1 Standardization opportunities of the technological innovation

5.2.1.1 The promising role of wastewater treatment plants (WWTPs)

There is broad consensus within the power-to-gas (P2G) literature, especially in the power-to-methane (P2M) literature, as well as among industry actors that wastewater treatment plants (WWTPs) could play a significant role in scaling up P2G technology by ensuring key input factors, mainly efficiently useable carbon dioxide sources in the produced biogas which is needed for biomethane production (Bailera, et al., 2017).

While the promising role of the P2G technology in the energy sector has been argued comprehensively in recent years (e.g., from the aspect of long-term energy storage (Blanco & Faaij, 2018), system analysis (Schiebahn, et al., 2015) or technological and economic factors (Götz, et al., 2016)), researchers have also started to focus on the role of WWTPs with respect to different aspects of renewable energy transition and power-to-X technologies. Schäfer et al. (2020) pointed out that WWTPs have notable synergy potential in sector coupling, for example, hydrogen and methane can be produced at WWTPs (with P2G technologies), and the oxygen (as the byproduct of the electrolysis) can be used to enhance purification processes. Gretzschel et al. (2020) focused on power-to-hydrogen (P2H) technology and the elimination of organic micropollutants at WWTPs, considering the possibility of offering system service, as well: automatic frequency restoration reserve (aFRR), which can provide short-term flexibility for network operators. Ceballos-Escalera et al. (2020) examined the energy storage attributes of a prototype with a bioelectrochemical system for electromethanogenesis (EMG-BES) at a WWTP, which is an emerging technology in the P2M segment besides chemical and biological methanation. They also showed the future potential of the interconnectedness of renewable energy overproduction, biomethane production, and wastewater treatment. (Csedő, Sinóros-Szabó & Zavarkó, 2020)

5.2.1.2 WWTPs in Hungary

WWTPs in Hungary are units of regional or municipal waterworks, typically owned by municipals responsible for water supply, wastewater drainage, and treatment. There were 826 WWTPs in Hungary in 2016, ca. 96% of which were under 100,000 PE (Population Equivalent). Considering the goal of grid-scale P2M technology implementation and its complex infrastructural and input conditions (Csedő & Zavarkó, 2020), the 28 WWTPs above 100,000 PE could be relevant. (Csedő, Sinóros-Szabó & Zavarkó, 2020)

5.2.1.3 Theoretical and practical P2G potential

Based on the above, we identified not only the theoretical P2G potential of an average WWTP (according to the capacity of the electrolyzer), but the practical potential as well, by building on the 7 WWTPs above 100.000 PE of the peripheric case studies. Concrete calculations are presented in Appendix 4.

By following two calculation methods and comparing of them, although P_{P2G} is more than two times higher than P'_{P2G}, due to the constraints of site conditions we justified P2G potential at a lower value than P'_{P2G}. In accordance with the information collected onsite and all the datasets provided by WWTP site managers, a P2G plant with 1 MWel electrolyzer capacity could be fit to the WWTPs with the load exceeding 100,000 PE in general, because

a. the methane content is usually higher (around 60–65%) than expected based on the literature, which is beneficial for biogas production but not for P2M because there is less CO2 (around 35–40%) to convert to biomethane;
b. the raw biogas flow is around 130 Nm3/h on average at the empirically examined WWTPs, which slightly exceed 100,000 PE, but there are 9 WWTPs that are above even 250,000 PE (obviously they are still within the necessary scope for P2M deployment);
c. there is some seasonality in the case of several WWTPs (e.g., at Lake Balaton) that affects biogas production, but the higher values are typically in the summer, which fits the seasonal energy storage concept.

The 1 MW_{el} P2M size, however, meets the current state of the technology, demonstrated by Electrochaea in Avedøre, Denmark, where the largest P2G plant with biological methanation has been built. As there are around 20 relevant WWTPs exceeding 100,000 PE with biogas production, the total P2M potential at them is around 20 MW_{el}. (Csedő, Sinóros-Szabó & Zavarkó, 2020)

5.2.1.4 Aspects of the top managements

We calculated the capital expenditures (CAPEX) of a 1 MW_{el} P2M plant at a WWTP (detailed in the Appendix). The 4,806,000 EUR CAPEX is rather high for a WWTP, if its annual revenue is around 20,000,000 EUR (illustrative data). Moreover, some large rural WWTPs operated unprofitably in previous years, some operated with almost zero balance, and even the profitable ones, which could generate over 500,000 EUR per year, argued that this profit must be handled as retained earnings for unexpected maintenance tasks, not for R&D&I investments. One technical director put it this way:

> *"We struggle with multiple challenges currently. On the one hand, we struggle with the utilization sewage sludge, quantity reduction, but*

financial sources for the operations are also scarce. [...] We could provide raw materials for the technology, but not financial or other resource.”[17]

Based on their financial background, WWTPs are not motivated to take risks of the commercial-scale operations and the uncertainties of the P2G-related regulatory and business environment. This uncertainty is mainly deriving from the prudent risk management approach of the top management of the WWTPs, as they did not meet such technology, especially not in Hungary. However, serious interest was experienced for the technology, which can be illustrated with a question of a site manager:

“Is it possible, to bring here the prototype to try it with our biogas?

Consequently, the demonstration of the technology in an industrial or in a semi-industrial environment can be a precondition of the wide-range implementation of the technology. (Csedő, Sinóros-Szabó & Zavarkó, 2020)

5.2.1.5 Conclusions

In sum, findings show that a standardized 1 MW_{el} P2G technology would fit with most potential sites (technical aspect). This is in line with the current technology readiness level of P2G but increasing electricity prices and limited financial resources of WWTPs would decrease the commercial attractiveness of P2M technology deployment (economic aspect), so the supporting regulatory environment can be important to exploit the potential of the P2G (strategic aspect). (Csedő, Sinóros-Szabó & Zavarkó, 2020)

[17] Quotes are translations from Hungarian

5.2.2 The disruptiveness of the technological innovation

5.2.2.1 Research sub-model for analyzing the disruptiveness

The counterpoint of the disruptive technology is the "sustaining technology". The sustaining technologies incorporate incremental developments and fit the mainstream customer needs. In contrast, disruptive technologies are wholly new solutions, they create value with an entirely different attribute package that initially does not meet the mainstream need (Bower & Christensen, 1995). Instead, they are viable in a niche or low-end market (which is less profitable), or even on a previously non-existing market which is created by a disruptive technology itself, changing non-consumers to consumers (Christensen, et al., 2015). So, an important question is in the case of the possible disruptiveness of P2M, that *(D1[18]) what are the key attributes of P2M[19] for potential technology adopters and how they evaluate them compared to other (maybe sustaining) technologies?*

Because of the special characteristics of the P2G industry and the energy sector, instead of focusing on the possible number of consumers, we should focus on possible plant sizes on different sites and their compared cost-benefit ratio. This is in line with recent P2M-specific research of Böhm et al (2020) who found a growing need for multi-MW_{el} plants, as global demand for electrolysis and also for methanation can far exceed 1.000 GW_{el}. Hence, the second research question is *(D2) what is the largest P2M plant size possible at different types of sites and what sites are preferred for commercial-scale P2M deployments as possible low-end and high-end segments?* This comparison is relevant to explore the low-end and high-end segments of P2M.

Finally, we should pay attention to the theoretical phenomenon, that over time, changes in the environment and the further development of the disruptive technology leads to higher performance than sustaining technologies could achieve, so mainstream customers will choose the disruptive solutions (Govindarajan & Kopalle, 2006). Based on these expected changes, regarding P2M a relevant question is *(D3) which environmental factors*

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[18] First question focusing on disruption

[19] In the next part, I use the „P2M" term instead of the broader „P2G" term, as the difference between methane production (P2M) and hydrogen production (P2H) within the P2G will be relevant.

and technological advancements could lead to superior performance compared to other (maybe sustaining) technologies and accelerate the process of P2M implementation?

Figure 21 illustrates the research (sub-)model based on which the questions emerged. The model was applied to examine P2M as a *potentially* disruptive technology and did not fix ex-ante that P2M *was* a disruptive technology. It means that the research framework has also left space to empirically identify whether the underlying assumption was correct and if it was, why. (Pörzse, Csedő & Zavarkó, 2021)

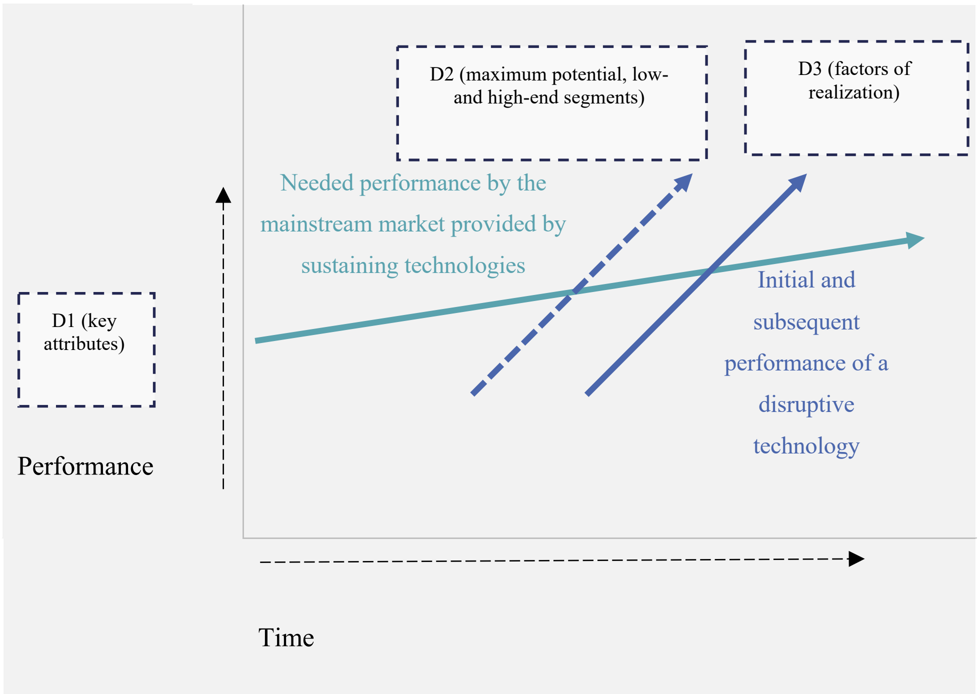

Figure 21. Research model for analyzing disruptiveness

Source: Pörzse, Csedő & Zavarkó, 2021

5.2.2.2 Mainstream needs and the alternatives of P2M at different sites

Based on interviews with top management teams of the potential sites, the overall mainstream need, which is relevant in case of P2G implementation, is producing and utilizing more renewable energy. One deputy CEO said the following:

> *"We could implement a solar park on the site, we considered the realization as well, but we don't have financial resources for the investment"*
>
> *"Our goal is to produce more biogas, then electricity from the biogas, and to reduce the energy balance by feeding back the electricity into the grid."*

In multiple cases, surplus biogas is produced as well:

> *"In this site, we don't have a gas engine, we use it (the biogas) for heating and hot water production with a gas boiler. Sometimes there is surplus biogas for which we use biogas flares."*

While meeting this need, P2M has faced different competing technologies at different sites. Table 3 presents the specific opportunities and competing technologies by the identified valuable attributes for potential adopters in producing and utilizing more renewable energy. The table does not contain every possible technology and every aspect of potential competitive advantages of them, because it is built on empirical data from the field, the evaluation aspects of the interviewees, but it was iterated with scientific literature:

a) In case of biogas plants both in an agricultural environment and at WWTPs, biogas upgrading (BGU) can be considered as a competing technology to produce renewable gas (biomethane). As there were more than 400 facilities with BGU to produce biomethane in 2015 worldwide (Angelidaki, et al., 2018), and even in Hungary there are two (Gabnai, 2017), one could argue that BGU is a more mature technology than P2M. This higher technology readiness level (TRL) which is associated with lower risks, seemed to be an important factor for decision-makers, as prudent risk management appeared as a strategic task, especially in the case of WWTPs. Regarding the other elements of the attribute package, focal P2M technology with a separate reactor and the patented archaea could have a higher decarbonization effect, as some BGU technologies do not involve CO_2 conversion (only separation) and even if H_2 is injected to be reacted with endogenous CO_2 to produce CH_4 during in-situ biological upgrading, the average CO_2 removal rate is varying between 43-100%, depending on reactor type and substrate (Angelidaki, et al., 2018). Furthermore, a clean archaea culture could provide more flexibility for utilizing H_2 from renewable sources than in-situ biological BGU based on the rapid shifts between operation modes of the focal solution based on prototype data of Power-to-Gas Hungary Kft. (Csedő, et al., 2020).

b) In case of industrial companies emitting CO_2 that could be used with P2M to produce renewable or low-carbon gas depending on the source of input factors (van Melle & al., 2018), power-to-liquid technology (P2L) emerged as an alternative technology. P2L has also a high potential in the future energy sector, especially for transportation, but the plan for the first commercial-scale P2L plant is only recently published (Sunfire, 2020).

c) The first phase of renewable methane production, power-to-hydrogen (P2H) can be a standalone solution, as well. As presented before, the fast warm start of PEMEL or AEL can be useful for providing grid-balancing services for network operators (IRENA, 2018) (Buttler & Spliethoff, 2018). Even though it means that producing renewable energy (gas) and grid-balancing can be achieved with decreased CAPEX, adding the methanation step with a biocatalyst could also provide flexibility, not only in terms of methane production (avoiding the need for the challenging high volume hydrogen storage (Yong, 2019)), but also by assuring market-flexibility. Market-flexibility means here the opportunity to switch between end-products (hydrogen and methane) according to their market demand. On technical director of a site said the following:

„If we don't need electricity for own use, we could produce hydrogen with the power-to-gas system, that we can mix into heating gas for own technology; we don't have to produce methane."

d) Based on the empirical data, if the sites would plan to deploy a large solar park for renewable electricity production, battery energy storage systems (BESS) emerged as a viable option. (In this research, mostly INPs, ABPs and BEPs have mentioned this option.) The main advantages of BESS related to on-site energy storage are the fast response, geographical independence, other energy management functions (Yang, et al., 2018) and also the grid-balancing services (Faessler, et al., 2017). One deputy CTO outlined their priorities in the following way:

„A reliable battery park is an absolute priority for storing surplus production, but great attention must be paid for proper sizing and redundancies"

While BESS efficiency for the short-term can be higher than the focal solution's (55-60%), P2M could provide sector coupling and seasonal energy storage which could be valued or supported by state administration as it appeared as an important goal in the Hungarian National Energy Strategy 2030. (ITM, 2020)

e) Finally, regarding direct decarbonization, Carbon Capture technologies can be relevant. For example, post-combustion capture using wet scrubbing with aqueous amine solutions is commercially advanced (Gibbins & Chalmers, 2008), but pre-combustion, oxy-fuel combustion and chemical looping combustion are also promising to capture CO_2 from flue gas (Leung, et al., 2014) that a P2M solution is not capable solely (in contrast to biogas which also contains CO_2 and can be injected to the P2M bioreactor). P2M, however, could utilize CO_2 for renewable energy production.

P2M attribute package	Competing technologies	Relevant sites based on empirical data	Main advantage of P2M	Main advantage of competing technology
Producing renewable gas or another energy carrier different from electricity	BGU, CO_2 removal or conversion by mixed culture with hydrogenotrophic methanogens	ABPs WWTPs	Higher CO_2 conversion and technical flexibility	Higher TRL
	Power-to-Liquid (P2L)	INPs	Higher TRL	Applicability for another sector (transportation)
Providing grid balancing services	Solely power-to-hydrogen (P2H)	INPs	Market-flexibility	Smaller CAPEX for producing renewable energy and providing flexibility
Short-term and long-term energy storage	Battery energy storage systems (BESS)	INPs ABPs BEPs	Applicability for sector coupling and long-term energy storage	Higher efficiency for short-term energy storage
Direct decarbonization	Carbon Capture (CC) technologies	INPs	CO_2 reuse	Serving decarbonization efforts in case of flue gas, as well

Table 18. P2M attribute package and alternative technologies

(based on the evaluation of potential adopters iterated with previous studies)

Source: Pörzse, Csedő & Zavarkó, 2021

Based on the presented iteration of empirical data and former studies, four main findings can be outlined:

1. There is no other technology that has the same attribute package as P2M (producing renewable energy, providing grid-balancing services, energy storage, and decarbonization).
2. The most unique attribute in the P2M package is the capability for long-term energy storage with CO_2 reuse. Renewable gas production is possible with BGU, as well, or P2L is suitable for sector coupling (renewable energy production with transportation), it also assures market flexibility (hydrogen or hydrocarbon fuel production) and direct decarbonization effect, but not with long-term (seasonal) energy storage. In contrast of BGU and P2L, the maturity of P2M is also favorable: the technology is newer than BGU, and it has been implemented in grid-scale, unlike P2L.
3. The least unique attribute of P2M is providing grid-balancing services because P2H and battery energy storage systems are also similarly capable to provide this short-term flexibility.
4. The listed alternative technologies may compete with P2M in one dimension of the value creation, but they can be complementary solutions not only at national energy system-level but also in a given case of a potential technology adopter. For example, battery energy storage and P2M can be combined for short-term and long-term energy storage. Carbon Capture could also provide the main input (CO_2) for methanation. Similarly, P2H is inevitable for P2M if seasonal energy storage is considered (because electrolysis is the first step to absorb surplus renewable electricity), even though they may compete in renewable gas production or grid-balancing.

In sum, based on potential adopter evaluation of P2M and its potential competitor technologies the parallel function of decarbonization and seasonal energy storage is the unique element of the P2M attribute package. Competitor technologies in one value-creating dimension are rather complementary solutions if we take a holistic view on all value-creating dimensions. (Pörzse, Csedő & Zavarkó, 2021)

5.2.2.3 Sites for commercial-scale P2M implementation

From the 14 potential sites of the second-round data collection and analysis, the authors identified those sites where the largest P2M plant could be deployed with biological methanation. The potential plant size can be determined based on the CO_2 input with regard to the stoichiometric ratio of hydrogen and carbon dioxide (4.1:1). Consequently, the maximum electrolyzer capacity (as the indicator of plant size) of a P2M facility is calculated with the presumption of the 4.7 kWh electrical energy demand (see Table 1) for the yield of 1 Nm^3 of biomethane is 4.7 kWh/Nm^3 (Csedő, et al., 2020):

$$P_{\mathrm{P2M}max} = \dot{V}_{H_2} \cdot 4.7\frac{\mathrm{kWh}}{\mathrm{Nm^3}} = \dot{V}_{CO_{2max}} \cdot 4.1 \cdot 4.7\frac{\mathrm{kWh}}{\mathrm{Nm^3}}$$

Table 19 shows the largest possible plants by site type based on empirical data collection and the presented equation based on the characteristics of the focal technology. Because of practical reasons, the calculation considered the autonomous development plans of the sites for the next 2-3 years. For example, a biogas plant plans to expand its biogas producing capacities that would result in higher possible P2M plant size.

	$\dot{V}_{CO_{2max}}$ **Max. monthly average CO_2 input (ca. Nm^3/h)**	$P_{\mathrm{P2M}max}$ **Max. plant size (ca. MW_{el})**
ABP	700	12,5
BEP	850	15
WWTP	300	5
INP	1650	30

Table 19. Largest possible P2M plants by site type based on empirical data collection (with rounding because of confidentiality)

Source: Pörzse, Csedő & Zavarkó, 2021

Based on these empirical data and theoretical calculations, the largest P2M plant could be deployed at INPs. Two additional factors, however, should be considered:

1. First, some seasonality could be seen on yearly data of CO_2 production. At certain sites, CO_2 input can be 30-50% lower in certain months than the maximum

monthly average. For example, in case of some WWTPs and ABPs, the beginning and the end of the year has lower volumes of biogas production, consequently, there is less CO_2 available to be converted into methane. This phenomenon may lead to a need for balancing renewable energy gas production (and seasonal energy storage) and decarbonization: while from the decarbonization aspect it would be important to convert as much CO_2 to methane as possible, seasonality in CO_2 emissions limits the financial attractiveness of scaling the plant size up to the maximum emission level.

2. Second, in case of ABPs, BEPs, and WWTPs, CO_2 is available for efficient use within the P2M plant, but in case of INPs (where the largest P2M plants could be deployed), there is need for carbon capture (CC) technologies, as well, to separate CO_2 from the flue gas. CC would increase technical complexity, capital and operational expenditures, as well. (Pörzse, Csedő & Zavarkó, 2021)

5.2.2.4 Evaluating disruptiveness based on the largest P2M potential

Cost-benefit analyses were undertaken at the sites with the largest possible size. These analyses are presented in Appendix 6 and 7. In the following, the results will be interpreted from the viewpoint of disruptiveness, with regard on the questions of the research sub-model and the latest literature results, as well.

D1 was focusing on key attributes of P2M for potential technology adopters and their evaluation compared to other technologies. According to the literature, disruptive technologies create value with a different attribute package than sustaining technologies, and initially do not meet the mainstream needs. To justify this assumption for P2M, it must be identified whether there are sustaining and disruptive technologies in this market segment at all. As sustaining technologies mean continuous incremental improvements in satisfying mainstream needs, it assumes technologies with widespread utilization and high TRL (maximum: 9). Regarding the identified mainstream needs of potential P2M adopters (producing and utilizing more renewable energy) and the recent literature about the identified alternative technologies, mainly BGU and BESS could be considered as sustaining technologies. In case of BGU and BESS frequent use and relatively high TRL can be seen (Wenge, et al., 2020) (Sitompul, et al., 2020) for renewable energy production and utilization, but there are also novel ways for BGU (TRL3-7) (Bienert, et al., 2019) and there are also efforts to optimize and develop the efficiency of batteries (Nguyen & Kim, 2021), which may indicate incremental developments.

In contrast, P2H, CC, and P2L are rather in the demonstration phase or at less frequent use.

1. In the case of P2H, while low-temperature electrolyzers are at TRL9 (readiness for full-scale implementation), high-temperature electrolysis processes are at TRL6-8 (Drünert, et al., 2020). A recent study, however, pointed out that "the scale of P2H pilots is very small" (Hu, et al., 2020, p. 1369) and these are demonstration projects, even if one reaches 100 MW (Hybridge).
2. Regarding CC, there are several technologies from TRL2-3, (such as oxygen transport membranes which integrate O_2 separation and combustion) to TRL8-9 (e.g., the commercial CO_2 capture plant in Canada, the Boundary Dam project) (Kapetaki & Miranda Barbosa, 2019).
3. Finally, as there are only plans for P2L facilities on commercial-scale (Sunfire, 2020) and the P2L technology is rather in demonstration phase with TRL-5-6 (Bauen, et al., 2020), P2L cannot be considered as a sustaining technology.

Based on the above, one could argue that P2M can be disruptive against BGU and BESS. This statement can be justified based on the P2M unique attribute package (producing renewable energy, providing grid-balancing services, energy storage, and decarbonization), which is different from BGU and BESS. While BGU is less flexible to provide grid-balancing, BESS does not produce renewable energy. However, it can be also seen that the initial performance of the P2M is inferior compared to them. For example, the capital costs of traditional BGU technologies can be lower, where there is no need for electrolyzers to generate hydrogen (Khan, et al., 2017). Furthermore, Lithium-Ion Battery (LIB) can provide 95-98% efficiency (Kucevic, et al., 2020). Assuming that the mainstream market need naturally integrates *cost-efficient* renewable gas production and *high-efficiency* energy storage (on the short-term) at ABPs, BEPs, WWTPs or INPs, P2M has the disruption potential because of this inferiority. Nevertheless, according to the theory, this inferiority of P2M will turn into superior performance later due to the fit of the unique attribute package and environmental changes. Regarding the growing share of renewables in the energy mix, the volatile production may go beyond the capacities of BESSs, and long-term, high volume, seasonal energy storage will be needed. The incitement of this may result in better business opportunities (e.g., high biomethane feed-in-tariff) due to state interventions (Csedő & Zavarkó, 2020). This would justify the investments into more CAPEX intensive projects with P2H and P2M (compared to traditional BGU) or expanding the battery-dominated energy storage systems with P2M to realize profits from low priced surplus electricity.

As the empirical research pointed out based on D2, really large P2M plants which could impact the sector intensely can be deployed at INPs (in Hungary). Results also showed that these large P2M plants with CC can have a better cost-benefit ratio than smaller P2M plants at ABPs or BEPs if CC costs would decrease significantly (detailed in Appendix 6-7). If one considers that P2M at INPs are not only relevant by their size but by the commissioned number of them, and emitted CO_2[20], CO_2 reuse with parallel energy storage of P2M at INPs can lead to disruption, but only if CC costs would radically fall.

If INPs can be the high-end market for P2M this is because the better cost-benefit ratio, the higher potential of a single P2M plant size, and the higher number of possible plants (market potential). In contrast, WWTPs, ABPs, and BEPs representing the low-end segment of the market are might be more suitable for P2M implementations in grid-scale. Nevertheless, the applicability of the revised theory about disruptive innovation (not technology) by Christensen et al. (2015) is limited in this study, as incumbents (established large companies with sustaining technologies) who may overlook the low-end segment and will be challenged by disruption were not identified. Probably, this is because of the relatively new market generated by sustainability efforts.

In sum, due to its unique attribute package, P2M today is rather a value innovation (Kim & Mauborgne, 1997), and a potentially disruptive technology of the future. Figure 22 shows the unique attribute package of P2M as a value curve indicating the value innovation.

[20] Energy supply and industry together was responsible for 48.3% of the greenhouse gas emission, agriculture for only 11.3% in Europe in 2014 (European Environmental Agency, 2016).

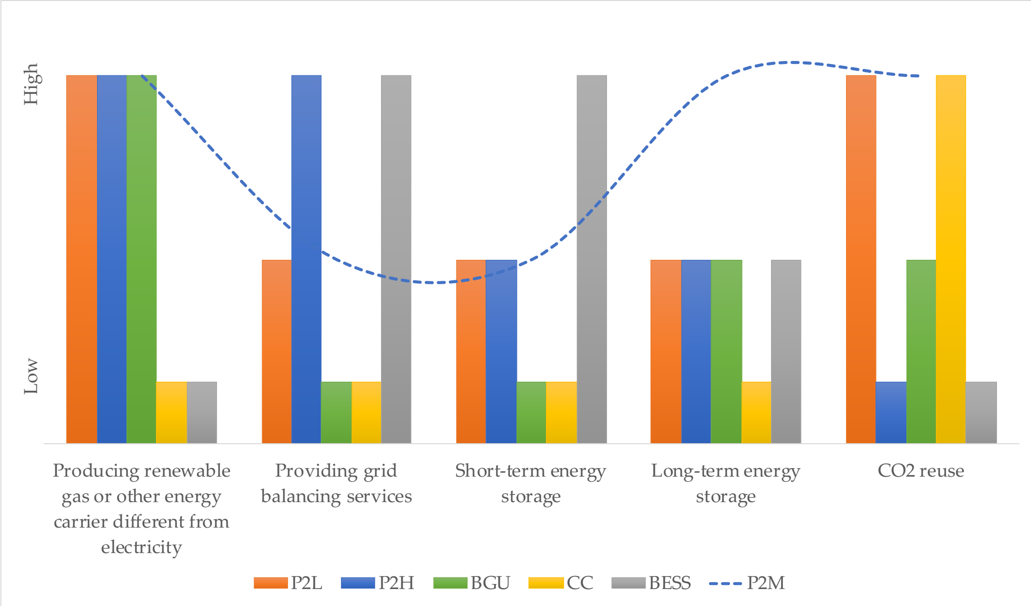

Figure 22. P2M attribute package as a new value curve (relative values)

Source: Pörzse, Csedő & Zavarkó, 2021

P2L: Power-to-hiquid, P2H: Power-to-hydrogen, BGU: Biogas upgrading, CC: Carbon Capture, BESS: Batter energy storage system, P2M: Power-to-methane

P2M and CC together can become disruptive after a time as CC costs decrease and volatile renewable energy production and decarbonization pressure increase further. Regarding the CC technologies, oxy-combustion is seen as a promising and cost-effective method in the literature (Wu, et al., 2018), but regarding the oxygen by-product of the electrolysis in the P2M process, it can lead to even more synergies in theory (see Figure 23).

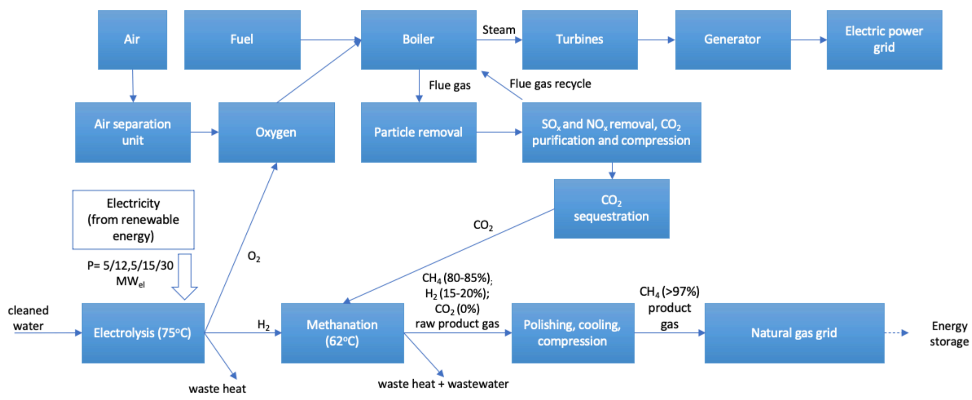

Figure 23. Possible synergies between an oxy-combustion and a P2M system

Source: Own edit based on (Wu, et al., 2018) (Sinóros-Szabó, 2019)

Finally, two other points should be highlighted based on the empirical results.

1. First, in contrast to underlying assumptions, no "competition" between catalytic or biological methanation, nor between AEL or PEMEL was relevant from a disruptive point of view.
2. Second, findings suggest that P2H, P2M and P2L, and even BESS can be parts of an integrated energy system at a large industrial company, providing short-term and long-term energy storage, renewable energy production with market-flexibility (hydrogen, methane or hydrocarbon fuel), and capability for grid-balancing. (Pörzse, Csedő & Zavarkó, 2021)

5.2.2.5 Conclusions

The starting point of these peripheric case studies was that P2M could be considered a disruptive technology because of its predicted future impact on the energy sector, and the new opportunities and new challenges it generates. However, to confirm the disruptiveness of the technology, further questions should be answered. Three questions (D1-D3) were formulated based on the theory of disruptive technologies, and it was concluded that P2M currently is rather a value innovation due to its unique attribute package, the combined seasonal energy storage and direct decarbonization function. Besides that, P2M has the potential of becoming a disruptive technology if associated with CC technologies, and if the current CAPEX volumes related to this technology would decrease significantly. It was also presumed that renewable energy generation would continue to grow, because the largest P2M potential can be identified at those industrial plants where CO_2 should be captured from flue gas. This conclusion has another practical contribution, as well, by highlighting that CC technology developments should get a higher priority to completely exploit the disruption potential of the P2M technology. Figure 24 summarizes the conclusions aligned with the research sub-model.

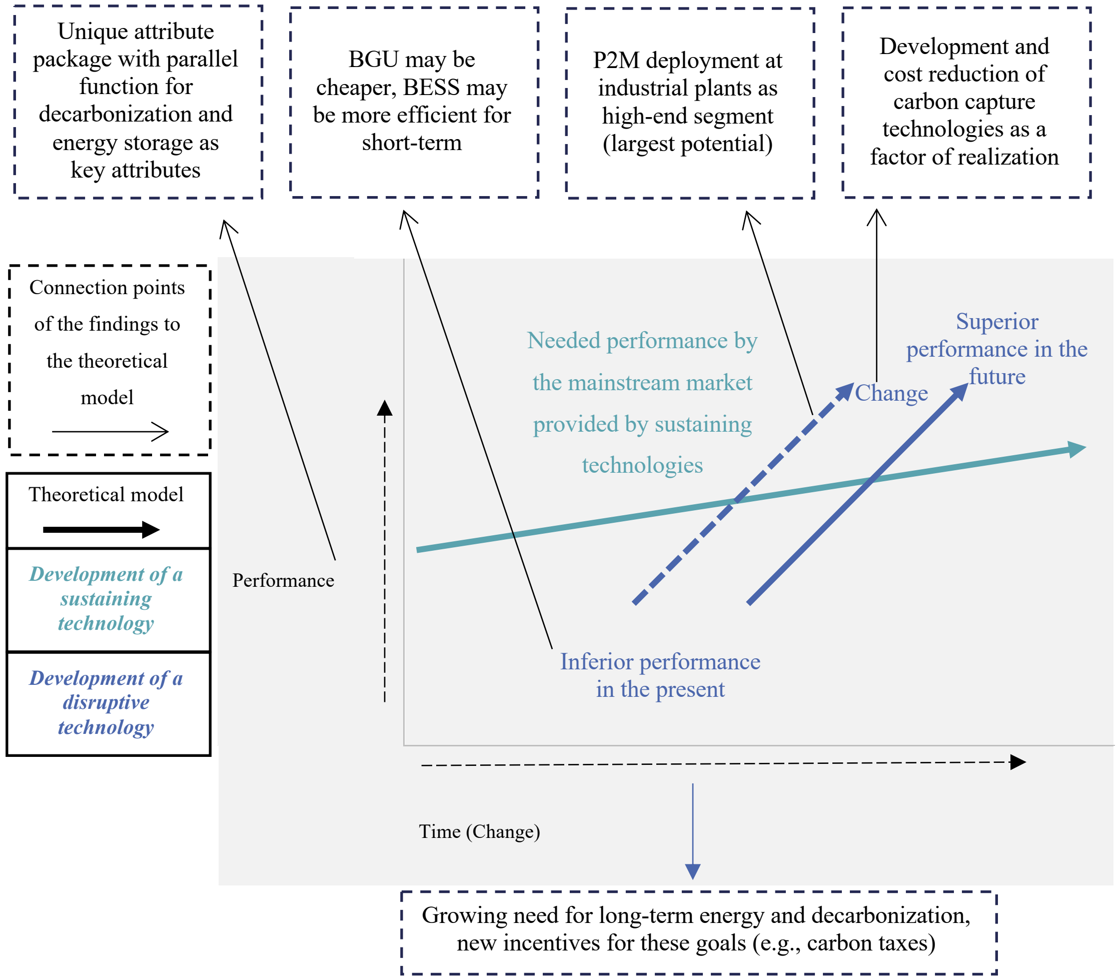

Figure 24. The disruption potential of P2M technology

(A part of the empirical findings aligned with one of the research models)

Source: Pörzse, Csedő & Zavarkó, 2021

From a practical point of view, findings suggest that agricultural biogas plants and bioethanol plants with efficiently usable carbon sources, as well as industrial sites with carbon capture solutions could be equally suitable from the aspect of CO_2 input for building the largest P2M plant worldwide, that could also be located in Hungary (over 6 MW_{el}). (Pörzse, Csedő & Zavarkó, 2021)

5.3 Extended case study: Change within the organization and the inter-organization network

I aimed to answer the following two research sub-questions with the extended case study:

Q2: What innovation management tasks must be conducted to reach the widespread and commercial-scale implementation of the potentially disruptive technology in the relation system of explorative and exploitative activities?

Q3: What organizational changes are induced by the focal innovative technology development within the stakeholder organizations?

In line with the historic approach of the extended case study method, I present the results from the narrower topic of the technological innovation that emerged earlier, to the innovation and change topics that emerged later.

5.3.1 Innovation opportunities and challenges of the technology development

Based on the intense technology development and market research activities of Power-to-Gas Hungary Kft. between 2017 and 2019, the technology has such new characteristics which are promising and competitive against other technologies on an operative level, but micro-, meso- and macro-level challenges can be identified in relation to the implementation. These are presented in the following.

5.3.1.1 Technological opportunities and performance indicators

First, it must be emphasized that the archaea strain can convert ca. 99% of the CO_2 into methane during the methanation phase, which is really promising regarding the decarbonization efforts.

The total P2G plant efficiency can be in the range of 55–60%. (Csedő, et al., 2020)

The other performance indicators of a 1 MW_{el} P2G plant (which is the same size as the largest biomethanation P2G plant in the world) are presented in Table 20.

Performance aspect	Base data, description in case of a 1 MW_{el} biomethanation plant
CO_2 input	Ca. 53 CO_2 Nm^3/h.
CH_4 production	Ca. 52 Nm^3/h (ca. 97-98% of the CO_2 input)
Energy storage	No limit, if a connection to the natural gas grid is available
H_2 output (P2H) and input (P2M)	Ca. 212 Nm^3/h (with regard to the ca. 4:1 or 4.1:1 ratio of H_2 and CO_2)
Electricity consumption	Ca. 4,7 kWh / Nm^3 H_2

Table 20. Performance indicators of a 1 MW_{el} P2G plant

Source: *Pörzse, Csedő & Zavarkó, 2021*

Table 21 and 22 shows the main characteristics of the available electrolysis and methanation technologies and highlight the technologies of the Power-to-Gas Hungary Kft. prototype.

Electrolysis technologies	Commercial-scale use	Flexibility for utilizing surplus electricity production	Sources
Alkaline electrolysis (AEL)	Yes	It can be 1-10 minutes	(Wang, et al., 2018; Bailera, et al., 2017; Schmidt & Weindorf, 2016; IRENA, 2018)
Polymer electrolyte membrane electrolysis (PEMEL)	Yes	Seconds	
Solid-oxide electrolysis (SOEL)	Under development	-	

Table 21. Electrolysis technologies and the applied technology (PEMEL)

Source: *own construction*

Methanation technologies	Commercial-scale use	Flexibility for stopping and restarting methane production	Other features	Sources
Chemical (catalytic) methanation	Yes	Lower	Sometimes more than 100 °C is needed to reach high CO_2 conversion, which can be 50-60% and 80-90% or higher in proper conditions	(Bailera, et al., 2017; Ghaib & Ben-Fares, 2018) (Leeuwen, 2018; Electrochaea GmbH, 2019) (Frontera, et al., 2017)
Biological methanation	Yes	Higher	Needs lower pressure and temperature (ca. 60-70 °C) than catalytic methanation; CO_2 conversion is higher than 95%	
Bioelectrochemical system for electromethanogenesis (EMG-BES)	Under development	Lower	Using electro-active microorganisms; Reaction on 25-35 °C	(Ceballos-Escalera, et al., 2020)
Injecting hydrogen during biological biogas upgrading	Under development	Lower	Hydrogenotrophic methanogens in a mixed culture, no need for separate bioreactor	(Ács, et al., 2019)

Table 22. Methanation technologies and the applied technology (Biological methanation)

Source: *own construction*

Based on these tables, the combination of the two focal technologies is promising regarding flexibility, high CO_2 conversion, and technological maturity for the implementation, not only on their own but compared to other technologies, as well.

5.3.1.2 Technology-related challenges

Despite the biomethanation technologies are highly efficient (the rate of carbon dioxide conversion can be above 99% under optimal circumstances based on the data of the prototype), there are two efficiency challenges in different levels.

1) On sector-level, the problem with efficiency is the higher electricity input upstream, higher pace of RES deployment (on top of what is already needed for electricity demand growth) and possibly reaching the maximum potential in some areas. High pace of RES deployment also increases maintenance costs of TSOs, which could be solved by deliberate sizing and location of more P2G facilities.
2) On technology-level, the efficiency of overall energy conversion could be increased. For example, the utilization of waste heat for power generation could be another source for biomethane production. The produced waste heat at 70 Co, however, is currently too low for efficient electricity production which indicates the development of new technology solutions (Györke, et al., 2019). Moreover, there are other uncovered research areas in case of new biomethanation solutions: other types of reactors, stirring or nutrition of biocatalysts could also affect the overall efficiency of energy conversion.

Regarding scalability, also two key points should be discussed:

1) Financing: Assuring a reasonable return of investment is an important challenge because of the high costs of the focal new technologies. The return of investment (mainly because of the high prices of electrolyzers), can be realized only over 10 years. Industrial-scale P2G facilities need low-cost electricity, the electricity costs being the highest amount (43%) of the full production costs/kg methane. This meant 0,83 €/kg methane for electricity. (Leeuwen & Zauner, 2018)
2) CO2 availability: Finding ideal sites for P2G facilities might also be challenging because of large volumes of carbon dioxide are needed: For example, a 2 MW P2G facility would need ca. 105 Nm^3 carbon dioxide per hour. The access for proper carbon dioxide sources (gathered, efficiently useable, without harmful contaminants for biocatalysts) might be also difficult[21]. This amount could be sourced only at larger wastewater treatment plants, agricultural biogas plants or bioethanol plants since current costs of carbon capture and storage technologies are rather high. Furthermore, a P2G facility would need a nearby connection for the natural gas grid for efficient storage and transport. If there is no connection

[21] This induced the locations of the peripheric case studies.

for the natural gas grid on the site, compressing the biomethane to CNG fuel would require new investments, meaning higher operation costs, as well. (Götz, et al., 2016; Blanco & Faaij, 2018)

P2G technology could contribute to reaching national and regional energy policy objectives and could solve significant challenges of grid balancing (Schiebahn, et al., 2015). There are, however, significant legal and regulatory barriers.

1) Hydrogen production, storage and injection into the natural gas grid are challenged by safety and administrative requirements in some countries (e.g., Spain), but there are also incentives for production or usage in other countries (e.g. Belgium) (Dolci & Thomas, 2019). Regarding the biomethane production, feed-in tariffs were introduced in many EU member states as incentive (e.g., France, Germany) (Koonaphapdeelert, et al., 2020). There are several legal and regulatory details which should be answered to support P2G technologies: e.g., clarification of the aim of the technology (energy storage and/or gas production), harmonization of quality standards, shaping a system for network tariffs for energy storage (Kreeft, 2017).
2) The regulation of the mentioned feed-in tariffs and energy storage tariffs as revenue streams could be critical because of price disparity between the electricity and the biomethane. This could lead to very small incentives for such energy conversion. Financial sustainability also depends on the price of the sourced CO2 as well (Brynolf, et al., 2018), regarding which a favorable trend could help the spread of the P2G technology. If "carbon tax" (Dolci & Thomas, 2019) and similar additional costs of CO2 emissions increase, large CO2 producers will be interested to find alternative solutions which increases the bargaining power of the P2G operators on the CO2 price. (Csedő & Zavarkó, 2020)

5.3.2 Innovation management for seizing opportunities and overcoming challenges

5.3.2.1 Actions for solving the challenges

Table 23 categorizes the previously detailed complex challenges, and the actions to overcome them. To exploit the potential of the technology, the following action should be undertaken:

	Topics	**Examples of subtopics**	**Required actions**
Micro-level	Technology: The efficiency of overall energy conversion	Reuse of waste heat Reactor structure Nutrition of biocatalyst	Further R&D
Meso-level	Efficiency on sector-level	High pace of RES-deployment Maximum potential	Scenario analyses, deliberate location, and sizing
	Scalability	Financing: Investment volume	Raising capital
		CO_2 availability: Sourcing carbon dioxide Finding distribution channel	Involving experts from other energy market segments
Macro-level	Legal and regulatory environment	Clear definitions and regulations Financial incentives for renewable energy storage Financial incentives to produce green gas	Change of legal environment

Table 23. P2G technology-specific challenges and required actions

Source: *Csedő & Zavarkó, 2020*

Between 2018 and 2020, the activities of the company became broader (from the narrower technology development activities in 2017-2018), and three organizational actions were dominant to react to the mentioned opportunities and challenges:

1) Looking for partners for collaborations, networking
2) The development of the own knowledge base (in depth and in width), involving external partners, supported by digital tools
3) Project management on the whole value chain of the P2G development and implementation as a network node.

I describe these areas in detail below.

5.3.2.2 Overcoming the impeding factors of innovation with inter-organizational innovation networks

The importance of collaboration partners

According to Power-to-Gas Hungary Kft's business model, the primary value propositions (Osterwalder & Pigneur, 2010) are providing innovative energy storage solutions and producing biomethane, as the environment-friendly alternative of natural gas. The key resources of value creation are knowledge capital that is achieved from R&D and prototype operations, as well as financial and technical resources for plant establishments. As Power-to-Gas Hungary Kft. is a technology start-up founded in 2016 focusing on its core business (technology development and related project management), these resources could all be assured with the involvement of key partners.

As I presented it at the literature review, the need for key partners is not unique in the P2G industry. According to the analysis of Baleira et al (2017) of more than 40 P2G projects, 3–4 partners have collaborated on average. Considering the newer and more efficient biomethanation technology (Blanco & Faaij, 2018) the need for partners might be even higher. For example, Electrochaea, strategic partner of Power-to-Gas Hungary Kft., or MicrobEnergy, subsidiary of Viessmann Group established their biomethanation facilities with the participation of seven other organizations: strategic and financial investors, professional service providers, state administration institutions, traditional energy companies, research centres (Bailera, et al., 2017).

During the research, those motives and conditions was identified that frame the collaboration of potential partners.

a) P2G technology developer companies do not own all financial and infrastructural resources to scale up the technology but have disruptive core solutions, based on that profitable business models could be built. If complementary resources (broad industry-specific knowledge, infrastructural equipment, and related investment) are granted by strategic and financial investors, innovation and business opportunities could be realized:
    a. profits for P2G developer companies;
    b. synergies with core business for strategic investors;
    c. high returns for financial investors;
    d. high impact on local energy system management and sustainability targets.
b) There are many uncovered, or not fully covered topics related to the technology for further research and development (e.g. utilization of by-products, nutrition of biocatalyst, modified reactor structures), which could increase the efficiency of the technology. These areas cannot be individually researched by a start-up with limited resources and clear strategic focus, but research centres, other start-ups or consulting companies could participate in developing further such improvements of the technology. (Csedő & Zavarkó, 2020)

The impact of the inter-organizational innovation network on the regulatory environment

The local energy sector is strongly regulated, the rigid institutional background and stability-focused short-term incentives do not support the development of disruptive innovations (Csedő, et al., 2018). That is why governments are always key stakeholders regarding the commercialization of P2G technology in grid-scale. It is found that two actions could lead to favorable changes of the legal environment:

a) Collaboration partners need to demonstrate the viability of local business models and future development opportunities of P2G technology with the involvement of local research and development, and local commercialization of the technology in small-scale.
b) A regulatory sandbox model would be a great first step to test the viability of local business models in a real business environment. A regulatory sandbox model means a unique legal framework for disruptive technologies in which certain laws and obligations could be applied in a modified version for the test period of the technology. The concept originates from the UK where FinTech solutions needed special conditions to prove their value. In 2019, there were more than 50 operating or planned regulatory sandboxes in different sectors, such as telecommunication, data or environment protection, globally (Martin & Balestra, 2019). There are examples in the energy sector as well: the Energy Market Authority in Singapore has introduced a regulatory sandbox for new energy products and services to leverage new technologies (Energy Market Authority, 2018; The Business Times, 2017); the Netherlands also created a local experimental environment for innovative energy services (van der Waal, et al., 2020). Even though the regulatory sandbox model is relatively new, the volume of available data is limited, so measuring its impacts is difficult, it is expected that open and active dialogue between regulators and innovators can result in better regulatory assessment for innovations and can decrease uncertainty for investors (Martin & Balestra, 2019).

Although the Hungarian legal and regulatory environment does (did) not contain incentives for the development and operations of innovative energy storage technologies yet, the new National Energy Strategy 2030 of Hungary (introduced in January 2020) aims to develop a regulatory environment which supports the commercialization and utilization of the P2G technology. Furthermore, other actions are assigned which can be financially supported as well:

a) Installing a pilot P2G facility which is capable to inject biomethane into the natural gas grid
b) Building a 2,5 MW_{el} P2G facility

c) Developing a mandatory national purchasing system for biomethane to incite biomethane production (ITM, 2020).

I identified during the action research, that the appearance of the P2G technology in the new national energy strategy can be considered as a significant achievement and recognition of the work of the Hungarian P2G technology-oriented inter-organizational networks.

Moving forward from dyad-level open innovation to inter-organizational innovation network

One could see that the research and development results achieved with a special Archea strain created economic and environmental opportunity (Sarasvathy, et al., 2003). This opportunity led to a dyad-level open innovation, developing a P2G prototype with a proprietary biocatalyst and demonstrating the viability of the business model. With regard on the point of Vanhaverbeke (2006) that open innovation can be analyzed on dyad-level and on inter-organizational-level, the exploitation of P2G technology innovations, however, requires more than that: an inter-organizational innovation network. Its commercialization requires significant complementary resources, further development of the technology on related fields, and changes in the local legal environment.

Results imply that dyadic collaborations and inter-organizational innovation networks can have different characteristics of open innovation. Dyadic collaboration is rather temporary to solve a clear problem or create a new solution, while inter-organizational innovation networks could mean a long-term commitment or continuous collaboration for further incremental development on complex areas related to the previously created core solutions, driving the commercialization of the technology, and might also be able to have significant impact on legal and institutional environmental changes.

Table 24 illustrates the characteristics of open innovation based on P2G technologies development and commercialization, the needed inputs from partners for a scaled-up and efficient P2G technologies, and potential outputs which would add value to them. The table is built on empirical data from the interviews, it does not contain every possible combination of actors or inputs/ outputs, but it highlights the clear need for collaboration.

It means that this is not a prescriptive but a descriptive table, as it shows that what was needed to have an impact on the institutional environment. (Csedő & Zavarkó, 2020)

<table>
<tr><th></th><th></th><th colspan="4">Dyadic collaboration</th><th colspan="6">Inter-organizational innovation network</th></tr>
<tr><td rowspan="5">Theoretical aspects</td><td>Number of collaborators</td><td colspan="4">2</td><td colspan="6">More than 2</td></tr>
<tr><td>Temporality</td><td colspan="4">Temporary/Short-term</td><td colspan="6">Continuous/Long-term</td></tr>
<tr><td>Development problems to solve</td><td colspan="4">Clear, focused</td><td colspan="6">Unclear, diffused</td></tr>
<tr><td>Number of development problems to solve</td><td colspan="4">Few</td><td colspan="6">Many</td></tr>
<tr><td>Goal of development in general</td><td colspan="4">To create something new, disruptive innovation</td><td colspan="6">To utilize and develop a disruptive solution incrementally</td></tr>
<tr><td rowspan="6">Empirical data</td><td>Location</td><td colspan="4">Outside Hungary</td><td colspan="6">Inside Hungary</td></tr>
<tr><td>Collaborators</td><td>University / Research centre</td><td colspan="2">Biotechnology - P2G developer company</td><td colspan="2">P2G technology developer company</td><td>Strategic investor (e.g. TSO or DSO)</td><td>Financial investor</td><td>University / Research centre</td><td>Other start-ups, Management consulting companies</td><td>Government, State administratio n</td></tr>
<tr><td>Goal of development in the case of P2G technology development</td><td colspan="2">1) Discovery of the proprietary biocatalyst</td><td colspan="2">2) Development of a prototype</td><td colspan="6">3) Scaling-up and commercialization of the technology
Increasing the efficiency of the technology
Achieving favourable legal and institutional environmental changes</td></tr>
<tr><td>Input</td><td colspan="2">R&D knowledge and capacities</td><td>Core technology</td><td>Local expert knowledge, business development</td><td>Innovative technology and project management</td><td>Extensive infrastructural resources, sector-specific knowledge</td><td>Financial resources</td><td>R&D knowledge and capacities</td><td>Expert knowledge, innovative services, social capital</td><td>Supporting legal environment</td></tr>
<tr><td>Output of the single organization</td><td>Publishable research results, patent</td><td>Market-able patent</td><td>Inter-national business</td><td>Innovative technology</td><td>Innovation and profit</td><td>Synergies with core business</td><td>Profit (exit)</td><td>Publishable research results</td><td>New projects and business opportunities</td><td>Reached energy policy objectives</td></tr>
<tr><td>Output in broader sense</td><td colspan="4">Economic and environmental opportunity</td><td colspan="6">Exploited technological innovation (exploited opportunity) with impact on the energy sector</td></tr>
</table>

Table 24.: Dyad-level open innovation and inter-organizational innovation network during the P2G technology development

Source: Csedő & Zavarkó, 2020

The table shows that exploiting the technological innovation requires complementary resources which can be granted by several stakeholders. If one or more stakeholder is missing from the network, it can

1) increase investment costs (e.g., if there is no strategic investor who is interested to share its infrastructure expecting future synergies),
2) lead to lost opportunity (e.g., if there is no scientific research, which could increase efficiency),
3) make the project impossible (e.g., there is no core technology, financial resources or supporting legal and regulatory environment). (Csedő & Zavarkó, 2020)

5.3.2.3 Digital knowledge management aiming know-how development and open innovation

One of the company's strategic priorities in the 2018-2020 period – in line with networking – was to develop the knowledge base which was incomplete in many areas even at the international level owing to the significant innovation content of the technology. As part of this, the company has built relationships in three main directions:

1) Towards university research centers (for example in the fields of engineering, biology, chemistry, energy management), through which exploratory learning has become possible, access to new scientific results in related technological fields.
2) Towards larger companies, mainly in the energy, agricultural and industrial sectors[22], which serve industrial know-how and applied R&D purposes and were more concerned with exploiting the existing technological solution.
3) Non-profit organizations and stakeholders on the regulatory side who are also interested in the development and industry-scale application of innovative energy storage solutions.

The company has created a digital open innovation platform on one hand, to develop technological know-how based on its own research, on the other hand, to combine academic, scientific, and industrial know-how. The aim of the platform is to

[22] These relationships appeared in the peripheral case studies as well.

a) ensure an efficient flow of technological know-how among stakeholders in the inter-organizational innovation network;
b) develop the company's own knowledge base in a structured and rapid manner;
c) prepare the knowledge base for the operation of the commercial-level P2G units that are to be set up.

Concerning these goals, four main modules have been developed on the platform:

a) idea generation, innovation problem solving
b) prototype management (grounding the subsequent plant management)
c) digital know-how development
d) e-learning. (Sára, 2019)

In addition to the fact that the modules can also operate in isolation (for example, it is possible to develop an independent know-how element), the flow of knowledge among them can also be realized, the method of which is described in Table 25.

Input module (source of knowledge element) ↓ / Output module (use of knowledge element) →	Prototype management/ plant management	Idea generation, innovational problem solving	Digital know-how development	E-learning
Prototype management/ plant management		Question about development or operation	Knowledge development based on monitoring data	
Idea generation, innovational problem solving	Prototype development or more efficient operation based on idea generation		Answered innovation question	
Digital know-how development		Question based on a missing element of knowledge		New training material based on know-how
E-learning	Initial / advanced operational knowledge (non-codified)	Question based on an e-learning material		

Table 25. Modular connections of the digital platform for the technological know-how

Source: own construction

Going beyond the functionality, the document analysis and the interviews also revealed how

a) exploratory and exploitative learning,
b) the company's external network,
c) the content of the technological know-how

are connected. (Table 26)

<table>
<tr><th></th><th>Actors of the knowledge network</th><th>The main topics of the technological know-how flow (examples)</th></tr>
<tr><td rowspan="2">Exploitative learning</td><td>Large energy companies, potential sites, infrastructure providers
Regulatory and public administration stakeholders</td><td rowspan="2">P2H - AEL, PEMEL industrial-scale operation
P2M – industrial-scale operation of biological methanation</td></tr>
<tr><td rowspan="2">Power-to-Gas Hungary Kft.</td></tr>
<tr><td rowspan="2">Explorative learning</td><td rowspan="2">P2H - SOEL technology development
New P2M technologies (EMG-BES)
P2L - hydrocarbon fuel production
Efficiency-enhancing solutions (e.g., waste heat recovery)
Development and integration of Carbon Capture technologies with P2G plants</td></tr>
<tr><td>Non - profit professional organizations
Universities, research centers</td></tr>
</table>

Table 26. Exploratory and exploitative learning in the P2G inter-organizational innovation network

Source: own construction

The table shows that Power-to-Gas Hungary Kft. also learns on the exploratory and exploitative "side" of the network, and thus connects the otherwise isolated stakeholders.

5.3.2.4 The technology developer company as the "engine" of the innovation and network node

At the end of the extended case study's time horizon (2020), due to the network building and knowledge management activities described above, Power-to-Gas Hungary Kft. has become a kind of network node that connects

a) universities, research centers
b) large energy corporations
c) companies active in other fields, sectors

d) the stakeholders of the regulatory side, the state administration
e) non-profit professional organizations.

Due to the innovative technology, the conscious exploitative and exploratory learning, and the network node role, the company is competent and performs P2G project management tasks throughout the entire P2G development and implementation value chain.

Reflecting on the prior results of the qualitative content analysis, it also became clear from the empirical data that it is not only the P2G technology development company that needs large companies due to the complementary resources, but vice versa: the general renewal challenges of the energy industry are also relevant for Hungarian large energy companies. The definition of the industry, in this case, includes only the segments of gas and electricity supply (thus, for example, oil companies are not covered). From the point of view of P2G, these two segments can be said to be the most relevant, as they can be used to connect the electricity and natural gas systems. Among the internal factors limiting innovation in large companies, the following were identified based on the interviews:

a) Strong hierarchy and control
b) Closed thinking
c) Incentives focusing on stability and short-term performance
d) Risk aversion
e) Lack of knowledge regarding the management of highly innovative projects.

Interviewees also suggested that several obstacles stem from the rigid institutional background of the industry. In a market environment where there is such a demand for short-term stability, major industry players are not encouraged to invest their resources in exploration and the development of disruptive innovations. That is why collaboration in an inter-organizational innovation network and the network-building role of the technology developer company have been important. (Csedő & Zavarkó, 2020)

5.3.3 Organizational changes at the organizations participating of the disruptive technology development

5.3.3.1 Innovation and change inside and outside the organization

Through the extended case study, I analyzed deeply the role of inter-organizational networks and innovation management related to P2G technology development and commercialization. Based on a three year-long action research, two dyadic collaborations led to the development of an innovative P2G prototype, representing a significant opportunity for industry-scale local energy storage, grid-balancing and higher integration of renewables. It has been shown that industry-specific and P2G technology-specific challenges might limit the exploitation of the innovation potential of this disruptive technology. To overcome innovation barriers, the dyad-level open innovation seems not enough. The research results demonstrated that inter-organizational innovation networks might be essential to achieve breakthrough results in increasing the efficiency of P2G technologies, scaling them up and prove their value for local decision-makers in small-scale. These actions are also needed to initiate legal environmental changes locally. The rigid regulatory environment and incentives for short-term performance are the most significant limiting factors of further innovation and commercialization. Figure 25 summarizes these findings.

Based on the results, a rather cyclic than linear model could be drawn. The appearance of the P2G technology in the national energy strategy could be interpreted as a new opportunity. This means that the inter-organizational innovation network had an impact on the institutional environment, and the new environment will mean new opportunities for the actors of the energy sector (and maybe challenges to others).

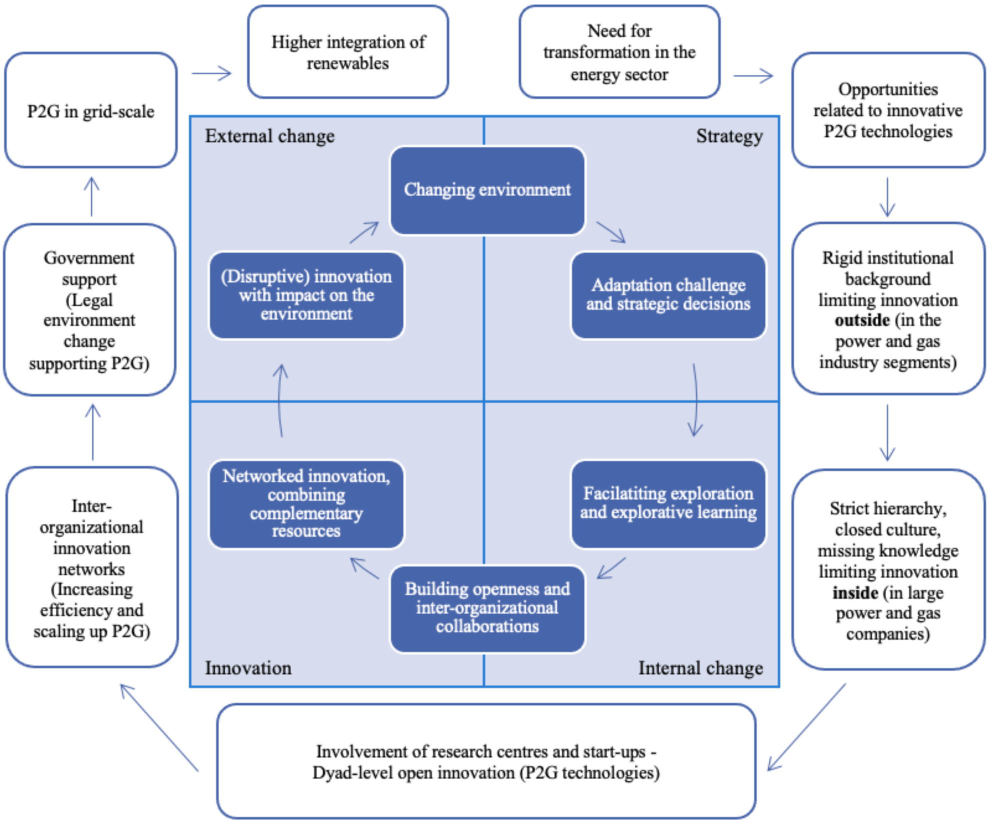

Figure 25. Innovation and change opportunities through P2G technology development (Empirical findings aligned with the theoretical framework of the research)

Source: Csedő & Zavarkó, 2020

These findings emphasize the importance of inter-organizational innovation networks in facilitating the development of a more favorable socio-economic environment that would incite P2G technology development and commercialization.

5.3.3.2 Organizational changes at the collaboration partners

Through the implementation of project management tasks within a network, it has become apparent that these P2G technology development and implementation projects, in line with the change management literature, can induce and do induce organizational changes in the organizations of the collaborating partners. Furthermore, not only the organizational change *generated* by the projects is relevant, but also the organizational changes *needed* to exploit the potential of P2G in a broader sense.

Table 27 shows the organizational changes observed so far and outlines the necessary organizational changes of the future.

Actor	The main organizational changes[23] observed so far that have been *generated* by the projects	Further organizational changes *needed* to exploit the full potential of P2G
Power-to-Gas Hungary Kft.	**Outputs**: In addition to a new technology, expert services are provided in the P2G value chain **Operational processes:** After the unique prototype development, the prototype operation and the continuous R&D were organized differently (e.g. introduction of digital know-how development) **Strategy:** In addition to P2G, P2L technology is coming to the forefront	**Outputs, organizational size, and structure:** The scaling up and widespread application of the technology will require new tasks (e.g. implementation consulting, professional training, operation support), which may lead to staff expansion.
Large energy company / Strategic investor	**Strategy:** Appearance of P2G and related technologies in the renewable energy / innovation-oriented investment strategy	**Culture, behavior, and structure:** Involvement in R&D&I activities requires a new approach or a new unit (a project team) with a new approach (contextual development or structural separation) **Power relations:** Significant top management support is required to provide the extensive infrastructure and financial resources needed to scale up and deploy P2G
P2G operator, site	*There have been no significant organizational changes so far*	**Technology, operational processes:** The on-site technology system is extended with a new solution, the physical processes change **Organizational structure** Resources must be allocated for the operation and control of the new technology

Continued

[23] There may have been changes in the relevant organizational characteristics besides the ones listed, as these may change at the same time.

Actor	The main organizational changes observed so far that have been *generated* by the projects	Further organizational changes *needed* to exploit the full potential of P2G
University, research center	**Organizational structure:** Establishment of a new research group on P2G and related technologies	**Outputs:** Producing new scientific and practical results on P2G and related new technologies
Financial investor	*There have been no significant organizational changes so far (owing to P2G)*	*No significant organizational changes are expected (for P2G)*
Companies developing related technologies (e.g. ICT or Carbon Capture (CC) technology development)	**Strategy:** (ICT) Promoting software developments in support of renewable energy integration and other energy processes	**Operational processes:** Closer cooperation with P2G development companies and universities, for example, (ICT) to offer IT support for P2G operations and fluctuating renewable energy production, or (CC) to synchronize Carbon Capture processes with P2G processes
Expert companies (e.g., business development consultants, technical quality assurance)	*There have been no significant organizational changes so far (due to P2G)*	**Behavior, operational processes:** Due to the previously unknown technology, it is necessary to absorb special expertise in supporting the implementation

Table 27. Observed and further necessary organizational changes

Source: own construction

Based on the results, projects related to P2G technology development have generated organizational changes for most of the actors involved. These organizational changes can be said to be incremental rather than radical. At the same time, unlocking the full potential of P2G technology may require additional organizational changes at the collaborating partners, which do not necessarily need to be radical to help scale up the technology, but they need to point in one direction and fit the organizational changes of the other actors.

The following *coordinated, aligned* organizational changes were identified during the action research:

a) in the strategy of a potential industrial site, which can also be a strategic investor in further P2G technology developments, the P2L process, which is also based on the P2G process, has been appeared (strategic change). The role of P2L was introduced by one of the Deputy CEOs as follows:

> *"Looking at our extensive portfolio, it would be worth looking further in relation with power-to-gas, or rather sideways, what else we could do with hydrogen and methane. [...]Fuel production, for example, would absolutely fit into the portfolio, and hydrocarbons can be used in many ways after all."*

In response, the P2G technology development company itself has begun to expand its existing capabilities towards the development of the new technology, as this may also allow for the commercial application of P2G technology (strategic change). The company's chief technology officer spoke about this:

> *"Regarding the power-to-liquid process, we opened for several directions, as we also know the Fischer-Tropsch synthesis, but we can also call it P2G2L when we turn methane into LNG with an extra liquefaction step."*

b) in order to maintain its strategic focus, the P2G technology development company does not deal with waste heat utilization, which is an important but special area in improving the efficiency of the whole process, however, this task induced the creation of a specialized research group at a university research center (structural change).

In addition, the interviews raised examples of the alignment needs of further changes that may be needed:

a) due to the promise of flue gas use, the study of the operational relationships of carbon dioxide separation and P2G may also induce new tasks at university research center(s) and thus induce modified resource allocation.
b) the commercial application of P2G, for example, at a wastewater treatment plant or an agricultural biogas plant would fundamentally change the physical

processes, while it would also require a change in the logic of organizing work. According to the Deputy Chief Technology Officer of a company with a biogas plant, this would involve a process reengineering:

"I assume the P2G unit should be monitored, secured, maintained daily. [...] If this is really just a supportive task and the special expertise can be provided from the outside, then we can solve these with the existing workforce, but for that, we have to reorganize the work on the site."

c) the involvement of a large energy company in the development of P2G, even at the semi-industrial level, would similarly involve infrastructure intervention, which may necessitate changes to the regulations. However, changes to these regulations and thus to the processes must be made concerning the solutions and technological capabilities that can be provided by the P2G technology developer and other partners. It generates further organizational change if a large energy company not only provides infrastructure but also creates its own project team and plans (complementary) developments, which can mean a change in structure and outputs (or - based on the literature - the relationship of the project team and the main organization can also generate cultural change). In connection with one such complementary technology development concept, the CEO of one of the major energy companies pointed out the interdependence as well:

"We have already started designing the (complementary) technology in-house with a separate team, but we should see more precisely what capabilities the site has now and how the infrastructure will change with the power-to-gas implementation. It would be good if these processes were accelerated in the future."

In summary, based on empirical data, and especially based on the interviews, partners collaborating in a P2G inter-organizational innovation network need to align their activities to each other. Moreover, to ensure the efficiency of the collaboration, organizational changes are (would be) needed either sequentially or in parallel.

5.4 Change management models induced by disruptive technology development

The results of the theory-building phase are presented in the following, which provides answers to the main research question:

Main research question (Q4): What organizational changes are induced by a disruptive energy technology development (power-to-gas technology development), and what models can be used to lead these changes for the widespread, commercial-scale implementation of the technology?

5.4.1 One-dimensional and multi-dimensional change management, closed and open organizational change

Based on the results of my empirical research, the models presented in the "Change Management" chapter of the "Theoretical Framework" part of the dissertation are in fact about "*one-dimensional change management*" and "*closed organizational change*". It means that the change management conducted by top managers only considers the context and substantial characteristics of the own organization and only aims to change the substantial characteristics of the own organization.

However, in the context of P2G technology development, I identified that when developing (potentially) disruptive technologies in an inter-organizational innovation network, the management of organizational changes *generated* or *made necessary* by innovation happening at different stakeholders needs to be aligned so that network members realize greater profit as quickly as possible through their joint developments and investment of resources. This means that the top management of each organization must consider

a) the capabilities of the cooperating partners,
b) possible organizational changes taking place in parallel at the partners,
c) the common goals of the cooperating partners,

and they must also align these, in addition to

a) leading the internal change along with the strategic and innovation goals of the own organization and their substantial organizational characteristics,
b) and thus, allowing for the autonomous renewal and environmental adaptation of the organization.

If one-dimensional change refers to a single (own) organization, then in the case of organizational changes aligned to a single collaborating partner, we need to talk about two-dimensional change management, in the case of alignment to two partners, three-dimensional change management, and so on. Because *multidimensional change management*

a) is relevant in the case of the analyzed disruptive technology due to the necessity for open innovation,
b) involves the alignment of changes of the organizations in line with the goals of the network, the capabilities, and changes of the partner organizations,

thus, we no longer just talk about closed organizational change, but – by analogy with open innovation – about *open organizational change*. Importantly, the ability to change one's own organization is an essential condition for changes aligned to the collaborations, i.e., multidimensional change *cannot be imagined* without one-dimensional change management.

Based on the theoretical models described in the "Change Management" chapter and extended, the main features of one-dimensional and multidimensional change management are presented in Table 28.

	One-dimensional change management	**Multidimensional change management**
Trigger	Loss or threat of loss of the environment-organization fit	Loss or threat of loss of the environment-organization fit **Open innovation, aiming at disruptive technology development**
Goal	Organizational renewal, environmental adaptation Ensuring environment-organization fit (proactive, preactive or reactive adaptation)	Organizational renewal, environmental adaptation Ensuring environment-organization fit, **significant effect on the external environment,** shaping the system of environmental conditions (proactive adaptation)
Context	Strategic, structural, capability-based, and managerial dilemmas	In addition to strategic, structural, capability-based, and managerial dilemmas, there are also **collaboration dilemmas** (e.g., giving up on short-term organizational benefits to maximize network benefits)
Content	Management of closed organizational change: Identifying, preparing, planning, implementing, and maintaining the necessary changes for the own organization	Management of **open** organizational change: Recognizing, preparing, planning, implementing, and maintaining the necessary changes in an **inter-organizational (innovation) network, in cooperation with other organizations, in accordance with the objectives of the cooperating network and the organizational characteristics and / or changes of its members**
The key to renewal in a continuously changing environment	Dynamic capabilities: a) sensing the opportunity, b) seizing the opportunity, c) transforming. Managing efficient and flexible knowledge integration processes, overcoming knowledge retention within the organization.	Dynamic **co-**capabilities: a) sensing the opportunity *for cooperation*, b) seizing *together* the opportunity c) *aligned* transforming. Managing efficient and flexible knowledge integration processes, overcoming knowledge retention within the **inter-organizational innovation network.**

Table 28. One-dimensional and multidimensional change management

Source: own construction

According to the concept of multidimensional change management, disruptive innovation that has a significant impact on the external environment and shapes the system of environmental conditions requires an inter-organizational innovation network; and as innovation involves organizational changes, their management in the network needs to be aligned by the top management of the organizations. Figure 26 illustrates that aligned organizational changes allow organizations with complementary capabilities to combine these capabilities in a way that results in a disruptive innovation that has a significant impact on the external environment. It is important to emphasize, however, that multidimensional change management in an inter-organizational innovation network *does not necessarily mean that all participating organizations need to change at the same time or with certainty*, but rather that, each organization must consider the characteristics of the other organizations, the shared goals, and the *possible* current or future changes of the partners during the autonomous organization change.

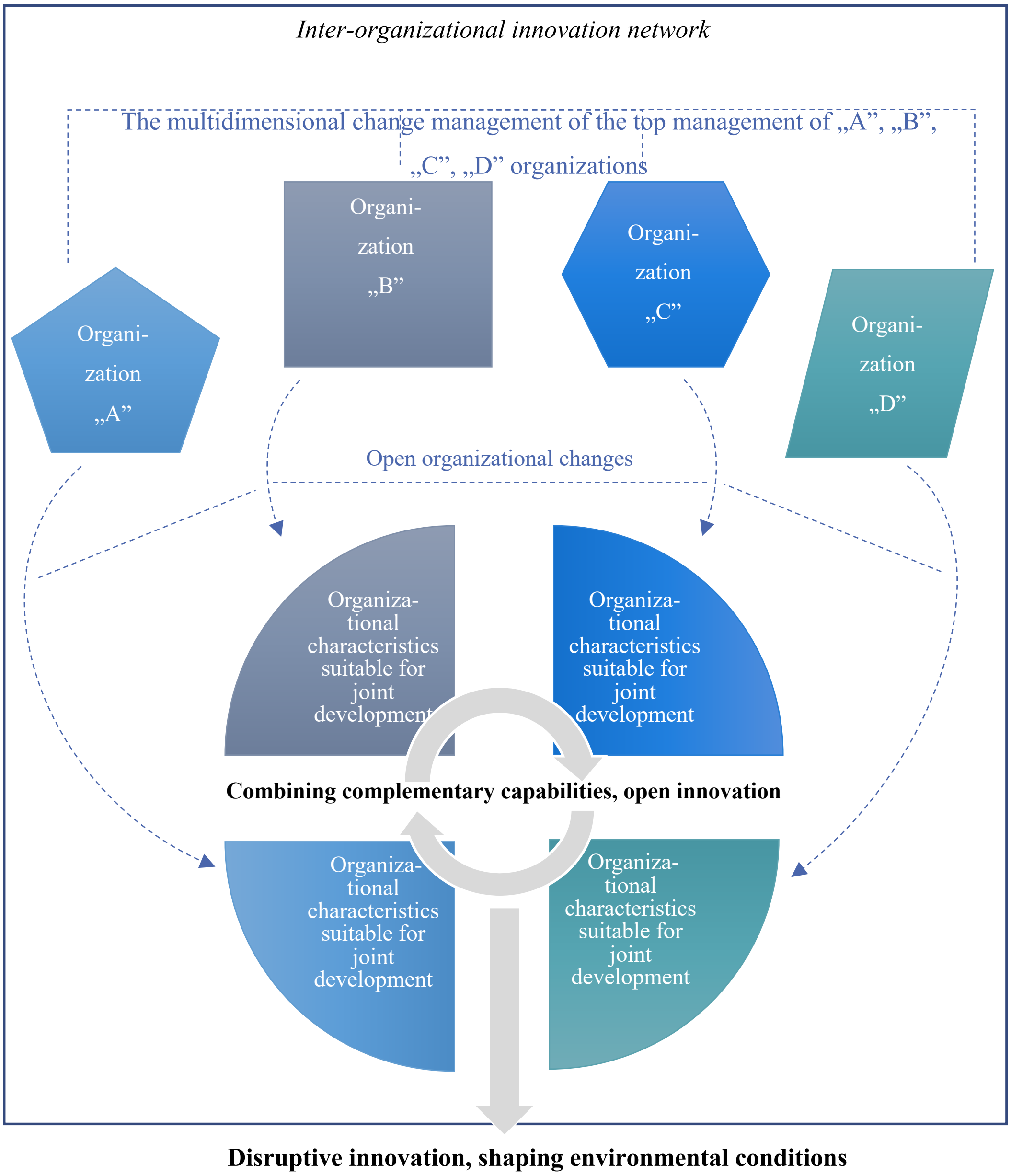

Figure 26. Disruptive innovation in an inter-organizational innovation network generated by multidimensional change management and open change

Source: own construction

5.4.2 Theoretical propositions for the models of multi-dimensional change management

The models, created through the synthesis of the literature and presented in the "Change Management" chapter, can be reworked, and extended according to the multidimensional change management model built on empirical data, and they also designate new research directions.

In this chapter, therefore, I present models that are purely theoretical propositions for further research. The reason for this is that although these propositions follow logically from my PhD research, it was not yet possible to test these theoretical models in the research environment, as the application of P2G technology in Hungary has not yet reached the level that would allow for them to be proved or refuted. At the same time, these propositions can be a good guide, *from a practical point of view,* for the application of P2G technology in Hungary to reach the level at which these theories can be tested.

Such is the case with the comprehensive process model of change management, which needs to be complemented by the collaboration challenges and impacts from partners, considering – based on my resource-based approach – the framework of dynamic capabilities. The relevant proposal is presented in Figure 27, according to which the cooperating partners can have an impact

a) on discoveries and creativity through joint R&D;
b) on the idea of change, if opportunities for cooperation are sensed;
c) on implementation, as opportunities are jointly seized, a disruptive technology is developed in an open innovation approach;
d) moreover, the evaluation and closure may reflect the alignment of capabilities and organizational changes in the inter-organizational network, which may generate further changes.

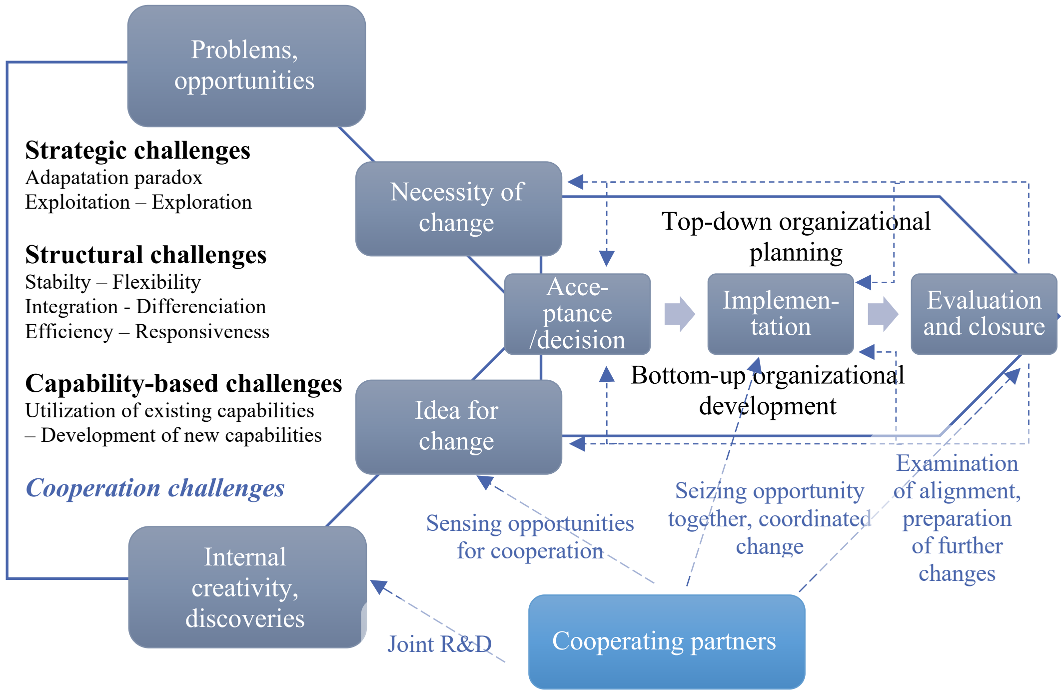

Figure 27. Concept of a comprehensive process model of multidimensional change management by identifying dynamic (cooperation) capabilities

Source: own construction

Moreover, according to this concept, the phases of the integrated process of change management can be complemented with new activity groups, which will be specific versions of each activity group of the one-dimensional change in the case of multidimensional change management. Examples for these are shown in Figure 28 based on what was identified during the action research.

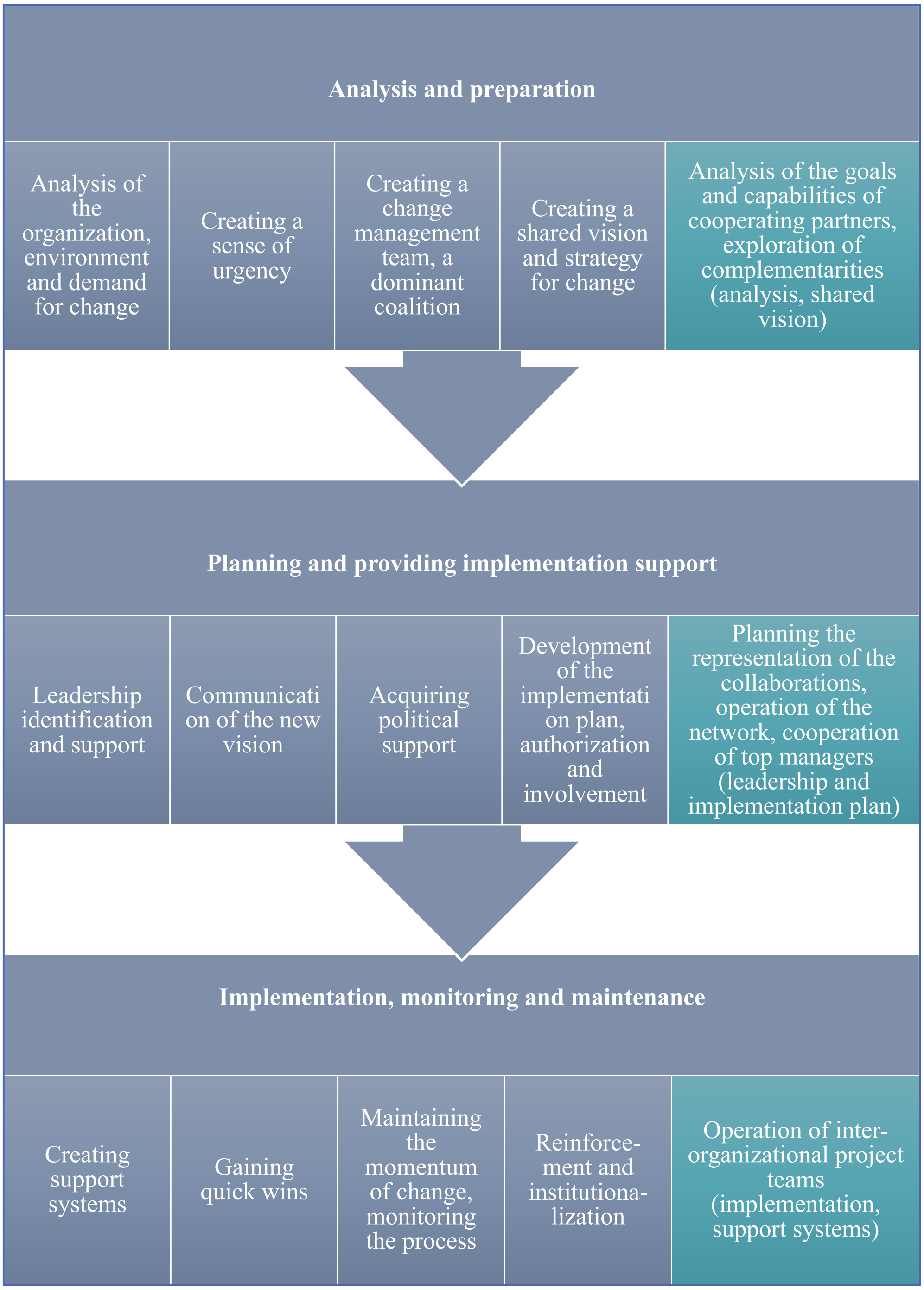

Figure 28. An integrated change management model, extended with the activity groups of multidimensional change management
(highlighted in green)
Source: own construction

Finally, the last model in the "Change Management" chapter studied the relationship between continuous organizational learning and onefold change management. It found that onefold change management may be necessary because of path dependency, but the results may be catalyzed by the support of ongoing organizational learning. This can be extended in the context of multidimensional change management, inter-organizational innovation networks, and potentially disruptive technology development with the phenomenon that, if an organization collaborates with other organizations and learns from partners in an innovation network to aim for disruptive innovation, the organization itself can (proactively) cause the significant environmental change, the kind of changes it only "suffered" before (Figure 29).

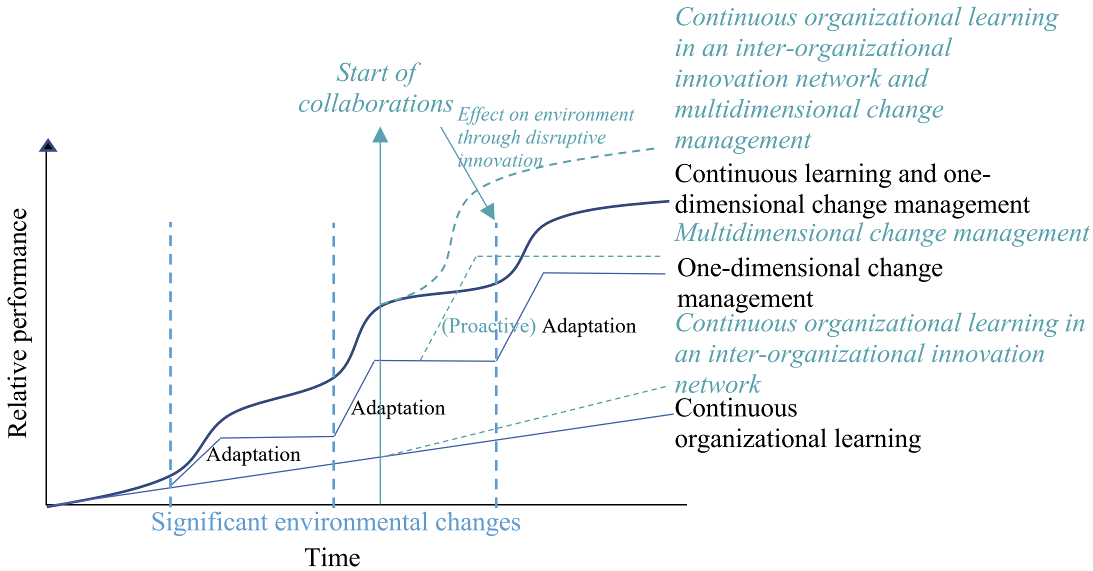

Figure 29. The importance of continuous organizational learning (in an inter-organizational innovation network) in parallel with (multidimensional) change management

Source: *own construction*

5.4.3 Analysis of the multi-dimensional change management and open organizational change through the lens of organizational theories

At the beginning of the presentation of the theoretical framework, I described relevant organizational theories for the research. By analyzing some of the outstanding change management models in the literature, I pointed out that combining elements which are contradictory from the perspective of the philosophy of science can be useful for creating theories that support complex managerial tasks.

This conclusion also seems to be a relevant factor in further research on models of multidimensional change management and open organizational change. Thus, conducting the organizational theory analysis regarding the main conclusion is also worthwhile.

Possible functionalist assumptions of open organizational change and multidimensional change management:

a) Realism: There is a system of "external" environmental conditions (stable structure) that can be affected by the disruptive innovation created by multidimensional change management.
b) Positivism: A general causal relationship is that multidimensional change management leads to open organizational change in an inter-organizational innovation network, which together can enable disruptive innovation.
c) Determinism: The adaptation pressure as a situation determines the commitment of the organizations and top managers (as individuals) participating in the network towards the joint innovation activity and aligned change.
d) Nomothetic methodology: The characteristics of open change can be examined at the network level by action-reaction analysis, it is not necessary to examine the autonomous organizational realities in depth. The success of multidimensional change management can be measured by breaking it down to its elements (organizations) of the cooperating network as a system, by analyzing the autonomous and collective performance of the system elements.

Possible interpretative assumptions for open organizational change and multidimensional change management:

a) Nominalism: If strategic and innovation goals are influenced by changes and further changes are needed to achieve these goals, moreover disruptive innovation and proactive adaptation generate further change, then change can be considered continuous, i.e., there is no stability and permanence, and thus, there is no "external" structure to grasp.
b) Anti-positivism: The autonomous change management strategy of multidimensional change management for a given organization cannot be established universally, it can only be defined in a given organizational context.
c) Voluntarism: If individuals and organizations can influence the environment by changing themselves and through their joint (disruptive) innovation activities, then the situation does not unilaterally define behavior.

d) Ideographic methodology: The characteristics of open organizational change can only be known in the natural context of autonomous organizational change, by direct data collection, in the field, by analyzing the background influencing autonomous organizational behavior in depth.

Furthermore, the synthesized functionalist and interpretative-functionalist (one-dimensional) definitions of change management can be extended to multidimensional change management:

a) Functionalist approach: The role of multidimensional change management is to implement the open organizational changes required for disruptive innovation to achieve proactive adaptation by modifying autonomous organizational systems in a way that is aligned to the collaborating organizations.
b) Interpretative-functionalist approach: The role of multidimensional change management is to support cooperating organizations through continuous organizational and environmental change, to gain a deeper understanding of the factors behind change and the characteristics of open organizational change (motivations, shared meanings) through personal leadership and to modify these factors for the purposes of the inter-organizational innovation network. (The definition will become functionalist through the "modification".)

6 CONCLUSION

6.1 Theses and analyzing their novelty

The theoretical focus of my PhD research is organizational change and its conscious management, change management, which I analyzed from the point of view of innovation and knowledge management based on the main theories of the resource-based view of the firm.

The environment of my PhD research was broadly defined as the Hungarian energy sector, within this the power-to-gas (P2G) industry, and within this the power-to-methane (P2M) segment (bio- or carbon-neutral methane production). In the P2M segment, I focused on newer and more innovative biological methanation technology.

My main research question was the following:

What organizational changes are induced by a disruptive energy technology development (power-to-gas technology development), and what models can be used to lead these changes for widespread, commercial application of the technology?

To answer this question, I followed a qualitative research methodology, and within the framework of action research, I performed a preliminary document analysis, prepared an extended case study at a startup company developing P2G technology, and prepared 14 peripheral case studies at potential sites. In accordance with the principles of the extended case study and the coding technique of grounded theory, the more than 3 year-long research was conducted with iteration between theory and data collection and analysis. As a result, I divided my main research question into three research sub-questions and answered them separately.

As I used qualitative research methodology and action research, I was able to define theoretical, propositional "knowledge," i.e., presumptions based on the literature, for the research questions, instead of hypotheses (Coghlan & Brydon-Miller, 2014). In the phase of the *preliminary fieldwork*, I aimed for prior understanding and I pointed out that the focal technology development has innovation potential in Hungary. Moreover, the smaller technology developer companies and large energy companies participating in the development process have complementary resources (e.g., innovative core technology – extended infrastructure and resource base) and contradictory organizational characteristics (e.g., dynamic, project-based operation – strong hierarchy and strict regulations). These findings oriented the case studies of the *intervention* phase, the sub-questions of which (Q1-3) and the main research question (of the *theory-building* phase) (Q4) were supplemented with presumptions based on the literature (P1-4). **The theses fine-tune and supplement the presumptions with new aspects, they do not refute them.** This result is consistent with the chosen methodology, the iteration between theory and practice, the literature, and empirical data collection and analysis.

6.1.1 First research sub-question, presumption, and thesis

During the peripheric case studies, I researched the environmental and organizational changes related to the focal technology development with an "outside-in" approach, and I dealt with the disruptivity of the focal technology, which is a research gap in the international literature. The first research sub-question was the following:

Q1: What changes are needed for the widespread, commercial-scale application and the disruption of the technological innovation?

Besides organizational change and change management, the presumption for the research sub-question considered the examination of the disruption as well, because it also appeared in the main research question.

P1: The focal technology may become disruptive based on the literature results (Christensen, et al., 2015). The widespread and commercial-scale implementation of a potentially disruptive technology requires organizational changes at the companies that apply the focal technology. This is because technology can be substantial organizational characteristic in the examined organizational context (Dobák, 2002), which changes (must change) owing to the implementation and this affects the other substantial organizational characteristics as well.

To empirically answer the research question, I conducted peripheric case studies at potential sites. The standardized implementation of biomethanation P2G technology of the approx. size of $1MW_{el}$ is promising at larger Hungarian wastewater treatment plants, however, due to the economic aspects, the supportive regulatory environment may also be important for exploiting the potential of P2G. Nowadays, the technology is rather a value innovation due to its unique attribute package (parallel seasonal energy storage and direct decarbonization), while the condition for disruptiveness is a further increase in the volume of renewable energy production and a significant reduction in the costs of carbon dioxide separation (Carbon Capture). These factors are important because the technology would then be able to be implemented on a larger scale with a favorable cost-benefit ratio even at flue gas emitting industrial plants.

Based on the results, the widespread, commercial-scale implementation of the technology requires not only organizational changes at the sites. The answer to this research sub-question fills technology-specific research gaps and also contributes to theory-building, as potential disruption predicts proactive adaptation through successful technology development, changing the system of environmental conditions.

T1: The focal technology is a value innovation today, however, it can be a disruptive technology of the future depending on complementary technology developments and organizational changes. However, the widespread and commercial-scale implementation of such a potentially disruptive technology requires not only organizational changes. Complementary technology developments must be realized with inter-organizational collaborations and shaping the environmental (institutional) system of conditions for the widespread, commercial-scale application, and it requires change management beyond internal organizational changes in the case of disruptive technologies.

One of the novelties of the first thesis is that it is the first in the international literature to evaluate the disruptiveness of P2G technology, and to integrate strategic aspects into the study of the technological innovation in addition to technical and economic aspects. From the point of view of management sciences, the novelty of the thesis is that it makes explicit the dependence of disruptiveness on the development of complementary technologies and *changes in the regulatory environment, (1) which appears only implicitly in the original model (Christensen, et al., 2015)* [24]*, and (2) which goes beyond the necessity of managing autonomous organizational changes, pointing out the importance of managing inter-organizational networks and innovation ecosystems.*

6.1.2 Second research sub-question, presumption, and thesis

After analyzing the necessary changes connected to the examined technology development during the peripheral case studies with an "outside-in" approach, the extended case study conducted at the technology development startup was prepared with an "inside out" approach, for which I defined two research sub-questions. One of these research sub-questions was the following:

Q2: What innovation management tasks must be conducted to reach the widespread and commercial-scale implementation of the potentially disruptive technology in the relation system of explorative and exploitative activities?

In line with my research framework, the presumption to the research sub-question is built on the importance of explorative and exploitative learning, moreover, digital innovation and knowledge management.

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[24] An important element of the theory is that disruption is a process that requires time (and change). The authors cite as an example that new technologies made disruption possible for Netflix. The development of these "new technologies" was not part of the core business model and can therefore be considered as complementary development.

P2: In order to seize opportunities and address challenges, innovation management tasks, especially idea management, development, learning, and resource and competency management may be required (Tidd & Thuriaux-Alemán, 2016), the efficiency of which can be enhanced by digital innovation management (Nambisan, et al., 2017) and open innovation (Chesbrough, 2003), knowledge and technology transfer (Millar, et al., 1997) between startups and large organizations with complementary resources (innovative core technology – extended infrastructure and resource basis). The determinants of learning and resource and competency management are knowledge management mechanisms that enhance exploitation and / or exploration (March, 1991; Grant, 1996), and these can be supported by digital solutions that enable the codification, systematization, sharing, and utilization of knowledge (Alavi & Leidner, 2001; Zhang & Venkatesh, 2017).

Based on the empirical results, the performance indicators of the focal technology mean value creation opportunities (e.g., efficient long-term energy storage, green gas production, network-balancing), but innovation challenges emerged on micro-, meso- and macro-level (efficiency gains at the technology and sector level, ensuring the conditions for scalability, uncertain regulatory environment). After exploring the operative opportunities and challenges it became clear that organizational actions are needed to exploit the potential of the focal technology: further research and development, deliberate site selection, access to financial resources, the involvement of experts from other sectors, and change in the regulatory environment.

The dyad-level open innovation (development of the prototype) led to further innovation opportunities (e.g., scaling up the technology, commercial-scale implementation). However, based on the results, a dyad-level collaboration is not enough on its own to overcome the innovation challenges of the disruptive technology. Instead, an inter-organizational innovation network is needed, in which universities, research centers, other startups, investors, state administration also get a place besides smaller technology developers and large companies. In this network,

a) from the aspect of the technology developer company, the parallel realization of exploitative and explorative learning with connecting the actors can be considered as success factors. It means that the company has (had) to affect the external environment as the "engine" of the innovation with the creation of the P2G inter-organizational innovation network.

b) from the aspect of a large energy company, opening the organization for the (disruptive) technology developers are important to facilitate exploration.

Based on these results, a further success factor can be both in the case of dyad-level or network-level open innovation the support of the technological know-how flow with integrated digital platforms, the functionality of which partly goes beyond knowledge management (know-how development, innovation problem solving – idea generation, prototype / plant management, e-learning).

Consequently, the presumption was correct, but not complete, so I defined the following thesis:

T2: To seize the opportunities and overcome the micro-, meso-, and macro-level challenges of the potentially disruptive technology, dyad-level open innovation is not enough, it is necessary to form an inter-organizational innovation network that has an impact on the change of the external environment. Furthermore, both exploitative and exploratory learning is relevant, not only at the organizational level but also at the level of the inter-organizational network. This learning and the related technological know-how flow can be efficiently supported by an integrated digital platform that provides not only codification, systematization, sharing and utilization, but allows for the flow of knowledge elements between organizations and *also* among modules beyond the scope of traditional knowledge management functions.

On the one hand, the novelty of the second thesis is that it points out the need for generating macro-level change, which was not listed either in the technological or organizational (micro) approach of the list of innovation management practices (Tidd & Thuriaux-Alemán, 2016), or in the network (meso) approach of digital innovation management (Nambisan, et al., 2017). On the other hand, it distinguishes dyad-level collaboration from the inter-organizational network not only as a level of analysis of open innovation (Chesbrough, et al., 2006) but also as developmental phases of the open innovation structure. It also points out that the knowledge management tools listed in the literature (Zhang & Venkatesh, 2017) need to be expanded for disruptive innovation, both *functionally (idea management, prototype management, e-learning) and in terms of users (inter-organizational network instead of a single organization).*

6.1.3 Third research sub-question, presumption, and thesis

The need for the inter-organizational innovation network, and the disruptive technology development pointed out that generated change by innovation or the needed change for innovation must be analyzed not only at a single organization:

Q3: What organizational changes are induced by the focal innovative technology development within the stakeholder organizations?

Based on the literature, the realization of the innovation (as a process) and the realized innovation (as an output) can also generate organizational changes, and the adaptation can be supported with partnerships with other organizations.

P3: Among the organizations involved, there will be some that need organizational change for innovation purposes (Teece, et al., 1997; Kotter, 2012), while – through partially open innovation processes (Chesbrough, 2003) – the achieved innovation goal will generate organizational changes in other organizations (Csedő, 2006; Hammer, 2004).

The results showed that P2G technology development and its network implementation induces changes both inside and outside the organizations of the cooperating partners. Collaborating organizations (especially large energy companies following exploitative routines, but also other organizations) "open up" their organizations to each other for the autonomous benefits of P2G (e.g., organizational renewal, adaptation to changing energy trends). This "opening up" also entails organizational changes: the changes observed so far were incremental changes in operational processes, strategy, outputs, and structure, but further changes are (would be) needed (1) the content of which also depends on the capabilities and changes of other organizations involved, and (2) which are necessary for the success of network collaboration (for example, to improve the regulatory environment or to effectively exploit the potential of P2G to the benefit of every partner).

An example for such an aligned change, that the technology developer company expanded its R&D&I focus, in line with the strategic priorities of a large energy company (strategy, outputs), or a new research group started to work in a research center on complementary technologies which can increase efficiency, in line with the solution of the technology developer company (structure, outputs).

In case of further needed changes, alignment is also important for efficiency. For example, the actual implementation of the technology must be aligned with the characteristics of the company that provides the site of the implementation, but this company must modify its processes according to the core technology. Moreover, this complexity is increased further, because this is relevant not only in case of the core technology but complementary technologies as well (which are developed e.g., by dedicated project teams of large companies or research centers) (process, structure, outputs).

If these organizational changes are not aligned, the period of the development, so the invested resources (e.g., workforce) may increase, moreover, redundant, missing, or incompatible results can be produced. Regarding the novelty of the core technology and the complementary technologies, this is a real risk. For example, P2G, Carbon Capture, waste-heat utilization technologies, and related ICT solutions can be developed in several directors, but the related organizational changes (e.g., new R&D process or output, new project team or research group, new operational processes) must be aligned to the shared goals and the autonomous and the complementary (organizational and/or technological) capabilities (e.g., synchronized R&D and implementation of biological methanation, oxyfuel Carbon Capture, low-temperature waste heat recovery and real-time remote control of these).

T3: Because of the novelty (disruptiveness) of the technology, open innovation is no longer enough, the potentially disruptive technology also requires organizational changes in the cooperating organizations. This means that in organizations developing a disruptive technology, organizational change *and* open innovation processes are (can be) interrelated. It is also necessary to align the changes implemented in the different organizations to have a (further) impact on the external environment with the inter-organizational network and to be efficient at the network level. For example: the company which provides the physical infrastructure must reconfigure the operational process according to the core- and complementary technology developers' capabilities for the implementation; (2) a large energy company and a research center must share the complementary R&D&I tasks according to the core technology and the specific attributes of the infrastructure-provider, and creating project teams and research groups. The efficiency of the development is higher when organizational changes are aligned because the period, so the invested resources can be decreased in this way, moreover, no redundant, missing, or incompatible organization outputs are produced in the network.

The novelty of the third thesis is that open innovation not only requires or generates organizational changes in collaborating organizations (Peris-Ortiz & Liñán, 2019)*, but these changes must also be aligned because of the goals of the inter-organizational network and efficiency expectations.*

6.1.4 Main research question, presumption, and thesis

Along the three research sub-questions presented, I approached my research topic from several aspects (environmental change and strategic alignment; resource-based examination; analysis of technical, economic, strategic issues and disruptiveness; technology-specific innovational opportunities and challenges; innovation management tasks; organizational changes), to cover every aspect of my research question with my research.

Main research question (Q4): What organizational changes are induced by a disruptive energy technology development (power-to-gas technology development), and what models can be used to lead these changes for the widespread, commercial-scale implementation of the technology?

Based on the analysis of change management theories and their (re)interpretation, I defined the following presumption:

P4: Disruptive energy technology development (power-to-gas technology development) can induce incremental and/or radical organizational changes. The changes induced by technology development can be managed according to the following models: (1) top-down organizational planning and type "E" change, (2) bottom-up organizational development and type "O" change, (3) combined model (one top-down and one bottom-up element each) or (4) an integrated model (integration of bottom-up elements into the dominantly top-down process). (Dobák, 2002; Beer & Nohria, 2000; Csedő & Zavarkó, 2019b)

As a result of the application of the grounded theory coding technique, a new change management concept was developed, which of course builds on the previous findings in the literature.

Summarizing the content of the central concept of the theory, multidimensional change management

a) is necessary for the development of (potentially) disruptive technologies, according to the open innovation paradigm in an inter-organizational network;
b) involves an 'open' organizational change, according to which the substantial characteristics change not only according to the environment-organization fit, but also according to the characteristics and possible changes of the collaborating organizations;
c) results in disruptive innovation, thus an impact on the external environment, a change in the system of environmental conditions.

Main thesis (T4): A disruptive energy technology development (power-to-gas technology development) has generated incremental changes in various substantial characteristics of several organizations and requires further changes in the inter-organizational innovation network. These can be managed by a "one-dimensional" and a "multidimensional" change management model, the latter involving "open" organizational change. To implement the disruptive technology as quickly and efficiently as possible, widely and on a commercial-scale, a new, multidimensional change management model should be followed instead of the "traditional", "one-dimensional" change management models.

I present the novelty of the fourth thesis in detail in Chapter 6.2.

The primary limitation of the present theoretical model is that it was developed following a qualitative methodology and, according to the principles of grounded theory, is valid only in a limited social context.

6.2 Presenting the novelty of the main conclusions

6.2.1 The area of organizational changes and change management

The research produced new theoretical results and models in the field of change management, which is not yet covered in the international literature. The concept of multidimensional change management and open organizational change is most closely related to the publications published by Emerald in the 2019 special issue of the *Journal of Organizational Change Management (JOCM)* "Open Change in Open Innovation". As the JOCM has the highest H-index of the journals focusing on organizational change and change management based on the Scimago-Scopus list[25], on the one hand, the special

[25] H-index of journals focusing of organizational change and change management: Journal of Organizational Change Management (Emerald) – 66; Journal of Change Management (Routledge) – 25; Journal of Accounting and Organizational Change (Emerald) – 23; Research in Organizational Change and Development (Emerald) – 15; Strategic Change (Wiley) – 12.

issue supports the theoretical significance of the topic, on the other hand, it provides a good basis to evaluate the theoretical significance of my PhD research in context. The central theme of the special issue was what organizational changes occur in cases where firms follow an open innovation strategy and how these should be managed in different sectors and for different forms of innovation (Peris-Ortiz & Liñán, 2019). Based on the topics and results of the publications, the results of my PhD research also fulfill my research goal, to help corporate innovation processes with findings that complement the existing models of change management, both in terms of theoretical approach and concrete results.

The relevance of the topic and the theoretical contribution of my research to the development of the field can be justified on the one hand by the fact that based on the bibliometric analysis of Odriozola-Fernández et al. (2019), neither change, organizational change nor change management appears amongst the most common keywords of publications concerned with the topic of open innovation regarding small and medium-sized companies (startups). Filling this research gap in part, the results of my PhD research – analyzed primarily from the perspective of a smaller technology developing startup – envisage the need for aligned autonomous organizational changes of the partners cooperating in innovation. On the other hand, Fernandes et al. (2019) identified six theoretical perspectives on open innovation based on a comprehensive literature review: (1) the concept of open innovation, (2) open innovation and networks, (3) open innovation and knowledge, (4) open innovation management, (5) open innovation and innovation spillover, (6) open innovation and technology. While my PhD research considers these theoretical perspectives, especially the importance of networks, knowledge, and management, it also identifies a new theoretical perspective for further research: "open innovation and change management". It is also worth noting that none of the literature reviews cited contain the term "disruptive," which was also an important pillar of my research.

Source: Scimago, data of April 2020, downloaded: 18.03.2021., search filter only by subject area: „Business, Management and Accounting"

Comparing the concrete results of the research with similar research results, Arfi et al. (2019) – with a case study method similar to my PhD research – examined the importance of knowledge sharing platforms in the success of open innovation organizational changes. They pointed out, based on a dyadic open innovational relationship, that the creation of knowledge sharing platforms incites significant organizational changes. While the results of my research also supported this in relation to the technology developer company's digital R&D&I platform, I also highlighted that open innovation sometimes has to move from a dyadic level toward a larger innovation network, in the success of which a knowledge sharing platform and the management of organizational change can have a central role. Furthermore, Expósito et al. (2019) examined open innovation cooperation strategies and concluded that R&D relationships with market participants lead to higher innovation performance, while relationships with institutional actors (e.g., universities, public institutions) lead to lower ones. The results of my research supplement this with the fact that institutional relations in the case of R&D (cooperation with universities) and market introduction (shaping the regulatory environment) can be critical in the field of energy.

In addition to the thematic approach, the novelty of the dissertation can also be analyzed according to the introduced concepts. Not only does "multidimensional change management" not appear in the Hungarian literature ("többdimenziós változásvezetés"), but its English version (multidimensional / multi-dimensional change management) also appears only four times and *only mentioned ad-hoc* among the scientific works available in Google Scholar and in the EBSCO database.

1. In an article from 2013, the multidimensional change management *approach* denotes that not only that organizational resistance should be addressed, but also employee support is needed (Yilmaz, et al., 2013). In my approach, this is the fundamental task of change management, as I have presented based on the change management literature.
2. In a proceeding of a 2018 conference on e-learning, a multidimensional change management *strategy* appears once as a tool for pedagogical development collaborations between blended learning and university networks (Dion, 2018). The authors suggested that top-down processes had to be mixed with bottom-up

processes, which – as I have shown – has not been a novelty in the change management literature since the model of Beer and Nohria (2000).

3. The multidimensional approach to change management emerges in a learning context once more and suggests that flexible and online education also requires change in business processes and funding structures (Kemelfield, 2002). In fact, this only means that several substantial characteristics change at the same time, this has been discussed in detail in the literature before (Dobák, 2002; Csedő, 2006).
4. Finally, also in a similar topic, a multidimensional change management *project* is also mentioned as a factor needed to develop problem-based learning (Nair, et al., 2020).

Based on all this, the content of multidimensional change management I have outlined can be considered more detailed and newer compared to these four instances.

The other new "open organizational change" term also appears only as an open organizational change *process* in the book titled "Competence Management for Open Innovation" (Hafkesbrink, et al., 2010). In addition, *multidimensional organizational change*, meaning the combination of the two terms, also appears once a while, for example in a 1998 article (Teng, et al., 1998), once in a case study from 2006 (Hassan & Velayutham, 2006), and as an attribute of a data collection scale (Hung, et al., 2013). *Open change management* also appears once in the context of involving stakeholders (Rosado, 2016), and once in the context of aligning to industrial organization systems, performance indicators, and operating methods (Zaïda, et al., 2007), which all deal with only one company (in my approach this is one-dimensional change management).

Although it is not possible to state with certainty given the almost unlimited amount of literature available today, but I hope that the concepts of "multidimensional change management" and "open organizational change" as the main theoretical conclusions, which are presented with a more developed and novel content based on the literature research, and especially the considerations behind them, can be forward-looking in the development of the field of change management.

6.2.2 The field of energy innovation management

During the research, I analyzed the development and implementation of the innovative energy storage technology, the power-to-gas (P2G) process realized through biological methanation, from the perspective of innovation, change, and the management of inter-organizational networks. Due to the continuous iteration between empirical research, the P2G literature and management theory, the results

a) emphasize the key role of inter-organizational networks in the development of P2G technology;
b) allowed P2G to be approached from a new aspect, from the perspective of "soft" management;
c) proved that conducting action research focusing on renewable energy technologies is not only possible but also important and effective to generate social change for the energy transition. (Csedő & Zavarkó, 2020)

Furthermore, it is worth pointing out the finding of the research that highlights that P2G technology development requires not only networking but also conscious exploitative and exploratory learning in the network (and its digital support). This is because (1) the technology developer company is thus able to utilize its unique capabilities throughout the P2G development and implementation value chain and in the development of related new technologies, and (2) it allows industry, academic and regulatory stakeholders to make coordinated efforts to exploit the potential of P2G on the country-level.

Additionally, another practical significance of the research is that it provided insight into the site-specific opportunities and limitations of P2G technology development and highlighted the role of a supportive institutional environment and complementary technology development (especially Carbon Capture technologies) in the widespread and commercial-scale implementation of the technology and its disruptiveness.

6.3 Limitations and future research

6.3.1 Further research of the change management models

Building on action research, case study approach, and grounded theory, the conclusions can be considered as a substantive theory (Glaser & Strauss, 1967), which is valid in a given research context. Nonetheless, there are many other complementary areas that could be researched with different methodologies or in different research contexts. The findings of this paper could serve as opportunities for further research in other countries about the role of inter-organizational networks in the improvement and exploitation of P2G or other innovative technologies.

Furthermore, although the theoretical conclusions and propositions presented are based on iterations of empirics and theory, there are still several change management questions that require new research in order to be answered. Examples include how to realize multidimensional organizational change in practice, what are the challenges of collaborations, and what tools can be used to address them? As the environment of my PhD research, P2G technology development was not (yet) adequate to research these questions, in the short term it is possible to answer these questions and test the theoretical propositions only in other areas. Moreover, given the nature of multidimensional change management, it may be necessary to analyze the highest level of organizational leadership, the corporate governance literature, to answer the new questions. Relevant areas include, for example, the theory of resource dependency from classical perspectives (Pfeffer & Salancik, 1978) or, according to its recent approaches, the study of networks (Sytch & Tatarynowicz, 2014; Hernandez & Menon, 2021).

6.3.2 P2G-specific research areas

My PhD research studied the P2G technology primarily form management aspects, secondly from techno-economic aspects, to support the exploitation of the potential of the technology. In line with the examples in the international literature (Schiebahn, et al., 2015), an overall (quantitative) research could focus on the topic that how P2G could affect the future Hungarian energy sector in different scenarios.

Furthermore, while this qualitative study gave an insight into key factors that lead to the formation of an inter-organizational P2G innovation network. A future quantitative analysis could be applied to examine the power-to-methane segment for example with the technological innovation system (TIS) model (Decourt, 2019). Similarly, as action research was focusing on generating new research results and social change parallelly, some interesting points have not been covered, such as evaluating the performance of the network and its impact on the environment (van der Valk, et al., 2011), identifying its critical success factors with statistical methods (Ceptureanu, et al., 2018) or exploring how inter-organizational governance could or should work in this segment (Roehrich, et al., 2020).

Nevertheless, some technological possibilities or alternatives might have not emerged because of the disruption-focused research sub-model. For example, while P2L was relevant for opening new market opportunities in the transportation sector, solutions for CNG or LNG production are one step ahead after P2M in the value chain. The combination of the P2M process and LNG production (Imre, et al., 2019) would be, however, the competitor of P2L in the transforming transportation sector. Accordingly, future research could focus on the techno-economic comparisons of P2L and P2M+LNG. Another limitation of the study is that cost-benefit ratios were determined based on CAPEX, but hardly predictable operational expenses and revenue streams can accelerate or decelerate the possible disruption process of P2M. Furthermore, the background of mainstream consumer needs could be also deeper explored.

Finally, analyzing the synergies of oxy-combustion and P2H/P2M process could be a relevant topic in relation to increasing the market attractiveness of seasonal energy storage and decarbonization for multiple stakeholders, which this research also aimed.

Despite these issues for further exploration, I believe that the findings which were formulated with the help of my supervisor and research fellows could contribute to the widespread, commercial-scale implementation of P2G technology.

7 Appendix

1. Abbreviations

AEL	Alkaline electrolysis
BEP	Bioethanol plant
BESS	Battery energy storage systems
BGU	Biogas upgrading
CAPEX	Capital expenditures
CC	Carbon capture
CHP	Combined heat and power (unit)
CNG	Compressed natural gas
EMG-BES	Bioelectrochemical system for electromethanogenesis
IGCC	Integrated gasification combined cycle
INP	Industrial plant
LIB	Lithium-ion battery
LNG	Liquified natural gas
NGCC	Natural gas combined cycle
OPEX	Operating expenditures
P2G	Power-to-Gas
P2H	Power-to-Hydrogen
P2L	Power-to-Liquid
P2M	Power-to-Methane
PC	Pulverized coal
PE	Population Equivalent
PEMEL	Polymer electrolyte membrane electrolysis
SOEL	Solid-oxide electrolysis
TRL	Technological readiness level
WWTP	Wastewater treatment plant

2. Organizational theoretical analysis of theoretical models about innovation and knowledge management

Similar to the change management theories, I present the components of a few innovation management and knowledge management theoretical models in tables which may refer to functionalist or interpretative assumptions (Table 29 and 30).

Author, date, page number	Highlighted definition/model	Examples for components that suggest functionalist assumptions	Examples for components that suggest interpretative assumptions
Burns & Stalker, 1961, p. 5, 77	Based on the stability of the external environment, mechanical or organic structure is needed. The organization is also an interpretive system.	The external environment determines the required structure for survival. (Determinism)	If the organization and the operation is built on the interpretation of information, a community-dependent interpretation of reality is assumed. (Nominalism)
Utterback, 1994, p. 17, 184, 231	Product and process innovation curves about innovation content and temporality. Continuous and discontinuous changes follow each other in the environment.	Explains the phenomena of innovations with a general model (Positivism)	If continuous and discontinuous changes follow each other, there is no stability in the world. (Nominalism)
Teece et al., 1997, p. 509, 528	Too much attention on positioning within the industry distract decision-makers from investing to core competencies and dynamic capabilities. A strategy analysis must be situational, and competitiveness can be studied from the inside.	The lack of dynamic capabilities impedes long-term efficiency (and endangers survival). (Determinism, positivism)	The source of the competitiveness of the organization can be identified in the given organizational context. (Ideographic methodology)
Ches-brough et al., 2006, p. 11, 22	The open innovation paradigm is more effective for innovation than the closed innovation paradigm. Selecting the innovation projects from the aspect of the business model is naturally not objective.	Higher innovation potential in the open innovation paradigm is described as a general correlation. (Positivism)	Fitting to the business model is a personally/ collectively created label on innovation projects. (Nominalism)
Dobák, et al., 2012, pp. 45, 46	An organization can operate with permanent change. Low or high growth effort is aimed according to the intention of the manager.	Stability or the possibility of stability is assumed. (Realism)	The intention of the manager about growth is/can be depending on the own motivations and environmental perceptions. (Voluntarism)

Table 29. Analysis of innovation management models from functionalist and interpretative aspects

Source: *Csedő – Zavarkó, 2019a*

Author, date, page number	Highlighted definition/model	Examples for components that suggest functionalist assumptions	Examples for components that suggest interpretative assumptions
Johanson & Vahlne, 1977, p. 26, 28	Successful international expansion can be built on acquiring and using knowledge about the foreign market, but experiential knowledge cannot be transferred from one individual to another.	There is an "external structure" that must/can be known for the international expansion. (Realism)	If knowledge about the external market cannot be transferred, then it cannot be independent from the individual. (Nominalism)
Grant, 1996, p. 116, 120	Coordination mechanism must be created for knowledge integration by the management. The creation of a common language, symbolic communication, shared meanings and understandings are all the parts of knowledge integration.	Mechanisms as a system will influence the knowledge-sharing behavior of the individuals. (Determinism)	Common language and symbolic communication assume the construction of reality by the community. (Nominalism)
Hansen, et al., 1999, p. 106, 107, 108	Two knowledge management strategies: codification and personalization strategy.	Codification strategy is based on the consideration that knowledge about reality is independent of the individual and can be coded, stored, used (explicit knowledge) (Realism)	Personalization strategy is based on the consideration that knowledge is inseparable from the individual and that is why it can be learned only in person (tacit knowledge). (Nominalism)
Alavi & Leidner, 2001, p. 111, 131	There is not a single or optimal knowledge management or knowledge management system approach, that is why multiple KM approaches and KM systems are needed in organizations, to deal with the many kinds of knowledge. Knowledge can be personalized information and a state of understanding.	It describes a general suggestion for better knowledge management. (Positivism)	The personalized information and the understanding as knowledge are inseparable from the individual. (Nominalism)
Gaál, et al., 2009, pp. 2,15)	Change is the only certainty in the knowledge economy. The knowledge management practice of an organization can be described with the knowledge management profile maturity model.	Knowledge management maturity can be measured in general and with quantitative methods. (Positivism and nomothetic methodology)	The only certainty is change. (Nominalism)

Table 30. Analysis of knowledge management models from functionalist and interpretative aspects

Source: *Csedő – Zavarkó, 2019a*

3. Site-specific questions

Biogas plants:

a) Fermentation (e.g., temperature)

b) Raw biogas composition (e.g., sulfur)

c) Gas characteristics (e.g., gas flow, pressure)

d) Gas engines (e.g., type)

Wastewater treatment plants:

a) Features of the biogas plant (see above)

b) Utilization of the oxygen byproduct

Bioethanol plants:

a) Production process description

b) Volume of CO_2 from fermentation

Industrial plants:

a) Flue gas characteristics (e.g., source, composition)

b) CO_2 in the flue gas

c) Waste-heat utilization at auxiliary plant

4. Energy storage potential at an average WWTP

The storage potential is evaluated by taking WWTPs exceeding 100,000 PE into consideration. Based on previous research, the biogas yield of an average sewage anaerobic digestion (AD) facility in Hungary reaches 0.04 m^3/day/PE (Bai, 2007). The relevant 20 WWTPs exceeding 100,000 PE with the PE value of 5,901,866 existed in Hungary. Based on the data above, the average size of a Hungarian WWTP which is relevant for P2G technology (C_{P2G}): $C_{P2G} = \frac{5{,}901{,}866\ PE}{20} = 295{,}093\ PE$

The average biogas yield of an average WWTP:

$$\boldsymbol{P_{P2G} = 0.04 \frac{Nm^3}{day \cdot PE} \cdot C_{P2G} = 0.04 \frac{Nm^3}{day \cdot PE} \cdot 295{,}093\ PE}$$
$$\boldsymbol{= 11{,}804 \frac{Nm^3}{day}}$$

Presuming the methane ratio of the biogas yield is 0.55 the hourly volumetric carbon dioxide flow of an average WWTP is calculated by the equation below:

$$\dot{V}_{CO2} = (1 - 0.55) \cdot \frac{P_{P2G}}{24} = 0.45 \cdot \frac{11{,}804}{24} = 221.2\frac{Nm^3}{h}$$

The electrolyzer capacity of a P2G facility using biogas of an average WWTP is calculated with the presumption of the 4.7 kWh electrical energy demand for the yield of 1 Nm^3 of biomethane is 4. 7 kWh/Nm^3:

$$P_{P2G} = \dot{V}_{H2} \cdot 4.7\frac{kWh}{Nm^3} = \dot{V}_{CO2} \cdot 4.1 \cdot 4.7\frac{kWh}{Nm^3}$$
$$= 221.2\frac{Nm^3}{h} \cdot 4.1 \cdot 4.7\frac{kWh}{Nm^3} = 4{,}263\ kW = 4.26\ MW_{el}$$

The other way of calculating P2G capacity for an average WWTP is by using the biogas volumetric flow rates burned in combined heat and power (CHP) units at WWTP sites. Kisari (2017) defined regional WWTPs onsite CHP capacity by analyzing 10 relevant biogas plants using biogas generated from anaerobic degradation of sewage slurry. In accordance with his research, the average built-in CHP capacity was 730 kW_{el} (P_{CHP}). Sinóros-Szabó (2019) calculated the theoretical P2G potential with the focus on available regional bioethanol and biogas yield in Hungary. That research carried out conclusions on total biogas annual yield and made no difference in the sources, particularly on WWTP biogas streams.

The calculation of P2G plant capacity on the basis of built-in CHP capacity of WWTPs:

$$P'_{P2G} = (\dot{V}'_{CO2}) \cdot 4.1 \cdot 4.7\frac{kWh}{Nm^3}$$
$$= \left(\frac{P_{CHP} \cdot (1 - 0.55)}{\frac{\eta_{CHP}}{100} \cdot \left(\frac{100 - r_s}{100}\right) \cdot HHV_{CH4}}\right) \cdot 4.1 \cdot 4.7\frac{kWh}{Nm^3}$$

$$where$$

r_s - AD plant electric self-consumption percentage – 15%

η_{CHP} - CHP electric efficiency – 35%

HHV_{CH4} – Higher heating value of methane – 10.3 kWh/Nm^3

After executing the substitution, the calculated capacity is:

$$P'_{P2G} = \left(\frac{730\ kW \cdot (1 - 0.55)}{\frac{35}{100} \cdot \left(\frac{100 - 15}{100}\right) \cdot 10.3}\right) \cdot\ 4.1 \cdot 4.7 \frac{kWh}{Nm^3}$$

$$= 107.2\ \frac{Nm^3}{h} \cdot 4.1 \cdot 4.7 \frac{kWh}{Nm^3} = 2,065\ kW_{el} = 2,065\ MW_{el}$$

(Csedő, et al., 2020)

5. CAPEX of a 1 MW_{el} P2M plant

An important statement of the financial analyses of the STORE&GO project is that a high range of possible investment costs of electrolyzers and methanation systems can be seen in the literature (Böhm & al., 2018). The economies of scale are a determining factor of CAPEX (Böhm & al., 2018). The investment costs in this study are based on the calculations of van Leeuwen and Zauner (2018) with minor modifications according to the technical infrastructure of the analyzed WWTPs and additional costs of a public-funded technology development projects. Interviewees also pointed out that one must take into account the costs of public grant / public financing-specific R&D and maintenance tasks, furthermore, the needed software background supporting the P2M technology operations (not only the hardware and the physical infrastructure). Table 31 shows the basis of the CAPEX calculations.

<table>
<tr><th>Category</th><th>Item</th><th>thousand EUR</th><th>Unit</th><th>Source</th></tr>
<tr><td rowspan="3">Components, physical infrastructure</td><td>Electrolyzer system (PEM)</td><td>1.6</td><td>/kW_{el}</td><td rowspan="4">STORE&GO:

D8.3. p. 14, 25, 34, 35

D7.5. p. 48</td></tr>
<tr><td>Methanation system (biological)</td><td>0.5</td><td>/kW_{el}</td></tr>
<tr><td>Infrastructure, installation, storage for gas puffer (H₂, CO₂), injection</td><td>1.1</td><td>/kW_{el}</td></tr>
<tr><td rowspan="2">Other</td><td>Project development, planning, expert services, quality management</td><td>+28%</td><td rowspan="2">on costs of total components</td></tr>
<tr><td>Tender-specific R&D, software and maintenance tasks</td><td>+50%</td><td>Own estimation based on interviews</td></tr>
</table>

Table 31. Base case for CAPEX calculation

(at a single WWTP)

Source: Csedő, et al., 2020

1. The specific investment cost of the PEM electrolyzer system is 1,640 EUR/kW which is the base case according to van Leeuwen and Zauner.
2. In the case of the methanation system, a slightly higher CAPEX than the base case, 0.5 EUR/kW_{el} is considered because of some high specific investment costs for biomethanation presented by Böhm et al (2018).
3. There is an integrated "infrastructure" cost item, as well, because different kind of infrastructure development is needed at the analyzed WWTPs (e.g., there is gas storage at a few WWTPs or the new infrastructure for the utilization of the oxygen as a byproduct can be also relevant in this cost item).
4. An additional 28% investment is needed for project development, planning, expert services, quality management, according to van Leeuwen and Zauner, and an additional 50% for public grant / public financing-specific R&D, software development, and maintenance tasks.

Based on the above, the CAPEX of a 1 MW_{el} P2M plant at an “average” WWTP is 5,696,000 EUR if the investment would be realized this year.

The deployment of even one P2M plant, however, could require even more than a year-long project planning. Consequently, the time horizon must be extended for the investment. Previous P2G research has shown that there is a significant cost reduction potential regarding the investment costs because of the experience curves and learning rates. Böhm et al (2018) calculated that PEMEL CAPEX will decrease from 1,200 EUR/kW_{el} (2017) to 530 EUR/kW_{el} (2030), and biological methanation CAPEX will decrease from 600 EUR/kW_{SNG} (2017) to 360 EUR/kW_{SNG}. It means that CAPEX of these components will decrease by 55% and 45% in 13 years. As the authors in this research assume that P2M plants in question will be deployed between 2020 and 2030, parallelly with the planned growth of PV capacities in Hungary, some CAPEX reduction is needed based on the quoted estimation. Assuming even distribution of P2M deployment for the next 10 years, the year 2025 can be the basis of the calculation, so the 1 MW_{el} P2M CAPEX for 2025 with PEMEL CAPEX can be decreased by 25% and the CAPEX of biomethanation system can be decreased by 20%. Consequently, the model calculates with the reduced, 4,806,000 EUR CAPEX. (Csedő, et al., 2020)

6. Performance potential of commercial-scale P2M plants at different sites

The cost-benefit ratios of P2M plants have been assessed according to decarbonization and renewable gas production (as a prerequisite to long-term, seasonal energy storage) at the largest possible plant size, based on CO_2 source. Even though the deployment of such large P2M plants may not be financially attractive for a single technology adopter, following the decarbonization efforts, it is worth analyzing what is the performance potential at different sites regarding not only the methane production but the CO_2 reuse. As mentioned in the Introduction section, these comparisons may orient public funding decisions to facilitate decarbonization and seasonal energy storage (ITM, 2020; Csedő, et al., 2020). As P2M deployment requires significant investments, the socio-economic value creation at these sites may influence the location, the number and the size of P2M plants that will be deployed. From a disruptive point of view, these comparisons can outline low-end and high-end segments of the P2M technology.

Figure 30 shows the unit cost of CO_2 reuse by CAPEX at different sites with the largest possible P2M plant size.

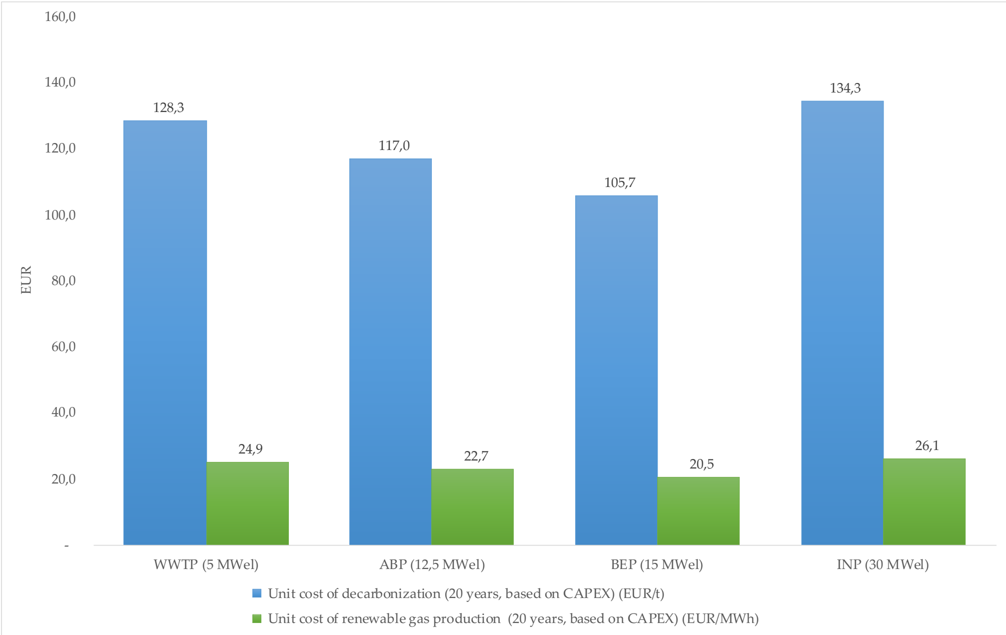

Figure 30. Unit capital cost of decarbonization and renewable gas production (as a pre-requisite of seasonal energy storage) of commercial-scale P2M plants at different sites

during their operation, based on CAPEX (2025-2045)

Source: Pörzse, Csedő & Zavarkó, 2021

The unit cost is calculated based on the following factors.

CAPEX of the P2M plant is based on a recent study by Böhm et al (Böhm, et al., 2020) which focuses on future commercial-scale P2G technology implementations and takes into account the scaling effects, as well. Accordingly, cost reductions due to scaling up differ by site types. Current calculations are predictions for 2025 based on the data of 2020 and estimations for 2030 of Böhm et al. Table 32 presents the basis of CAPEX calculations.

kW_{el}	5.000	12.500	15.000	30.000	Source
2025					
Electrolyzer system (PEMEL) ($thEUR/kW_{el}$)	0,90	0,85	0,80	0,75	(Böhm, et al., 2020)
Methanation system (biological) ($thEUR/kW_{el}$)	0,35	0,30	0,25	0,2	(Böhm, et al., 2020)
Infrastructure, installation, storage for gas puffer (H2, CO2), injection ($thEUR/kW_{el}$)	0,45	0,40	0,35	0,30	ca. 20% of CAPEX (Leeuwen & Zauner, 2018, p. 34)
Project development, planning, expert services, quality management (+ %)	28%	28%	28%	28%	(Leeuwen & Zauner, 2018, p. 34)
2030					
Electrolyzer system (PEMEL) ($thEUR/kW_{el}$)	0,90	0,85	0,80	0,75	(Böhm, et al., 2020)
Methanation system (biological) ($thEUR/kW_{el}$)	0,35	0,30	0,25	0,2	(Böhm, et al., 2020)
Infrastructure, installation, storage for gas puffer (H2, CO2), injection ($thEUR/kW_{el}$)	0,45	0,40	0,35	0,30	ca. 20% of CAPEX (Leeuwen & Zauner, 2018, p. 34)
Project development, planning, expert services, quality management (+ %)	28%	28%	28%	28%	(Leeuwen & Zauner, 2018, p. 34)

Table 32. CAPEX estimation of commercial-scale P2M plants with biological methanation for 2025 and 2030

Source: Pörzse, Csedő & Zavarkó, 2021

In case of INP, CC technologies would mean additional costs. It was predicted at ca. 40 EUR/tCO_2 (49 USD/tCO_2) for 2025 by Fan et al (Fan, et al., 2018).

CO_2 conversion and CH_4 production has been determined based on the prototype data of the Power-to-Gas Hungary Kft with the focal technology. In line with a former study (Csedő, et al., 2020), the 1 MW_{el} base case would mean the conversion of 848 tCO_2 and 4.363 MWh CH_4 yearly.

The ratio of CAPEX and the converted CO_2 and the produced CH_4 is calculated for 20 year-long operations of the plant, with 8.000 h operations per year. Detailed data can be seen in Table 33.

	WWTP	ABP	BEP	INP
Size (MW_{el})	5	12,5	15	30
Converted CO_2/year (tons)	4 240	10 600	12 720	25 440
Produced CH_4/year (MWh)	21 815	54 538	65 445	130 890
Converted CO_2/ 20 years (tons)	84 800	212 000	254 400	508 800
Produced CH_4/ 20 years (MWh)	436 300	1 090 750	1 308 900	2 617 800
P2M CAPEX (EUR, prediction for 2025)	10 880 000	24 800 000	26 880 000	48 000 000
Cost of carbon capture (20 years) (EUR)	-	-	-	20 352 000
Unit cost of decarbonization (20 years) (EUR/t)	128	117	106	134
Unit cost of renewable gas production (20 years) (EUR/MWh)	25	23	21	26

Table 33. CAPEX estimation of commercial-scale P2M plants with biological methanation for 2025 and 2030

Source: Pörzse, Csedő & Zavarkó, 2021

The figure above shows that P2M is capable of the best performance at a BEP with 15 MW_{el} P2M potential regarding decarbonization and renewable gas production, due to the scaling effects and the efficiently useable carbon source (no need for CC), and the worst in case of INP where the cost of CC weakens the cost-benefit ratio more than scaling effects improve it. Nevertheless, as previously mentioned, the uniqueness of P2M derives from the capability to provide seasonal energy storage and sector coupling with parallel decarbonization. Consequently, it is important whether infrastructural connections to the natural gas grid are available at (1) these site types and (2) the sites where the largest P2M plants could be deployed. Results showed that while WWTPs (where smaller plants could be deployed), mostly have a nearby connection to the natural gas grid, this is less frequent in the case of ABPs and BEPs in Hungary. For example, at a BEP with the largest P2M potential, the nearest connection point is 5 km away, while at a ABP with the largest P2M potential, it is 10 km away, where the produced biomethane could be injected into the natural gas grid. Building these missing infrastructural connections would significantly decrease the financial feasibility of P2M seasonal energy storage. If CC technologies would be available at INPs, connection points to the natural gas grid would be more favorable. Consequently, CC technology associated costs could be an accelerating factor for seasonal energy storage and decarbonization by commercial-scale P2M plants.

7. Scenarios of Carbon Capture cost reductions for 2025 and 2030

To examine how forecasted CC cost reductions might increase the cost-benefit ratio of commercial-scale P2M deployments at INPs compared to ABPs or BEPs, 3-3 scenarios have been built for 2025 and 2030. Moreover, further scenarios have been built on the prediction of the P2M CAPEX following Böhm et al (2020). Scenarios S1-S3 are differing regarding CC costs, as well (Table 34), which were estimated by

1. following Fan et al. (Fan, et al., 2018) for the 2025 and 2030 values (S1, ca. 40 EUR/tCO_2 in 2025, indicated as 100%; ca. 32 EUR/tCO_2 in 2030)
2. following Wilberforce et al (Wilberforce, et al., 2021) showing that CC costs can be around 25 USD/tCO_2 mainly at integrated gasification combined cycle (IGCC) and pulverized coal (PC) plants, but also at natural gas combined cycle (NGCC)

plants. This is a more optimistic scenario with its 50% reduction (S2), meaning 20 EUR/tCO_2 in 2025 and 16 EUR/tCO_2 in 2030.

3. generating an own scenario to identify the CC cost level which could trigger decision-makers to choose industrial sites with the necessity of CC to deploy a commercial-scale P2M plant there (S3). For this, another 50% cost reduction is determined.

CC cost	**Cost reductions by scenario**	**2025**	**2030**	**Source**
Scenario 1 (S1)	-	40 EUR/tCO_2	32 EUR/tCO_2	based on Fan et al. (Fan, et al., 2018)
Scenario 2 (S2)	-50%	20 EUR/tCO_2	16 EUR/tCO_2	based on Wilberforce et al (Wilberforce, et al., 2021)
Scenario 3 (S3)	-50%	10 EUR/tCO_2	8 EUR/tCO_2	Own estimation

Table 34. Scenarios based on different carbon capture cost-levels for 2025 and 2030

Source: Pörzse, Csedő & Zavarkó, 2021

Figure 31 shows how site preference would change if CC costs would fall by 50% twice. In case of the lines which indicate the cost-benefit ratios of different comparisons, 100% means the performance of the ABP/BEP/WWTP regarding the unit costs presented in the previous chapter and their value in 2030. If the unit cost of decarbonization and seasonal energy storage is lower in case of 30 MW_{el} P2M+CC configuration at an INP, than the value of 5/12,5/5 MW_{el} P2M configurations at a(n) ABP/BEP/WWTP, it means that the cost-benefit ratio of P2M+CC is higher than theirs, so the indicating line goes beyond 100%. Regarding CC costs, 100% means 40 EUR/tCO_2 in line with Table 22.

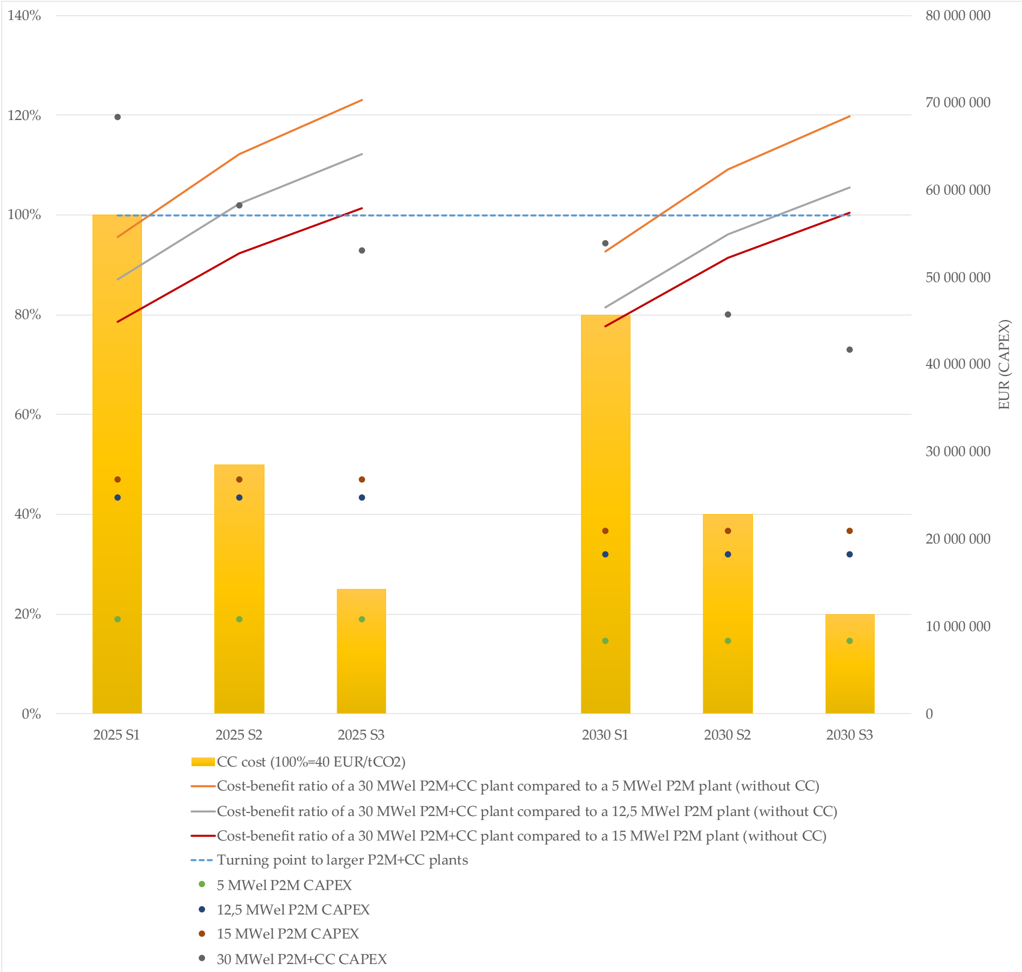

Figure 31. The role of carbon capture costs in chosing certain sites and plant sizes for decarbonization and renewable gas production with P2M

Source: Pörzse, Csedő & Zavarkó, 2021

Findings suggest that the cost-benefit ratio of 30 MW_{el} INPs would be better regarding renewable gas production, seasonal energy storage, and decarbonization at CC costs 20-30 EUR/tCO_2 or lower than 5-15 MW_{el} P2M facilities at ABPs or BEPs even if they would have a connection to the natural gas grid in 2025. Nevertheless, due to the estimated cost reductions of P2M CAPEX for 2030, a 12,5 MW_{el} P2M plant would have a better cost-benefit ratio at 16 EUR/tCO_2 CC cost than a 30 MW_{el} P2M+CC configuration plant. Assuming that the main goal is seasonal energy storage and the connection to the grid is not an obstacle, 15 MW_{el} or larger P2M facilities at ABPs or BEPs would be competitive with P2M facilities at INPs for decarbonization and seasonal energy storage (renewable gas production and injecting it into the grid) even if costs of

CC would radically decrease. Besides, it is important to highlight that as CC cost would start to decrease from 40 EUR/tCO_2 a 30 MW_{el} P2M+CC plant would outperform 5MW_{el} or smaller P2M plants based on the unit capital costs of decarbonization and renewable gas production.

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