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Smart knowledge management driving green transformation: A comparative case study

József Magyari [a,b], Máté Zavarkó [a,c,*], Zoltán Csedő [a,c]

[a] Department of Management and Organization, Corvinus University of Budapest, 1093, Budapest, Hungary
[b] Vértes Power Plant Zrt., 2841, Oroszlány, Hungary
[c] Power-to-Gas Hungary Kft, 5000, Szolnok, Hungary

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ABSTRACT

Large energy companies and energy startups are increasingly focusing their resources to build new businesses concerning smart energy systems (SES). The development and integration of related innovative technologies for green transformation with traditional business models are often hampered, however, by the challenge of parallel management of exploitation of current business areas, and the exploration of new business areas with breakthrough innovation. While knowledge management could be key in this balancing strategy and shifting the organization to a more sustainable future, little is known about the challenges in the context of the energy sector. Applying a comparative case study method at a large energy company and a small energy startup, path dependency is reflected in KMS design in both cases, which could result in a slower shift to new technologies in case of the incumbent, and slower exploitation of the technological innovation in case of the startup. If a partnership is not an option for simulating structural ambidexterity, energy companies could speed up green transformation individually with smart knowledge management systems (SKMS) that support the development of contextual ambidexterity and SES.

1. Introduction

Research on green transformation is heavily focused on renewable energies and smart energy systems (SES) that can be important tools to meet the Paris Agreement [1]. As new concepts emerge, e.g., digitization, power-to-X solutions, operative, mainly optimization-focused technical studies appear, then they are followed-up by techno-economic and system integration studies [2–4], as well as analyzes of their impact on public policies come [5–7]. In line with this, a growing number of papers are published focusing on the relationship between suitable business models and smart energy solutions [8–10]. While these studies show that new technologies and new or modified business models might be required for green transformation, internal organizational processes, and especially knowledge management (KM) has also got some attention that it could drive the implementation of innovative concepts [11]. Accordingly, KM as a focal topic appeared in recent publications of the broader sustainability research area, e.g., focusing on efficient energy utilization with an intelligent energy management system [12], transition to biofuels [13], or cleaner production and sustainable competitive advantage [14], yet, “this area is still little explored and there are many possibilities of academic research” [[15], p. 489].

This study responds to this call and takes further steps in this area. Studies tend to disregard or not pay enough attention to the fundamental strategic dilemmas of top management teams (TMTs) of energy companies when discussing the role of KM in novel energy technologies and business models. Namely, competitive (energy) companies must be able to operate in the present in the most efficient ways possible using their available resources (e.g., by optimizing the distribution system [16]). At the same time, these companies need to focus on the future and seek new opportunities, generate breakthrough innovations (e.g., power-to-gas (P2G) or carbon capture, utilization or storage (CCUS) [17], and integrate them into a SES), ensuring their long-term successful operations [18,19]. While this strategic ambidexterity can also be relevant in KM by distinguishing exploratory and exploitative learning [20], little is known about its impact on energy companies that can drive green transformation.

Among recent studies, it is hard to find a similar, theoretical reflexive approach to strategic KM from the energy sector. Spanellis et al. [21] discussed the need for a dynamic KM model with managing explicit knowledge, knowledge sharing, and knowledge creation to support

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* Corresponding author. Department of Management and Organization, Corvinus University of Budapest, 1093, Budapest, Hungary.
E-mail address: mate.zavarko@uni-corvinus.hu (M. Zavarkó).

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Abbreviations:

CCUS:	Carbon capture, utilization or storage
D-CCSM	Dynamic-comparative case study method
DMO	Distribution market operator
DSO	Distribution system operator
ECSM	Extended case study method
KM	Knowledge management
KMS	Knowledge management system
LNG	Liquefied natural gas
P2G	Power-to-gas
P2L:	Power-to-liquid
PT	Project team
SES	Smart energy system
SKMS	Smart knowledge management system
TaaS	Transport as a Service
TMT	Top management team

innovative technology development based on empirical research from the energy sector. Nevertheless, besides the influential findings, the managerial challenge of balancing between exploitation and exploration did not appear (explicitly) here either. This is not very surprising, considering that ambidexterity-orientation is sometimes “takes a back seat” in the KM literature, as well. For example, even though the “SMART KM” model introduced by Ahmed and Elhag [22] involves the need for strategic alignment, strategic ambidexterity is not mentioned and can be interpreted only as an underlying factor. Given the strategic significance of green transformation and SES for energy companies and even society, this study explicates the strategic dilemmas behind the strategic KM in the energy sector and proposes a new approach to interpret and develop smart KM systems (SKMS) for energy companies.

In this sense, two main conditions were pre-defined for the term. First, as detailed above, SKMS must be “strategically smart” which means that the system design meets the organization’s strategic needs in the exploitation-exploration axis. Second, based on the background of becoming “techno-economically smart” in the energy sector with a holistic approach [23], SKMS must enable SES development. While SES development is a socio-environmental responsibility, it is a promising technological direction, as well, for organizational survival in the changing energy environment. Understanding related knowledge processes is important because even though SES means an opportunity to ensure the flexibility to balance volatile renewable energy production [24], its development is also a technological and market challenge, as SES generates complex Smart Energy Markets with mutual influences between electricity, green gas, and fuel segments [25]. Following the way of Lund et al., who provided a “scientific basis for a paradigm shift away from single-sector thinking into a coherent and integrated understanding of how to design and identify the most achievable and affordable strategies to implement coherent future sustainable energy systems” [23, p. 557], this study aspires to build this basis further by channeling in the strategic and knowledge management theory into this research field, while practically contributing to future-oriented KMS design in the energy sector. The main research question was the following:

How could a smart knowledge management system design support green transformation, from a strategically ambidextrous perspective?

To answer the research question, the authors conducted a comparative case study at (1) a large energy company and (2) a small cleantech developer startup. Answering this research question has specific relevance to the green transformation. For example, as an information and communications technology, KMS could be a good example of those general-purpose technologies that could be used in numerous fields, including green energy [26]. As knowledge is generally found to be a key input for innovation [11], analyzing KMS support is important in case of innovative green technologies. Their development was previously characterized, for example, by high complexity and novelty, the potential positive effect of public research [27], the need for strong external and internal collaborations [28], and diversified knowledge and capabilities [29]. Because little is known about KMS design and/or application in this field, this study contributes to the literature in multiple ways. First, the study fills in the research gap on strategic challenges of green transformation with an in-depth analysis of KMS design aspects of two very different energy companies. Second, it also aims to expand the knowledge base provided by qualitative studies that recently appeared in energy technology literature to address managerial opportunities and challenges, as well (e.g., Refs. [30–34]). Third, as significant advancements were presented in the literature in case of SES design, e.g., by Mathiesen et al. [35] about integrating smart electricity, thermal, and gas grids for 100% renewable energy systems, researching opportunities and challenges of its realization could be useful even on the level of energy companies. So in this study, a company level, KM-focused approach is introduced to accelerate SES development which could supplement country and sector level approaches.

2. Research framework

According to theories of the resource-based view of the firm, sustainable competitive advantage can be gained by unique organizational resources [36], or dynamic capabilities for sensing and seizing business opportunities and transforming the organization [19]. Other theorists, however, emphasize the central role of knowledge. Most importantly, Grant’s [11] approach is based on the premise that the company’s main resource in a turbulent environment is the specific, tacit knowledge of employees, as this cannot be copied by competitors, so it can be a source of sustainable competitive advantage.

The potential of KM and KMS has been recognized in case of energy companies, as well, even in the 1990s and 2000s. For example, ExxonMobil and ChevronTexaco aimed to improve efficiency by transferring best practices within the organization, while Schlumberger and Halliburton tried to link better data management and systems with human expertise [37]. Time and the changing environment, however, reshape the focus of KM as well, nowadays to green transformation. Accordingly, green transformation from organizational KM perspectives can be realized in the section of organizational strategy (i.e., new goals and resource allocation patterns supporting sustainability), innovation (e.g., developing renewable and smart energy technologies), and change (shaping behavior, culture, structures, control mechanisms to enable innovations) supported by a KMS (Fig. 1).

Recognizing, developing, and leveraging the needed knowledge and capabilities, however, are difficult. This is because companies need strategic ambidexterity to exploit their current business areas efficiently in the present and explore new business areas for the future to remain competitive in a changing environment [18,38], but the more an organization adapts to current external factors, the more its ability to adapt to the future decreases [39]. Nevertheless, through structural ambidexterity, an organization can implement exploration and exploitation in different organizational units [40]. In contrast, according to contextual ambidexterity, the two activities can be balanced on the individual level in a properly managed context, for example, supporting leadership, organizational culture, and – especially in this study – a learning context driven by KMS [38,41]. Indeed, ambidextrous KM systems were developed in larger and smaller companies, as presented by Filippini et al. [42] in the refrigeration, software, and ICT security sectors.

SKMS is interpreted as a strategic tool to balance between exploitation and exploration (in favor of the focal company), and to accelerate the SES development (in favor of the society and the company), including its individual technologies (e.g., power-to-gas), as well. It is important to highlight, that the SKMS approach fundamentally differs from other tools that could also belong to the energy management,

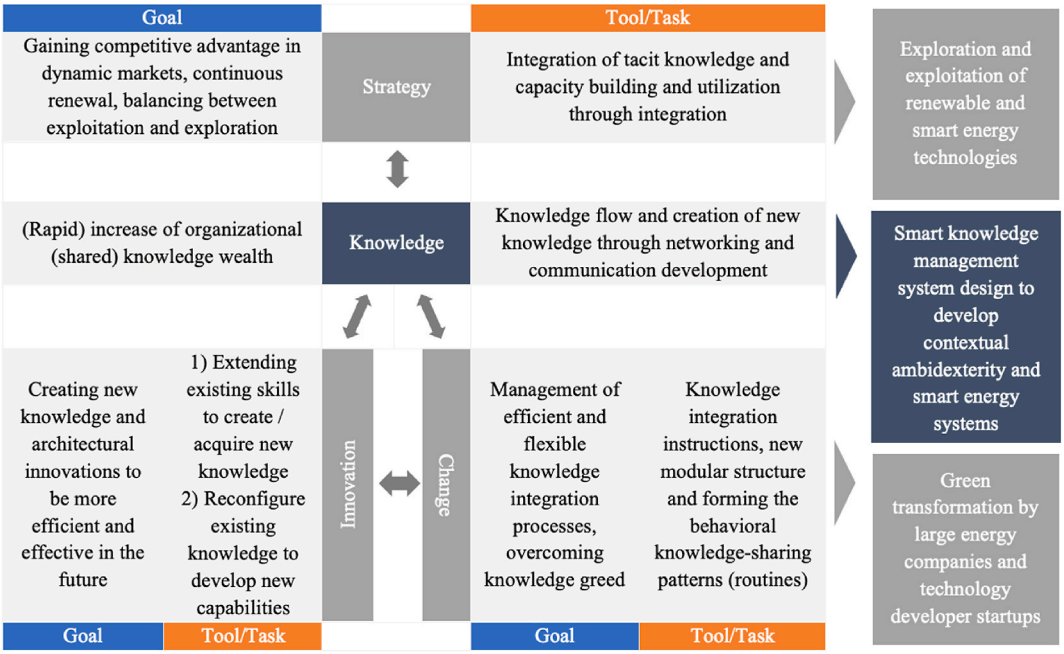

Fig. 1. Research framework (own construction, mainly based on [11,20]).

planning or modeling category. For example, the choice awareness approach [43,44] with high public participation and debate, aligned policies and behavior of power companies is different in the level of intervention. It is because the choice awareness approach was (could be) realized at country level, in contrast to SKMS (company level). Regarding the sector level tools, SES modeling with simulation or optimization [45], for example, by the EnergyPLAN model [46] is focusing on finding optimal solutions for electricity, gas and thermal grids and the system as a whole. Energy-flow-diagrams and scenario analyses of such integrated systems with different conversion technologies could provide an applicable system design approach on sector level [35]. In contrast, SKSM is focusing on the development of an organizational context where valuable knowledge – based on, e.g., the EnergyPLAN modeling – could be created, utilized, and reconfigured. These differences derive from the different knowledge domains. While models in the renewable energy research field are usually turning techno-economic knowledge into managerial suggestions (e.g., system design or investment guidelines), this research framework uses management science within the renewable energy field.

3. Methodology

3.1. Research design and preliminary propositions

Considering that the research was (1) focused on phenomena happening in the present, (2) oriented to answer a “how”-type main research question, (3) aimed to generate in-depth analysis, qualitative methodology was chosen with conducting case studies [47]. Qualitative research is traditionally challenged by many positivist scholars regarding its capability to develop general and valid theories (but the hypotetico-deductive and quantitative methods also have critics [48]). Nevertheless, notable methodological advancements also happened, that theories can be built or extended based on qualitative research, with conditions in terms of generalizability, reliability, validity, though.

First, the abductive approach of qualitative research should be mentioned which involves iteration between empirics and theory, and sometimes iteration with research questions to build a theory that is empirically grounded [49]. The main methods include the grounded theory [50], the extended case study method (ECSM) and the abductive theory of method [48]. These have been already used in energy, knowledge or innovation management research [51–55].

Second, the other important advancement in qualitative research is the ability to develop a systematic process for theoretical contributions. In this sense, the dynamic-comparative case study method (D-CSSM) [56] was chosen as the other methodological foundation of this study. It was developed to research similar goals, i.e., strategic change in organizations and generating a midrange theory based on the “dynamic redescription of the phenomenon, in more than one organization” [56, p. 441]. This study combines the D-CSSM and the ECSM to compare two companies within one industry and to extend the theory.

Based on these methodological roots, preliminary propositions must be defined for the main research question instead of hypotheses [56]. Based on former research results and presented theories, it was assumed that

a) in case of the large energy company, because of the slow and long decision procedures [57], the dominance of traditional technologies limiting the progress of renewable and smart energy technologies [58,59], rigid internal structures and external institutional background [60], SKMS design could mean more intensive support of exploration;
b) in case of the startup with an entrepreneurial, innovative culture [61] the focus may shift from exploration to exploitation when the company steps into a more mature phase [62]. This could be even more relevant after a new, specific technology is developed and ready to be commercialized, i.e., there is a transition from technology development to the up-scaling and commercial-scale operation [63].

The main research question was divided into two research sub-questions during the empirical research:

- *SQ1: What functions are considered in the specific organizational environments when designing a new KMS for supporting green transformation and how do evaluate the project teams (PTs) the possible functions in terms of supporting exploitation and/or exploration? (PTs include top managers of both companies)*

- *SQ2: What functions do prioritize the top management teams (TMTs) of both companies to support green transformation initiatives with KMS and why?*

Because of the strategic approach of this study, the considered functions and their operative attributes are less important (even though it was a necessary step to explore them). The focus of the study is on the evaluation and prioritization of the possible functions from the aspect of supporting green transformation and strategic ambidexterity.

Fig. 2 shows the research design, highlighting that previously the strategic context of the cases was explored. The answers for each subquestion led to the empirical foundation that was compared to the theory, former results, and propositions.

3.2. *Data and research context*

Data collection and analysis processes were based on the D-CCSM [56] to enhance the systematic process, but modified according to the ECSM [64] to enhance the iterative, abductive approach (Table 1). As a comparative case study, the research was based on one-one KMS design projects at a large energy company and an energy technology developer startup (with different IT suppliers in the projects).

The authors participated as observers in the preparation (system design) phase of the KMS development projects. During the several months of data collection, the authors participated in 31 meetings and analyzed nearly 450 pages of company documents. Besides, semi-structured interviews were conducted with top managers and middle managers, focusing on (1) the overall purpose of the system, and (2) individual evaluation of the technology solutions presented by the suppliers. In addition to participant observations and semi-structured interviews, the complete documentation concluding the project preparation phase was also analyzed (assessments and proposal for the order).

During the meetings, notes were made, and interviews were also recorded in writing (audio recording was not allowed). Data analysis was performed according to Danneels [64] who followed the ECSM and also conducted multi-case studies with interviews, observations, and document analyses. Based on Gibbert et al. [65], theory triangulation for internal validity, data triangulation for construct validity, detailed case study protocol (see above) for reliability, and multiple cases for external validity were applied. Starting the research question from the available functions makes the case studies replicable, which is also a requirement of D-CSSM [56].

3.3. *Research context*

The research environment was formed by two companies, which were chosen based on theoretical sampling in line with the chosen methods [56]. First, as SES “is defined as an approach in which smart electricity, thermal and gas grids are combined with storage technologies and coordinated to identify synergies between them in order to achieve an optimal solution for each individual sector as well as for the overall energy system” [23, p. 560], the first energy company is a key local player in the electricity and gas markets and grid operations, while the second develops an innovative energy storage technology which interconnects the individual sectors (P2G). Moreover, theoretical sampling considered (1) the fit for the ambidextrous objectives that a new KMS can support, (2) the different organizational characteristics to provide an opportunity to detect differences in KMS design approaches. The characteristics of the companies are presented in Table 2.

The KMS system design projects aimed to develop and implement fully customized, unique KMSs, the purpose of the preparation phase was to assess the needs and define the overall system functionality.

4. Results

Results of the two cases are presented together in the following sections to highlight key similarities and differences.

4.1. *Evaluation of technological possibilities*

The explored and synthesized functions from the two cases are presented in Appendix A with their short description. During the evaluation of these functions, three main aspects emerged:

1) the exploration-supporting nature of the function (green innovation),
2) the exploitation-supporting nature of the function (increasing operational efficiency in existing business areas),
3) the expected development cost of the function.

The functions received a relative score concerning each of the three aspects on a 1–4 scale. The practical aim of the evaluation was to simplify the wide and complex range to select a function package that suited the goals and resource limits of the companies. The use of rating scales, i.e., score-based classification, was a request from TMTs.

The evaluation was carried out in a three-step process in both cases:

1) After meetings and discussions about the needs, suppliers sent the potential function list with a brief description and expected cost level to the customer. This was evaluated by the middle managers and senior professionals of each customer from the perspective of exploration and exploitation support.
2) The evaluation defined by middle managers and senior professionals was finalized in discussions where top managers were also present.
3) Subsequently, the potential return on exploitation and exploration for each function was determined based on final evaluation scores, calculated by proportioning the two evaluation scores to the cost level.

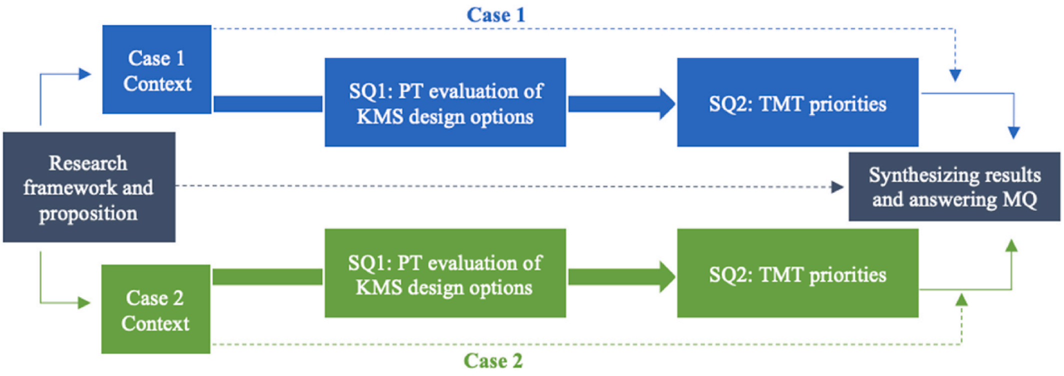

Fig. 2. *Research design.*

Table 1
Data collection and analysis process (based on [56,64]).

Step	Task	Process variables	Large energy company	Energy technology developer startup
1	Obtain basic information, document analysis	-	Website Strategy, mission statement Organizational chart Annual reports Meeting memos IT supplier's descriptions about KMS options Final proposition for KMS system design (order for IT development) ca. 300 pages in sum	Website Strategy, mission statement Annual reports Meeting memos IT supplier's descriptions about KMS options Final proposition for KMS system design (order for IT development) ca. 150 pages in sum
2	Personal, participative observations in the meetings with the IT suppliers	-	5 top managers, 10 middle managers, 17 senior professionals from human resources, production, operation, strategy, and innovation areas; *IT supplier: 3 top managers, 1 project manager, 5 senior developers, 9 business analysts* 24 meetings in sum	4 top managers, 1 middle manager, 4 senior professionals from strategy, technology development business development, and laboratory areas*IT supplier: 1 top manager, 1 business analyst, 4 senior developers* 7 meetings in sum
3	Taking field notes and theoretical/ analytical notes during and after the meeting	Last meeting? If not, back to Step 2		
4	Conducting open ended interviews	-	4 top managers, 7 middle managers 1-1,5 h each	2 top managers, 2 senior professionals 1-1,5 h each
5	Taking field notes and theoretical/ analytical notes during and after the interviews, grouping notes to conceptual clusters	Last interview? If not, back to Step 4		
7	Developing case profile according to context and theory	Case-specific theoretical saturation reached? If not, back to Step 4 All cases analyzed? If not, back to Step 1	-	-
8	Comparing cases to each other, theory, and propositions, developing a concept	Theoretical saturation reached? If not, do more literature review	-	-
9	Validating concept with interviewees	Concept verified? If not, back to Step 7 or 8	Feedback from 2 top managers and 3 middle managers in email	Feedback from 1 top manager, 1 middle manager and 1 senior professional in email
10	Fine-tuning concept based on feedbacks	-		

Table 2
Case descriptions.

Case	1 ("Incumbent" case)	2 ("Startup" case)
Short description	Traditional, large energy company with an extended energy portfolio	Startup company focusing on innovative energy technology development
Type	Multinational, operating also in Hungary	Hungarian, expansion in Central and Eastern Europe is planned
Operation	Well-structured, hierarchical, and highly regulated	Flat, flexible, and project-based
Staff	Over 250 in Hungary	8–12
Activities	Heterogenous business in different segments, e.g., energy production, distribution, trade, customer services, on the electricity and natural gas segments as well	Scientific and applied research and development, providing project management and professional services for technology implementation projects
Ambidextrous strategic objectives	"Operational efficiency", "optimization of the value chain" (exploitation) and "innovation", "future-orientation" (exploration) appears in the strategy	"Developing disruptive solutions" (exploration) is the mission statement, while "grid-scale plant development" (exploitation) appears in the strategy
Relevance to support contextual ambidexterity with KMS	Only the first phases of exploration are organized in a separate unit that focuses on external knowledge, startup incubation and acceleration, and more internal innovative initiations would be also necessary	Small company, no separate units for exploration and exploitation
Key technological /innovation priorities for exploration	Smart metering, renewable energy production, and utilization, ICT solutions, and related new business models	Power-to-X (P2G, P2L) and CCUS

Based on the synthesis of the evaluation and choices of the two cases, in Fig. 3, functions are presented according to their absolute rating regarding their expected benefits for exploitation and/or exploration, while in Fig. 4, these rates are transformed into cost-benefit rates.

4.2. TMT visions influencing system design

In addition to the three evaluation aspects presented, another factor influenced the decisions during the meetings and interviews: TMT's vision about KMS.

4.2.1. The incumbent case

In the incumbent case, the project involved five senior executives from the TMT: CEO and executives from human resource management, production, operation, strategy, and innovation areas. The visions about KMS of these five members of TMT did not match. While top managers from the areas of human resource management, production and

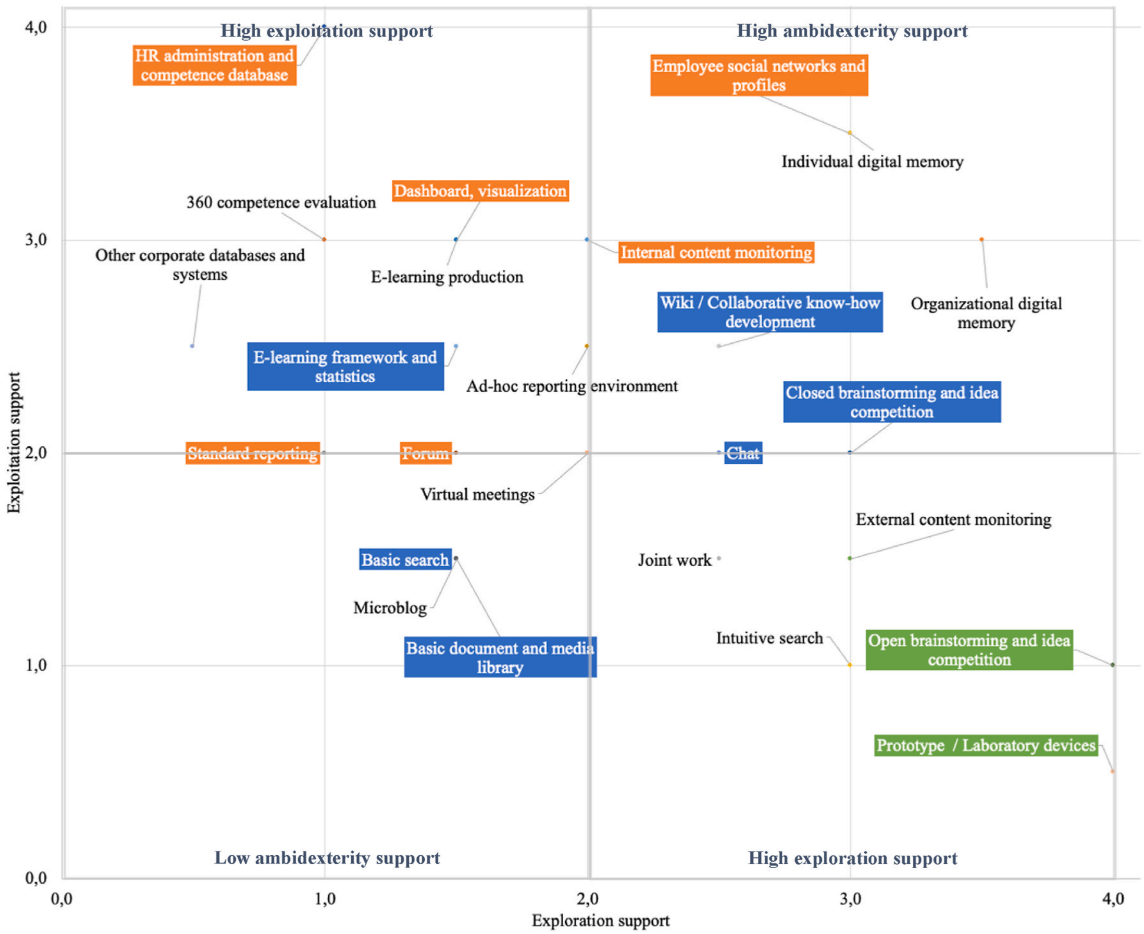

Fig. 3. Evaluation of KMS functions by PTs, according to their exploitation and/or exploitation support
(orange: only incumbent selected; green: only startup selected; blue: both selected). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

operations envisioned a KMS that is more classical, documentary and database-like, more supportive for operational efficiency, as “this is the first step and innovation is the second”, the CEO, the top manager from the field of strategy and innovation, perceived no hierarchy between the two dimensions. Nevertheless, as the Figures showed, cost-effective exploitation was more dominant in the selection, and only one function was chosen that explicitly supports only exploration (closed brainstorming and idea competition).

The strategic objectives of the incumbent in this time period explicitly contained to (1) improve operational excellence (exploitation) and (2) support innovation and new services (exploration). The strategy, however, involved other key pillars as well, mainly related to growth (e.g., further regional expansion, renewable energy generation, integration along the value chain). Even though investment into the future might be needed to achieve these goals, these growth-related goals were more related to the current, already-known business areas and the need for efficient operation (exploitation) rather than breakthrough innovation towards green transformation. Consequently, if one evaluates the KMS design in the mirror of strategic goals based on the general contingency theory [66], the strategic “fit” can be seen. From the aspect of green transformation, however, there is a problem with the strategy itself, that would require more emphasis on supporting internal breakthrough innovations in terms of goals and tools (e.g., KMS for contextual ambidexterity), as well.

4.2.2. The startup case

In the startup case, the TMT had a more unified vision about the KMS, but it was more related to knowledge flows and creation than managing strategic ambidexterity. The vision of the continuous knowledge flows aimed to

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

In this continuous explorative and exploitative learning, the most important was to choose functions that can fit both goals. Consequently, collaborative know-how development and open or closed brainstorming and idea competition were considered key functions in the desired system, as the topic for know-how development or idea generation can be flexibly oriented according to the explorative or exploitative learning needs. In addition to the fact that the functions can also operate in isolation (e.g., developing an independent know-how element), the flow of knowledge among them might also be realized, the envisioned logic of which is presented in Table 3.

In case of the startup, the vision of continuous renewal and know-how flows resulted in choosing more explorative and less exploitative functions. Even though the small organization, the simple control and reporting mechanisms do not generate needs for exploitative functions, the startup prepared for exploitation of its P2G know-how with e-learning framework and materials.

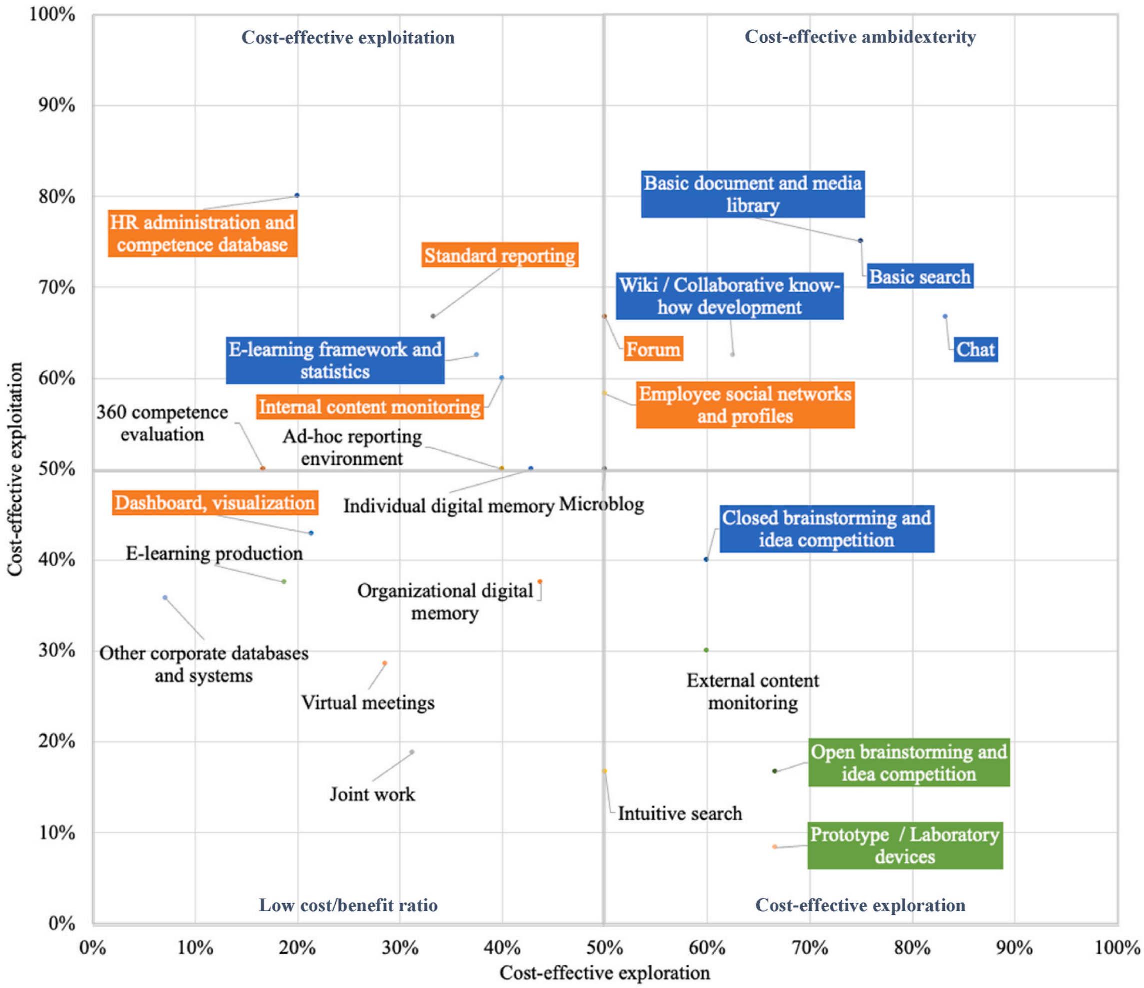

Fig. 4. Evaluation of KMS functions by PTs, according to their exploitation-exploitation support and expected cost
(orange: only incumbent selected; green: only startup selected; blue: both selected) Percentages: Return on investment regarding the generated benefit of the function above its cost, i.e., 100% would mean that a function generates twice as much benefit as its cost. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 3
Vision about the know-how flows within the startup KMS.

Input function (source of knowledge element)	Input → Output	Output function (use of knowledge element)			
		Interface to prototype / laboratory devices	**Open brainstorming and idea competition**	**Collaborative know-how development**	**E-learning**
	Interface to prototype / laboratory devices	-	Question about development or operation	Knowledge development based on monitoring data	-
	Open brainstorming and idea competition	Prototype development or more efficient operation based on idea generation	-	Answered innovation question	-
	Collaborative 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	-	-

From another strategic perspective, the startup was more focused on sustaining its competitive advantage with know-how development in new energy technologies (stepping towards from P2G to P2L and CCUS). Based on the interviews, this strategy is not fully an internal ambition of course, for example, the missing regulatory environment also means an obstacle to scale-up and operate P2G efficiently [60].

5. Discussion: Opportunities of the SKMS design

5.1. Path dependency of large energy companies and energy startups

Even though a fit between strategy and KMS design could be seen in both cases, neither the large energy company, nor the energy startup was ambidextrous enough to support green transformation, neither regarding the KMS design, nor the TMT interpretation of the corporate strategy. The incumbent would need more sustainable solutions, innovations to integrate into its traditional energy value chain that would require more KMS support for exploration. In contrast, even though the startup aimed (and still aims) to exploit the potential on P2G technology development on commercial scales, partly because of market conditions, it was focused more on research and development of even newer technologies.

Based on the iteration between these empirical results and theory, the phenomena of path dependency emerged. In this sense, organizations tend to follow existing routines that derive from efficient adaptation to the current (past) environment, but this efficient adaptation limits their capability to implement appropriate strategic changes to future environmental changes (i.e., adaptation paradox) [39].

Moreover, path dependency leads to a lock-in, where “alternative courses of action are no longer feasible for various reasons: high switching costs, sunk costs, monopoly, and so forth” [[67], p. 694].

Connecting this to the empirical results, a traditional, large energy company faces a vast amount of switching costs or sunk costs by transitioning to a more sustainable business portfolio. Path-dependency, however, can be interpreted in case of an energy startup, as well: while the incumbent might get locked-in to exploitative path (their traditional energy value chain), the startup might get locked-in to a path with continuously searching and developing R&D opportunities and new business areas. This can be interpreted as exploration, especially from a sectoral perspective [68] because of the innovations and the flexible R&D-orientation. On the other hand, it can be interpreted as exploitation as well, if one considers that the company mainly use their existing assets (R&D know-how, laboratory capacity, industrial and academic network) and business model. From the aspect of green transformation in the sector and in the society, neither strategy is desirable, i.e., the incumbent needs to develop and integrate more sustainable technologies that fit its business and infrastructure, while the startup needs to scale up an innovative technology more rapidly.

There are two ways to solve this problem. In an ideal situation, the incumbent and the startup can cooperate, simulating structural ambidexterity. It can be a feasible option for both as the incumbent uses (buys) a “ready-for-commercialization” technology, and the startup provides (sells) its know-how, then generates new ones with R&D. Nevertheless, as cooperation opportunities can be unseen or disregarded because of several reasons (e.g., incompatibility, different strategic motives or lack of trust and perceived risk of losing a valuable (knowledge) asset [69]), some organizations might be forced to develop their contextual ambidexterity with SKMS design.

5.2. *SES development and green transformation*

In an organizational context, supporting green transformation is not equal to supporting SES development, as the former is a higher-level strategic goal, which could certainly cover SES, but other non-technological elements as well (e.g., structure, culture [19]). According to the research framework, SES could be interpreted as a desired breakthrough innovation which needs exploration. Green transformation, however, requires more than exploration, especially in case of large energy companies. It could be seen in the turbulent environment of 2022, where the uncertain macroeconomic context generates even energy supply challenges in the traditional supply chain of many European countries, because of the war. This phenomenon reinforces that there is no opportunity to realize breakthrough innovation (here: SES) for a long-term strategic goal (here: green transformation) if fundamental business areas are threatened (here: centralized energy production, distribution, and stable supply). Consequently, it can be argued that stability (exploitation) and change (exploration) are equally important not only for energy companies but for society as well; therefore, SKMS must contribute to stabilizing the standard operations.

Regarding this exploitation side, continuous development by incremental innovation [70] could be more important than ever before (e.g., rapid efficiency-increase of restarted fossil energy production to reduce import-dependency), but “forgetting” the exploration of breakthrough innovations [71] (e.g., technologies that enable SES development at lower costs) would risk the future of the company (and the sector). Consequently, SKMS design must support exploitative and explorative knowledge processes for incremental and breakthrough innovations, which could be based on the utilization and reconfiguration of the existing knowledge or the creation of new knowledge [11]. A SKSM design matrix with illustrative examples from the literature is shown in Table 4, regarding focal segments of the analyzed companies. While the Table presents relevant individual technologies, the exploration part also reflects the idea of cross-sectoral subjects for SES development [23]. The listed illustrative subjects were categorized based on their relative technological and commercial maturity, but the content of such a matrix would differ according to time and company. The main message of the

Table 4
Possible SKMS design matrix in case of large energy company.

Theory			Practice (Illustrative examples of key sectors)			KMS design
Strategic pillars of green transformation		KM processes	Electricity	Gas /Heating	Transportation	Options based on empirics and theory
Stability & Incremental innovation	**Exploitation: Continuous development of the existing energy supply chain**	**Existing knowledge utilization and reconfiguration**	Increasing efficiency and decreasing emissions of fossil power plants (e.g., Ref. [78])	Increasing biomethane production, e.g., by in-situ biogas upgrading (e.g., Ref. [79])	Improved methods for electric vehicle charging infrastructure development (e.g., Ref. [80])	Basic KM functions (e.g., document and media library, forum, e-learning), Integration with enterprise management systems and existing infrastructure, Internal content monitoring
		New knowledge creation	Optimization of renewable energy integration by new forecasting methods (e.g., Ref. [81])	Blending higher volumes of hydrogen into natural gas pipeline (e.g., Ref. [82])	Transport as a Service (TaaS) model development for urban mobility (e.g., Ref. [83])	*Depending on use:* Open and closed brainstorming and idea competition, Collaborative know-how development
Change & Breakthrough innovation	**Exploration: Smart Energy System Development**	**Existing knowledge utilization and reconfiguration**	Integration of blockchain and smart meters /smart grids (e.g., Ref. [84])	Low temperature electrolysis implementation in grid-scale and hydrogen infrastructure development (e.g., Ref. [85])	Bio-LNG production through biogas upgrading and liquefaction (e.g., Ref. [86])	*Depending on context:* Connecting people for knowledge sharing (e.g., chat, virtual meetings, joint work, social network platform)
			Grid-scale power-to-methane implementation with post-combustion or oxyfuel carbon capture (e.g., Ref. [87])			
		New knowledge creation	Community energy storage model with microgrids and batteries [88]	High-temperature electrolysis development [89]	Realization of vehicle-to-grid concept (e.g., Refs. [90,91])	Individual knowledge mapping, External content monitoring, integration with prototype /laboratory /smart devices
			Overall system design of the combination of power-to-gas-to-liquid pathways (e.g., the power-to-hydrogen, Fischer-Tropsch synthesis; power-to-methane-to-liquid process with methane compression or liquefaction, or algae-based biofuel production) (e.g., Refs. [92,93])			

Table is that different technological elements of green transformation and SES development might require different KMS functions.

Indeed, SKSM is more than finding and categorizing of certain SES areas, as these must be matched with proper KM functions which fit the strategic environment of the company, as well. Our empirical data and theoretical extensions are in line with previous managerial characterizations of green technology developments and supplement them from the KMS perspective. First, in line with Messeni Petruzzelli at al., the role of "external and, especially, internal networks, through which relevant environmental knowledge can be exchanged" [28, p. 305] appeared in both cases, while – from the ambidexterity perspective – recent KM studies fine-tune the proper application of network building based on the given context [72,73]. For example, in case of a distribution market operator (DMO), who is embedded into the local electricity market and continuously exchanges information with energy suppliers, prosumers, and the distribution system operator (DSO) [74], or in case of an energy startup with connection to several universities, industrial partners and regulators [68], improving internal social networks might contribute to the exploration of new solutions for green transformation. Nevertheless, where an (energy) company is missing the channels to external knowledge or there are structural knowledge holes for easy internal knowledge combination, strong internal networks would strengthen exploitation instead of breakthrough (green) innovation [72,73].

Second, frequent uncertainty of green innovations which might hamper their introduction [28] was reflected in the startup case, where the missing regulatory environment of P2G pushed the startup towards new green technology developments instead of the exploitation of the core innovation. Even though SKMS has obvious limitations to help overcome such market or regulatory barriers that would need government support [28], prior research showed that an inter-organizational knowledge network or innovation ecosystem building could affect the regulatory environment [60,68].

Third, the thinking about the functionality of the SKMS could go beyond the traditional, database-based, and even networking-oriented KMSs [75,76] and emphasizes the integration of external knowledge and even the internal information flows from other systems, existing infrastructure or raw data from an innovative prototype or smart devices. For example, Leira et al. [77] suggested that district heating with smart energy meters must be built on careful planning, and raw data from smart meters might be useful for generating knowledge supporting new technology or infrastructure development aiming at green transformation.

6. Conclusions

While the literature on green transformation continuously generates valuable knowledge about techno-economic opportunities or policy recommendations of promising solutions and systems, less is known about organizational best practices of those industry actors who can fundamentally influence green transformation in certain regions and countries, especially regarding their challenges about managing strategic ambidexterity. In contrast to the propositions, the empirical results and the iteration with prior theories draw attention to the phenomenon of path dependency, as the incumbent preferred more exploitative KMS functions than explorative ones, while the startup rather remained in continuously searching R&D opportunities and developing novel solutions (e.g., P2L, CCU), despite its innovative core P2G technology. This means that an incumbent can be locked into exploitation and a startup can be locked into exploration, which hampers or slows down green transformation in the energy sector. The study highlighted that the strategic goal, i.e., green transformation might require also stability, not only change. Thus, SKMS must support exploitation and exploration according to the company's strategic needs, as well. So, if a partnership is not an option (meaning simulated structural ambidexterity) because of incompatibilities in motivations, goals, etc., contextual ambidexterity must be developed separately in organizations with SKMS.

From a theoretical perspective, this study has provided a new approach for accelerated green transformation by the specific application of the strategic and knowledge management theory in this field, which could supplement the other levels of energy management and modeling (e.g., Choice Awareness, EnergyPLAN). The SKMS approach has, however, a clear limitation regarding SES development because of the level of the analysis. Namely, certain solutions, e.g., power-to-X and CCUS could be developed and implemented by energy companies, while other SES elements are beyond their authority, e.g., energy efficiency of households or diffusion of renewable energy producer units.

From a practical perspective, the research provided in-depth KMS analysis regarding green technology development and highlighted the need for strategically balanced KMS as SES development could be disregarded without stable traditional energy supply chains in the present. A further contribution of the study is that it suggested a SKMS design matrix for combining potential functions with strategic ambidexterity and certain SES development areas of different segments (electricity, gas/heat, transportation).

From a methodological perspective, despite the steps to improve generalizability, conclusions of a qualitative study cannot mean a general theory, but rather an extension for the existing theories that is valid in a context of a specific energy market. So, further research may be conducted with a retrospective, quantitative approach and/or on how to implement a SKMS and encourage the use of system functions in energy companies. Furthermore, based on a concrete SES development project, the SKMS approach could be combined with the more systematic approach of SES research [35] to explore specific knowledge processes in light of the focal system and infrastructure. The level of such analysis could be a single, large energy company or an inter-organizational innovation network which could realize a cross-sectoral development.

Declaration of competing interest

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

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Appendix A

Table A1
Synthetized functions and descriptions based on the two cases

Function	Main attributes	Incumbent options	Incumbent selected	Startup options	Startup selected
Individual digital memory	Knowledge map	☑			
Organizational digital memory		☑			
Basic search	Keywords, filters, tags, categories, metadata, etc.	☑	☑	☑	☑
Intuitive search	Suggesting relevant content to users with automatic search	☑			
Internal content monitoring	Notification about new contents of the KMS with certain tags and topics	☑	☑		
External content monitoring	Notification about new content from the web with certain tags and topics	☑			
Basic document and media library	Storage and display for documents, data, audiovisuals	☑	☑	☑	☑
Forum	Discussions about a topic	☑	☑		
Microblog	Writing, sharing short notes quickly by the user	☑		☑	
Wiki /Collaborative know-how development	Writing longer descriptions of certain subjects by a group of users	☑	☑	☑	☑
Closed brainstorming and idea competition	Solving problems, answering questions by only company employees	☑	☑	☑	☑
Open brainstorming and idea competition	Solving problems, answering questions by company employees and external professionals as well			☑	☑
Chat	Quick and direct messages	☑	☑	☑	☑
Virtual meetings	Audio and video conferences, presentations, webinars	☑			
Joint work	Parallel document editing in real-time, collaborative drawing table	☑			
Employee social networks and profiles	Corporate “Facebook” and/or internal “LinkedIn”	☑	☑	☑	
E-learning framework and statistics	Managing e-learning contents and trainings	☑	☑	☑	☑
E-learning production	Developing e-learning materials	☑			
HR administration and competence database	Database for competencies, certificates, trainings, evaluations	☑	☑	☑	
360 competence evaluation	Decentralized competence evaluation, feedbacks for each other	☑			
Standard reporting	Pre-defined reports, e.g., about user activity or knowledge base	☑	☑	☑	
Ad-hoc reporting environment	Opportunity to browse data and statistics with a user-friendly interface	☑		☑	
Dashboard, visualization	Visualized statistics about pre-defined areas	☑	☑	☑	
Other corporate databases and systems	Search in or data migration from other enterprise management systems	☑			
Prototype /Laboratory devices	Real-time monitoring and control of devices, importing data from devices for analysis			☑	☑
TOTAL		23	12	14	8

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