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Abstract

This paper conceptualizes a hybrid package of products and services which ensures the energy efficient planning, realization and operation of IT infrastructure. It follows the well-established procedure model of product-service systems engineering and pursues a qualitative research approach that is based on two industry workshops with more than 60 participants from science and practice and on semi-structured interviews with 8 experts. Based on the findings from the interviews and the workshops, customer requirements to the hybrid package are described, a product model is developed and evaluated. Finally, an application scenario is derived.

Keywords: Product-service systems, PSS, IT infrastructure, sustainability, coaching.

1 Motivation and Background

In view of rising energy prices and increasing public pressure many organizations have put energy- and eco-efficiency on top of their agenda – in fact, it is now even regarded as an important competitive factor of its own (Sarkar & Young 2009). Therefore, the challenges and potentials inherent in the resource-efficient planning, realization and operation of IT are becoming a more decisive factor for the sustainable and successful use of IT (Gartner Inc. 2009; Melville 2010). Server rooms and data centers play a central role in any IT infrastructure and efficiency questions are now top concerns of data center operators (Gartner Inc. 2010).

The steady increase in computing power results in advanced requirements regarding the energy supply and cooling of server rooms and data centers, which directs the focus of Green IT to technical components (Melville 2010; Schmidt et al. 2010; Watson et al. 2010). Power utilization, the sustainable development of the enterprise and the improvement of environmental information management have often been neglected. Furthermore, in most organizations outside the IT industry there is a lack of expertise regarding the planning, realization and operation of server rooms and data centers (Farhoomand 2005; Schmidt et al. 2010), since they procure both their IT and the related heating and air-conditioning technology from specialized service providers or from the manufacturers themselves. Facility management and energy suppliers provide additional products and services that a company needs to run its IT infrastructure, yet without aiming at an integrated approach. For manufacturers and service providers this situation is not satisfactory either, as they hardly receive any feedback on the quality of their products and services or on current energy efficiency requirements.

Individual aspects of energy efficiency and sustainability have been discussed in the IS community (Teuteberg & Staßenburg 2009). We conducted a literature review (Webster & Watson 2002) on leading journals (top 20 journals according to AIS) and conferences (ICIS, ECIS, WI, AMCIS, HICCS) by searching relevant papers within 2009 to 2011 and using search terms like Green IT, data center, IT infrastructure as well as energy, resource and cost efficiency. Selected related approaches on resource-efficiency in server rooms and data centers are depicted in Table 1. While Pretorius et al. (2010) focus on a technical solution in form of server virtualization, Hedwig et al. (2010) consider decision support for investment decisions. Witkowski et al. (2010) present a prototype of a data center which only considers cooling and the utilization of waste heat. The other references have their specific focus, too. Therefore, a comprehensive concept for the integration of all actors has not been developed so far.

Reference	Focus	Contribution
Pretorius et al. (2010)	Server Virtualiza-tion	By utilizing a virtualized data center infrastructure the energy consumption can be reduced by approx. 32% in comparison to an infrastructure that consists of physical servers only.
Hedwig et al. (2010)	Investment Decisions	This paper proposes a formal model that supports investment decisions for data centers. Using this approach the total cost of operation can be reduced.
Witkowski et al. (2010)	Cooling / Waste Heat	A prototype of a data center is introduced that operates with outside air cooling. The generated waste heat is utilized in a greenhouse facility.
Wang et al. (2011)	Power Control	The proposed power controller shifts power among multiple high-density servers based on their performance needs while abiding to a total power constraint.
Meisner et al. (2011)	Idle Power Consump-tion	The authors introduce an approach to rapidly transition servers in and out of an ultra-low power state in order to realize power savings. Moreover, a power delivery system that suits this approach is suggested.
Schmidt et al. (2009)	Procedural Model	A procedural model for IS management is shown that is intended to function as a guideline for the implementation of sustainability within organizations.

Table 1. Selected related approaches on resource-efficiency in server rooms and data centers

The planning, realization and operation of server rooms and data centers involves several substitutable IT infrastructure products and services. Hence, the provision of a hybrid product-service system (PSS) has to be made transparent and measureable to all involved stakeholders, so that even companies outside the IT industry are enabled to achieve resource-efficiency and utilize their IT infrastructure as a basis for the company-wide improvement of the use of natural resources (Schmidt et al. 2010; Watson et al. 2010). In response to these requirements, our research is guided by the question how to integrate those products and services into a cohesive PSS for resource-efficient IT infrastructure.

2 Methodology

The research described in this article aims at creating a new and innovative artifact. Standard methods of software engineering, as, for example, the waterfall model (Pfleeger & Atlee 2010), are not suitable for designing a product-service system since they focus on software only. In the light of the growing importance of hybrid products, different approaches for the design of a PSS have been introduced into the academic discussion. However, no approach has been widely accepted as standard (Sadek & Köster 2010; Thomas et al. 2008). Since we intend to develop a holistic product-service system that comprises all aspects of resource-efficiency and satisfies the requirements of all stakeholders, we need to focus especially on the integrated design of products and services (Thomas et al. 2008; Becker et al. 2010; Sadek & Köster 2010). It is essential that the dependencies between single components of the PSS can be acknowledged in the early stages of the development process without determining whether a certain requirement has to be fulfilled by a product or a service. Considering the practical aim of our research, the chosen approach also needs to be viable in practice (Sadek & Köster 2010).

We chose to follow the procedure model for modeling product-service systems developed by Weber et al. (2004) because it suits the requirements mentioned above. The procedure model discerns between to-be properties which are perceived by the customer and the product behavior and characteristics that are determined within the construction process of the hybrid package. The to-be properties are expressed in customer terminology. Therefore, they have to be translated into the constructor terminology and finally converted into characteristics. This transformation is called synthesis. The analysis is the subsequent translation and comparison of the created product with the customer requirements. By following this procedure both the customer and the constructor can each use their own terminology (Weber et al. 2004; Thomas et al. 2008).

The selected procedure model is extended by a preliminary phase in which the customer requirements are determined. By separating the inquiry of the customer requirements from the definition of properties of the product-service system, the authors both acknowledge the high complexity of the problem domain and – in contrast to the original procedure model – make the transformation of customer requirements into properties of the PSS transparent (Thomas et al. 2008). Figure 1 depicts the resulting process model that the research described here is based on.

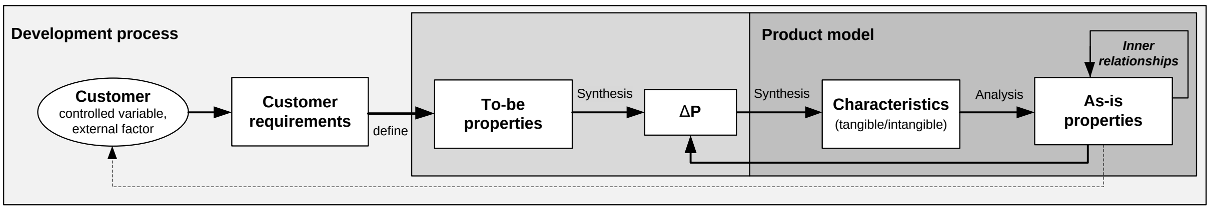

Figure 1. Research design (based on Weber et al. 2004).

Initially, the customer requirements are identified which provide the foundation for the definition of the to-be properties of the hybrid product. During the following synthesis steps, new or modified characteristics of the product and its inner relationships are derived. Here, deviations between the defined as-is properties and the to-be properties which are desired by the customers are incorporated. The as-is properties result from the analysis of the characteristics. Finally, the as-is properties are compared to and aligned with the to-be properties (ΔP). The procedure model is run through until the gap between the as-is properties and to-be properties is sufficiently reduced. At the end of each cycle the product model is adapted accordingly (Weber et al. 2004). From the perspective of design science research, the described cycle of synthesis and analysis can be interpreted as the evaluation and refinement step within the design cycle (Hevner et al. 2004; Hevner 2007; Carlsson et al. 2009). Hence, by linking this procedure with a practical problem and a methodological foundation all three cycles of this research approach are carried out.

3 Concept and Implementation

3.1 Determination of Customer Requirements

The customer requirements to the PSS are determined by means of focus group interviews (Morgan 1993) and semi-structured expert interviews (Horton et al. 2004). Through this two-tier approach, the needs of manufacturers and service providers and the requirements of the end users are equally accounted for (Carlsson et al. 2008). The first part of the analysis – the focus group interviews – serve as a preliminary explorative study to identify specific problem areas and to get a first idea of customer requirements. The interviews were conducted in the context of moderated group discussions. In turn, these were part of two industry workshops which were held in January and March 2010, involving a total of over 60 participants from science and practice. Following the methodological approach of focus group interviews, several separate discussion groups were formed. Each group focused on a particular core topic (as, for example, Green IT, management systems and compliance or sustainability reporting) and discussed related practical problems and possible solutions (Morgan 1993). At the end, the results of each group discussion were recorded and briefly presented to the other groups. The participants come from different industries, as, for example, the manufacturing sector, public administration or the energy supply sector. Therefore, the heterogeneous customer requirements of different industrial sectors are adequately represented. Free choice of focus groups leads to a high degree of homogeneity within the groups and the members of each group are likely to have similar interests. This group structure (heterogeneity between the groups and homogeneity within them) is in line with existing recommendations regarding the conduction of focus group interviews (Morgan 1993). The results of the preliminary study are summarized in Table 2 and can be roughly categorized into political/legal, economic, organizational and technical requirements.

Political/legal requirements	Selection of different abstraction levels
	Application of different standards and corresponding sets of key performance indicators
	Checking of efficiency of the method by measuring economic and ecological values
	Monetary or timely savings and/or noticeable quality improvements
Organizational requirements	Combination of software, infrastructure and integration into the organizational structure
	Solution must provide decision support
	Solution must not only support daily business, but also be of long-term strategic significance
Technical requirements	Covering of interface issues, e.g. heterogeneity of existing solutions, inconsistent data etc.
	Possibility to generate ad-hoc reports
	Timeliness, appropriate complexity and quality of data

Table 2. Results of the focus group interviews.

In the second part of the study, semi-structured expert interviews (Horton et al. 2004) are conducted in order to complement and deepen the insights gained from the focus group interviews. In particular, the preliminary study identified the manufacturing industry as a potential market for the product-service system. Therefore, the second part of the analysis focuses especially on the requirements of this sector. The expert interviews confirmed and extended the results of the focus group interviews. Table 3 provides a short overview of the most important additional requirements mentioned by the interviewees.

Political/legal requirements	Compliance with dynamically changing legal requirements and implementation of the necessary information flows
Economic requirements	Faster and more efficient establishment of legal compliance and provision of software training
	Management cockpit to derive goals and efficiency measures for environmental controlling
Organizational requirements	Facilitation and support of top-management commitment
	Establishment of environmental management as an integral part of corporate culture and day-to-day operations
	Alignment with the corporate strategy and vision
	Motivation and coaching of employees and business partners
Technical requirements	Substitution of stand-alone software such as Microsoft Office for an integrated software platform for integrated environmental management
	Automated generation of environmental reports
	Document storage of guidelines, procedures and certificates
	Integration of hardware sensors

Table 3. Results of the semi-structured expert interviews.

3.2 Definition of To-Be Properties

After the completion of the two-tier survey of customer requirements, the to-be properties of the hybrid PSS are defined on the basis of a requirements classification. At this point in time, no concrete products or services are specified to meet the desired characteristics. In this sense, our approach differs from classic product development processes (Weber et al. 2004; Becker et al. 2010).

The data collected in the focus group interviews and the expert interviews (cf. Table 2 and Table 3) is grouped into functional aspects and subsequently transferred to the level of properties of the product model. In Figure 2 an excerpt from the final product model of the development process is shown. Important characteristics and properties and their relations are depicted. The proposed framework is a generic model which has to be adapted to the respective project and developer. Nevertheless, the product model has been discussed and approved of in the context of an expert workshop, which also served to establish a consensus about the further procedure.

The product model needs to be continuously improved and adapted to customer requirements (Weber et al. 2004; Becker et al. 2010), since these tend to change over time. Our procedure model meets this challenge by taking a cyclic approach consisting of a requirements analysis, the subsequent adaption of the product-service system to the identified requirements and a target-performance comparison.

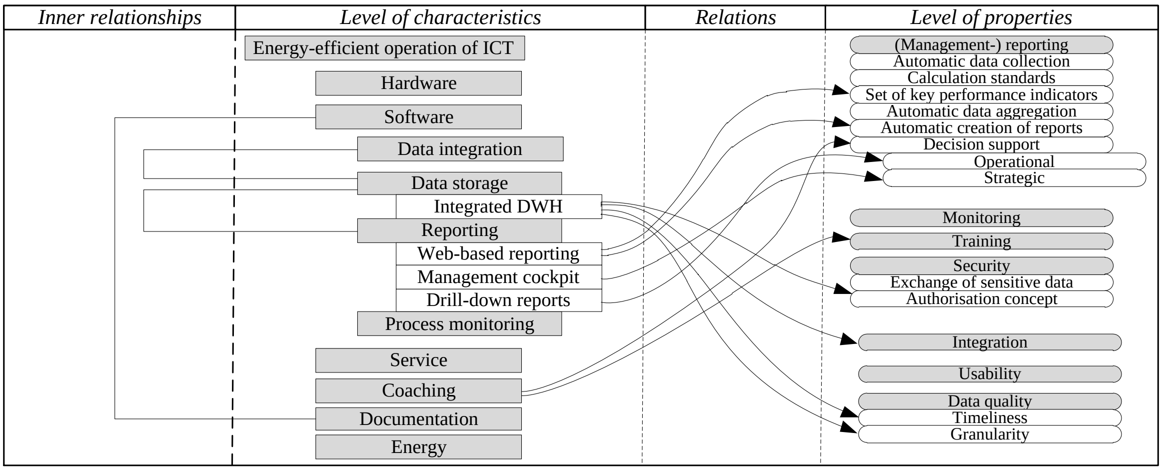

Figure 2. Excerpt from the level of characteristics and level of properties of the product model.

3.3 Synthesis of Properties of the Product-Service System

In the context of the synthesis, the to-be properties of the product-service system are realized by the definition of system characteristics. The inner relationships between the characteristics illustrate the existing logical relations and interdependencies between product and service components within the PSS. Based on the customer requirements new characteristics of the product-service system are added in order to analyze their impact on the previously determined requirements in the form of relations (Weber et al. 2004).

Compared to the product-service system configured by Weber et al. (2004), the development of a hybrid PSS for the resource-efficient operation of IT infrastructure is a more complex task. Hence, based on the level of properties, a framework for the level of characteristics is created by drawing a conclusion by analogy from existing cockpit systems. This framework contains information on the types of components (hardware, software or services etc.) that are suitable to satisfy the customer-defined to-be properties. It has been noted that although using such analogies no exact archetypes or predecessor solutions are existing. Therefore, at the beginning of the synthesis the differences between to-be properties and as-is properties (ΔP in Figure 1) are congruent with the to-be properties. The analysis of requirements at the level of properties (cf. Table 2 and Table 3) revealed that the potential buyers of energy efficiency software regard technology-related and coaching-related aspects as especially important. Hence, the systematic development of the product model focuses on these aspects in a way that the characteristics of the software component of the PSS are constituted and their relations to the level of properties are determined as well as coaching service for planning, realization and operation of server rooms and data centers are described (cf. Figure 2).

3.4 Analysis of As-Is Properties

The analysis of the as-is properties allows us to monitor the fulfillment of the design goals from various perspectives. In the course of this process it has become clear that the requirements regarding timeliness, granularity and quality of data, the degree of integration as well as the generation of analyses and reports can only be fulfilled by introducing a data warehouse (DWH) to the IT architecture, as is illustrated in Figure 2 (Baars & Kemper 2010). Hence, technical requirements regarding the construction and enhancement of the product model are derived from the analysis of the as-is properties. Every customer must decide individually whether to procure a DWH in the form of a software service or to purchase it as a product component of the hybrid package (Baars & Kemper 2010). Furthermore, the necessity for a web-based management and consulting cockpit arises from the multitude of actors involved in the realization of the product-service system and the customer requirements, which have been incorporated into the to-be properties. Such a cockpit provides access to relevant information without proprietary or complex software. During the analysis of the as-is properties, new differences between as-is and to-be properties can emerge (ΔP in Figure 1). Besides the software component, consulting and coaching services are necessary, for they can support the top management in taking well-structured strategic and operational decisions. Additionally, they facilitate the training of all stakeholders.

3.5 Implementation and Application Scenario

After the completion of the described synthesis-analysis-cycle, a preliminary version of the management and consulting cockpit was prototypically designed. Based on the derived product model and requirements we choose to use web technologies to implement especially the properties of monitoring, management reporting and usability without neglecting the others. On the left hand side in Figure 3 the resulting cockpit that provides access for all actors and stakeholders by using a web browser is shown. In the upper section a tachometer indicates the total power consumption induced by the operation of the IT infrastructure at a given point in time, as well as the warranted maximum power provided by the energy supplier. Furthermore, a pie chart shows the proportions of power consumed by individual components of the infrastructure. Hence, the cockpit satisfies the customer requirement of increased transparency regarding energy consumption. The lower section of the screen is divided into two parts. In the lower left part the most relevant key performance indicators (KPIs) are listed. This section provides more detailed information both on the overall energy consumption and on the consumption of each single component within the server room or data center; ranging from the energy consumption of complete server racks to KPIs which are crucial for Green IT like power usage effectiveness, server utilization, quotas of virtualization etc. (Erek et al. 2009). Traffic lights and trend arrows facilitate the interpretation of the data and indicate the development in comparison to the previous period. On the bottom right, a line chart illustrates the development of energy consumption within a certain selectable time horizon. In this way, time-of-the-day dependent consumption patterns and possible load peaks can be easily detected.

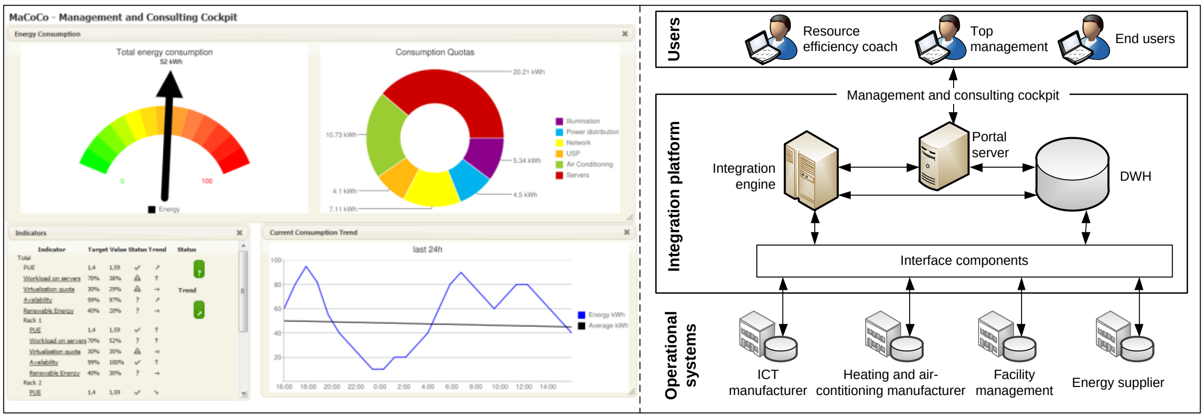

Figure 3. The management and consulting cockpit and the underlying IT architecture.

The management and consulting cockpit offers a consolidated view on the energy efficiency of an organization's IT infrastructure, its current state as well as its development over time. The linkage to detail pages in all three areas allows a deeper analysis of the aggregated view in the cockpit (drill down). The web-based cockpit component satisfies the desired characteristics of a management cockpit which were defined on the level of properties in the product model. In detail, the following to-be properties, which are linked by relations in Figure 2, are satisfied: 1) Usage of a consistent and elaborated set of key performance indicators, 2) Automatic and hence less complex creation of reports, 3) Intuitive usability and hence less effort for trainings, and 4) Strategic and operative decision support. The underlying IT architecture (cf. right hand side in Figure 3) constitutes the foundation of the management and consulting cockpit: data from the operative systems of the previously isolated product and service providers are integrated via ETL (extraction, transformation and loading) processes embedded in interface components and is stored in a way suitable for reporting. Both the end user operating the IT infrastructure as well as the involved manufacturers and service providers can access the reports via the internet. The proposed IT architecture satisfies the to-be properties of an integrated DWH solution as noted in the product model. The DWH provides the basis for management reporting via ETL processes as described above and helps to satisfy the following to-be properties: 1) Implementation of automated data collection and aggregation (to the greatest possible extent), which ensures consistent calculation standards and 2) Realization of software interfaces to the operative systems of all stakeholders and implementation of an integrated data storage that guarantees the timeliness of the data and facilitates the simultaneous storage of data at different levels of granularity.

To satisfy the remaining requirements (cf. Table 2 and Table 3) and to facilitate the optimal adoption of the hardware and software products described above, energy efficiency coaching needs to be incorporated into the product-service system. Energy efficiency coaching is not restricted to one-time trainings or workshops on the usage of the integration platform or the management and consulting cockpit. Rather, it provides a way of creating the necessary awareness regarding questions of Green IT at the strategic level and of achieving sustainable change in behavior (Sarkar & Young 2009).

4 Evaluation

Following a design-science-oriented research approach, we evaluate our designed artifact – a product-service system for the energy-efficient operation of IT infrastructure (cf. Section 3.5) – by measuring the fulfillment of the customer requirements identified in the expert interviews (Hevner et al. 2004; Hevner 2007; Carlsson et al. 2008). To quantify the importance of each customer requirement we calculate its relative frequency on the basis of the number of experts articulating it. To ensure the relevance of the derived findings we only include those customer requirements in our evaluation that have a calculated importance of at least 0.5, i.e. that were mentioned by at least half of the interviewed experts. The result of this filtering process is a list of the most important customer requirements which are of the highest relevance for the practical implementation of the developed product-service system. We assess whether or not a requirement is fulfilled and whether this is achieved directly or indirectly. The evaluation is conducted at a conceptual, technical and economic level.

Conceptual evaluation: The most important conceptual requirements that are fulfilled by our approach are depicted in Table 4. The motivation and coaching of employees and business partners is directly achieved by our coaching component as well as by the clarifying function of our management cockpit. Facilitation and support of top-management commitment are achieved in the same way. The establishment of environmental management as an integral part of corporate culture and day-to-day operations is indirectly supported by our conception. The management and consulting cockpit as well as the coaching component can facilitate necessary changes. However, in order to integrate them into every aspect of corporate culture a sophisticated change management might be helpful.

Customer requirements	**Importance**	**Fulfillment**	**Directly/ Indirectly**
Motivation and coaching of employees and business partners	0.63	✓	directly
Facilitation and support of top-management commitment	0.50	✓	directly
Establishment of environmental management as an integral part of corporate culture and day-to-day operations	0.50	(✓)	indirectly

Table 4. Conceptual evaluation: fulfillment of customer requirements.

Technical evaluation: Our prototype and its architecture directly satisfy the requirement of a management cockpit to derive goals and efficiency measures for environmental controlling. The next requirement combines two criteria: compliance with dynamically changing legal requirements and the implementation of the necessary information flows. Compliance with these requirements can only be indirectly achieved, since our software and coaching components can only support the monitoring of legal requirements by providing required information and assistance in the interpretation and application of legal requirements. The next requirement, i.e. the automated generation of environmental reports is also directly fulfilled by our concept. This is especially due to the integrating nature of its IT architecture, which also serves as the basis for the required integration of hardware sensors. The sensors can be directly integrated into our architecture as data providers for the data warehouse. Hence, we regard this requirement as fulfilled. Our management and consulting cockpit does not include a document storage component for guidelines, procedures and certificates, as we regard this as a functionality of document management systems (DMS). Furthermore, we think that a DMS is a more suitable tool to meet regulatory demands for document archiving and long-term storage, as well as for managing revisions of the document (Sui et al. 2008).

Customer requirements	**Importance**	**Fulfillment**	**Directly/ Indirectly**
Management cockpit to derive goals and efficiency measures for environmental controlling	0.75	✓	directly
Compliance with dynamically changing legal requirements and implementation of the necessary information flows	0.75	✓	indirectly and directly
Automated generation of environmental reports	0.75	✓	directly
Integration of hardware sensors	0.63	✓	directly
Document storage for guidelines, procedures and certificates	0.63	–	–

Table 5. Technical evaluation: fulfillment of customer requirements.

Economic evaluation: Finally, we evaluate our approach from an economic perspective by conducting a descriptive and argumentative evaluation (Frank 2006). According to this evaluation, certain institutional preconditions must be fulfilled to make our approach profitable in a real-world setting. In the first place, top management must be convinced of the necessity to achieve resource-efficiency in server rooms and data centers. If this precondition is fulfilled and our strategy is consistently followed, the proposed integrated approach may pay off – not only in terms of financial revenues but also in terms of public awareness of environmental consciousness. However, the actual economic value has to be calculated as part of future research.

In summary, the most important customer requirements are satisfied by the product model of our product-service system, with the exception of integrated document storage. It also becomes clear that IT merely serves as a tool to facilitate and support the implementation of strategies and decisions (Farhoomand 2005). In order to improve the eco- and resource-efficiency of server rooms and data centers, the use of IT needs to be combined with additional services such as coaching.

5 Discussion

From our point of view, the implementation of the proposed product-service system has the potential to substantially transform value chains for the planning, realization and operation of server rooms and data centers. While the current situation is characterized by isolated vendors, isolated applications and inefficient coordination between the stakeholders, our conceptualized product-service system can create a win-win-situation for all stakeholders involved: Each stakeholder can focus on his/her respective core competencies, whereas the integration platform establishes transparency regarding energy use and efficiency along the entire value chain. This integration platform is also the basis for the previously described management cockpit and the coaching services. The integration platform also facilitates multidirectional communication on customer requirements and customer feedback by providing a single point of contact for manufacturers, service providers and user companies alike.

In turn, this creates a business model for an additional hybrid vendor. Such a PSS provider acts as an independent consultant and mediator of products and services (cf. Figure 4), i.e. as an interface between the manufacturers and the end user company. The PSS provider possesses the required professional competence to assist companies whose core business is outside IT in selecting appropriate manufacturer as well as service providers in any given scenario. For this task, the presented management and consulting cockpit is utilized. By using the management and consulting cockpit the PSS provider constitutes a focal point of contact for both suppliers and the companies that use the created product-service system. In this function, the PSS provider collects and channels user feedback on the quality of the received products and services. There is one feedback channel for new or changed energy efficiency requirements and another one for information-related requirements to the implementation platform. The latter one can be provided by an independent platform implementation partner, which enables the PSS provider to focus on developing customized solutions.

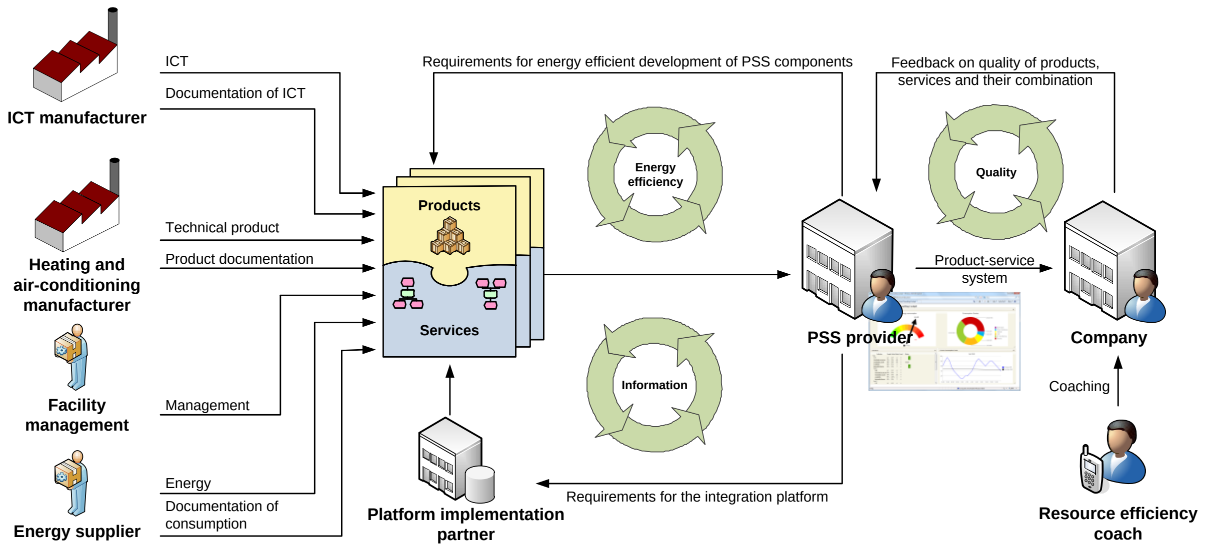

Figure 4. Transformed value chain.

6 Conclusion and Outlook

In the course of this paper, synthesis-analysis cycles of a systematic procedure model have been run through in order to develop a hybrid package for the energy-efficient operation of IT infrastructure. In view of customer requirements and in due consideration of the complexity of the problem domain, we developed a product model that focuses on the reporting and coaching component of the product-service system. Furthermore, we have illustrated the prototypical design of the software component in the form of a management and consulting cockpit and the IT architecture. Additionally, the coaching services that are necessary for a successful realization of the proposed hybrid package have been described. An application scenario for the production of the hybrid package has been developed, including a hybrid vendor that acts as a mediator between end users on the one side and manufacturers and service providers on the other side. The presented approach enables companies to substantially change the value chain in order to achieve a truly energy-efficient IT infrastructure. By comparing our approach with other contributions (cf. Table 1), one recognizes that all of them neglect the required integration. The resource efficiency coach takes over the consulting (Schmidt et al. 2009) and investment decisions (Hedwig et al. 2010). Cooling and utilization of waste heat (Witkowski et al.

2010) is task of the facility management, whilst power control (Wang et al. 2011) and monitoring of results (Schmidt et al. 2009) are ensured by the management and consulting cockpit. Therefore, our approach advances theory by providing an integrated view on existing concepts as well as contributing to the body of knowledge on resource efficient design of server rooms and data centers. Practitioners also will be able to get access to our approach in order to implement it.

The transformation of the value chain raises new research questions: Firstly, trust among the partners is necessary to achieve a high degree of collaboration between all stakeholders. However, development methods like the one presented have evolved from an engineering background and focus solely on the task of development as such. Therefore, our approach needs to be accompanied by methods that are more firmly grounded in the social sciences. Secondly, the practical application needs to take into account that many publicly traded companies strongly focus on shareholder value, which leads to a general short-term orientation. Those companies operate server rooms and data centers as well, but due to the financial pressure they usually refrain from long-term endeavors. Therefore, the cost-effectiveness of the proposed approach may need to be further investigated in order to convince companies that focus on shareholder value to contribute to a more resource-efficient IT.

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