Understanding Energy Informatics: A Gestalt-Fit Perspective

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ABSTRACT

World energy consumption is on the rise. Consequently, there is increasing focus on research on energy informatics (EI). Given the nascent state of research in EI, it is important for researchers to understand what has been accomplished within the EI literature and to be provided with a roadmap of what should be examined in future studies. Our study attempts to contribute towards this by providing a comprehensive review of the EI literature. Our analysis reveals that EI studies can be grouped into four different categories, and that there is an overfocus on viewing EI as only an energy-saving mechanism. Such a focus ignores EI's potential to serve non-environmental goals. Our manuscript provides a holistic understanding of EI success by drawing on the gestalt-fit perspective, and highlighting the multi-dimensionality of EI. The model should also help future researchers in understanding the salient topics of investigation with respect to EI.

Keywords

Energy informatics, fit as gestalts, sustainability, environmental sustainability, Green IS, Green IT, IS Success.

INTRODUCTION

World energy consumption is on the rise (from 2009-2010 it has risen by 5.6%) (BP, 2011). However, despite this increase, the infrastructure that provides primary and secondary energy is insufficient. This current state of energy consumption combined with the intimidating energy infrastructure forecast implies that greater amounts of energy will be consumed in the future. At the same time, a movement to rethink energy consumption by employing information systems (IS) to lessen energy costs, and thereby reduce energy expenditures and carbon footprints, is breaking ground (Melville, 2010; Watson, Boudreau and Chen, 2010a). Businesses are installing automation technologies that use sensors to turn off fans and lights (Snoonian, 2003). Governments are making efforts to improve traffic congestion by planting wireless sensors in roads (Watson, Boudreau, Chen, and Huber, 2008). Households are adopting smart meters, which allow individuals and families to monitor their energy usage (Kranz, Gallenkamp, and Picot, 2010). Universities are researching ways to commercialize and to model smart grids (Farhangi, 2010). These technologies that utilize information to improve a supply and demand energy process are grouped into an academic subfield: energy informatics (EI) (Watson et al., 2010a).

However, given the nascent state of research on this topic, a road map is required for researchers to understand what the salient topics of investigation (with respect to EI) should be. A key to such a roadmap is a review of the existing literature. We contribute towards this by first conducting a thorough review of the academic, practitioner, and hybrid IS literature. Our analysis suggests a paucity of IS literature on EI. Moreover, the existing literature is preoccupied with the goal of environmental sustainability, and thus ignores the potential of EI to achieve multiple, context-specific goals. The literature further reveals that current definitions of EI overlook the continuous, multidimensional nature of information systems (DeLone and McLean, 2003). We find that the novelty of EI research has lead to a misconception as to what EI research is, where EI research fits in the IS discipline, and what EI systems should entail.

By building a knowledge base of current research and defining EI, we hope to channel future research in the area of EI. To do so, we develop a model by drawing on the concept of fit as gestalts (Venkatraman, 1989). This model was derived from our analysis of the stakeholders present in EI systems as well as the examination of the recurring patterns found in the main categories of EI research. Through this, we propose that for EI to achieve success, a fit must exist among the multi-level dimensions of EI. This proposal is then established through a multi-level model of the energy industry (Jagstaidt, Kossahl, and Kolbe, 2011).

The paper proceeds as follows. In the next section, we give a brief overview of the existing EI Framework (Watson et al., 2010a). Next, we review academic, practitioner, and hybrid EI literature to showcase the current state of EI research. Third, we analyze existing EI literature. Thereafter, we discuss our findings and redefine EI based on our literature review. We also present a figure that showcases EI's role in the Green IS concept. Fifth, we propose a fit as gestalts perspective on EI. Finally, contributions are discussed and future research directions are proposed.

DEFINING ENERGY INFORMATICS

The Existing Energy Informatics Framework

As a review, we present Watson et al.'s (2010a) EI framework, which introduces EI through a simple equation: Energy + Information < Energy. The authors define EI as an environmentally conscious, energy-focused research agenda through which businesses can "analyze, design, and implement" an information system in order to improve a "supply and demand" energy process (2010a; pp. 24). Through this definition, the authors introduce the EI framework (Figure 1), which is rooted in three environmentally sustainable goals (eco-goals): eco-efficiency, eco-equity, and eco-effectiveness. The framework also comprises three major stakeholders – consumers, suppliers, and governments – that impact the supply and demand of an energy system. These stakeholders, in order to uphold the eco-goals, influence a supply and demand energy system by way of conforming to or refashioning social/corporate norms, reconsidering economic strategies, and fighting for, conforming to, or enforcing environmental policies and/or regulations. Further, the framework showcases the technological infrastructure needed to support a supply and demand energy process.

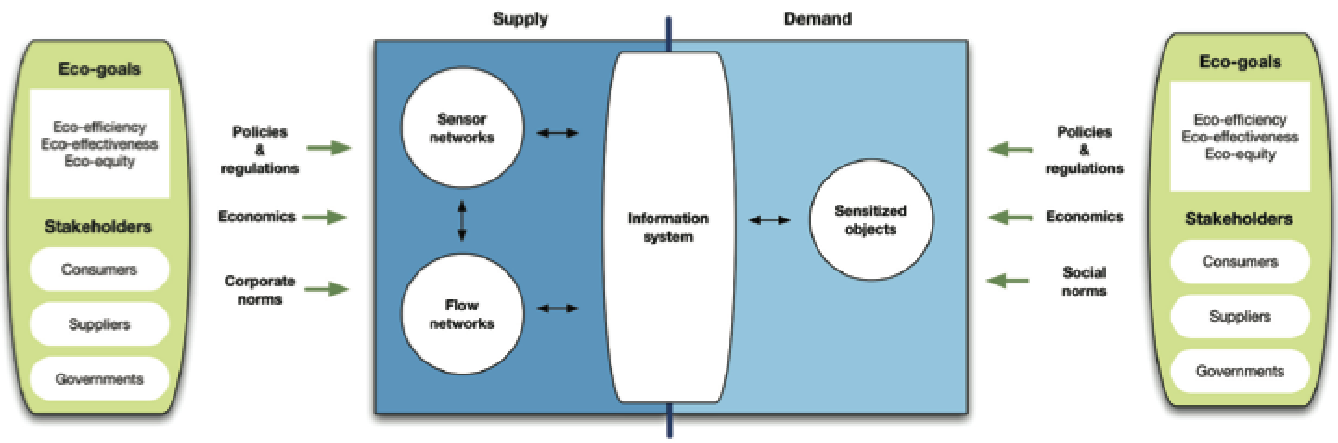

Figure 1: Energy Informatics Framework (Watson et al., 2010a)

LITERATURE REVIEW

In this section, we review existing IS literature surrounding EI. Moreover, we categorize EI research into four streams: initiation, design and implementation, adoption, and benefits.

Research Method

Our goal was to review all the IS literature related to EI. To do so, we used the inductive categorization method (Dubé and Paré, 2003). We considered publication outlets academic, hybrid, and practitioner journals.

Outlets

After consulting recent IS journal ranking literature, we used the six premier academic IS journals (Saunders et al., 2007). Two others were then added to the list. To this list of eight, we added three more that were considered highly ranked. After performing our search, we only found one paper. The search was then expanded to include the major IS academic conference proceedings and IEEE.com. Thus, the final list of journals selected included: *DSS*, *EJIS*, *I&M*, *IJEC*, *ISR*, *ISJ*, *JIT*, *JMIS*, *JSIS*, *JAIS*, *MISQ*, *IEEE.com*, *AMCIS*, *HICSS*, *ICIS*, *PACIS*, and *ECIS*. We also considered "hybrid" publication outlets, which publish articles by academics and practitioners that are focused on applying academic research to practice. The list of journals selected included: *CACM*, *CAIS*, *HBR*, *SMR*, and *MISQE*. Finally, we considered two practitioner outlets: *CIO* and *Computerworld*.

Finding Relevant Articles

We used "*energy informatics*" as the keyword query in academic and hybrid search engines, which included EBSCO Business Source Complete, Google Scholar, and IEEE.com. This resulted in a total of fifteen articles: fourteen academic and one hybrid. As EI is a novel concept only recently introduced to IS researchers, we extended our queries when searching the two practitioner outlets to the following: *energy informatics*, *energy information systems*, *sustainable information systems*, *energy efficient information systems*, and *energy and information*. This resulted in three practitioner articles. The grand total of the literature review was eighteen articles.

Analysis

Analysis by category of publication in each outlet:

Academic		
Reference	*Research Interest*	*Category*
Kranz, Arnold, and Picot, (2011)	The role of environmental concerns in adoption choice	Adoption
Graml, Loock, Baeriswyl, and Staake, (2011)	Energy conservation behavior	Adoption
Yim, (2011)	Energy informatics in energy conservation behavior	Benefits
Kranz, Munich, Gallenkamp, and Picot, (2010)	Private Consumers' Acceptance of Smart Meters	Adoption
Watson et al., (2010a)	A comprehensive framework of Energy Informatics	Initiation
Corbett, Webster, Sayili, Zelenika, and Pearce, (2010)	Demand Management in the Smart Grid	Benefits
Luo and Chan, (2010)	An Architectural Framework for Developing Intelligent Systems for the CO_2 Capture Process	Design and Implementation
Teng and Yamazaki, (2010)	Bit-Watt Home System with Hybrid Power Supply	Design and Implementation
Zhou, Chan, Tontiwachwuthikul, (2010)	Development of a Knowledge-Based System for Monitoring and Diagnosis of the CO_2 Capture Process	Design and Implementation
Potter, Archambault, and Westrick, (2009)	Building a Smarter Smart Grid Through Better Renewable Energy Information	Design and Implementation
Watson, Aronson, Donnellan, and Desautels, (2009)	Panel topic: Energy + Information < Energy	Initiation

Table 1: Categories of EI Literature (continued on following page)

Wall, Platt, and Valencia, (2007)	Wireless Sensor Networks as Agents for Intelligent Control of Distributed Energy Resources	Design and Implementation
Zhang et al., (2006)	Towards a Model-based Application Integration Framework for Smart Oilfields	Design and Implementation
Kastner, Neugschwandtner, Soucek, and Newmann, (2005)	Communication Systems for Building Automation and Control	Design and Implementation
Hybrid		
Watson, Boudreau, Li, and Levis, (2010b)	Introduces EI framework through telematics project at UPS	Initiation
Practitioner		
Sayer, (2011)	Introducing a new service in Intel	Benefits
Anonymous, (2007)	Improving IT Efficiency While going Green	Benefits
Varon, (2007)	How your ERP System Can Help Your Company Manages Its Energy Use	Benefits

Table 1: Categories of EI Literature (continued from previous page)

Our findings suggest that EI literature is grouped into four major categories: initiation, design and implementation, adoption, and benefits. *Initiation* comprises articles about answering the question, "What is energy informatics?" *Design and implementation* embodies the practical usage of EI and answer the question, "How should EI be implemented?" *Adoption* articles discuss the aspects that drive EI adoption/acceptance and answer, "What needs to be done for EI to be adopted in different contexts?" Articles about the *benefits* of EI answer, "How can EI-focused systems benefit stakeholders?"

Initiation

At AMCIS 2009, Watson et al. (2009) proposed energy informatics and the conceptual nature behind EI to the IS discipline. A year later, Watson et al. (2010a) formally introduced energy informatics into IS research by describing energy informatics and advocating a research agenda for the new subfield. Also Watson et al. (2010b) provided an understanding of EI through a study of UPS.

Design and Implementation

Design and implementation represent the articles found in our IEEE search. Such topics include designing a framework for smart oilfields (Zhang et al., 2006), considering the necessary infrastructure for building and home automation (Kastner et al., 2005; Wall et al., 2007), and proposing process improvements to support a better smart grid (Potter et al., 2009). The literature also reflected testing home appliances to optimize energy consumption (Teng and Yamazaki, 2010), and monitoring and modeling the CO_2 capture process (Luo and Chan, 2010; Zhou et al., 2010).

Adoption

Graml et al., (2011) and Kranz and Picot (2011) both present a framework to understand the adoption of energy informatics. Graml et al., (2011) describe different factors that drive people to engage in energy conservation behavior, and Kranz and Picot (2011) discuss the independent variables of adopting smart meter technology. Kranz et al., (2010) employ an extension of TAM to enquire into the adoption of smart meters.

Benefits

Corbett et al., (2010) presents a theoretical model and tests how energy informatics could be used to improve the effectiveness of electricity demand management, and thus reduce energy consumption. In addition, Yim (2011) and Sayer (2011) examined the impact of energy informatics on energy conservation behavior by using competition. Further, Varon (2007) and Anonymous (2007) are concerned with how energy information systems can improve IT efficiency and reduce energy consumption.

Academic, Hybrid, and Practitioner Literature

Figure 2 illustrates the relationship between academic, hybrid and practitioner literature. As shown below, academic literature encompasses every category found in our literature review. Moreover, it appears that academic literature is central to the energy informatics concept. Hybrid literature meets academic literature at initiation, and practitioner literature intersects with academic at the benefits of an EI-related system.

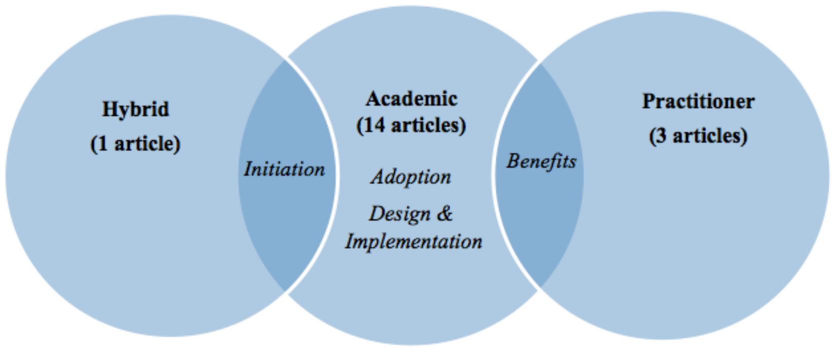

Figure 2: Relationship between Academic, Hybrid, and Practitioner Literature

Figure 2 provides opportunity to discuss the current state of EI research. It appears that practitioners have focused primarily on the benefits of EI, a subject that academics have also considered, along with adoption issues and design and implementation concerns. The lack of congruency highlights that practitioners may be overlooking fundamental elements (e.g., adoption, design and implementation) necessary for the benefits of EI to reach fruition. Given this lack of focus on the adoption and design of EI systems, it can very well be that practitioners are building EI systems that do not anticipate the socio-technical needs of each stakeholder, therefore, running the risk of not being adopted. It is thus important that academics not only conduct rigorous research in EI to inspire other academics, but also communicate the relevance of adoption, and design and implementation issues to practitioners. One way academics can accomplish this is to publish in hybrid outlets. Another approach is to introduce EI topics into the classroom. In the following section, based on our literature review, we redefine EI so as to give practitioners and academics a basis for understanding EI.

Redefining Energy Informatics

As mentioned above, the purpose of EI, in Watson et al.'s (2010a) viewpoint, is for a centralized information system to assist with the reduction of carbon emissions, and thereby "solve global warming" (2010a, pg. 24). While the global warming objective of EI is commendable, and could potentially be a byproduct of an EI-centric information system, framing EI as a fundamental means to save the environment ignores its potential to serve the goals of society, individuals, or an organization. For example, an organization's goals for EI could be to promote collaboration, reduce uncertainty, or increase accuracy of decision-making (Zhang et al., 2006). Further, because the success of an information system is critical and does not end at deployment (Delone and McLean, 2003), EI research should not only consider the "analysis, design, and implementation" of a system (Watson et al., 2010a), but the progression of a system. Based on these reasons and the analysis presented in our literature review, we redefine EI as *a lens through which researchers and practitioners can analyze, design, deploy, and improve an information system built to enhance a supply and demand energy process in order to promote a sustainable outcome*. This definition contrasts Watson et al.'s (2010a) in that it emphasizes the continuous improvement of an information system, and that a benefit is context specific (i.e., a benefit could not only be to solve global warming, but also to reduce energy costs or uncertainty).

Based on the definitions above, we propose that EI not only encompasses environmental issues present in the Green IS/IT concept, but also considers those of the individual, an organization, and/or society (Figure 3). Thus, as depicted in Figure 3, EI involves multiple contexts.

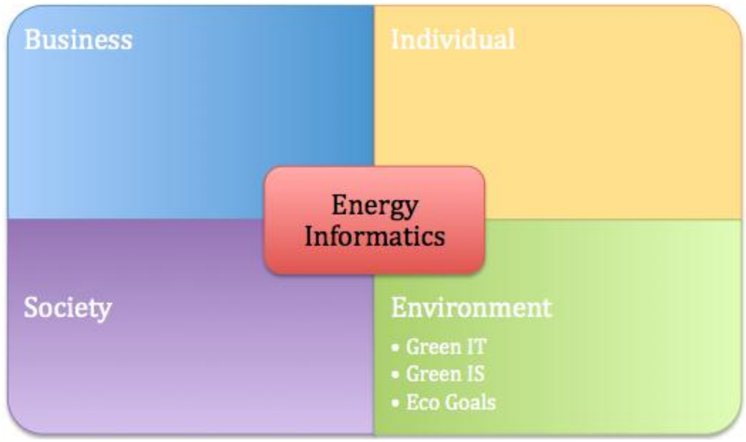

Figure 3: Multiple Contexts of Energy Informatics

Analysis of Stakeholders and Categories

As our interest lies in a deeper understanding of EI, we used three of the four categories of EI literature (design and implementation, adoption, and benefits) to identify recurring patterns. To reflect common patterns embedded in the literature, 'design and implementation' materialized into two critical issues: one 'user interface' category and one 'infrastructure' category. Therefore, a total of four issues (benefits, adoption, user interface, and infrastructure) were considered. Moreover, we analyzed the 18 articles to detect the levels of analyses (Markus and Robey, 1988; Webster and Watson, 2002), which we declared as stakeholders.

The results of our analysis suggest that EI literature covers three primary stakeholders (levels of analyses): individual, organizational, and societal - findings that match Watson et al.'s (2010a) Energy Informatics Framework. While this framework is useful for examining EI from an isolated viewpoint, we propose that the EI framework, along with the EI literature, refers to each stakeholder in seclusion and thus ignores the congruence that must exist amongst each stakeholder. Moreover, our exploration of each category recovered common patterns for each category. First, technological infrastructure is vital to power an EI system. Second, the infrastructure must be standards compliant. Third, the infrastructure must communicate to stakeholders through an interface. Fourth, the interface should facilitate the achievement of the overall stakeholder benefits of an EI system. Last, both the benefits and the user interface interact with a stakeholder's issues surrounding EI system adoption. Based on the findings, we propose that (see Figure 4) for EI to achieve optimal success, a fit must exist between (1) the EI infrastructure; (2) the user interface; (3) the desired stakeholder benefits; and (4) the stakeholder's concern about adoption. Moreover, a fit among the technologies must pre present for EI success.

Based on the arguments above, we give the following propositions (see Figure 4):

Proposition 1: A fit between the underlying technologies present in the infrastructure leads to a greater chance of EI success.

Proposition 2: A fit between the infrastructure and a stakeholder's desires for a user interface leads to a greater chance of EI success.

Proposition 3: A fit between the user interface capabilities and a stakeholder's desired benefits for an EI system leads to a greater chance of EI success.

Proposition 4: A fit between the user interface capabilities and a stakeholder's EI adoption concerns leads to a greater chance of EI success.

Proposition 5: A fit between a stakeholder's desired benefits for an EI system and the infrastructure leads to a greater chance of EI success.

Proposition 6: A fit between a stakeholder's desired benefits for an EI system and a stakeholder's concern about adoption leads to a greater chance of EI success.

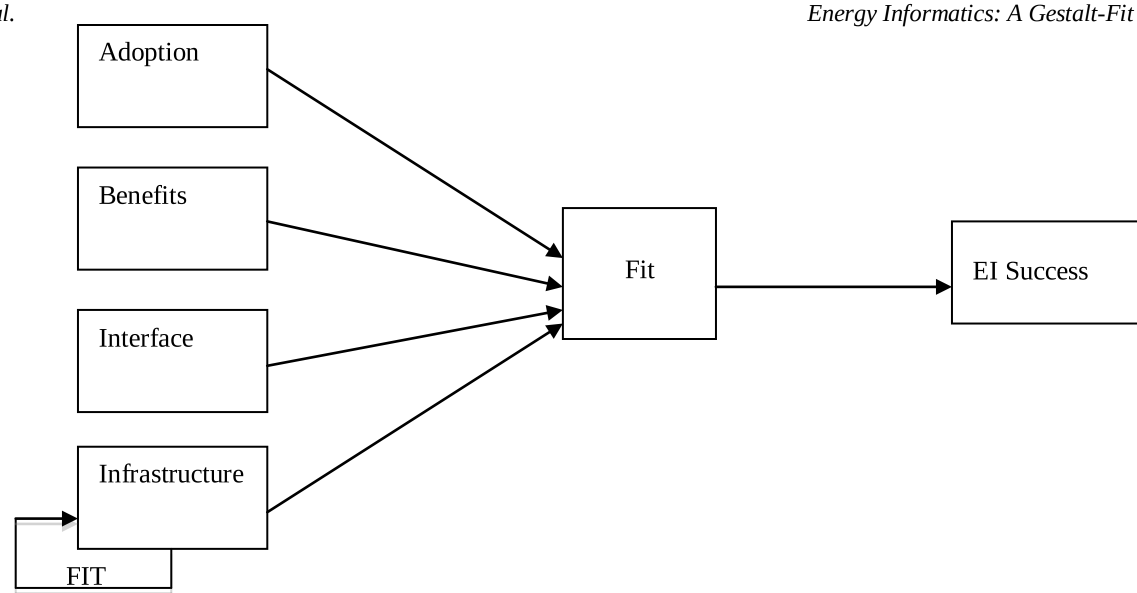

Figure 4: Fit Requirements for EI Success

Themes Within Categories

As stated above, four overarching categories of EI literature prevail: infrastructure, interface, adoption, and benefits. First, infrastructure involves the fundamental technologies that EI systems are built upon. The recurring themes in this category are *data capture technologies*, which are concerned with securing CO_2 gasses and consumption information, *flow networks*, which transport information or matter, *sensors*, which transmit data from a *sensitized object*, or tangible item. Also present are the need for *servers*, a *centralized database*, *security* concerns, and *data integration*. Next, the interface category entails issues surrounding the communication between EI infrastructure and an EI stakeholder. Common themes were *personalized data*, which are data adapted toward a specific stakeholder, *monitoring* tools, which give stakeholders the ability to oversee data, *data analysis tools*, which allow stakeholders to dissect their data, and *control tools*, which allow stakeholders to control sensitized objects. Third, benefits of EI represent the perceived benefits of an EI system. The most common benefits were *environmental sustainability*, the *reduction of energy consumption* and *energy cost*, the *measure*, *analysis* and *optimization of business processes*, and *productivity*. Finally, adoption topics were extracted. The most common topics were *attitudes*, *social norms*, *perceived behavioral control*, *environmental concerns*, *motivation*, and the *ability to use* the EI system. We believe that a fit between these components need to exist for EI success.

Employing Fit to EI

“Fit” as a concept is embedded in the contingency perspective (Venkatraman and Camillus, 1984). Venkatraman (1989) argues that when researchers select a concept of fit, they do so by articulating the “degree of specificity of the theoretical relationships” (pp. 424) and by adopting a “criterion-specific” or a “criterion-free” design (pp. 425). Based on these assessments, Venkatraman (1989) classifies fit into six perspectives: profile deviation, mediation, moderation, gestalts, covariation, and matching.

Among these, *fit as gestalts is most suited to this study*. As defined by Miller (1981), fit as gestalts are “frequently recurring clusters of attributes, or gestalts” (as cited in Venkatraman, 1989). Such patterns can “provide useful insight into a powerful concept of equifinality or the feasible sets of internally consistent and equally effective configurations” (Venkatraman, 1989; pp. 432). Therefore, because of the multi-level attributes involved in energy informatics, and the recurring nature of their interaction, fit as gestalts supplies the proper fit construct for EI.

A Fit as Gestalts Perspective on EI

To better support our argument of fit, we embrace Jagstaidt et al., (2011), who adopt the Federal Ministry of Economics and Technology’s Smart Watts Internet of Energy model (BMWi, 2010), a three-tiered model of the energy industry (Figure 5), which we deem highly representative of the core of energy informatics. Through this model, we apply the lens of ‘fit as gestalts’ to energy informatics and pinpoint multiple micro-level stakeholders who have vested interests in infrastructure, interface, benefits, and adoption.

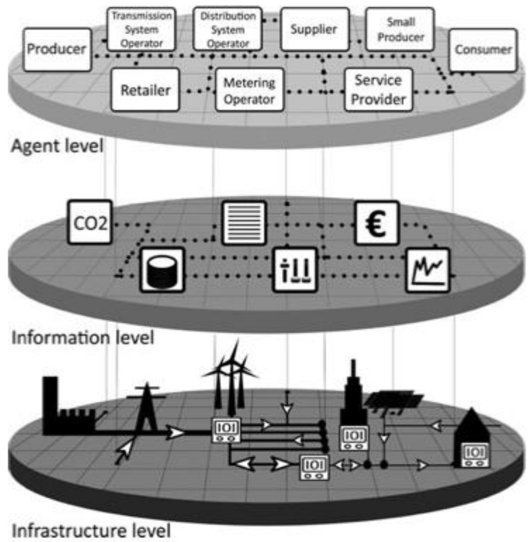

Figure 5: Level Perspectives of the Energy Industry (BMWi, 2010)

The three levels of the energy industry (agent, information, and infrastructure) are interdependent (Jagstaidt et al., 2011). In other words, each level requires a high level of congruence with another in order to function successfully. Moreover, each level comprises various components that must regularly interact with each other, both at a single level and through multiple levels.

The Agent Level (Stakeholders)

The top tier of the model depicts agent level, which represents the numerous stakeholders involved in the energy industry. As revealed in our literature review, little attention was paid to the interaction of stakeholders, especially at the micro-level. The micro-level stakeholders presented in the energy industry model include the energy producer, retailer, transmission system operator, metering operator, supplier, service provider, small producer, and consumer. When applying fit as gestalts to the agent level, there exists multiple levels of stakeholders, each with a range of interface needs, desired benefits, and adoption concerns.

The Information (Interface) Level

The information level "enables the vertical exchange of data between the technical infrastructure and the agents in the energy market" (Jagstaidt et al., 2011; p. 323). In other words, the information level is continuously interacting with the agent and the infrastructure level through frequent exchanges and multiple data sources. In relation to fit as gestalts, and as shown in Figure 6, the user interface and the information retrieved from the infrastructure level must fit the desires of each stakeholder for EI to be successful (Proposition 2).

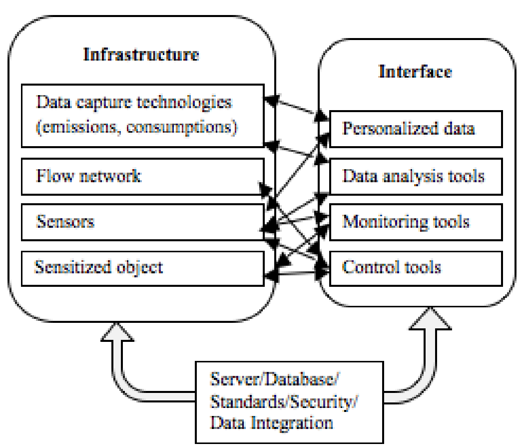

Figure 6: Infrastructure and Interface Fit as Gestalts

As previously mentioned, the interface must also match a stakeholder's desired benefits for the system. This is to say that the capabilities of the user interface present on a stakeholder's computer or mobile device must match his or her desires for an EI system (Proposition 3). As depicted in Figure 7, every dimension present in the interface category contributes to the realization of benefits associated with multiple stakeholders.

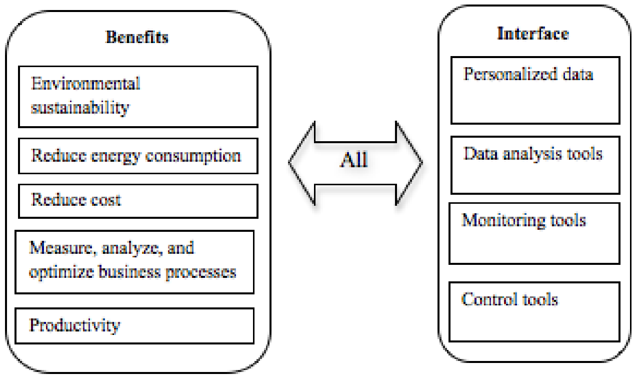

Figure 7: Interface and Benefits Fit as Gestalts

The interface dimensions should also match those present in technology adoption (Figure 8). In other words, a stakeholder's likelihood to adopt an EI system is dependent upon what the user interface presents. For example, if a stakeholder is genuinely concerned about the environment, and the interface presents monitoring tools that allow the stakeholder to monitor CO_2 emissions, then the stakeholder is more likely to adopt an EI system (Proposition 4).

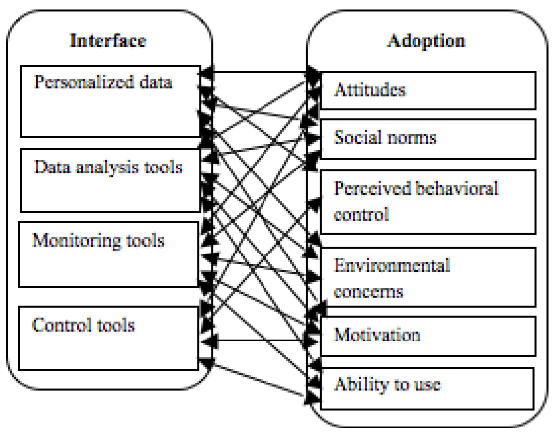

Figure 8: Interface and Adoption Fit as Gestalts

The Infrastructure Level

The bottom slice of the energy model (see Figure 5) illustrates the infrastructure level, which contains a countless number of technological configurations necessary for energy informatics. To serve the other two levels, the technologies present in the infrastructure must be congruent with one another (Proposition 1). Each technology must have a common server and data storage platform, along with data integration and standard protocols (Figure 9). Moreover, security settings must be engaged to ensure secure data transfer (Figure 9).

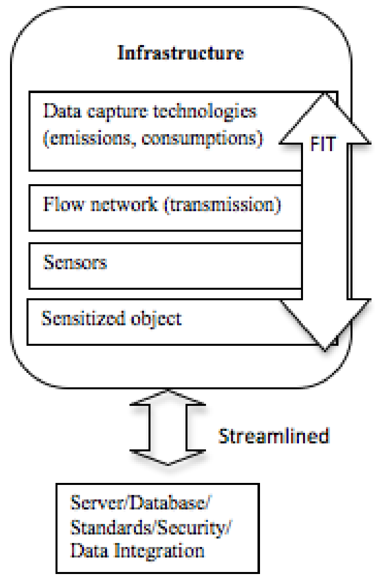

Figure 9: Infrastructure Technologies Fit as Gestalts

The infrastructure should also serve the desired benefits of each stakeholder (Proposition 5). For example, if a stakeholder's aim was to reduce energy consumption, then the infrastructure must be built to support this goal. This relationship should be a continuous interaction, as the benefits and infrastructure should be mutually dependent (Figure 10).

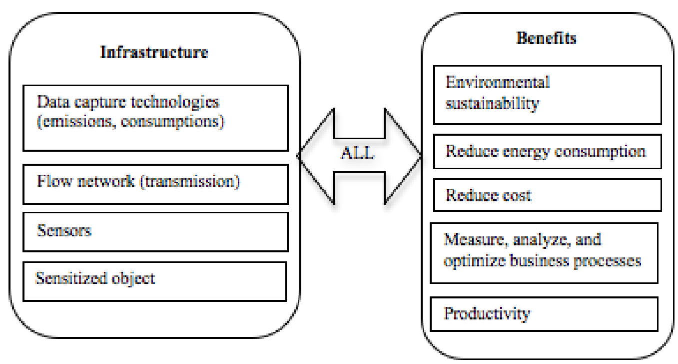

Figure 10: Infrastructure and Benefits Fit as Gestalts

Lastly, a stakeholder's desired benefits for an EI system and their adoption concerns should go hand in hand (Proposition 6). For example, if a stakeholder is subjected to environmentally friendly social norms and one of the perceived benefits of the EI system is to contribute to environmental sustainability, then the stakeholder will be more likely to adopt the system. As depicted in Figure 11, we suggest that not all benefits will alleviate every adoption concern. However, those that relate to one another should contribute to overall EI success.

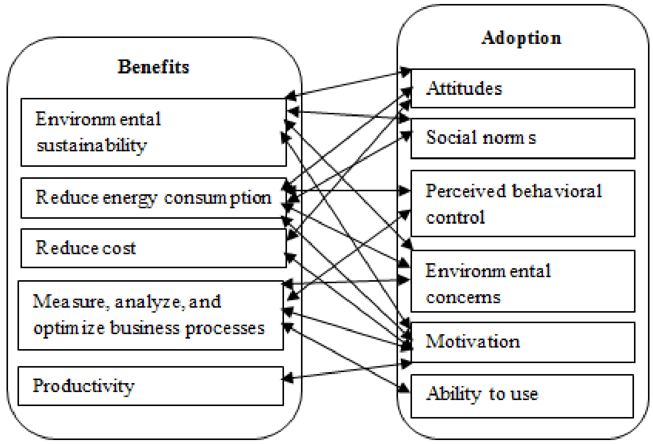

Figure 11: Adoption and Benefits Fit as Gestalts

Contributions of Fit as Gestalts

Applying the fit as gestalts concept to energy informatics contributes to the literature by offering a multivariate, theoretical viewpoint about fit amongst the multiple EI stakeholders, rather than the typical isolationist position taken by the literature. Specifically, the concept provides a theoretical basis for examining the congruencies of the underlying dimensions of EI. Moreover, fit as gestalts provides basis for investigating how the match between an EI-driven system's infrastructure, its user interface, and its perceived benefits congregate to influence to EI success. Finally, the concept gives insight into the mitigation of adoption issues surrounding EI.

CONCLUSION

This study reviewed existing EI literature and revealed that the benefits of EI center on environmental sustainability. We argued that approaching EI from an environmental standpoint ignores its potential to facilitate individual, organizational, and societal goals. A redefinition of energy informatics was given that extended Watson et al., (2010a) and included the context-specific nature of sustainability and the continuous nature of information systems (Delone and McLean, 2003). We then applied the 'fit as gestalts' lens so as to provide a theoretical understanding of EI success.

The distinctions, definitions, and theory presented in this paper are useful for both researchers and practitioners in many ways. First, it allows researchers and practitioners to view the goals of energy informatics not just as a means to reduce global warming but also find innovative ways to research EI. Second, redefining the goals of EI as context dependent, and reaffirming that information systems success is continuous in nature, introduces a more complete perspective of EI. Third, categorizing EI research offers insight into where research gaps exist and promotes the opportunity to discover new research avenues. Last, employing a fit as gestalts lens to energy informatics establishes a theoretical foundation on which EI should rest, and gives insight into the complexities of the success of EI.

Future research will consider a more in-depth analysis of the articles in order to identify categories and possibly subcategories above and beyond those presented by Watson et al. (2010a). To do so, we plan to extend the keywords to locate a larger range articles and to broaden the selection of outlets.

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