Department of Energy Technology

Success factors of energy management in energy-intensive industries: Energy performance measurement

Leena Sivill

Aalto University

DOCTORAL DISSERTATIONS

Aalto University publication series
DOCTORAL DISSERTATIONS 68/2011

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Leena Sivill

Doctoral dissertation for the degree of Doctor of Science in Technology to be presented with due permission of the School of Engineering for public examination and debate in Auditorium K216 at the Aalto University School of Engineering (Espoo, Finland) on the 7th of October 2011 at 12 noon.

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Aalto University publication series
DOCTORAL DISSERTATIONS 68/2011

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ISBN 978-952-60-4239-8 (pdf)
ISBN 978-952-60-4238-1 (printed)
ISSN-L 1799-4934
ISSN 1799-4942 (pdf)
ISSN 1799-4934 (printed)

Aalto Print
Helsinki 2011

Finland

The dissertation can be read at http://lib.tkk.fi/Diss/

Aalto University

Abstract

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Author
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Name of the doctoral dissertation
Success factors of energy management in energy-intensive industries: Energy performance measurement

Publisher School of Engineering

Unit Department of Energy Technology

Series Aalto University publication series DOCTORAL DISSERTATIONS 68/2011

Field of research Industrial energy engineering

Manuscript submitted 18 April 2011 **Manuscript revised** 20 June 2011

Date of the defence 7 October 2011 **Language** English

☐ **Monograph** ☒ **Article dissertation (summary + original articles)**

Abstract

This thesis explores energy performance measurement in support of energy management in the energy-intensive industries. In general, performance measurement is used in management for raising awareness, evaluating performance, setting targets and offering decision support. These purposes also apply to energy management, defined here as the management of all activities related to the economic and responsible use of energy in an organisation.

This thesis answers the following three questions: 1) what is the concept of energy performance in a business organisation? 2) what is the importance of energy performance measurement to energy management in the energy-intensive industries? and 3) what are the subsequent needs for future research and development? A variety of methods are used, ranging from qualitative research to the modelling of energy systems and case demonstrations.

The findings indicate that energy management should focus on improving energy performance, not energy efficiency, because this broader view is able to capture both the operational and strategic perspectives of energy management. This is in line with the trends of managerial integration and the adoption of sustainable development into management practice. The domain of energy performance indicators should entail organisational, systemic and temporal dimensions. From the perspective of operational management, performance measurement should address all the three means to improve energy performance, namely technology, operation and process integration. In addition to the operational management, future research and development should define the role of energy performance measurement in all the other management functions. These recommendations provide a wide spectrum of opportunities for the development of energy performance indicators, energy performance measurement systems and their underlying deployment processes in different industrial sectors, organisations and systems.

Keywords energy management, energy efficiency, performance measurement, industry

ISBN (printed) 978-952-60-4238-1 **ISBN (pdf)** 978-952-60-4239-8

ISSN-L 1799-4934 **ISSN (printed)** 1799-4934 **ISSN (pdf)** 1799-4942

Location of publisher Espoo **Location of printing** Helsinki **Year** 2011

Pages 156 **The dissertation can be read at** http://lib.tkk.fi/Diss/

A? Aalto-yliopisto

Tiivistelmä

Aalto-yliopisto, PL 11000, 00076 Aalto www.aalto.fi

Tekijä
Leena Sivill

Väitöskirjan nimi
Energianhallinnan menestystekijät energiaintensiivisessä teollisuudessa: Energiatehokkuuden mittaaminen

Julkaisija Insinööritieteiden korkeakoulu

Yksikkö Energiatekniikan laitos

Sarja Aalto University publication series DOCTORAL DISSERTATIONS 68/2011

Tutkimusala Teollisuuden energiatekniikka

Käsikirjoituksen pvm 18.04.2011 **Korjatun käsikirjoituksen pvm** 20.06.2011

Väitöspäivä 07.10.2011 **Kieli** Englanti

☐ **Monografia** ☒ **Yhdistelmäväitöskirja (yhteenveto-osa + erillisartikkelit)**

Tiivistelmä

Tässä väitöskirjassa tarkastellaan energiatehokkuuden mittaamista energiankäytön hallinnan tukena energiaintensiivisessä teollisuudessa. Mittaamisen avulla lisätään tietoisuutta, arvioidaan suoriutumista, asetetaan tavoitteita ja tuetaan päätöksentekoa. Tämä pätee myös energiankäytön hallintaan, joka on tässä määritelty kaikkien niiden toimintojen ohjaamisena ja hallintana, jotka liittyvät taloudelliseen ja vastuulliseen energiankäyttöön yrityksen sisällä.

Väitöskirja vastaa seuraaviin kolmeen kysymykseen: 1) mitä on käsite energiatehokkuus liiketoimintaorganisaatiossa, 2) kuinka tärkeää energiatehokkuuden mittaaminen on energiankäytön hallinnalle energiaintensiivisessä teollisuudessa tällä hetkellä ja 3) mitkä ovat näistä seuraavat tulevaisuuden tutkimus- ja kehitystarpeet. Näitä kysymyksiä lähestytään useiden tutkimusmenetelmien avulla, mm. laadullisen tutkimuksen menetelmin, mallintamalla energiajärjestelmiä ja tarjoamalla soveltavia case-esimerkkejä.

Tulosten perusteella energiankäytön hallinnan pitäisi keskittyä energiatehokkuuden parantamiseen organisaation asettamien kokonaisvaltaisten tavoitteiden - ei energiankäytön hyötysuhteen - näkökulmasta, koska tämä korostaa energianhallinnan merkitystä sekä operatiiviselta että strategiselta kannalta. Tämä myös vastaa suuntausta kohti johtamisen integraatiota ja kestävän kehityksen omaksumista johtamiskäytäntöihin. Energiatehokkuuden mittareiden tulisi käsittää ulottuvuudet organisaatio-, järjestelmä- ja aikatasoilla. Jatkuvan parantamisen näkökulmasta, siis operatiivisessa johtamisessa, energiatehokkuuden mittaamisen pitäisi huomioida kaikki kolme tapaa parantaa energiatehokkuutta: teknologia, käyttö ja prosessi-integraatio. Tutkimuksen ja kehityksen tulisi myös määritellä energiatehokkuuden mittaamisen rooli kaikilla muilla johtamisen toiminnallisilla alueilla tässä väitöskirjassa käsitellyn operatiivisen johtamisen lisäksi. Suositukset avaavat laajan tutkimuskentän energiatehokkuuden mittareista, mittausjärjestelmistä ja käyttöönottoprosesseista niiden soveltamiseen eri teollisuudenaloilla, erityyppisissä organisaatioissa ja järjestelmissä.

Avainsanat energiatehokkuuden hallinta, energiatehokkuus, suorituskyvyn mittaaminen, teollisuus

ISBN (painettu) 978-952-60-4238-1 **ISBN (pdf)** 978-952-60-4239-8

ISSN-L 1799-4934 **ISSN (painettu)** 1799-4934 **ISSN (pdf)** 1799-4942

Julkaisupaikka Espoo **Painopaikka** Helsinki **Vuosi** 2011

Sivumäärä 156 **Luettavissa verkossa osoitteessa** http://lib.tkk.fi/Diss/

Preface

Think how much our everyday lives are affected by metrics. We are constantly making decisions based on quantitative data, whether they are about managing financials, meeting deadlines, or some other criteria set as a goal. Metrics can help us to quantify objectives, determine our position and reveal the need for taking corrective measures. But what if we have multiple goals, a team of people trying to achieve a common goal, or the goal is abstract? The task of decision making becomes rather complex. This is where scientific research may provide answers. This thesis contributes to the understanding of energy performance as an organisational goal. In addition to serving sustainable development in a broader context, this is essential for firms, irrespective of their size, to achieve tangible results from their energy management programmes.

Finding a research subject for this thesis has been a story in itself. Everything began in early 2000, when the late Matti Taimisto, a devoted process development manager from UPM-Kymmene Oyj, presented his observations on paper machine heat recovery systems to Professor Pekka Ahtila. This meeting later resulted in a Licentiate's Thesis and two publications written by the author and the question of why these significant energy efficiency gaps exist. While we seem to have accomplished so much in production technology and management, we still have blind spots in managing energy end-use. The more I learned about the explanatory reasons behind this, the more I became convinced that energy performance measurement was a problem still waiting to be solved. It took me a while to discover an approach that, in my opinion, would best add to current knowledge and provide leverage for future research on the implementation of energy management in business organisations.

The thesis was written in the Laboratory of Energy Economics and Power Plant Engineering in 2008-2010. I wish to thank Professor Pekka Ahtila for the opportunity to produce this thesis. He has ensured continuity and helped me to open doors to academia, industry and public organisations. I am equally grateful to my instructor, Jussi

Manninen from VTT, who gave thrust to this work at a time when it needed creative forces. I owe special thanks to Professor Markku Lampinen for his excellent teaching on applied thermodynamics. In addition, I am most indebted to my former and present colleagues, Jaana Federley, Ilkka Hippinen, Henrik Holmberg, Ilkka Keppo, Jukka Paatero, Pekka Ruohonen, Kari Saari, Ari Seppälä, Sari Siitonen, Mari Tuomaala, Ralf Wikstén and many others, for creating such a supportive and fun-to-work-with research environment.

I also wish to thank all the numerous people from Finnish industry who have contributed to this dissertation by giving their time and thought. Without you, this thesis would have missed its relevance. I dedicate special thanks to Hille Hyytiä from Motiva Oy for cooperation and Petri Aaltonen, Ph.D., for consultation. Several large companies operating in Finland are gratefully acknowledged for funding, as well as Tekes – The Finnish Funding Agency for Technology and Innovation, the Graduate School of Papermaking Science and Technology, PaPSaT, and the Graduate School of Energy Science and Technology accredited by the Academy of Finland and the former Department of Mechanical Engineering at Helsinki University of Technology.

Professor Simon Harvey from Chalmers University of Technology in Sweden and Professor Esa Vakkilainen from Lappeenranta University of Technology are greatly acknowledged for pre-examining this dissertation.

Last and but not least, I wish to thank my husband, Kalle, and children, Henri and Venla, for making each day vivid.

Espoo, August 2011

Leena Sivill

Contents

List of publications

This thesis consists of an overview and of the following publications, which are referred to in the text by their Roman numerals.

I Sivill, L., Manninen, J., Hippinen, I. and Ahtila, P., 2011, Success factors of energy management in energy-intensive industries: Development priority of energy performance measurement, International Journal of Energy Research (submitted)

II Sivill, L., Manninen, J. and Ahtila, P., 2009, A combined approach to energy efficiency monitoring in the pulp and paper industry, In: Proceedings of the 22nd International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems (ECOS'09), Foz do Iguaçu, 1513-1521.

III Sivill, L. and Ahtila, P., 2009, Paper machine production efficiency as a key performance indicator of energy efficiency, Chemical Engineering Transactions 18, 905-910.

IV Sivill, L. and Ahtila, P., 2009, Energy efficiency index as an energy efficiency indicator for integrated pulp and paper mills – A case study, In: Proceedings of International Conference on Applied Energy (ICAE'09), Hong Kong, 582-593.

V Sivill, L., Manninen, J. and Ahtila, P., 2010, On-line energy efficiency monitoring for heat exchanger networks, Computer-Aided Chemical Engineering 28, 1757-1762.

VI Sivill, L. and Ahtila, P., 2009, Energy efficiency improvement of dryer section heat recovery systems in paper machines – A case study, Applied Thermal Engineering 29 (17-18), 3663-3668.

VII Sivill, L., Ahtila, P. and Taimisto, M., 2005, Thermodynamic simulation of dryer section heat recovery in paper machines, Applied Thermal Engineering 25(8-9), 1273-1292.

Author's contribution

All the articles are independent research and writing carried out by the author. The co-author, Jussi Manninen, proposed the use of an interview methodology for paper I and provided valuable comments on the manuscripts of papers I-II and V.

1 Introduction

"If you cannot measure it, you cannot improve it."

- Lord William Thomson Kelvin, 1824-1907

The above quotation and versions of it have become well established in science and practice. Our society relies on measurement in many ways. It is used for causal and comparative analysis, research, control and management from the level of elementary particles to systems, organisations, global issues and beyond. Measurement provides us with a valuable tool for decision making for the future.

Measurement continues to evolve as our world is changing. At present we are striving to understand how we can use measurement to encourage sustainable development. This dissertation focuses on one specific field of sustainable development - improving energy end-use management in industry through *energy performance measurement*. This is believed to provide one of the most important next steps in energy-intensive industry[1] on its way towards an energy-efficient economy (Dyer *et al.*, 2008).

1.1 Objective

The objective of this dissertation is to contribute to the understanding of *energy performance measurement*, its ontology and application and the subsequent needs for research and development in energy-intensive industries. The main hypothesis is postulated as follows:

Energy end-use management in energy-intensive industries has reached a point where deficiencies in measurement and monitoring constitute a major hindrance to the improvement of energy performance. This information gap is due to several reasons,

[1] Energy-intensive industrial sectors include e.g. the pulp and paper, basic metals, chemical, petrochemical, and cement industries (ECORYS, 2009)

starting from the conceptual definition of energy performance and its relationship to sustainable development and business goals.

The hypothesis above is approached by answering the following research questions.

1. How should the concept of energy performance be defined in energy end-use management?

2. How important is the development of energy performance measurement to energy end-use management today?

3. What are the research and development needs of energy performance measurement?

1.2 Motivation

Pressure towards sustainable development in business organisations comes from many directions. The costs of materials and energy will continue to grow as the world economy expands and as rapidly industrialising countries make heavy demands on these resources (Kleindorfer *et al.*, 2005). International agreements to control negative externalities and to mitigate the climate change have resulted in a number of policy measures. These include legislative and regulatory policies, research and technology development, fiscal measures, information dissemination, awareness raising and other assisting or voluntary measures (Lund, 2007). New market based instruments, such as white certificates, emissions trading, clean development mechanism and joint implementation, have increasingly been taken in use (ADEME, 2009). In addition, rising public awareness affects consumer demand, shareholder preferences and industrial practice (Kleindorfer *et al.*, 2005).

Firms in energy-intensive industries are thereby inclined to form strategies for how to respond to this pressure in order to increase their profit and maintain their competitive position (Schönsleben *et al.*, 2010). However, a well-formulated strategy only produces superior performance when it is successfully implemented (Bonoma, 1984). There is evidence that energy use is not managed as effectively as it could be in firms today. For example, a persistent gap exists between viable energy conservation investments and those carried out in reality (for example, IEA, 2003, 2007; Martin *et al.*, 2000; Sathaye and Murtishaw, 2004; Sorrell *et al.*, 2004).

One of the integral contributors to strategy implementation is performance measurement (Noble, 1999). The need for performance measurement has also been recognised in the context of energy management in industry (IEA, 2008). However, the extant literature on energy management does not provide concise knowledge on what energy performance measurement actually means and how companies should apply energy performance measurement in practice. Hence, knowledge is needed of the related concepts and the situation of energy performance measurement in firms today. This enables a direction to be formulated for future research and development in energy performance measurement.

2 Research domain

Energy is a significant cost and environmental impact factor for the energy-intensive industries. Energy management in this sector is therefore closely interlinked with overall business management, environmental management and the theme of sustainable development. From this it follows that there are different approaches to *energy performance* and how it can be defined and measured. In this chapter, we introduce these approaches and their current research problems.

2.1 Performance measurement in business management

Management in manufacturing industries largely follows the functional division laid out by Henry Fayol at the beginning of the 20th century (Pindur *et al.*, 1995). Today, these management functions can be classified into strategic management, operations or production management, marketing management, financial management, human resource management and information technology management. Each function carries out the basic management tasks of planning, organising, leading and controlling, where measurement can be used as a tool in control and decision making.

Performance measurement and its ontology, design and use, originate in and inherently belong to the research field of management accounting. The extant literature uses two different terms, performance management systems (PMS) and management control systems (MCS), in reference to measurement systems that aim to control and improve organisational performance (Ferreira and Otley, 2009). A variety of definitions have been given for both types of systems (reviews by Malmi and Brown, 2008 and Ferreira and Otley, 2009). A performance measurement system can also be defined as including management control, which is the outline chosen for this thesis.

Performance measurement was originally developed for financial management, i.e. financial control and economic performance evaluation, on the basis of the fact that all

organisations are subject to financial constraints. Financial accounting serves both internal and external reporting purposes. Its extension, cost accounting, is a management control tool that is used for monitoring the difference between the expected and actual financial performance of an organisation or its sub-divisions, such as departments, sites and divisions. Since the early 1990s, there has been increasing interest in the use of non-financial metrics and integrated management accounting, particularly among the researchers and practitioners of strategic and operations management (Neely, 2007; Simons, 1999). This interest stems from the understanding that financial measures mainly serve financial management, not management as a whole.

Performance measurement can be characterised as 1) *translating vision into action* in strategic management and 2) *continuous improvement* in operations management, although the outcome, a performance measurement system, may serve both purposes at the same time. Strategic management places stress on the ways in which organisations match their resources to the needs of the market place, particularly to competitive pressures, in order to achieve defined organisational objectives (Schaltegger *et al.*, 2006). Operations management entails the strategic and internal dimensions of operations, focusing on such continuous improvement tasks as maintaining and reducing costs, compliance with product or service specifications, the speed and reliability of delivery, inventory management and managing supply chains (Hill, 2005). Several different approaches have been proposed for developing these integrated performance measurement systems, including the balanced scorecard by Kaplan and Norton (1992) as the most widespread framework.

Performance measurement systems are built on several theories. Melnyk *et al.* (2004) find the theoretical grounding for performance measurement in agency theory, dependence theory, the need for strategic fit, information processing theory and linkage research. The first two theories relate to the understanding of how organisations function. *Agency theory* applies to the study of problems arising when one party, the principal, delegates work to another party, the agent (Eisenhardt, 1989a). Metrics

replace contracts as a motivating and control mechanism between the principal and the agent. *Dependency theory* states that the degree of interdependence and the nature of interactions among functional specialists within an organisation are influenced by the nature of the collective task they seek to accomplish (Pfeffer and Salancik, 1978). The *strategic fit* states the need for consistency between operations and business strategy (e.g. Skinner, 1969). The research field of *information processing theory* examines the quantification of how well signals encode information and how well systems are able to process information (Sinanović and Johnson, 2007). Since performance measurement provides a very wide and multidisciplinary field of research, one of its major challenges is the integration of these different approaches.

Ferreira and Otley (2009) formulated a holistic framework to tackle the subsequent variety of concepts, scopes and perspectives in research into performance measurement (Figure 1). Each topic in the framework represents a list of relevant research questions, including the questions that relate to links between the topics.

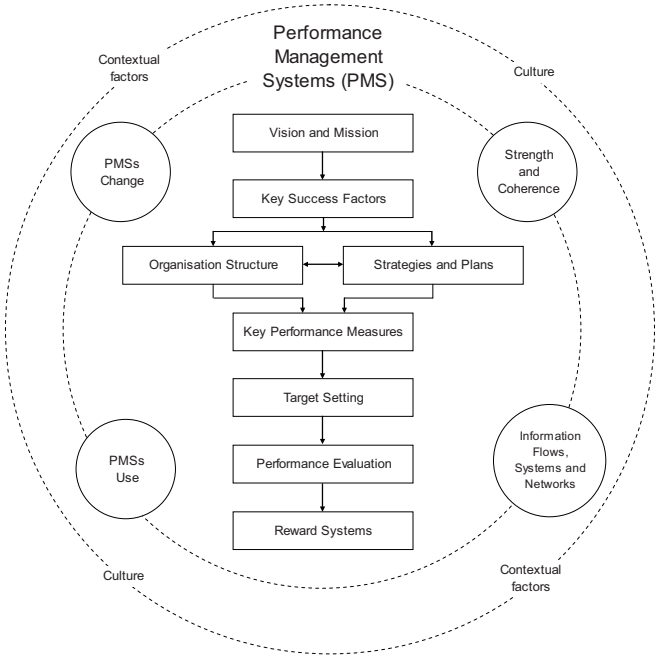

Figure 1. The performance management systems framework (Ferreira and Otley, 2009)

Future research on performance measurement continues towards understanding the detailed configuration and relationships of management control systems (Malmi and Brown, 2008), the needs of different types of firms and industries (Laitinen, 2002), supply chains (Folan and Browne, 2005; Staughton and Johnston, 2005), the use of optimisation for decision support (Grossmann, 2005; Varma *et al.*, 2007), performance measurement as a development process (Wouters, 2009) and the correct use of different research methodologies and strategies in the research into performance measurement (Bispe *et al.*, 2007; Vaivio and Sirén, 2010).

2.2 Energy-related themes in management

The boundaries between different management functions have become increasingly integrated over time, even though the functional framework prevails. In addition to this, external pressure has brought new themes to be defined and delivered in the functional framework: energy end-use management, environmental management and, as the emerging megatrend, sustainability management. The following sections discuss the roles of these themes in management and their topical research problems in terms of performance measurement.

2.2.1 Energy management

Energy management became topical in industry as a result of the oil crises in the 1970s. The term can be defined broadly as the management of energy production and procurement, energy services and energy conservation (Turner, 1993). Other definitions focus specifically on the management of energy end-use, similarly to the scope of this thesis. Capehart *et al.* (2003) state the goal of energy management as follows:

"The judicious and effective use of energy to maximize profits (minimize costs) and enhance competitive positions".

This definition perceives energy as a resource and cost factor. The role of energy management is functionally part of operations management, lacking direct linkage with strategic management. Energy management is typically approached in firms by adopting an energy efficiency programme or a management system (see e.g. programmatic guidelines by Caffall, 1995 and Connaghan and Wunderlich, 1999 and a review of management systems by Desai *et al.*, 2008).

The topic of energy management in industry has mainly intrigued policy researchers. To define the required policy measures to improve energy efficiency in industry, they have identified and classified a number of barriers and drivers (e.g. DeCanio, 1998; de

Groot, 2001; Hasanbeigi *et al*., 2010; Sandberg and Söderström, 2003; Sardianou, 2008; Thollander and Ottosson, 2008; Weber, 1997; Zilahy, 2004). Two of these barriers, namely organisational and behavioural barriers, are related to the practice of energy management within firms. These explain the persistent gap between technologically and economically viable energy efficiency measures and those carried out in reality. Organisational barriers include such factors as unclear division of tasks and the lack of financial resources, skilled personnel and time (Sardianou, 2008). Behavioural barriers include, e.g., personal attitudes and beliefs (Lindgren Soroye and Nilsson, 2010; Stern, 1992). The details of how energy management is practised in firms have remained largely unexplored by others than policy researchers (studies of management practice e.g. by Block Christoffersen *et al.*, 2006; Kannan and Boie, 2003; Thollander and Ottosson, 2010).

The improvement of energy management practice in firms has been recognised as an important but challenging issue by policy researchers. A combination of different policy measures has been introduced to influence industry both directly and indirectly, including a mix of voluntary and non-voluntary measures. Voluntary measures entail public research and education, information dissemination, voluntary agreements and subsidies (COM, 2006; Jollands *et al.*, 2010; Worrell and Price, 2001). Non-voluntary measures include fiscal measures, regulatory constraints and raising public awareness. Many countries have also established voluntary or regulatory standards on energy management. A common European standard, CEN 16001, became available in 2009 and an international standard, ISO 50001, will be launched by early 2011. Increasing attention is now being paid in the research to social and behavioural factors which influence decision making on energy efficiency investments (see e.g. Cooremans, 2007; Palm, 2009; Palm and Thollander, 2009; Stern and Aronson, 1984).

Guidelines and standards on energy management emphasise the importance of monitoring, evaluating and optimising energy performance at the process and system levels (IEA, 2008; Desai *et al.*, 2008). The reasons for this relate to the need to verify the results of investments, monitor development over time and pay attention to overall

goals instead of sub-optimal ones in reducing specific energy consumption. Monitoring and targeting (M&T) is a concept that is frequently associated with this context, especially in the UK and Ireland (Swords *et al.*, 2007). It is related to the mathematical modelling of energy consumption relative to its driving factors (Fawkes, 2007). While M&T may work well for deterministic systems, i.e. systems where the outcome can be precisely determined from a given input, it may fail to deliver decision support for large-scale systems with, e.g., stochastic behaviour, unknown factors, missing variables and the need for balancing between different objectives and their constraints. A few case studies have addressed the topic of information systems for energy end-use management (see e.g. Muller *et al.*, 2007; Swords *et al.*, 2007). These case studies contemplate energy end-use management as a stand-alone information system with integrated model-based monitoring and investment planning tools. Hence, these systems are intended for the use of energy managers and have no linkage with management accounting. There have also been very few attempts to connect energy indicators with other types of performance metrics, although the existence of many cause-and-effect relationships between them is known (Ó Gallahóir and Cahill, 2009). In addition to the above stand-alone information systems, practices have been established for many industrial sectors on energy efficiency benchmarking, based on the use of specific energy consumption at an aggregated level (Boyd *et al.*, 2008; CIPEC, 2008; Huenges Wajer, 2007). The drawback of these purely techno-economic approaches to measurement is their low behavioural realism (Algehed *et al*., 2009) and the lack of a connection with overall management.

In conclusion, there is a gap in the body of knowledge as there is no definition and framework for energy performance measurement from a holistic management perspective. This represents a risk of energy performance not being seen as an organisational performance goal. There is also very little information on how the concept of energy performance is interpreted by managers and operators in energy-intensive industries and how energy performance is being measured and monitored in firms today.

2.2.2 Environmental management

Environmental management is responsible for planning and implementing the environmental activities of a firm. It arrived in business organisations in the late 1980s as a result of tightening regulations and increasing public environmental concern. Energy management practice was later impelled by the widespread voluntary adoption of standards on environmental management, including the international ISO 14001 and European EMAS.

Similarly to energy management, environmental management is typically not integrated with other core managerial processes and functions (Wagner, 2007). However, the position of performance measurement is much more visible in environmental than energy management. This is explained by the importance of environmental accounting for external reporting. The fields of interest in the research into environmental accounting include the design, use and implications of different environmental measurement frameworks and indicators in different phases of product and production life-cycles (e.g. Burritt, 2004; Bartolomeo *et al.*, 2000; Henri and Journeault, 2008, 2010; Jasch, 2000).

The development of environmental accounting for environmental management in firms is rooted in conventional management accounting (Schaltegger *et al.*, 2006). It has followed the phases of overall management accounting from: 1) cost determination and financial control; 2) the provision of information for management planning and control and 3) a reduction of waste in resources used in business processes, to the phase of 4) the generation and creation of value through the effective use of resources (Jasch, 2006). Today, environmental performance indicators are of particular importance to large and public firms and firms that have an active environmental strategy and are compliant with environmental management systems. Within these firms, environmental performance indicators are used for, e.g., monitoring compliance with environmental policies and regulations, motivating continuous improvement activities and providing data for internal decision making and external reporting (Henri and Journeault, 2008). In

addition, the extant literature provides comprehensive knowledge on the tasks of environmental management in different management functions and the role of environmental accounting in these (Schaltegger *et al.*, 2003).

Environmental accounting indicators cannot, however, be considered a replacement for energy performance indicators. There is overlap at the aggregated level but significant differences are found at the operational one. For example, mass and energy indicators are characterised as input-output indicators by ISO 14001 (Jasch, 2000). This means that they do not pay attention to explanatory factors, such as the impact of weather conditions on energy use. This indicates a functional division between the tasks of environmental and energy management. Furthermore, the environmental accounting literature is now being used as a platform for management accounting to adopt the theme of sustainable development. This signifies a shift of focus to managerial integration, not to specific details, such as the role and needs of energy end-use management.

2.2.3 Sustainable development

The term *sustainable development* is most often defined according to the UN World Commission on Environment and Development report *Our Common Future*, also known as *the Brundtland Report*, from 1987, as follows:

"In essence, sustainable development is a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development; and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations."

This quest to integrate the dimensions of economic, environmental and social goals, also referred to as the *triple bottom line*, in business organisations continues to be controversial. Researchers and practitioners with different backgrounds in management, economics, social sciences and the environmental sciences are trying to integrate their

views of the term ‘sustainability management’. Consequently, there is literature on sustainability management from many different perspectives, with variable scopes and levels of conceptual integration.

Today, sustainable development is motivated in firms by financial goals and compliance with regulations and norms rather than purely environmental and societal concerns (Dummett, 2006; Porter and Kramer, 2006). Several recommendations exist on what indicators companies should use as their sustainability indicators (e.g. IChemE, 2002) and how companies should report on sustainability to their stakeholders (e.g. GRI, 2006). However, companies prefer using language that responds more to external pressures than towards discharging accountability in corporate sustainability reporting (Laine, 2005). This also shows in the way in which firms report on energy consumption and energy efficiency (see reviews by Mikkilä and Toppinen, 2008 and Perrini, 2005). Sustainability indicators that have been created for the use of stakeholders may therefore not contribute substantially to the implementation of sustainable development in firms (Palme and Tillman, 2008) and their use for decision making remains a challenge.

Burritt and Schaltegger (2010) have identified two main paths for the research into sustainability accounting. The first path sees sustainability accounting as a source of problems that lead to unsustainable development. The other path believes in the development of sustainability accounting as a provider of solutions to these problems. Burritt and Schaltegger (2010) continue by arguing that these critical views mainly highlight the deficiencies of conventional accounting systems. There is a call for the further development of scorecard-based sustainability accounting that is founded in internal management (Burritt and Schaltegger, 2010; Figge *et al.*, 2002).

2.3 Concluding remarks

In conclusion, the concept of energy performance measurement is not institutionalised and continues to evolve as the functional management approaches to performance measurement and the themes of energy performance, environmental responsibility and sustainable development interact with each other. Two challenges lie ahead for the development of energy performance measurement. Energy management should be seen as being both operationally and strategically relevant and this position should be made visible by setting energy performance as an organisational goal in management accounting too. The second challenge is to pay attention to the actual needs of managers and operators in their quest to manage energy performance, including the definition of the role of energy management in different management functions.

3 Methods

This thesis consists of seven appended articles presented in Table 1.

Table 1. Summary of the appended articles

Article and theme	*Research questions*	*Methods*	*Scope*
Article I Success factors of energy management in energy-intensive industries: Development priority of energy performance measurement	1, 2 & 3	Case study Interview study	Several industries Several organisational levels Several system levels
Article II A combined approach to energy efficiency monitoring in the pulp and paper industry	1 & 3	Literature survey Case demonstration Pinch technique	Pulp and paper industry All system levels All organisational levels Case system level: process, a heat exchanger network
Article III Paper machine production efficiency as a key performance indicator of energy efficiency	3	Case demonstration	System level: process, a paper machine
Article IV Energy efficiency index as an energy efficiency indicator for integrated pulp and paper mills - A case study	3	Case demonstration Statistical modelling	System level: departments of a site
Article V On-line energy efficiency monitoring for heat exchanger networks	3	Case demonstration Statistical modelling Thermodynamic modelling	System level: process, a heat exchanger network
Article VI Energy efficiency improvement of dryer section heat recovery systems in paper machines - A case study	3	Case demonstration Thermodynamic modelling	System level: process, a heat exchanger network
Article VII Thermodynamic modelling of dryer section heat recovery systems in paper machines	3	Case demonstration Thermodynamic modelling	System level: process, a heat exchanger network

The first two articles answer the first two research questions, defined below.

1. How should the concept of energy performance be defined in energy end-use management?

2. How important is the development of energy performance measurement to energy end-use management today?

Answers were sought on the basis of the literature and an interview study. A case study was used as a research strategy because the two questions are qualitative by nature and the subject of the research, energy performance measurement in practice, is a contemporary event over which the investigator has no control (Yin, 2009).

Article II first reviews the concept of energy efficiency monitoring in the pulp and paper industry. This assisted the formulation of the interview questions for Article I. The interview study included six companies in three energy-intensive industrial sectors in Finland, namely the pulp and paper, basic metals and petrochemicals industries. People at all organisational levels were interviewed in person. The interview questions and questionnaires were drafted on the basis of the *grounded theory approach* originally developed by Glaser and Strauss in the 1960s (Glaser and Strauss, 2009). In this approach, relevant themes and hypotheses are expected to emerge from the data through an iterative process of comparative analysis. Eisenhardt (1989b) describes the process of theory building more closely.

All the articles address the third question.

3. What are the research and development needs of energy performance measurement?

This question is approached from three perspectives:

a) practical challenges related to energy performance measurement;

b) methodological challenges related to energy performance measurement, and

c) demonstration of the potential for improvement in a specific system.

Article I focuses on the practical and methodological challenges by concentrating on the research and development needs that managers and operators associate with energy performance measurement in energy-intensive industries. Articles II-IV address the practical and methodological problems in one specific industry, the pulp and paper industry. Article II reviews the literature on the energy efficiency indicators that are used in this industry, Article III demonstrates the relationship between production efficiency and energy efficiency in paper production and Article IV explores the applicability of energy efficiency index as an energy performance indicator on the basis of data from an actual mill.

Articles II and V-VII demonstrate the significance of opportunities for energy conservation in one existing process system, the heat recovery of a paper machine. Article VII first provides a thermodynamic model for heat recovery that is able to cope with heat transfer under moist air condensation. Article VI uses this model to demonstrate the economic magnitude of the different types of improvement opportunities in three existing paper machines. Article V then validates this thermodynamic model with online data from another mill, applies the thermodynamic model for monitoring purposes and also tests the applicability of statistical methods for monitoring. Finally, Article II demonstrates the online use of the two models that were developed for fault detection and indicating a potential for operational and structural improvement.

4 Main results and their scientific contribution

This chapter summarises the main findings of the appended articles in the order of the three research questions. The chapter also includes a discussion of the limitations of this thesis.

4.1 Energy performance measurement as a concept

The concept of energy performance was developed in this thesis in three phases. Article II first explored the main themes, dimensions and contexts that have appeared between energy management and measurement in the literature. The most important contribution concerns the definition of *a domain for energy performance measurement*. First, three dimensions are indentified, namely the organisation level, system level and time in which indicators can be developed. Second, the relevant management domain entails both operational and strategic management. Third, energy performance measurement is relevant for the control and management of people and technology within the business organisation, as well as in communication with its shareholders and stakeholders.

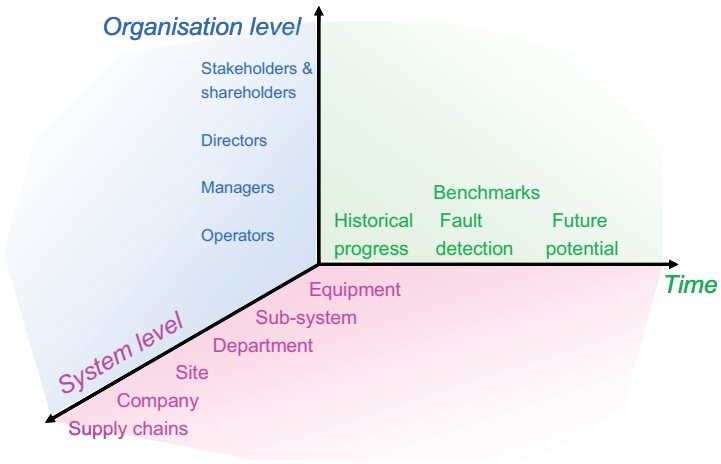

Figure 1. Dimensions of energy performance measurement

Article I elaborates the previous findings by connecting them with the theory of business performance measurement and existing standards on energy management. As a result, the early-stage term 'key performance indicator of energy efficiency' was replaced by 'indicator of energy performance'. Energy performance was finally defined as follows:

Energy end-use performance in business management is related to activities which influence: 1) the efficiency of energy production and consumption; 2) the sources of energy used for manufacturing products, and 3) the value added in the activities related to the previous two. The goal of energy performance is to increase the margin of profit or the growth of revenue.

Discussion on the option of firms to prioritise other than financial goals has been left beyond the scope of this thesis. The main contribution of the above definition to the extant literature is to separate the concept of 'energy performance' from 'energy efficiency'. The latter term is strongly associated with specific energy consumption and

its derivatives, whereas energy performance includes compromises between energy efficiency and other profitability factors. The three ways to improve energy efficiency are to invest in more efficient technology, improve operation and improve process integration. Other profitability factors, such as the market prices of electricity and fuels, determine the monetary value of these measures. Furthermore, paying attention to stakeholders' environmental and social concerns about energy-related issues may lead to indirect profitability benefits.

Article I also explored the views of people at different organisational levels on the meaning of the term 'energy efficiency'. Since there is no equivalent for 'performance' in the Finnish language, the concept of 'efficiency' is close to that of 'performance' in English. Objectives associated with energy efficiency varied, depending on the position and tasks of the interviewees. Production managers and operating personnel mainly focused on how to reduce the specific energy consumption. Company and site energy managers associated environmental objectives, especially the reduction of CO_2 emissions, with energy efficiency and highlighted the need for optimisation at the systems level. At the director level, economic targets and company image were mentioned most frequently. This means that people in different positions need different type of information on energy performance to carry out their personal activities related to energy management. Hence, there is *a need for defining the purposes and role of energy management in each management function* and *seeing energy performance as an organisational goal*.

4.2 Development priority of energy performance measurement

The questionnaire on energy management in Article I provided a reference to evaluate the importance of energy performance measurement for the development of energy management. *Energy performance measurement was perceived as being the third*

development priority, behind resource and commitment issues. The main explanatory reasons for this are presented in Figure 2.

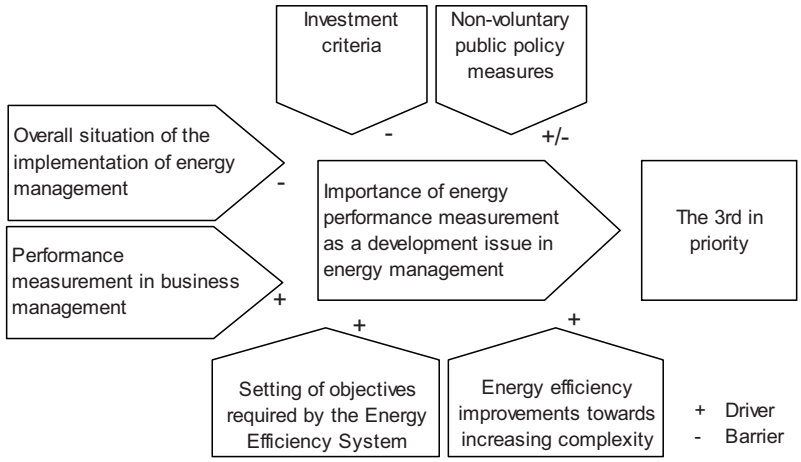

Figure 2. Factors explaining the perceived importance of energy performance measurement as a development issue in energy management

Article I identified three factors that have a positive influence on energy performance measurement as a development issue. First, the interviewees are familiar with the concept of performance measurement and shared the belief that performance measurement should be applied in energy management. Second, the Finnish Energy Efficiency System requires objectives to be set for energy efficiency improvements. This raised the question of how to define targets and measure performance against these targets. Finally, the interviewees found it a challenge to be able to find further opportunities for energy efficiency improvements after a long tradition of energy efficiency projects. The interviewees wanted to get access to more detailed energy-related data and these data to be processed into knowledge. However, the overall implementation of energy management does not favour the development of energy performance measurement at present, as other development issues were perceived as being more critical. The lack of resources and of commitment continue to be the most

important barriers to energy management, which also reflects on the willingness to invest in energy performance measurement. In addition, the requirement for energy performance measurement to lead to a direct and proven financial benefit reduces the probability of companies investing in energy performance measurement. Reporting energy-related information to external actors is perceived as a risk but also as an opportunity, since the companies have limited control over the implications derived from the data.

The result represents a paradox for the development of energy performance monitoring: resources and commitment are prerequisites for performance measurement to be developed in firms, while performance measurement influences the very same issues by enforcing changed behaviour. For this reason, it can be argued that *deficiencies in energy performance measurement and monitoring pose a significant hindrance to the further development of energy management.*

4.3 Research and development needs of energy performance measurement

Article I gives further details on the preferences of managers and operators for energy-related information. It is concluded that energy performance is not sufficiently visible in the daily activities of operating personnel. For this reason, the personnel are unable to assess the significance of energy-related decision variables in relation to other decision variables. Monthly and annual values of SEC, which are commonly used as a metric to monitor energy efficiency by managers, are able to express long-term trends at an aggregated level with focus on technical efficiency, not all relevant aspects of energy performance. Further attention in companies should therefore be paid to *the determination of what energy-related aspects energy performance should cover as an organisational goal, the identification of those activities which contribute to higher energy performance* and the subsequent *development of decision support for these activities*.

Article II indicates that only a few of the existing indicators associated with energy performance have been subjected to critical analysis. The lack of specifications implies that the existing performance indicators may have unknown consequences and can be misinterpreted and that important indicators may be lacking and there might be overlap between existing metrics. Article III demonstrates how an existing operational performance metric, production efficiency, has the ability to describe certain aspects of energy performance. Another example, in Article IV, shows that the energy efficiency index is not suitable as a performance metric unless a detailed model of how to calculate the reference energy consumption is presented for each process.

Article I lists the many challenges involved in the development of energy performance measurement. These entail challenges related to performance measurement in general, as well as challenges specific to energy performance. As one example of technical challenges, managers expect products and services related to energy performance measurement to be integrated into existing control and information systems, emphasising the need for embedded solutions. Another difficulty relates to the criteria that companies use to justify investments. It was found that indirect benefits are not always included in the investment criteria, which is likely to hinder the development of energy performance measurement. In any case, it is difficult to estimate the related economic improvement potential, since the role of performance measurement cannot be detached from other parts of energy management.

Future research should focus on the development of indicators, the demonstration of these indicators in different environments and examining *the deployment process of performance measurement* as a whole. Developing a performance measurement system is a coordination effort to understand current metrics in detail, to identify shortcomings and to include ongoing initiatives that affect performance measurement (Lohman *et al*., 2004). These initiatives include both in-house and external changes in the operating environment.

4.3.1 Monitoring application for the heat recovery systems of paper machines

Articles II and V-VII demonstrate a significant energy efficiency improvement opportunity that had remained undiscovered in a case mill as a result of a lack of access to appropriate data and on-site know-how for heat transfer modelling. Articles II and V-VII demonstrate how *the heat recovery systems of existing paper machines provide a significant opportunity for energy savings*, including those achievable by the improvement of monitoring. With the model developed in Article VII, the savings found in Article VI were 110 GWh/a in process heat, corresponding to over one million Euros per year and a 7-13% decrease in the specific heat consumption of the three paper machines that were examined. According to a follow-up, the case mill achieved 12% lower fuel use and 24% lower CO_2 emissions as a result of the investments. Article II demonstrates opportunities for further heat integration between paper machines and mechanical pulp plants using on-line pinch analysis that can be implemented as part of a performance monitoring system. In this paper, an on-line pinch analysis program was coded to demonstrate the annual duration curves of the heating and cooling demands. This information can be used in a performance measurement system to indicate a potential for energy efficiency improvements. Finally, Article IV provides online models for dryer section heat recovery being used for fault detection and operational improvement. These models require significantly less processing time than the original thermodynamic models, which could not have been directly applied online. In summary, Articles II and IV-VII contribute to the extant literature by demonstrating the energy efficiency improvement opportunities of a specific system and providing solutions to its energy performance monitoring.

4.4 Limitations

The chosen scope of this thesis sets several limitations. The interview study was carried out in Finland and is therefore subject to country-specific features, e.g., the implications

of the Finnish energy policy and Nordic electricity markets. The results are also sensitive to the economic recession at the time of the interviews. Subsequently, it would be interesting to continue towards exploring country-specific differences and development over time in comparison to the results presented here. In addition, the interviews focus on energy-intensive industries which are located at the upper end of firms in terms of the priority given to energy management. The views and needs of small- and medium-sized firms are likely to follow a different pattern. The third limitation of the interview study is related to the choice of the interviewees. This is particularly important with respect to exploring the role of energy performance as an organisational goal. The interviewees represented mainly the function of operations management, leaving out many other management functions which, in the light of overall management literature, are important for the success of energy management as a whole.

The literature review of extant indicators is limited to one industry, namely the pulp and paper one. The case demonstrations of indicators contemplate methodological and technical questions without paying attention to organisational and behavioural aspects. In addition, the demonstration of the extant indicators is carried out by only using selected indicators and systems as case examples.

5 Concluding remarks

This thesis provides knowledge of energy performance measurement for improving energy management in energy-intensive industries. The main scientific contributions relate to defining the concept of energy performance, the role of energy performance measurement for energy management and the research and development needs of energy performance measurement.

Energy performance is a much broader concept than energy efficiency in the context of business organisations. Energy efficiency departs from the conventional notion of efficiency as a physical or monetary input-output relationship. Energy performance goes beyond this by reflecting organisational goals and these goals being translated into activities, objectives and concrete targets and their performance measures. Today, the concept of energy performance is not institutionalised and continues to evolve as the functional management approaches to performance measurement and the themes of energy performance, environmental responsibility and sustainable development interact with each other. Future discussions on energy management should focus on improving energy performance, not energy efficiency, because this broader view is able to capture both operational and strategic dimensions. This conceptual transition is in line with the recent trends of managerial integration and the adoption of sustainable development into management practice.

This thesis confirms that energy management is not yet fully developed even in the energy-intensive industries. Although the concept itself has remained the same since 1970s, many internal and external factors have determined the course of events at implementation level. As increasing economic, environmental and social pressures continue to drive the move forward, energy management is on its way from project-based programmes towards a more systematic practice, taking advantage of operator know-how and opportunities in process, systems and management integration. This has two implications on energy performance measurement. First, the strategic and

operational relevance of energy management should be made visible by determining energy performance as an organisational goal (a top-down perspective). Second, attention should be paid to the actual needs of managers and operators in their quest to manage energy performance (a bottom-up perspective). Today, significant gaps exist in both perspectives confirmed by the interviews in this thesis.

Finally, there are major practical challenges that lie ahead. To proceed from this, it is inevitable that *energy-intensive industries need to invest in the development of energy performance measurement* in order for the implementation of energy management to improve from its present status. Still, we remain faced with a paradox: resources and commitment are prerequisites for performance measurement to be developed in firms, while performance measurement influences the very same issues by enforcing changed behaviour. Another challenge is the pursuit of short-term benefit, which still easily outweighs development in the long term. This emphasises the need for long-term top-level commitment and regulatory measures. The challenge of all future research is to manage the development of a wide variety of tailored solutions for particular sub-problems while serving the needs of management as a whole. The advances taken in information processing, information technology and optimisation provide technical means (see e.g. Grossmann, 2005; Grossmann and Guillén-Gosálbez, 2010; Klatt and Marquardt, 2009). Finally, research should provide an understanding of the underlying deployment processes that are needed in order to overcome the threshold between theory and practice. This requires an in-depth understanding of the scientific debate taking place, especially under the theme of sustainable development, with respect to all the relevant stakeholders of industry.

References

ADEME, 2009, Energy efficiency trends and policies in the industrial sector in the EU-27, ADEME, Paris, 100 p.

Algehed, J., Wirsenius, S. and Jönsson, J., 2009, Modelling energy efficiency and carbon dioxide emissions in energy-intensive industry under stringent CO2 policies: Comparison of top-down and bottom-up approaches and evaluation of usefulness to policy makers, In: Broussous, C. and Corisande, J. (Eds.), Proceedings of the ECEEE 2009 Summer Study, European Council for Energy Efficient Economy, 1181-1191.

Bartolomeo, M., Bennett, M., Bouma, J.J., Heydkamp, P., James, P. and Wolters, T., 2000, Environmental management accounting in Europe: current practice and future potential, The European Accounting Review 9(1), 31-52.

Bispe, J., Batista-Foguet, J. and Chenhall, R., 2007, Defining management accounting constructs: A methodological note on the risks of conceptual misspecification, Accounting, Organization and Society 32(7-8), 789-820.

Block Christoffersen, L., Larsen, A. and Togeby, M., 2006, Empirical analysis of energy management in Danish industry, Journal of Cleaner Production 14(5), 516-526.

Bonoma, T.V., 1984, Making your marketing strategy work, Harvard Business Review 62 (March/April), 69-76.

Boyd, G., Dutrow, E. and Tunnessen, W., 2008, The evolution of the ENERGY STAR® energy performance indicator for benchmarking industrial plant manufacturing energy use, Journal of Cleaner Production 16(6), 709-715.

Burritt, R.L., 2004, Environmental management accounting: Roadblocks on the way to the green and pleasant land, Business Strategy and the Environment 13(1), 13-32.

Burritt, R.L. and Schaltegger, S., 2010, Sustainability accounting and reporting: fad or trend?, Accounting, Auditing & Accountability Journal 23(7), 829-846.

Caffall, C., 1995, Learning from experiences with energy management in industry, CADDET Analyses Series No. 17, Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET), Sittard, 95 p.

Capehart, B.L., Turner, W.C. and Kennedy, W.J., 2003, Guide to energy management, 4th ed., The Fairmont Press, Inc., Lilburn, 553 p.

CIPEC, 2008, Benchmarking Energy Use in Canadian Pulp and Paper Mills, Canadian Industry Program for Energy Conservation (CIPEC), Pulp and Paper Research Institute of Canada, Ottawa, 60 p.

COM, 2006, Action plan for energy efficiency: Realizing the potential, COM(2006)545, European Commission, Brussels, 25 p.

Connaghan, C. and Wunderlich, R., 1999, Developing, implementing, and maintaining an energy efficiency program, In: Browne, T.C. and Williamson, P.N. (Eds.), Energy cost reduction in the pulp and paper industry: a monograph, Pulp and Paper Research Institute of Canada (Paprican), Montreal, 234 p.

Cooremans, C., 2007, Strategic fit of energy efficiency (Strategic and cultural dimensions of energy-efficiency investments). In: Proceedings of the ECEEE 2007 Summer Study, European Council for Energy Efficient Economy, pp. 73-82.

DeCanio, S.J., 1998, The efficiency paradox: bureaucratic and organizational barriers to profitable energy-saving investments, Energy Policy 26(5), 441-454.

de Groot, H.L.F, Verhoef, E.T., Nijkamp, P., 2001, Energy saving by firms: decision-making, barriers and policies, Energy Economics 23(6), 717-740.

Desai, D., Meffert, W.A., Grell-Lawe, H. and McKane, A., 2008, Summary comparison of national energy management standards, United Nations Industrial Development Organization (UNIDO), United States Department of Energy (DOE), 42 p.

Dummett, K., 2006, Drivers for corporate environmental responsibility (CER), Environment, Development and Sustainability 8(3), 375-389.

Dyer, C.H., Hammond, G.P., Jones, C.I. and McKenna, R.C., 2008, Enabling technologies for industrial energy demand management, Energy Policy 36(12), 4434-4443.

ECORYS, 2009, Study on European energy intensive industries – The usefulness of estimating sectoral price elasticities, ECORYS SCS Group, Rotterdam, 131 p.

Eisenhardt, K.M., 1989a, Agency theory: An assessment and review, Academy of Management Review 14(1), 57-74.

Eisenhardt, K.M., 1989b, Building theories from case study research, Academy of Management Review 14(4), 532-550.

Fawkes, S., 2007, Outsourcing energy management: Saving energy and carbon through partnering, Gower Publishing Ltd, Aldershot, 194 p.

Ferreira, A. and Otley, D., 2009, The design and use of performance management systems: An extended framework for analysis, Management Accounting Research 20(4), 263-282.

Figge, F., Hahn, T., Schaltegger, S. and Wagner, M., 2002, The sustainability balanced scorecard – Linking sustainability management to business strategy, Business Strategy and the Environment 11(5), 269-284.

Folan, P. and Browne, J., 2005, A review of performance measurement: Towards performance management, Computers in Industry 56, 336-680.

Glaser, B.G. and Strauss, A.L., 2009, The discovery of grounded theory: strategies for qualitative research, Aldine Transaction, New Brunswick, 271 p.

GRI, 2006, Sustainability reporting guidelines, Version 3.0, Global Reporting Initiative, Amsterdam, 44 p.

Grossmann, I., 2005, Enterprise-wide optimisation: A new frontier in process systems engineering, AIChE Journal 51(7), 1846-1857.

Grossmann, I.E. and Guillén-Gosálbez, G., 2010, Scope for the application of mathematical programming techniques in the synthesis and planning of sustainable processes, Computers and Chemical Engineering 34(9), 1365-1376.

Hasanbeigi, A., Menke, C., du Pont, P., 2010, Barriers to energy efficiency improvement and decision-making behaviour in Thai industry, Energy Efficiency 3(1), 33-52.

Henri, J.-F. and Journeault, M., 2010, Eco-control: the influence of management control systems on environmental and economic performance, Accounting, Organizations and Society 35(1), 63-80.

Henri, J.-F. and Journeault, M., 2008, Environmental performance indicators: An empirical study of Canadian manufacturing firms, Journal of Environmental Management 87, 165-176.

Hill, T., 2005, Operations management, 2nd Ed., Palgrave Macmillan, Basingstoke, 764 p.

Huenges Wajer, B., Helgerud, H.E. and Lackner, P., 2007, Benchmarking and energy management schemes in SMEs, In: Proceedings of ECEEE 2007 Summer Study, 1573-1582.

IEA, 2003, Creating Markets for Energy Technologies, International Energy Agency, Paris, 170 p.

IEA, 2007, Mind the Gap: Quantifying Principal-Agent Problems in Energy Efficiency, International Energy Agency, Paris, 219 p.

IEA, 2008, Energy efficiency policy recommendations in support of the G8 Plan of Action, International Energy Agency, Paris, 64 p.

IChemE, 2002, The sustainability metrics: Sustainable development progress metrics recommended for use in the process industries, Institution of Chemical Engineers (IChemE), Rugby, 30 p.

Jasch, C., 2006, Environmental management accounting (EMA) as the next step in the evolution of management accounting, Journal of Cleaner Production 14(14), 1190-1993.

Jasch, C., 2000, Environmental performance evaluation and indicators, Journal of Cleaner Production 8(1), 79-88.

Jollands, N., Waide, P., Ellis, M., Onoda, T., Laustsen, J., Tanaka, K., de T'Serclaes, P., Barnsley, I., Bradley, R. and Meier, A., 2010, The 25 IEA energy efficiency policy recommendations to the G8 Gleneagles Plan of Action, Energy Policy 38(11), 6409-6418.

Kannan, R. and Boie, W., 2003, Energy management practices in SME – case study of a bakery in Germany, Energy Conversion and Management 44(6), 945-959.

Kaplan, R.S. and Norton, D.P., 1992, The balanced scorecard - measures that drive performance, Harvard Business Review 70(1), 71-79.

Klatt, K.-U. and Marquardt, W., 2009, Perspectives for Process Systems Engineering – Personal Views from Academia and Industry, Computers and Chemical Engineering 33, 536-550.

Kleindorfer, P.R., Singhal, K. and Van Wassenhove, L.N., 2005, Sustainable operations management, Production and Operations Management 14(4), 482-492.

Laine, M., 2005, Meanings of the term 'sustainable development' in Finnish corporate disclosures, Accounting Forum 29(4), 395-413.

Laitinen, E.K., 2002, A dynamic performance measurement system: evidence from small Finnish technology companies, Scandinavian Journal of Management 18(1), 65-99.

Lindgren Soroye, K. and Nilsson, L.J., 2010, Building a business to close the efficiency gap: the Swedish ESCO experience, Energy Efficiency, (in press), DOI: 10.1007/s12053-009-9069-3.

Lohman, C., Fortuin, L. and Wouters, M., 2004, Designing a performance measurement system: A case study, European Journal of Operational Research 156, 267-286.

Lund, P.D., 2007, Effectiveness of policy measures in transforming the energy system. Energy Policy 35 (1), 627-639.

Malmi, T. and Brown, D.A., 2008, Management control systems as a package – Opportunities, challenges and research directions, Management Accounting Research 19, 287-300.

Martin, N., Anglani, N., Einstein, D., Khrushch, M., Worrell, E. and Price, L.K., 2000, Opportunities to improve energy efficiency and reduce greenhouse gas emissions in the U.S. pulp and paper industry, LBNL-46141, Environmental Energy Technologies Division, Ernest Orlando Lawrence Berkeley National Laboratory, 56 p.

Melnyk, S.A., Stewart, D.M. and Swink, M., 2004, Metrics and performance measurement in operations management: dealing with the metrics maze, Journal of Operations Management 22(3), 209-217.

Mikkilä, M. and Toppinen, A., 2008, Corporate responsibility reporting by large pulp and paper companies, Forest Policy and Economics 10(7-8), 500-506.

Muller, D.C.A, Marechal, F.M.A, Wolewinski, T. and Roux, P.J., 2007, An energy management method for the food industry, Applied Thermal Engineering 27(16), 2677-2686.

Neely, A. (Ed.), 2007, Business performance measurement: Unifying theories and integrating practice, 2nd edition, Cambridge University Press, Cambridge, 511 p.

Noble, C.H., 1999, The eclectic roots of strategy implementation research, Journal of Business Research 45(2), 119-134.

Ó Gallahóir, B. and Cahill, C., 2009, Modelling energy consumption in a manufacturing plant using productivity KPIs, In: Proceedings of the ECEEE 2009 Summer Study, 1155-1161.

Palm, J., 2009, Placing barriers to industrial energy efficiency in a social context: a discussion of lifestyle categorisation, Energy Efficiency 2, 263-270.

Palm, J. and Thollander, P., 2010, An interdisciplinary perspective on industrial energy efficiency, Applied Energy 87(10), 3255-3261.

Palme, U. and Tillman, A.-M., 2008, Sustainable development indicators: how are they used in Swedish water utilities?, Journal of Cleaner Production 16(13), 1346-1357.

Perrini, F., 2005, Building a European portrait of corporate social responsibility reporting, European Management Journal 23(6), 611-627.

Pfeffer, J. and Salancik, G.R., 1978, The external control of organizations: A resource dependence perspective, Harper and Row, New York, 336 p.

Pindur, W., Rogers, S.E. and Kim, P.S., 1995, The history of management: a global perspective, Journal of Management History 1(1), 59-77.

Porter, M.E. and Kramer, M.R., 2006, Strategy & society: The link between competitive advantage and corporate social responsibility, Harvard Business Review 84(12), 78-92.

Sandberg, P. and Söderström, M., 2003, Industrial energy efficiency: the need for investment decision support from a manager perspective, Energy Policy 31(15), 1623-1634.

Sardianou, E., 2008, Barriers to industrial energy efficiency investments in Greece, Journal of Cleaner Production 16 (13), 1416-1423.

Sathaye, J. and Murtishaw, S., 2004, Market failures, consumer preferences, and transaction costs in energy efficiency purchase decisions, Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory, Berkeley.

Schaltegger, S., Bennett, M. and Burritt, R., (Eds.), 2006, Sustainability accounting and reporting, Eco-Efficiency in Industry and Science 21, Springer, Dordrecht, 713 p.

Schaltegger, S., Burritt, R.L. and Petersen, H., 2003, An introduction to corporate environmental management: Striving for sustainability, Greenleaf Publishing Ltd., Sheffield, 384 p.

Schönsleben, P., Vodicka, M., Bunse, K. and Ernst, F.O., 2010, The changing concept of sustainability and economic opportunities for energy-intensive industries, CIRP Annals – Manufacturing Technology 59(1), 477-480.

Simons, R., 1999, Performance measurement & control systems for implementing strategy, Prentice Hall Inc., Upper Saddle River, 780 p.

Sinanović, S. and Johnson, D.H., 2007, Toward a theory of information processing, Signal Processing 87(6), 1326-1344.

Skinner, W., 1969, Manufacturing – missing link in corporate strategy, Harvard Business Review 47(3), 136-145.

Sorrell, S., O'Malley, E., Schleich, J. and Scott, S., 2004, The economics of energy efficiency: Barriers to cost-effective investment, Edward Elgar, Cheltenham, 349 p.

Staughton, R. and Johnston, R., 2005, Operational performance gaps in business relationships, International Journal of Operations & Production Management 25(4), 320-332.

Stern, P.C., 1992, What psychology knows about energy conservation, American Psychologist 47(10), 1224-1232.

Stern, P.C. and Aronson, E. (Eds.), 1984, Energy use: The human dimension, W.H. Freeman and Company, New York, 237 p.

Swords, B., Coyle, E. and Norton, B., 2007, An enterprise energy-information system, Applied Energy 85(1), 61-69.

Thollander, P. and Ottosson, M., 2008, An energy efficient Swedish pulp and paper industry – exploring barriers to and driving forces for cost-effective energy efficiency investments, Energy Efficiency 1, 21-34.

Thollander, P. and Ottosson, M., 2010, Energy management practices in Swedish energy-intensive industries, Journal of Cleaner Production 18(12), 1125-1133.

Turner, W.C., 1993, Energy management handbook. 2nd ed. The Fairmont Press Inc., Lilburn.

Vaivio, J. and Sirén, A., 2010, Insights into method triangulation and “paradigms” in interpretive management accounting research, Management Accounting Research 21(2), 130-141.

Varma, V.A., Reklaitis, G.V., Blau, G.E. and Pekny, J.F., 2007, Enterprise-wide modelling & optimisation – An overview of emerging research challenges and opportunities, Computers and Chemical Engineering 31(5-6), 692-711.

Wagner, M., 2007, Integration of environmental management with other managerial functions of the firm, Long Range Planning 40(6), 611-628.

Weber, L., 1997, Some reflections on barriers to the efficient use of energy, Energy Policy 25(10), 833-835.

Worrell, E. and Price, L., 2001, Policy scenarios for energy efficiency improvement in industry, Energy Policy 29, 1223-1241.

Wouters, M., 2009, A developmental approach to performance measures – Results from a longitudinal case study, European Management Journal 27(1), 64-78.

Yin, R.K., 2009, Case study research: Design and Methods, Applied Social Research Methods Series, Vol. 5, 4th Ed., Sage Publications, Inc., Thousand Oaks, 219 p.

Zilahy, G., 2004, Organisational factors determining the implementation of cleaner production measures in the corporate sector, Journal of Cleaner Production 12(4), 311-319.

Aalto-DD 68/2011

ISBN 978-952-60-4239-8 (pdf)
ISBN 978-952-60-4238-1
ISSN-L 1799-4934
ISSN 1799-4942 (pdf)
ISSN 1799-4934

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