Energy Efficiency Measures and Production Resources: Towards an Integrative Classification Framework for Decision Makers

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Abstract - **The adoption of energy efficiency measures (EEMs) is a significant area of concern for today's industrial organisations. Whilst literature on this subject has soared in recent decades, there remains a gap in understanding the extent of their impact on an organisation's operations as well as the manner, and whether, they are adopted in the first place. This paper provides a preliminary attempt at addressing these concerns by investing attention into the notion of production resources as a mechanism through which a deeper appreciation of EEM impact on operations could be provided through the development of a generalised decision-making framework. We end this paper with conclusions and areas for further work.**

Keywords – **energy efficiency measures, production resources, operational performance, industrial organisation**

I. INTRODUCTION

Energy efficiency measures (EEMs) has been, and become, an important consideration for practitioners, policy makers and academics alike. Whilst the inherent benefits of EEM adoption have been covered quite extensively in literature, there remains a significant gap in understanding 1) the extent of their wider impact on organisations and, 2) how, when and where they should be adopted.

Recent work has begun to address some of these gaps in developing holistic decision-making frameworks that allow for explicit and conscious consideration of their impact on operations within industrial organisations through what Krones and Müller [1] describe as government guidelines, principles [2] and methods [3, 4]. Others have also begun to address the difficulties in choice, implementation and service through an increased focus on the actual measurement of these co-called non-energy benefits [5] – bringing to light the constraints organisations face when basing implementation decisions on profits alone.

Though emerging research efforts have paved the way forward in both improving decision-makers' capabilities in selection and implementation of EEMs, the advice remains fragmented (consideration of very specialised technology domains e.g. electric motors) and incomplete [5]. In addition, the issue of metrics in the successful adoption and diffusion of EEMs to the wider organisational context remains a pressing concern. That is to say, we have some idea of what to adopt, when to adopt and how to adopt; though we still find it increasingly difficult to take all these into consideration in any meaningful way. The idea that some benefits (or losses) cannot necessarily be monetised (e.g. improving the working environment), or their impact on operational performance is not so clear (some impacts may eventuate much later than initial adoption and at different intensities effecting different functions of organisation), makes this exercise very complex indeed. Thus, providing such a link to operational performance outcomes would have the potential to highlight these impacts.

Taking on the calls for research by Cagno et al. [5], in this paper we forward the discussion on EEM adoption and diffusion by presenting a preliminary framework, developed through a literature review, that allows decision makers to explicitly take into consideration the impact of EEMs on a fundamental ingredient in all industrial organisations i.e. production resources. By placing production resources front and centre in the discussion, we begin to attenuate for the impact of industry classification and address the inherent difficulty and complexity associated with pin-pointing the stream of both direct and indirect impacts of their adoption throughout the production system – regardless of when and where such measures will be adopted. Indeed, whilst the research into manufacturing systems and processes is certainly worthwhile, "considering the interrelationships between products, processes and resources in the factory system is essential for a holistic integration of energy efficiency in the enterprise" [1].

To this end, we begin by providing an overview of EEMs and industrial production systems in Section 2. This is followed by a theory building exercise in describing the main building blocks of the preliminary conceptual framework in Section 3 that includes a discussion of operational performance, production resources and the link with EEM adoption. Section 4 provides a holistic overview of the developed framework through an application in industrial operations as a hypothetical scenario. Finally, Section 5 provides conclusions and possible areas of future research.

II. IMPACT OF EEMs AND INDUSTRIAL PRODUCTION SYSTEMS: AN OVERVIEW

The term energy efficiency is subject to multiple interpretations [6]. This study, in line with many others when it comes to industrial energy efficiency, considers energy efficiency as the "use of less energy to produce the same amount of services or useful output" [7]. Thus, an energy efficiency measure is characterised as any action (managerial, technological or processual) that contributes to this phenomenon [8]. Needless to say, this opens the discussion of their impact on industrial production systems to a broad range of disciplines.

Generally speaking, EEM literature typically concerns itself with barriers, drivers and, more recently, implications to adoption. Here, the focus tends to concern the closing of a so-called "energy efficiency gap"[9] i.e. if, as we describe further below, the adoption of EEMs is good for business, why aren't organisations adopting them? A multitude of barriers and drivers have been identified in the recent decades from the more obvious cost, knowledge and time dimensions to those concerning cognitive, managerial and policy related factors [see the review by 10]. The subsequent impacts of adoption – non-energy benefits - have also been observed to include those in relation to increased productivity, reduced waste and emissions as well as increased operational capabilities, amongst a host of others [5]. On the other hand, and in the fields of eco-innovation and advanced manufacturing technology, Fleiter, Hirzel [8] found complementary barriers and drivers that include the likes of relative advantage, characteristics of the energy efficiency innovation (type, complexity and novelty), effects on the production system, compatibility and so on.

Despite the wide-spread research on the topic, EEM scholars continue to be challenged by the seemingly low adoption rate [11], particularly when it comes to manufacturing/industrial organisations [12]. This has led the research efforts towards a trajectory that places focus on the decision-making behaviour of participating organisations [12]. Much like the counterparts in organisation science (more generally), taking explicit consideration of micro-level firm behaviour has begun to shed light on the intricacies associated with decision-making points for firm-level capability investments. Trianni et al. [13], along these lines, put forward the notion that barriers and drivers to EEM adoption should not be necessarily addressed as a unidimensional phenomenon, rather each EEM can potentially impact the decision-making process of adoption in different ways, at different times and with varying impacts. This is somewhat echoed by Rasmussen [14] in the recommendation of making explicit characterisations of non-energy benefits and including different benefits in the decision-making process under certain conditions, for example taking consideration of quantifiable non-energy benefits early in the decision-making process whilst bringing less quantifiable benefits much later in the process.

As such, numerous decision-making tools have been developed to help organisations (and policy makers) in closing the energy efficiency gap. Conservation supply curves, for instance, have been used in the evaluation of EEMs [15]. Benchmarking is another common example where large-scale empirical studies have begun to develop extensive energy audits in the attempt of increasing energy savings through awareness, information and, hence, knowledge [16]. Others have implemented the closely related notion of energy management systems within different industrial contexts [17], and others, still, have gone the route of multi-criteria decision-making [18]. Whilst considerable strides have been taken with regard to quantifying, in monetary terms, the multiple benefits of EEMs in, for example, earlier work by Worrell, Laitner [15], and the first attempt to bring about a broader perspective towards EEM impacts by Cagno et al. [5], a link between the adoption of EEMs and operational performance remains elusive. More specifically, there is limited support in this regard for shop-floor operations, where most decision support tools tend to focus on manufacturing processes and systems [1]. Thus, the subject of the sections to follow.

III. OPERATIONAL PERFORMANCE, PRODUCTION RESOURCES AND EEM ADOPTION

Operational Performance

Measures of operational performance have a long and rich history in organisation research, not least when it concerns industrial organisations [19]. Themes such as operational flexibility, cost, speed and quality remain a staple when it comes to assessing operational capabilities [20]. Though, when it concerns decision making in the context of EEM adoption, an understanding of their impact remains somewhat fragmented.

An explanation of this discrepancy lies in the decision-making process of the top management suite. Strategic management literature has long portrayed the importance in understanding the roots of capability investment decisions by taking into consideration the role of path dependence, current state of the organisations' resource repertoire, the characteristics of the market in which the organisation is expecting to breach and, of course, the organisations' strategic intent [21]. Similar "strategic-based" reasoning has begun to emerge in the space of EEM adoption with authors taking explicit account of the role of an organisation's strategic direction in the EEM adoption process where Cooremans and Schönenberger [17], as a more recent example, suggest an organisations' propensity to undertake effective energy management is elevated when energy efficiency is deemed critical in achieving competitive advantage. This then becomes a translation exercise as individual decision makers distil the impact of an EEMs adoption on their organisation's strategic objectives [22].

For the purposes of this study, then, we opt for a generic classification of performance measures that are specific to manufacturing shop-floor operations (internal) and present themselves as intuitive factors with a clear strategic focus for capability investments - whether in EEMs concerning management practices, technologies or otherwise. In this case, we turn our attention to the literature on KPI's in manufacturing shop-floor operations, given they offer some guidance as useful (and measurable) proxies for characterising the performance of a production system [23]. Here, the ISO 22400 [24] framework is often referred to as a foundational instrument in guiding the implementation and selection for operational (shop-floor) key performance metrics [25, 26]. In this international standard, KPI's are defined as "quantifiable and strategic measurements that reflect an enterprise's critical success factors" [24], demonstrating a clear link with so-called competitive priorities in manufacturing strategy [20]. Based on relevant manufacturing shopfloor KPI literature, Table 1 lists some more prevalent operational performance metrics.

TABLE I
OPERATIONAL PERFORMANCE METRICS AND EXAMPLES

Performance Measures	Examples	References
Quality	Adherence to standards	[27]
Flexibility	Mix, volume, new product, expansion modification	[28]
Maintenance	Downtime, corrective maintenance.	[23, 25]
Planning	Production lead time	[25, 29]
Energy	Consumption, waste	[24]

Production Resources

The assessment of production resources has endured as a relevant approach in helping organisations towards achieving manufacturing sustainability. Whilst there are numerous decision-making tools that incorporate production resources [c.f. 3, 4], great care should be taken in considering their relevance towards the manufacturing shop-floor, as well as the role they play in the overall decision-making framework.

Production resources can be characterised in a number of different ways. Organisation theorists, for instance, often speak of capabilities, assets, knowledge, information, processes, stocks and trust [30]. Economists, on the other hand, would speak of factors of production that could include land, labour, capital and more recently knowledge, ideas, capabilities and skills [31], running perhaps parallel to the wider-organisational perspective. Similarly, accountants may speak of information, material and machines [32], to mention a few. What is also apparent, then, is the classification of resources that may be characterised as intangible (e.g. knowledge) and tangible (e.g. capital) as well as transformational (e.g. energy) or transformed (e.g. raw materials). Indeed, there is also a case to distinguish between internal and external as well as static and dynamic resources [33] – all of which can draw markedly different insights.

For the purposes of this study, we opt to consider production resources that are internal to the firm and hold a tangible character. Besides issues concerning the practicality of adopting resources that can be readily identifiable and, in a sense, manageable, we opt for such a conceptualisation to offer a sound basis from which the impact of EEMs can be assessed. To this end, we adopt a pragmatic approach in the selection of production resources to cover a wide range of possible impacts. A sample of such resources based on a review of relevant literature pertaining specifically to a holistic overview of manufacturing shop floor resources (e.g. industrial accounting and manufacturing sustainability) is shown in Table 2.

TABLE II
PRODUCTION RESOURCES AND EXAMPLES

Production Resources	Examples	References
Materials	Consumables, raw materials,	[4, 32]
Energy	Energy generators, carriers and consumers	[4, 34, 35]
Waste	Material, energy wastes	[4]
Land	Production, storage space	[32]
Building	HVAC system, layout, rent	[36]
Human	Production personnel	[32]

IV. LINKING PRODUCTION RESOURCES AND OPERATIONAL PERFORMANCE: A CASE EXAMPLE

In this section, we finalise the description of our proposed preliminary framework by bringing to light the link between production resources and operational performance. This is accomplished by placing focus on a case example of EEM adoption in industrial organisations, namely utilising energy efficient belts and other improvement mechanisms for motor driven processes [37].

In the first instance, there are many options available to organisations when improving power transfer activities in processes [38]. For example, and as described in detail by Trianni et al. [38], one may adopt the use of synchronous belts instead of V-belts, whilst another may opt to remove belts all together and adopt a direct-drive application. In terms of performance impact, the former can result in better efficiency gains through improved grip (less slippage under high loads), though will require some equipment modification. In addition, synchronous belts are also stiffer and noisier compared to their v-belt counterparts [38]. In this example, increased energy efficiency has a positive impact on energy performance and the modifications to production equipment would relate to more dependable quality output and, hence, planning capabilities. The increased vibrations, however, may result in more maintenance activities if the hardware of existing machinery is not modified to suit. Along the same lines, increased vibration and noise can result in a less pleasant working environment for production personnel which can have knock-on effects on those operational activities that involve human intervention including quality, maintenance, planning and energy by virtue of ineffective equipment operation.

The latter, however, will result in higher efficiency gains (near-zero slip in high-torque applications) and greater control, though will require extensive modifications to equipment [38]. These modifications can result in improved quality, and planning, as well as considerably reduce plant flexibility. Though more efficient by way of output, the hardware required to run an effective direct drive motor assembly is often more complex, making maintenance activities potentially more resource intensive.

A summary of these relationships regarding synchronous belts (S) and direct-drive system (D) adoption is shown in Table 3. What is critical to portray here, is that we are not necessarily linking EEMs to operational performance. Rather, we demonstrate this link by highlighting the impact on production resources. Thus, multiple resources may have an impact on the same performance metric. For decision makers, this broadens the scope of reference from operational performance alone, to a frank consideration of the resources impacted by the EEM as well (whether they are more or less affected).

TABLE III
LINKING PRODUCTION RESOURCES TO OPERATIONAL PERFORMANCE

	Operational Performance				
Resources	Qual	Flex.	Maint.	Plan.	Energy
Electricity Consumption					+(S) ++(D)
Production Equipment	+ (S) ++(D)	- (D)	-(S) --(D)	+(S) ++(D)	
Production Personnel	-(S) -(D)		-(S) -(D)	-(S) -(D)	-(S) -(D)

V. CONCLUSIONS

The aim of this paper was to begin to shed some light on the intricacies associated with assessing the impact of EEM adoption on operational performance. Despite the surge in research efforts on the topic, there remains ambiguity and limitations in existing approaches that precludes current methods in providing a frank and holistic assessment of potential impacts. For this reason, we adopted the notion of production resources as a possible mechanism through which such impacts can be readily assessed in detail.

The case example highlighted the intricacies, beyond quantifiable impacts and those with a direct link with organisational costing mechanisms, of impacts on operational performance through production resources. In that, we begin to forward the discussions within this domain towards a more pragmatic and nuanced conceptualisation of operational performance impacts in aiding decision-makers with their capability investment options regarding EEMs.

Indeed, this paper presents only a preliminary overview of the concepts related to providing a link between operational performance outcomes of EEM adoption and production resources. Though providing a gateway for further discussions, the current framework incurs limitations with generalisation and, hence, validity. Thus, further work will contain a more thorough conceptualisation of impacts, beyond generalised descriptions, that will reveal greater practical use by key decision makers. Nonetheless, this paper provides a preliminary effort in outlining the significance of production resources in EEM adoption assessment based on operational performance factors. Adding to this, and from a practice-based perspective, the framework described in this paper can help to facilitate better industrial decision making, leading towards better (and more efficient) management of production-related activities by virtue of resource allocations. More specifically, bringing production resources to the forefront of EEM decisions has the potential to shed light on both the direct and indirect impacts of their adoption throughout production systems. As a decision-making aid, this provides for the opportunity to make timely and more effective resource allocation decisions in line with operational priorities and thus helping key decision makers in navigating the inherent complexity and uncertainty of EEM adoption decisions in industrial organisations.

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