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This paper addresses the challenges of finding and implementing profitable energy efficiency (EE) projects, a critical foundation for sustainable operations. We focus on manufacturing enterprises, but many of our findings are applicable to the back office of service operations as well. Our starting point is that there are many profitable EE projects in nearly every industrial enterprise that are not implemented. Two problems are often identified as the culprits for failing to harvest such projects: 1) lack of a rational and feasible approach to risk management and finance for these projects; 2) lack of an efficient internal operations management approach in the enterprise to package these projects in such a manner that they can be implemented while the "plant is running". Focusing on the second of these problems, we describe a framework for understanding the context of EE projects in industry, with an underlying analytic foundation in optimal portfolio analysis. We note behavioral and other impediments to finding and implementing EE projects as well as the characteristics of management systems required to overcome these impediments. A case example of a large manufacturing site illustrates emerging best practices, based on the principles of kaizen management, for the integration of EE project management with operations and engineering.

Key words: Sustainable Operations, Energy Efficiency, Kaizen, Carbon Footprinting

1. Introduction

There are many profitable energy efficiency (EE) projects in nearly every industrial enterprise that are not implemented (DeCanio 1998; Taylor et al. 2008; Ayres and Warr 2009; Muthulingam et al. 2009). Two problems are often identified as the culprits for failing to harvest such projects: 1) lack of a feasible approach to finance these projects; and 2) lack of an effective internal management approach in enterprises to identify and implement such projects. This paper addresses the second issue by building on the framework of sustainable operations developed in Kleindorfer et al. (2005). The proposed approach is based on field studies by ourselves and others of large manufacturing enterprises, and on companies that provide energy services to these firms. At the core of our approach is the familiar kaizen approach of operations, emphasizing measurement and continuous improvement, with a rigorous valuation component to assure profitability. The kaizen approach to finding and reducing energy wastes follows the same principles of lean manufacturing that have been so effective in finding and removing time, inventory and quality wastes in manufacturing organizations (e.g., Sarkis 2003).

Previous research on quality and environmental management systems as summarized by Corbett and Klassen (2006) suggests that any workable approach to EE must provide convincing answers to the following questions:

1. *Perceived importance*: Why is EE a potential source of profit for this company?
2. *Clarity and concreteness*: What are the most important EE projects that could be undertaken in this company and what results can be expected from these projects if they are properly implemented?
3. *Feasibility*: What means are there for financing and implementing these projects without jeopardizing revenue generation and without disrupting on-going operations? Does the firm have the skills or can the firm access the skills to implement specific EE projects at an acceptable cost?
4. *Customer perception*: Do customers give the firm a "premium" or "discount" for having EE/sustainability objectives and accomplishments? Increasing customer awareness and use of supplier EE metrics in customer buying criteria can be an important factor in promoting EE solutions. Such downstream pressure is becoming increasingly apparent for public projects (where the buyer is a public entity) and for major international buyers, which are facing their own customer demands for supply chain wide energy footprinting.[1]

[1]This is driven in part by new information services such as "GoodGuide" (http://www.goodguide.com/) that provide detailed online comparisons of consumer products in terms of energy, water and material use. These can influence consumer choices at the moment of purchase. In addition, new legislation and focused NGO activity provide constant pressure on companies to measure and reduce their environmental impact, including their energy use.

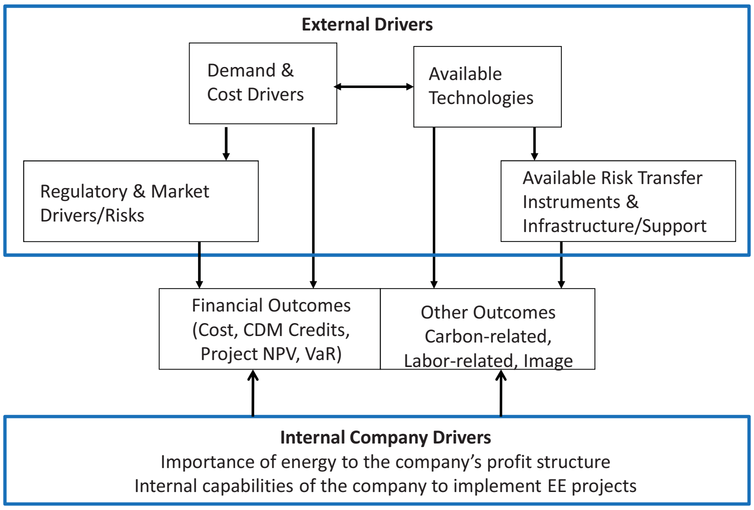

Figure 1 Valuation & Risk Drivers for Energy Efficiency (EE) Projects

5. *Technological reliability*: Closely linked to feasibility, yet distinct, is the issue of technological reliability. In the on-going operating context of most manufacturing companies, firms cannot afford to adopt technologies that are not tested and reliable.

The standard approach to existing EE project valuation is similar to what is sketched in the Figure 1. This approach encompasses demand estimates, regulatory and market scenarios, as well as trends in components contributing to capital costs, operating costs, and carbon offset revenues (if applicable). The objective is to understand and value the financial returns and eco-efficiency of a given project, or set of projects, and to provide a multi-year comparison of project returns and risks relative to a well-defined benchmark case (typically the *status quo*).

Figure 1 (and this paper) takes the specific viewpoint of a focal company in planning and executing EE initiatives. However, EE projects typically involve external suppliers of technology and capital, and a central aspect of management for such projects is structuring contracts and project execution so as to satisfy the focal firm while also assuring to these essential partners a reasonable level of project-related profits. In this paper we do not consider the contracting issues in detail[2], focusing here only on the internal managerial aspects of EE projects.

[2]These are examined in our companion paper Aflaki and Kleindorfer (2010b).

This paper proceeds as follows. In the next section we present a framework for analyzing EE initiatives, which we think of in terms of the portfolio of potential EE projects for a focal company. This leads to our discussion of management systems for discovering and implementing such projects in section 3, and further illustrated by a case study of the Pfizer Corporation's Freiburg facility in Section 4. Section 5 considers barriers and enablers encountered in EE projects, including behavioral issues and the increasing importance of carbon credits in cofinancing such projects. Section 6 concludes.

2. Understanding the Context of Industrial EE Projects

There are two underlying factors affecting the profitability of a particular industrial EE project: 1) the magnitude of the savings potential from the project itself; and 2) capabilities of the focal company and the organizational complexity of the project (the capabilities and internal transactions cost side of the project). Figure 2 shows four different environments for projects on these two dimensions. The first dimension (the horizontal axis) indicates the magnitude of energy expenditures (measured, say, in terms of the ratio of energy costs to the total cost of goods sold) for the focal company and the potential energy savings of a specific EE project. The higher the energy intensity and the larger the potential payoffs from EE, the easier it will be to focus management attention on that project. The vertical axis indicates the level of organizational and technical complexity of the project. Generally, the larger the number of external parties involved in a project (both financial and technical), the greater the complexity of assuring the ability to satisfy participation constraints of these parties and the greater the transactions costs of contracting.[3] Consider the four quadrants of Figure 2 in more detail.

Low Savings-Low Complexity: The Low-Low quadrant of Figure 2 features simple and transparent applications such as lighting, with proven technologies and relatively low cost. This quadrant would also include the no-cost and low-cost operations and maintenance (O&M) measures that

[3]There is an extensive theoretical and empirical literature on the subject of contractual complexity and its consequences for project feasibility. See, e.g., Laffont and Tirole (1993) and Williamson (1985).

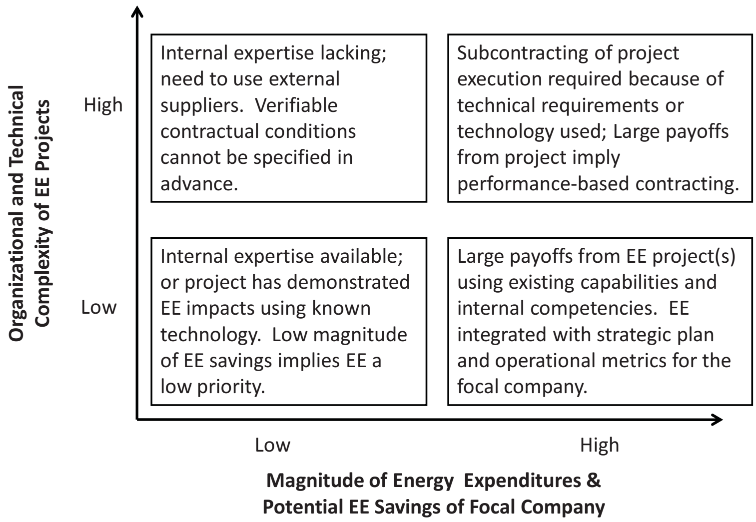

Figure 2 Alternative Contexts of EE Projects

can be implemented internally by companies in the course of normal operations improvement initiatives. Larger companies can empower their engineering division and facility maintenance groups to develop portfolios of EE projects, including those in the Low-Low quadrant, as part of company or facility cost and energy targets. Smaller companies may require the assistance of Energy Service Companies (ESCOs) or their local utility in implementing such projects. The central impediment for projects in this quadrant is that the savings are not sufficiently large to receive management attention and can easily get lost in the “noise” of the normal variability of energy bills.

Low Savings-High Complexity: The Low-High quadrant of Figure 2 will normally be empty as high transactions costs would typically undermine the interest of the focal company to invest in projects with low savings potential but requiring high initial investments in establishing the requisite competence to assure project success. ESCOs could reduce the fixed cost of such projects by bundling together many small projects using similar technology, as has occurred with solar power installations that are increasingly attracting larger energy companies such as ENEL and Veolia to commercial and manufacturing facilities with large rooftop surfaces.

High Savings-Low Complexity: The High-Low quadrant of Figure 2 features projects with high potential savings using proven technologies, such as using new sources of fuel in cement or electric power. To the extent that these projects are for specific modular purposes, use existing technology, and are provided by suppliers with a good track record, they are low in complexity and risk. For example, while using municipal waste or stressed cooking oils was considered an innovation in such industries 20 years ago, this is by now a proven technology with relatively low risk. Other examples of projects in this quadrant are one-on-one deals with major suppliers selling demonstrated solutions with in-built warranties.

High Savings-High Complexity: The High-High quadrant of Figure 2 encompasses projects with high potential savings and complex to implement, in that they may entail multiple organizational providers or require sophisticated contracting and guarantees to finance. Examples of such projects would include investments in new kiln technologies in cement or pulp & paper manufacturing or reinforcing grid operations in an electric utility company to allow reliable integration of significant amounts of wind and other renewables.

The EE management problem can be construed in three stages. First is generating the portfolio of potential EE projects that would populate a grid like that shown in Figure 2. Second is determining priorities for implementing these EE projects, which implies also decisions about the development of internal competencies and external resources required for these projects. Finally, implementation and monitoring of results occurs. As we will discuss in the next section, none of this will be effectively accomplished without the accompanying kaizen imperatives of prior measurement and participation of process owners. For the moment, however, we focus on the theoretical framework underlying project valuation.

Once a portfolio of potential EE projects has been identified, two interdependent decisions are fundamental to project selection: i) what is the subset of efficient projects for a given level of risk the EE project manager is prepared to assume? ii) How will projects on the efficient risk-return frontier be undertaken-i.e., using internal capabilities or using external sources? As analyzed in the Technical Appendix, this problem has the basic structure of the classic capital budgeting problem (e.g. Weingartner 1966; Rosenblatt and Sinuany-Stern 1989) of determining the efficient frontier for a discrete portfolio choice problem, where the investment choices for the portfolio are binary choices on whether or not to implement a given project and, if implemented, whether to undertake the project internally or via outsourcing.

Two characteristics of EE project portfolios deserve special note in this regard. a) EE projects have correlated returns/cash flows since many of them are driven by savings in energy and carbon, which are directly benchmarked off crude oil and other market indices.[4] b) EE projects can be partitioned into subsets requiring specific competencies and perhaps also having particular organizational attributes which determine project interdependencies. There may be additional interdependencies such as sequencing and mutual exclusivity (either-or) constraints, but these pose no problem in principle and are standard in the capital budgeting literature. These special characteristics of EE project portfolios imply an NP-hard choice problem (whose structure is basically an integer quadratic program). Heuristic solutions (e.g. Kochenberger et al. 2004) for various versions of this problem can nonetheless provide near-optimal solutions for problems of realistic size.

Figure 3 below shows the structure of the process suggested by this analysis. Baseline measurements of EE in a company (or a specific facility or supply chain) lead to the identification of opportunities and potential projects. Budgets, risk preferences and constraints (such as acceptable Value-at-Risk levels for the portfolio of EE projects initiated) are agreed. Valuation of individual projects identifies the usual cash flow characteristics (mean, variance, and correlations across projects) for each project. The correlations are identified and linked to underlying factors driving these correlations such as common energy and carbon prices. Competencies required for internal or external implementation are determined, together with the associated cost of establishing such competencies or with using external service partners. Finally, priorities are set for projects and for competency development. A theoretical framework for such priority setting is the efficient frontier

[4]Thus, a typical EE project i has a structure for the (stochastic) NPV of its cash flows of the form: $NPV_i = \xi_i + \alpha_i \tilde{P}_E + \beta_i \tilde{P}_C$, where ξ_i are cash flows resulting from idiosyncratic factors specific to the project, $\tilde{P}_E$ and $\tilde{P}_C$ are the random variables representing vectors of predicted prices of energy and carbon over time and α_i and β_i are the vectors of energy and carbon savings per period resulting from the project. Clearly if a set of projects $i \in \{1, \ldots, N\}$ all have this form, there will be correlation across these projects induced by the common energy and carbon price drivers of NPV.

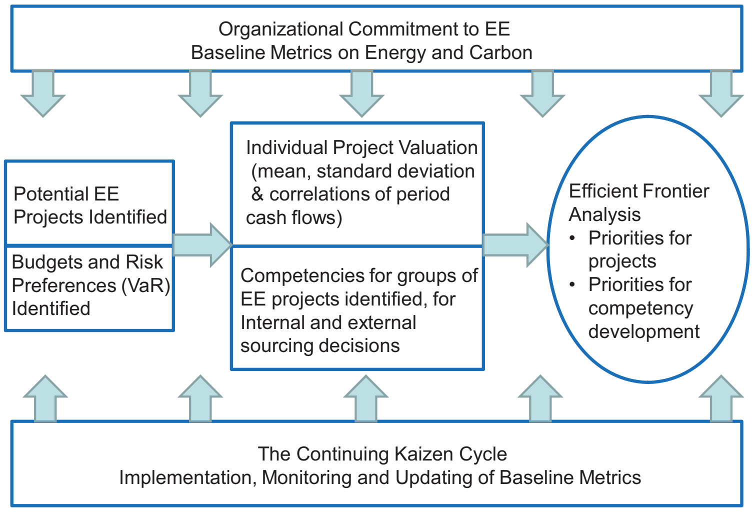

Figure 3 Choosing a Portfolio of EE Projects

analysis described in the Technical Appendix. Implementation, monitoring and updating of this process completes the cycle.

The objective of the bare bones process just described is the generation of a portfolio of EE projects, linked to company-wide metrics on energy use and efficiency, and to a plan for leveraging necessary internal and external competencies identified as part of the valuation analysis. The next two sections describe in more detail how flesh might be implanted on these bare bones through the management systems that are the necessary accompaniments for the effectiveness of this process.

3. Organizing for Effective Management of EE Projects

The above discussion underlines the importance of integrating EE within a framework that connects these projects to the strategy and profits of the company. With an eye on Figure 2, this is especially true of companies with high energy intensive operations. For such companies, EE is a strategic concern and should be managed like any other major cost driver.

Even companies with low energy intensity need to establish procedures for identifying and valuing EE projects or they will leave many cost-effective projects fallow. For low energy intensity companies large enough to have an engineering or facilities maintenance group, this is the obvious address to locate responsibility for EE projects. In companies too small to have the requisite technical manpower to identify and track EE projects, the solution is external service providers (ESCOs and Demand-side Management-DSM–programs from the local utility) coupled with internal metrics to track results.

In what follows, we consider the question of organizing for effective initiatives to find and implement EE projects, under the assumption that there are technically qualified individuals in the company who already have responsibility for maintenance and operational readiness of the company's plant and facilities. We will refer to this group as the CEMG (Company Engineering and Maintenance Group). We focus on a single facility or manufacturing process, the "Facility". EE management systems and capabilities may be replicable across facilities, but EE projects tend to be site specific and the real work in implementing these occurs at the level of individual manufacturing facilities.

Organizational responsibility and accountability: The first element in any effective management system is recognition of the responsibility and accountability for results. Such recognition for the results of EE projects needs to be further formalized in an Energy Master Plan. The Master Plan can include also other resources such as water and air pollutants (e.g., CO_2–discussed below). The Master Plan specifies system boundaries for EE projects, the objectives of EE within the company, and responsibility for monitoring and reporting. The primary element of any such plan is a measurement of the *status quo* of energy use and energy costs for internal operations, later possibly to be extended to supply chain partners and customers.

Identification and valuation of potential EE projects (the EE portfolio): Given baseline measurements of energy consumption for specific uses and processes, CEMG works with site process owners at the Facility and external service providers to form a set of alternative options for the Facility energy needs (heating, cooling, lighting, and manufacturing) in order to increase energy and carbon efficiency. An effective EE identification and valuation process is grounded on four basic principles:

1. Integration of all projects into a value-based Energy Master Plan to show progress over time, to identify synergies across projects and to show systemic interactions of these projects;

2. Objective measurement of energy inputs and useful work[5] accomplished with energy for the Facility as a whole as well as for individual processes at the site;
3. Working with process owners at the Facility in a participative way to identify opportunities for improving EE and to implement projects with the highest combined energy and cost impact;
4. Developing a transparent process for reporting and valuing the cash flows, risks and energy consequences of identified projects.

The CEMG, bearing overall responsibility for implementing EE, must be responsible for the measurement side. Various mapping tools based on Industrial Ecology and Life Cycle Analysis (LCA) are available to determine inputs and outputs of individual processes throughout the facility.[6] Valuing these projects in a uniform manner allows coordination of project results with objectives and milestones in the Energy Master Plan. Depending on how accounting is accomplished at the Facility, recognition might be immediate by process owners (e.g. if they are cost centers and are held responsible for overall process costs, including energy). If EE savings and process ownership are not aligned, then other means need to be found to share the "glory" for improved results achieved. Results on energy and cost need to carefully monitored and fed back into the measurement process, so that a cycle of accurate measurements, predicted benefits, monitored results and verified improvements is achieved. Communicating results of Facility performance to all employees can further enhance the importance of EE for the company, and for the broader community (the latter in terms of carbon and other polluting emissions avoided by EE improvements).

What is described here is effectively the EE version of continuous improvement which has been such an important part of manufacturing excellence and the quality movement since the worldwide recognition of kaizen principles transformed global manufacturing in the 1980s.[7] Integrating EE (and other key resources such as water and logistics) in a culture of continuous improvement is

[5] "Exergy" is the appropriate metric for useful work, as discussed in Ayres and Warr (2009).

[6] See, e.g., the resources available through the Rocky Mountain Institute: `http://www.rmi.org/rmi/About+RMI`. See also the general approach to integrating with sustainability strategy in Orsato (2009) and the case studies noted in Rouer and Gouyon (2007) of BeCitizen.

[7] For the foundations of kaizen, see the newly released 1959 classic by Shingo.

the primary means of identifying promising EE projects and having the cooperation of participating process owners in the implementation of such projects. The same culture can transform an underperforming, low-quality Facility onto a path of long-term profitability. In addition to its traction in operational results, the culture of kaizen also captures universal attributes of respect for people, fact-based management and the shared benefits of participating in a profitable, well-run enterprise. Following what Corbett and Klassen (2006) have described as the "law of the expected unexpected side benefits", kaizen-driven EE can be a portal to broader quality and cost effectiveness in the enterprise as a whole, just as quality and environmental management have been portals for profitability well beyond their initial focus.

4. Energy Efficiency at the Pfizer Corporation Freiburg Facility

In this section, we provide a successful example of managing EE projects based on Aflaki and Kleindorfer (2010a). The Freiburg Facility is an important manufacturing facility of the Pfizer Corporation, a global pharmaceutical company. Freiburg is located in Germany, which explains in part the commitment of Pfizer Freiburg's management to EE, given the strong "green" movement that has existed for many years in Germany. However, profits for Big Pharma derive primarily from R&D and marketing, and EE has not been high on the agenda of importance of any major company in Big Pharma until relatively recently. Indeed, globally only 2-3% of the cost of goods sold results from energy expenses for the pharmaceutical industry. Partly for this reason, the management of Pfizer Freiburg did not initially find a warm reception among senior management for its plans to launch a major EE initiative in the Freiburg Facility. Nonetheless, the head of engineering at the Facility decided that EE was something that needed to be done in order to move the Facility to a more sustainable energy future. With the support of the Facility Manager, a program similar to that described just above was launched in 2005 by the Pfizer Freiburg's CEMG. The initial form of the program was an Energy Master Plan that was based on a Facility-wide measurement system. The Master Plan consisted of some 200+ projects in various areas. These included larger projects such as geothermal heating and cooling, the installation of biomass (wood pellet) boiler and adiabatic cooling in the Facilities manufacturing and laboratory spaces. However, a host of smaller projects were also included, from weekend shutdown to better building controls and to behavioral programs. All of these projects were accompanied by an assessment of projected energy savings, carbon savings, and cost savings. They were also clearly identified with some process owner, with capital expenditure requirements and expected payback periods. Four general sources of profit for projects in the Energy Master Plan were identified and valued for each project:

1. Reduction in operational and maintenance costs relative to business as usual;
2. Reductions in greenhouse gas (GHG) emissions by using more eco friendly technologies; for the larger projects these emissions savings were certified for reductions in GHG emissions, with resulting revenues from the CO_2 emission credits;
3. Governmental incentives (including tax incentives and feed-in tariffs for excess electric energy resold to the grid from renewable energy sources);[8]
4. Further benefits in aligning operations with corporate environmental goals and Pfizer's corporate social responsibility objectives.

Some of the projects such as insulation and smart air-conditioning systems were "no brainers", with low upfront investments, relative certainty of the direct benefits of the project, and short payback periods (group 1), while others required significant capital expenditures and entailed operational risks or uncertainty in profitability (group 2). Representative group 2 projects included the installation of geothermal heating and cooling system and a biomass boiler fired by wood-pellets.[9]

[8]Feed-in tariffs provide incentives to adopt renewable energy resources. For example, in Germany, according to the Renewable Energy Law passed in 2008 and coming into force in 2009, companies generating electricity from renewable energy sources such as hydro, solar, biomass or wind receive a guaranteed payment per kWh of excess electricity fed into/resold to the grid. For electricity generated from biomass, for example, this payment amounted to 8.4 to 11.5 Euro Cents/kwh, depending on the size of the installation, with these guaranteed prices decreasing annually from 2010 on.

[9]Wood pellets are a type of bio fuel that are produced from the biomass harvested from sustainably managed forests and from waste products of sawmills. High density and low humidity make wood pellets an efficient combustion fuel option. Wood pellets have significantly lower GHG emissions in their production life cycle since if the excess wood from which they are made is left to simply decay naturally, it will yield basically the same GHG emissions as if it were burned as wood pellets. Biomass is therefore considered a near-zero net GHG emission source for energy.

Geothermal heating and cooling was the first major project implemented in the Energy Master Plan. It had a significant ecological and economic impact on the site. After careful test drills and geological studies had established the safety and feasibility of the project, access shafts around the facility were drilled reaching 130 meters into the ground. These provided access for closed loop piping that brought circulating water into contact with the underground water at a nearly constant year-round temperature of $12-14°C$. Water in the closed loop system that was pumped through this aquifer came out at this temperature. Since the resulting temperature of $12-14°C$ was considerably lower than the ambient temperature in the summer (around $25°C$) and considerably higher than the ambient temperature in the winter, circulating the water from the geothermal closed loop system through a network of piping embedded in the walls of the facility results in cooling of the ambient air in the summer and heating in the winter.

With a payback period of less than 2 years, the geothermal project was immediately hailed as a success for the Facility's vision of sustainable energy. The project yielded considerable savings in annual energy costs, reducing gas and fuel by 3325 megawatt hours (MWh) and reducing CO_2 emissions by 1,200 metric tons per annum. Harvesting the benefits of the geothermal project underlined the importance of having a comprehensive Master Energy Plan. The geothermal installation was an essential part of that plan, but its full benefits could only be harvested in connection with other projects in the Master Energy Plan. The entire process was driven by the vision of a low-energy consuming manufacturing site designed and constructed using the latest energy and resource conservation principles.

The next major step was the installation of a biomass boiler (BMB), which was considered to be one of the major projects in the Facility Energy Master Plan, with large benefits in both environmental and cost terms, and which would allow the Facility ultimately to generate all of its energy needs from locally available renewable energy sources. The BMB project consisted of the replacement of boilers #1 and #2 with a single efficient boiler fired by wood pellets. The initial cost of the replacement boiler was higher than an alternative gas boiler, but the payback period on that additional investment was easily less than two years. The installation of the boiler was

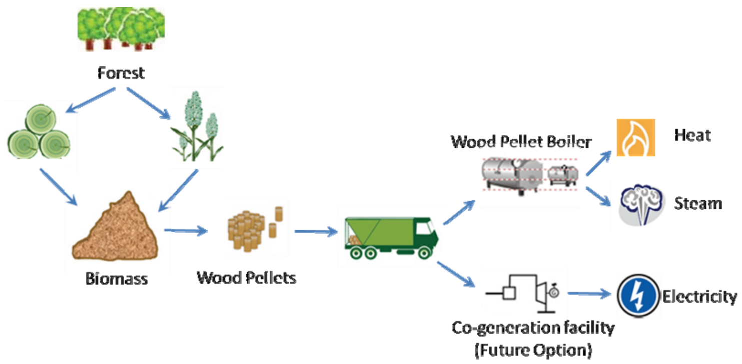

Figure 4 A schematic model of the Biomass Boiler (BMB) project

done with the technical assistance of a large ESCO specializing in biomass.[10] The ESCO was also contracted as the initial provider of wood pellets to fire the boiler.

The reduced emissions from the BMB project were in excess of 5,000 tons/annum. These reductions would not only contribute to achieving Pfizer's objective of reducing its overall carbon footprint, but would also be certified and the credits obtained would be sold in the European Emissions Trading System (ETS). While pharmaceutical companies and their facilities are not regulated directly on their GHG emissions, companies in the EU can obtain credits and sell them in the European carbon markets.

The cash flow assessment of the BMB project indicated that it was very profitable. Given the ready local supply of biomass and wood pellets, and the financial guarantees provided by the supplier, little risk was envisaged from disruptions. Moreover, some of the existing boiler capacity (fired by oil and gas) was kept as standby in case additional energy was required or in case of a disruption in BMB operations. The CEMG team at the Pfizer Freiburg Facility envisaged a three-phase process for the BMB project (see Figure 5). In phase 1, the Facility would contract with the ESCO supplier to install the boiler and supply wood pellets for the coming ten years. The supplier had sufficient long-term contracts itself that it was prepared to offer a ten-year supply contract to the Facility indexed by a market index of wood-pellet prices (an index of the cost of

[10]The ESCO in question is the Heidelberg-based subsidiary EC Bioenergie GmbH of the Dutch energy giant SHV Holdings N.V. See `http://www.ec-bioenergie.de/` for information on the innovative contracting and services provided by EC Bioenergie.

wood pellets sold in the region) and capped at 70% of the heat equivalent market cost of oil. The savings potential from the BMB project relative to business as usual was therefore manifest and credible.

Phase 2 of the BMB project was planned as the installation of an absorption cooling system that would use some of the steam generated in the BMB as input to an absorption cooler. This was viewed as an important complement to the cooling already provided by the geothermal system, and had the additional benefit of assuring a more seasonally balanced use of the thermal energy generated by the BMB.

Phase 3 of the BMB project foresaw the installation of a co-generation unit.[11] The electric power generated from the co-generation unit would be used for lighting and production, and the heat would be captured for building and process heat. The electricity produced would be used by the Facility or re-sold to the grid. With the completion of Phase 3, the Facility would supply 100% of its own energy needs from biomass obtained within 50 kilometres of its Facility, as well as producing and supplying additional renewable energy (with zero carbon net emissions) to the local grid.

Phase I of the project was implemented in 2008-2009 and fulfilled all expectations. If phases 2-3 of the Energy and Resource Master Plan are as successful as hoped, Pfizer could capture these as best practices and disseminate them, and the management and measurement systems on which they were based, to other sites around the world as part of their sustainability strategy. This dissemination of internal best practices is highly credible, inasmuch as it manifestly fits with company culture, accounting systems and management practices.

The most important lessons from this case study for EE derive from two reinforcing ideas. First is the fundamental importance of measurement as a foundation for identifying and valuing EE projects. Second is the key role of having a responsible group, with the necessary expertise, charged with the responsibility to deliver on EE. On the first point, the ability to value any EE project relies on both precise internal knowledge of energy flows, uses and costs, as well as external knowledge

[11] Co-generation refers to the process of generating both electricity and heat from the same electric generator.

on the prices of existing and alternative energy. While specialized knowledge in this case on carbon markets was provided by the ESCO involved (EC Bioenergie), the CEMG at the Freiburg Facility was clearly in control and had a full understanding of projected carbon reduction impacts from their projects. The continuing process of measurement, prediction, control and feedback in the Facility's approach to EE has not only paid off in profit terms. It has led to a deeper understanding of the nature of the production processes at the Facility and the development of internal competencies and knowledge that allow a rationale and reliable response to external contingencies. In the case of Pfizer's Freiburg Facility, the engineering division was able to integrate EE with its normal slate of responsibilities, and with the added precision of underlying energy use and cost measurement they were able to obtain a much better understanding of other engineering drivers of cost and performance. Just as in the quality movement of the 1980s, where cycle time was a fundamental lever to discovering quality problems, so in this case the analysis of EE is proving to be a means of discovering inefficiencies that go well beyond wasted energy.

5. Barriers and Enablers for Effective EE Management

This section considers a few of the important barriers to invest in EE and what might be done to improve these in the context of promoting effective management of EE projects. As examined in the Decision Sciences literature over the past several decades,[12] human decision makers are boundedly rational in that they attempt to make rational choices, but are confronted with judgment and cognitive limitations that impede this. Most important among these are limitations on attention, which Simon (1971) considered the most fundamental barrier to effective management choice. Using the framework above to discover and determine high value EE projects is therefore the most elemental building block of effective EE strategy. Beyond these problems of attention management, investment choices and project management are more difficult when complexity, ambiguity and intertemporal effects are present. Many EE problems have all three of these characteristics. From the perspective of the decision sciences, it is therefore not surprising that many apparently profitable EE projects are not implemented. Let us consider some of the details.

[12] See, e.g., Kleindorfer et al. (1993) for a summary of the literature on heuristics and biases in decision making under uncertainty.

5.1. Financial and Behavioral Aspects of Decision Making for EE

Results from field studies show that many profitable EE projects are not implemented (DeCanio 1998; Muthulingam et al. 2009). This very robust finding is linked to the literature on biases and information processing limitations of human decision makers. The two most important such biases related to project selection and execution are myopia and improper discounting of project savings.

5.1.1. Myopia: There is a well-documented tendency for decision makers to undervalue continuing payoffs from multi-period projects. This tendancy is referred to in the Decision Sciences literature as "myopia". The consequence of myopia is that many EE projects that should pass reasonable hurdle tests do not. The most extensive study of this is that of Muthulingam et al. (2009) which considered the results of thousands of projects filed with the Department of Energy in the U.S. that were of the general category of unharvested, yet putatively profitable EE projects. Their findings were consistent with the many experiments and the extensive literature verifying myopia and relating it to other behavioral phenomena such as loss aversion, risk aversion, budget constraints and cognitive limitations of human decision makers.[13]

The standard approach to debiasing (correcting for) myopia is better information and the use of guarantees. For example, in the Pfizer Case above, the cap on biomass prices provided by the ESCO partnering with Pfizer was a guarantee that the biomass boiler project would have fuel costs that were assuredly less than competing gas and oil prices. Similar guarantees are often provided for commercial and municipal lighting projects in which an ESCO implements lighting changes in return for a guaranteed portion of the savings off the historical energy bill of the organization in question. This arrangement is essentially equivalent to the ESCO "buying" the project from the organization, providing the upfront investment for the project technology and obtaining the rights to the resulting savings for some period after project implementation.

[13]See Kahneman and Tversky (2000) for details, especially chapters 32 and 33. For a recent survey of the intertemporal choice literature, see Andersen et al. (2008).

5.1.2. High Discount Rates: A phenomenon related to myopia (and often indistinguishable from it) is the apparent use of high discount factors or different forms of discounting than that implied by the usual constant discount rate model. "High" discounting is based on the notion of "implicit discount rate" defined as the discount rate that would just equalize a project's NPV to zero at the rate at which a decision maker is prepared to pay to have the project implemented.

There is a large experimental and empirical literature showing that projects, like EE projects, that require upfront investments in return for a series of implied savings give rise to observed implicit discount rates that are wildly out of line with available credit or debt costs in financial markets.[14] Of course, these results are computed on an as-if basis, based on observed behaviour, and they do not imply that decision makers are actually using a discounted NPV-type model. In particular, the high implicit discount rates found in laboratory and empirical studies could just be an indication of faulty logic or of very myopic decision making. Other explanations include alternative discounting models (e.g., hyperbolic discounting), risk aversion or ambiguity concerning returns far into the future, and budget constraints. Debiasing remedies for excessively high implicit discount rates are the same as for myopic decision making.

5.1.3. Complexity and Ambiguity: Complexity (in understanding the cause and effect chains that link decisions to outcomes) often translates into ambiguity about returns. Beginning with Frank Knight's work on risk and uncertainty (Knight 2002), and continuing through observations by John M. Keynes, Frank Ramsey and the philosophers of the Vienna School in the 1930s, the subject of "ambiguity" has remained an active research area in the Decision Sciences. More recently, work on the descriptive side of this question has highlighted the fact that laboratory subjects and decision makers "in the field" behave very differently under conditions of ambiguity than under conditions of well-specified risks. In particular, people tend to avoid situations where ambiguity is present. In terms of EE projects, this translates into not undertaking projects which may appear cost effective to external experts but are seen as either too complicated or too ambiguous to

[14]For a review of evidence on implicit discount rates for projects with upfront costs and payoffs over time, see Kleindorfer and Kunreuther (1999). For supportive findings in the EE area, see Muthulingam et al. (2009).

invest. Complexity and ambiguity are central barriers to cost-effective EE investment. Debiasing approaches to improve choice for projects that are so affected are information dissemination and technical assistance from trusted sources. Prototype projects by contemporary businesses in the country and sector in which EE is to be stimulated can be helpful in overcoming perceptions of ambiguity and complexity.

In the same vein, a company or government agency that can facilitate technical and financial assistance can play an important role in overcoming this barrier. This is perhaps the reason for the rise of Energy Service Companies (ESCOs), which provide a one-stop shopping option for companies in the form of expertise, implementation capacity and project financing.[15] Beyond technical assistance, ESCO contracts typically also involve some sort of risk sharing or guarantees of performance that reduce concerns with ambiguity and complexity of EE projects.[16].

5.2. Carbon Pricing and Emission Reduction Credits

A particular area for EE projects that acts as both an enabler and a barrier for EE projects is carbon pricing and its implications for cofinancing of EE Projects. EE projects lead to emissions savings which can be certified and sold in carbon markets.[17] The key question is how much such carbon offsets/credits are likely to be worth for a given EE project. This in turn depends on whether the focal company itself faces carbon regulation (and the need to pay for its emissions) or whether it is attempting to implement its own (i.e., voluntary) carbon reduction target at minimum cost. Such carbon emission credits are important for both EE project profitability and the visibility of EE initiatives.

As an example, suppose a focal company undertakes an EE project which is expected to reduce emissions by 10,000 tons of CO_2e for each of the next three years. If the company faces direct carbon regulation, it can value these emission reductions at the market value of carbon certificates (a price it would otherwise have to pay were it not for these reductions). If the company is not

[15]See Bertoldi et al. (2006), Vine (2005) and Taylor et al. (2008) for surveys of practices related to ESCOs.

[16]The analysis of performance-based contracting for ESCOs is developed in Aflaki and Kleindorfer (2010b)

[17]See Mansanet-Bataller and Tornero (2008) for a discussion of the market behavior in the first three years of its operation.

covered by direct regulation, it needs to certify these reductions through a registered certification agency. Thereafter, it can sell its certified reductions.

Assume for concreteness that the project is for a company that intends to sell the carbon certificates. The focal company would first obtain the certification and the carbon credits that go with it through one of the many brokers now active in this area. Brokers are important because most EE projects are not large enough on their own to warrant a company setting up its own carbon trading operations. Rather, an international broker will aggregate a number of these in order to have tradable quantities of carbon certificates. The broker might negotiate a fixed price for delivery of the 10,000 carbon credits at some fixed date (usually the end of the calendar year) for each of the next three years. Or the broker might negotiate a price benchmarked on some regional carbon price (such as the EU price) that obtains at some specific date for carbon certificates deliverable at the end of each of the three years. Each of these strategies would have different risk implications for the focal company. In either case, however, the basic price the focal company should expect (minus brokerage and sales fees) can be obtained by looking at the current price of futures contracts on the given regional market for the calendar years in question. The earlier the project is in its development stage, the higher the discount to current market prices will be when selling the credits forward (to reflect project development risk). These prices are market determined and transparent.

For large projects (say generating 10,000+ tons of annual CO_2e offsets), one-off deals can be set up with international brokers for the project itself. For smaller projects, ESCOs or Utilities will tend to be aggregators of carbon credits and will often bundle the benefits of such revenues into their pricing of individual projects. In either case, the value of such carbon credits for an EE project is usually not sufficiently large to be a determining factor of whether or not to undertake the project, but these carbon revenues can nonetheless add from 5% to 10% in incremental cash flows to projects which are already at or near desired hurdle rates.

From the above, carbon credits are an enabling feature of EE projects. At the same time, carbon credits entail two significant sources of risk. The first risk is the price risk of carbon credits, coupled with the amount and timing of the additionality offsets themselves, i.e. what will be certified as offsets against a business-as-usual scenario and when will the certification process for the project be completed. The second risk is the magnitude of the transactions costs of going through the certification process. While there are standards and rules for the certification process, there is also considerable judgment required in executing these rules. Together with timing uncertainty associated with the registration process, it is difficult in practice to count on a specific cash inflow for co-financing of EE projects using carbon credits.[18]

5.3. Implications for Improved EE Project Management

The principal barrier to improved EE project management is lack of actionable information relevant to identifying and valuing EE projects. Cures for myopia and complexity avoidance include 1st party cures in the form of a rational valuation process (see sections 3-4 above); 2nd party cures in the form of technical assistance by ESCOs and utilities with solid EE knowledge; and 3rd party cures in the form of guarantees and information from trusted sources. Given competing priorities for management attention, this implies that management systems of the type described in Section 3 above must be in place if effective EE is to be harnessed.

6. Concluding Comments

The above analysis, case study and discussion underline several important principles for project development and implementation of cost-effective EE projects. Most importantly, we have identified the following issues as essential for effective management of industrial EE projects: *Reliable measurement* so that a company understands its baseline energy consumption, including how much of its energy is used to actually provide useful work rather than waste;[19] *Management systems* and responsibilities to identify and manage win-win EE projects, including approaches to rational

[18]The time and complexity to file for JI and CDM project certification has been a continuing bone of contention since the launch of these certification procedures under the Kyoto Protocol. For details see Mansanet-Bataller and Tornero (2008). The time required to file for carbon credits for specific projects, and the level of detail of project documentation required for certification for both CDM and JI projects can be observed in the completed project registry of the UN Kyoto Executive Committee available at `http://unfccc.int/2860.php` .

[19]This basic point is central in the convincing argument made by Ayres and Warr (2009) that a great deal of energy in manufacturing activities in both the developed and developing world does not lead to useful work being done. The exergy framework they develop is central to mapping energy to useful work, but even intuitive frameworks that attempt to map a facility's total energy onto its activities can begin to produce useful insights on EE.

project evaluation and project management; *Tested and reliable technologies* to harvest EE and credible demonstration projects that promote trust in their profitability; *Financial and technical expertise* that will provide the necessary competence and resources for project valuation and implementation.

Two approaches are emerging in industry relative to energy. The first is the traditional approach of treating energy like any other input, subject to the normal processes for managing supply to assure cost minimizing procurement and use. The second approach, deriving from the sustainability imperative, is to treat energy, and its near cousin carbon, with special attention. Certainly for energy-intensive companies, the second strategy will be the right approach. However, even for non-energy-intensive companies, a special assessment of energy, and other resources underlying sustainable operations such as water, may well be worth the effort. If this is coupled with an existing competency center, like facility engineering, and managed properly, the returns can contribute to both profits as well as employee motivation and loyalty. As in the quality movement of the 1980s and 1990s, the synergies of excellence surrounding a well implemented EE initiative can extend well beyond the boundaries of energy.

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7. Technical Appendix

This appendix provides a theoretical framework for the selection of EE projects, as well as the decision associated with whether to undertake specific projects internally or to outsource them. Our analysis is based on the classic capital budgeting problem (Weingartner 1966). In contrast to the analysis of the discrete efficient frontier model presented in (Rosenblatt and Sinuany-Stern 1989), the presented model includes correlated returns, which are an essential aspect of the EE portfolio selection problem. Computational approaches for the general problem stated below are available in the binary quadratic programming optimization literature, e.g. (Kochenberger et al. 2004). We first state the general problem of interest and then present explicit results and some intuition for the case where only two internally sourced projects are considered.

Let the binary variable $x_i \in \{0,1\}$ represent the decision associated with the execution of project $i \in N$, where N is the set of all possible projects. Projects in N will be considered distinct if they are undertaken in different ways. For example, if a project can be executed either internally or through outsourcing, we will represent the internally sourced project and the outsourced project as distinct. As is common in the capital budgeting literature, various types of constraints can be imposed to capture mutually exclusive projects or sequencing of projects. Thus, if projects 1 and 2 are mutually exclusive, then we would impose a constraint of the form $x_1 + x_2 \leq 1$. Similarly, if project 1 is a prerequisite for 2, then we would impose a constraint of the form $x_1 \geq x_2$. Denoting the set of such feasibility restrictions by $\mathbf{X}$, we require that the solutions to the problem belong to this feasible set–i.e. $\mathbf{x} \in \mathbf{X}$.

Each project incurs a project-specific fixed cost F_i, with $i \in N$, the magnitude of which may depend on whether the project is undertaken internally or outsourced. In addition, specific technological competencies and organizational capabilities may be required to undertake some projects, and developing or buying these externally is assumed to incur the further fixed cost H_t for $t \in T$, where T is the set of technologies or capabilities that need to be licensed, purchased or developed. We denote by $N_t \subset N$ the set of projects requiring technology $t \in T$.

The final element to the EE portfolio problem is a risk constraint. The typical approach in industry is to use a Value-at-Risk (or VaR) constraint, which requires that portfolio returns (for a specific period of time) be no less than a specified level with some given probability (e.g., annual portfolio returns should lose no more than the specified VaR with probability .99). Define the efficient frontier for a given portfolio problem, called the E-VaR frontier, as the locus of points in $\mathbb{R}^2$ that represent for each level of VaR the highest expected profit $\mathbb{E}(\mathbf{x})$ achievable from the portfolio while satisfying the VaR constraint. As shown in Kleindorfer and Li (2005), under a mild regularity condition that holds for standard distributions of portfolio returns, this frontier is isomorphic to the efficient frontier, called the E-VAR frontier, for the same portfolio problem derived from maximizing $\mathbb{E}(\mathbf{x}) - k\,VAR(\mathbf{x})$ for varying levels of $k \geq 0$, where $VAR(\mathbf{x})$ is the variance of the portfolio $\mathbf{x}$.

The corresponding optimal VaR-constrained portfolio can be obtained directly from the E-VAR efficient frontier problem by finding the appropriate level of the risk appetite parameter k on the E-VAR frontier that delivers the desired VAR. Given this, we focus on the E-VAR portfolio problem.

Let the random savings from project i be denoted $\tilde{S}_i$, with mean $\bar{S}_i$, variance σ_i^2 and with ρ_{ij} representing the correlation coefficient between $\tilde{S}_i$ and $\tilde{S}_j$. The E-VAR efficient frontier (EVEF) problem of interest takes the following form.

Problem EVEF:[20]

$$\begin{aligned} \max_{x,y} \quad & \sum_{i\in N}(\bar{S}_i - F_i)x_i - k\sum_{i\in N}\sum_{j\in N}\rho_{ij}\sigma_i\sigma_j x_i x_j - \sum_{t\in T} H_t y_t \qquad (1) \\ s.t. \quad & \sum_{i\in N_t} x_i \le n y_t, \quad t\in T \\ & x\in X;\, x_i\in\{0,1\}\, i\in N;\, y_t\in\{0,1\}\, t\in T. \end{aligned}$$

where $n = \#(N)$ is the cardinality of N. The first constraint above ensures that $y_t = 1$ whenever any of the projects requiring technology t are implemented (i.e. whenever $x_i = 1$ for some $i \in N_t$). The first term in the objective function represents mean project returns; the second term is the variance of the portfolio times the risk appetite parameter k; the third term represents the costs of technology acquisition and capability development.

The simplest example of Problem EVEF is where there are no cross-project constraints ($\mathbf{X} = \emptyset$), only project-specific fixed costs and no additional cross-project technology costs ($T = \emptyset$), and where, in addition, all projects are independent ($\rho_{ij} = 0, \forall\, i, j$). In this case, as shown by (Rosenblatt and Sinuany-Stern 1989), the optimal solution for any k is to select for the portfolio precisely those projects satisfying $\frac{\bar{S}_i - F_i}{\sigma^2} \ge k$. This leads to a nested portfolio, in which increasing risk appetite (i.e., decreasing k) leads to adding projects to the existing portfolio, until the point is reached at which all projects with positive expected value ($\bar{S}_i - F_i > 0$) are in the portfolio. As we will see

[20] In general, one would represent this problem in terms of the multi-period cash flows of the projects over a specific planning horizon, with appropriate discounting to obtain the mean and variance of portfolio returns. Also correlations would be expressed in terms of the common underlying factors, such as energy and carbon prices, driving these. We spare the reader the additional notation.

below, the existence of correlations across projects does not lead in general to a nested solution to the EVEF Problem.

To get some insight on the structure of the solution when cross-project correlations are non-zero, consider the case of two projects $N = \{1,2\}$. Let $B_i = \bar{S}_i - F_i$ denote the expected benefit associated with each project, and assume that all projects are done internally to the company and that there are no other costs incurred by the company beyond the project-specific costs F_i. In this case, the EVEF Problem becomes:

$$\max_{x_1,x_2} \quad \Pi(x_1,x_2) = B_1x_1 + B_2x_2 - k\Big(x_1^2\sigma_1^2 + x_2^2\sigma_2^2 + 2x_1x_2\rho\sigma_1\sigma_2\Big). \tag{2}$$

where $\Pi(x_1,x_2)$ is the total profit and k is the risk factor, which is to be varied in mapping the efficient frontier. To solve this problem, we calculate $\Pi(x_1,x_2)$ for all possible combinations of project implementations and determine by direct comparison the values of k where each specific portfolio is optimal:

$$\begin{aligned}
\Pi(1,1) &= B_1 + B_2 - k(\sigma_1^2 + \sigma_2^2 + 2\rho\sigma_1\sigma_2)\\
\Pi(1,0) &= B_1 - k\sigma_1^2\\
\Pi(0,1) &= B_2 - k\sigma_1^2\\
\Pi(0,0) &= 0.
\end{aligned}$$

Assume without loss of generality that projects are labeled so that $B_1 \geq B_2 > 0$. Let $k_1^* = \frac{B_2}{\sigma_2^2+2\rho\sigma_1\sigma_2}$, $k_2^* = \frac{B_1}{\sigma_1^2+2\rho\sigma_1\sigma_2}$, and $\hat{\rho} = \min\Big\{\frac{B_2\sigma_1^2 - B_1\sigma_2^2}{2\sigma_1\sigma_2(B_1-B_2)}, 1\Big\}$, and $\overline{\overline{k_i}} = \frac{B_i}{\sigma_i^2}$, $i \in \{1,2\}$. As we are interested here in positive (or at least not large negative) correlations, we also assume that ρ satisfies $\rho > \max\{-\frac{\sigma_1}{2\sigma_2}, -\frac{\sigma_2}{2\sigma_1}\}$, which implies that $k_i^* > 0, I \in \{1,2\}$. The optimal solution to the firm's optimization problem $\mathbf{x}^* = (x_1^*, x_2^*)$ is characterized by the following proposition (the proof of which follows from an exhaustive comparison of the above four profit outcomes).

Proposition 1. *Assume $B_1 \geq B_2 > 0$. (i) If $\sigma_2^2 \geq \sigma_1^2$, then $\mathbf{x}^*$ is characterized as in Figure 5(a). (ii) If $\sigma_2^2 < \sigma_1^2$, then $\mathbf{x}^*$ is characterized as shown in Figure 5(b).*

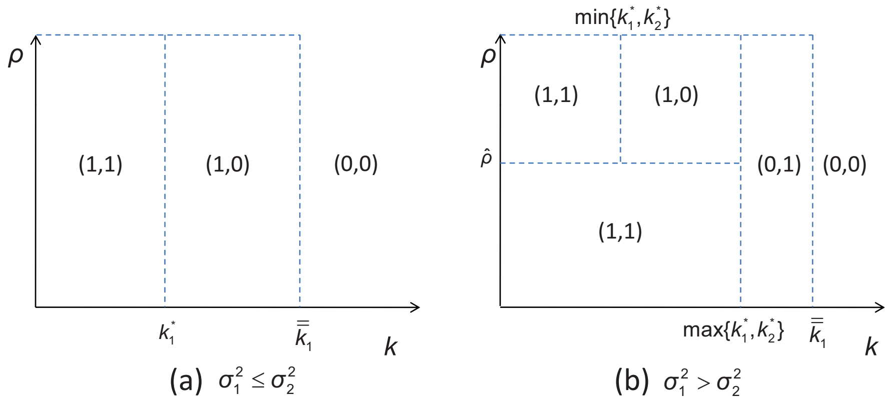

Figure 5

Proposition 1 states that when project 2 is Pareto-dominated by project 1 in the sense of mean-variance analysis, then when k is low–that is, the EE Project Manager is allowed to take more risk, it is optimal to implement both projects. When k is sufficiently high, however, the Manager implements only project 1 which has higher expected savings and lower variance.

The situation is more complicated in case one of the projects has higher expected savings with lower risk (which given our labeling convention here means that this is project 1). In this case, depending on the degree of correlation between the risky savings of these projects, different optimal portfolios result. When k is very low, then regardless of the value of ρ,[21] it is optimal to implement both projects. However, in the up-center part of Figure 5, where ρ is high and k has a middle value, it is only optimal to implement project 1 which has higher risk and lower expected returns. On the other hand, when k is high and the Manager is not allowed to take large risks, it is optimal to implement the safer project, with lower risk. We see, in particular, that a nested policy is no longer optimal in the presence of project correlation. It can also be noticed from Figure 5 that when the correlation coefficient is low (viz. when $\rho < \hat{\rho}$), implementation of the two projects is optimal for a larger range of k.

In concluding this Appendix, we note that the critical challenge for obtaining insights on project priorities and sequencing is, as usual, generating the necessary data. This means obtaining at

[21]We note that the assumption that $\sigma_1^2 > \sigma_2^2$, with $B_1 \geq B_2$ can be shown to imply that $\hat{\rho} \geq \max\{-\frac{\sigma_1}{2\sigma_2}, -\frac{\sigma_2}{2\sigma_1}\}$ as required by our assumption on ρ.

least rough estimates of potential project payoffs, correlations and the structure of additional fixed costs required to launch supporting technologies and competencies. The main purpose of the above exposition is, indeed, to provide the basic outline of the data necessary for prioritizing correlated EE projects. This implies foremost obtaining reliable data on project cash flows and supporting competency costs for potential EE projects. This crucial first step is the foundation for ensuing insights, priorities and objectives for EE implementation.

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