



A portfolio decision analysis approach to support energy research and development resource allocation



Margaret Kurth^a, Jeffrey M. Keisler^b, Matthew E. Bates^a, Todd S. Bridges^a, Jeffrey Summers^c, Igor Linkov^{a,*}

^a Environmental Laboratory, Engineer Research and Development Center, US Army Corps of Engineers, United States

^b College of Management, University of Massachusetts Boston, Boston, MA, United States

^c Office of Carbon Capture and Storage Research and Development, US Department of Energy, Germantown, MD, United States

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ABSTRACT

Research sponsored by the US Department of Energy (DOE) aims to facilitate a clean and independent energy future for the nation. Strategic planning for energy research and development (R & D) can be complex and dynamic, in part due to federal budgetary constraints and volatility. Managing R & D funding to advance energy technologies, in spite of these challenges, is a crucial component of the nation's long term energy policy. This study demonstrates a portfolio decision analysis (PDA) approach to support R & D resource allocation decisions for the DOE Office of Fossil Energy's Carbon Capture and Storage R & D program. A multi-attribute value model uses technology readiness levels (TRLs) and other metrics to represent the overall objectives of the R & D program in order to evaluate alternative research portfolios given limited funding. Mathematical optimization identifies efficient funding allocations for each technology program area to maximize the multi-attribute value generated from the total budget. This is especially useful for responding to externally imposed budget changes. As the case study demonstrates, explicitly funding the most value-generating options leads to greater expected R & D programmatic value than typical strategies of equal or proportional distributions of a budget change among technology program areas.

1. Introduction

The Presidential Climate Action Plan, released in June 2013, sets the groundwork for plans to abate the country's contribution to anthropogenic climate change and achieve greater energy independence (Executive Office of the President [EOP], 2013). The US Department of Energy (DOE) is responsible for conducting research and development (R & D) that will, in combination with carefully crafted policy, drive the nation to meet its aspirational clean energy goals (Anadon et al., 2014; Folger, 2013). Government R & D has the ability to catalyze the development of second generation and breakthrough technologies; drive down costs and overcome other barriers to implementation at scale; and build confidence in the market by adequately demonstrating technologies, all of which are necessary before significant uptake of new technologies will occur in the current power generation market (Folger, 2014). However, the characteristics of newly emerging and yet-to-be-discovered technologies that make them more suitable for government R & D are some of the same factors that confound decisions about R & D prioritization. Specifically, the

DOE and other government agencies sponsor exploration of technologies where market failures and high risk prevent private sector investment, and where payoffs exist primarily in the realm of shared social benefits (Anadon et al., 2014), factors which obfuscate the links between R & D investment and eventual quantifiable benefit.

DOE offices that administer R & D programs face these challenges in their strategic planning, which involves predicting budgetary needs and engaging in the iterative congressional budget process (Heniff, 2008). Strategic planning for R & D is concerned with allocating finite resources among portfolios of projects and partnerships that will advance a suite of technologies suitable for introduction into the marketplace, balancing progress between technologies with progress across the overall portfolio. A decision support tool can benefit DOE management given the volatility of external influences and necessity to plan for potential programmatic readjustment.

The history of R & D budget decision making at DOE includes periodic attempts to employ systematic budget planning, such as by tying funding levels to estimated benefits, but these attempts have lacked the consistency and transparency necessary to become common

* Corresponding author.

E-mail address: Igor.Linkov@usace.army.mil (I. Linkov).

practice (Anadon et al., 2014). Decision analysis, a discipline built on the pillars of systems analysis, decision theory, probability, and cognitive psychology (Howard, 2007), is often used to explicitly remedy this problem and further, it affords decision makers a way to leverage diverse sources of information and expert judgment. Portfolio Decision Analysis (PDA), as summarized by Salo et al. (2011), augments traditional decision support methods such as financial portfolio management and capital budgeting tools with techniques from decision analysis and operations research. The appropriateness of decision-analytic methods for developing an effective R & D strategy to meet US energy goals was asserted in a 2010 workshop by the DOE Office of Policy and International Affairs that convened at the Joint Global Change Research Institute to recognize and coordinate the role of portfolio analysis (Baker and Clarke, 2011). A special issue in Energy Policy on defining robust energy R & D portfolios, further articulates this need and highlights the research response to the workshop (Baker et al., 2015).

The present study contributes to the community's effort to develop energy technology portfolio analyses that support current and pressing energy decisions. A PDA model (PDAM) is developed and demonstrated for the carbon capture and storage (CCS) R & D allocation efforts that are administered by the DOE Office of Fossil Energy (DOE/FE). DOE/FE is currently exploring a wide range of approaches to CCS to make short-term incremental cost improvements as well as long-term transformational scientific advances (National Energy Technology Laboratory [NETL], 2013). R & D resource allocation for CCS technologies presents a complex and dynamic decision problem due to a finite budget, inherent risks from investing in emerging technologies, the multi-objective goals required to satisfy a heterogeneous marketplace, and the constraints imposed by numerous external drivers. A decision support system (DSS) that is tailored to the decision-making structure of the DOE CCS R & D management to support resource allocation could benefit the program and streamline progress towards national goals. Our case study illustrates how PDA methods can advance DOE R & D resource allocation decision making and support strategic planning, especially for the purposes of budget justification and allocation readjustment in response to external drivers that impact total budget.

2. Background and literature review

The DOE/FE CCS R & D program administers resources among systems of technologies that are needed to successfully reduce carbon emissions from the heterogeneous fleet of fossil fuel fired utility infrastructure. CCS technology has been designated as an important component of the national carbon management agenda for a number of reasons. First, conventional pulverized coal-fueled plants comprise a substantial portion (40%) of the country's electricity generation and, as a result, account for 35% of US CO₂ emissions (Office of Fossil Energy, n.d.). Thus, there is tremendous potential to impact the nation's contribution to the rising concentration of greenhouse gases in the atmosphere by addressing these emissions. Additionally, although alternative fuel and energy generation modes continue to comprise a growing portion of the energy profile, pulverized coal will likely remain an important energy source long into the future in the United States and elsewhere due to its low cost and wide distribution globally ("The Future of Coal", 2007). Lastly, while a shift to cleaner modes of energy generation is recognized as a critical and even primary driving force of the economy and society, energy supplies need to be maintained throughout the transition in a reliable and affordable fashion (EOP, 2013).

The challenge of how to allocate finite resources is well known in business and government, as well as widely addressed in the operations research and management science communities that seek to develop improved decision making approaches and decision support systems, e.g., with methods ranging from dominance sets (Augeri et al., 2011) to simulation based optimization (Lee et al., 2006) and in areas ranging

from counterterrorism (Haphuriwat and Bier, 2011) to healthcare (McKenna et al., 2010). Support for resource allocation decisions from the research community arises in the form of analytic tools and, while they diverge somewhat by discipline and industry, share foundations in how to structure complexity and leverage mathematical programming techniques. Although many of the fundamentals of making decisions in the face of multiple objectives are long established (Keeney and Raiffa, 1976), novel and decision-specific formulations continue to be sought. Government sector R & D strategic planning shares qualities with classic model-supported resource allocation cases from which techniques can be adapted to formulate a model that is tailored to the salient problem characteristics and decision maker requirements. The following paragraphs highlight the relevant theoretical support for the DSS developed in this study and previews its connection to the CCS R & D model application. The elements that are integral to the model are decision analysis, technology forecasting, and portfolio level performance metrics.

Similar to financial portfolio investments, CCS R & D strategic resource planning allocates a limited budget among portfolios of technologies with the expectation of potential reward in exchange for investment risk, without certainty about either the reward or the risk. However, unlike traditional investment decisions, which are often based on predictions about monetary returns expressed by a single metric (e.g., net present value) (Steuer et al., 2005), public sector R & D funding decisions are also motivated by non-financial factors and, in turn, also generate non-monetary value (Kleinmuntz, 2007). Adapting traditional portfolio management tools with decision analysis methods can enable a more flexible and sophisticated process (Duncan and Merrick, 2011). This is because decision analysis offers methods to expand the definition of value to include multiple domain-specific (and often non-monetary) attributes that influence decisions (Fernholz, 2011).

Growing concern about climate change has increasingly motivated researchers to take up the question of how government funding for energy technology R & D should be allocated. Whereas previous decision models to support energy R & D evaluate investment alternatives in terms of high level, fundamental climate objectives (e.g., to optimal cost of emissions abatement (Baker and Solak, 2011), economic and social welfare (Blanford, 2009), quantity of emissions reduction (Pugh et al., 2011)), it is more appropriate for the Division of CCS R & D to align funding and define value with respect to strategic goals. The office does not promote one particular CCS technology pathway over another, but seeks to develop a suite of technologies suitable for introduction into the marketplace, and therefore, are concerned with balanced progress in addition to total progress overall. Rouse and Boff (2001) define value of R & D in terms of readiness for transition, productivity, and innovation. A particularly poignant elaboration they make is that "value implies relevance, usability, and usefulness" as assessed by the beneficiaries of the R & D outcomes. For the case of CCS R & D resource administration, it is appropriate to use similar intermediate objectives; evaluating the technological modes for capturing carbon by the extent to which they are ready to be deployed in the market place, can be integrated into existing utility infrastructure, and have an attractive cost/tonne of carbon captured. Collapsing these multiple dimensions of benefit into a single value function (Phillips and Bana e Costa, 2007) enables the formulation of an optimization model to identify resource allocations that maximize the aggregated dimensions.

The level of funding that each pathway receives should be driven, in part, by how much it will advance technologies toward maturity, or a state that constitutes readiness for deployment. The DOE R & D implementation arm, NETL, evaluates the maturity of each active project and benchmarks the advancement of technologies under R & D from concept to deployment with a Technology Readiness Level (TRL) (United States Department of Energy [DOE], 2012). Initially developed by NASA (n.d.) in the 1970s, the TRL scale has become common place

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