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Future costs of key low-carbon energy technologies: Harmonization and aggregation of energy technology expert elicitation data

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HIGHLIGHTS

- Harmonization of unique dataset on probabilistic evolution of key energy technologies.
- Expectations about the impact of public R&D investments on future costs.
- Highlighting the key uncertainties and a lack of consensus on cost evolution.

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ABSTRACT

In this paper we standardize, compare, and aggregate results from thirteen surveys of technology experts, performed over a period of five years using a range of different methodologies, but all aiming at eliciting expert judgment on the future cost of five key energy technologies and how future costs might be influenced by public R&D investments. To enable researchers and policy makers to use the wealth of collective knowledge obtained through these expert elicitations we develop and present a set of assumptions to harmonize them. We also aggregate expert estimates within each study and across studies to facilitate the comparison. The analysis showed that, as expected, technology costs are expected to go down by 2030 with increasing levels of R&D investments, but that there is not a high level of agreement between individual experts or between studies regarding the technology areas that would benefit the most from R&D investments. This indicates that further study of prospective cost data may be useful to further inform R&D investments. We also found that the contributions of additional studies to the variance of costs in one technology area differed by technology area, suggesting that (barring new information about the downsides of particular forms of elicitations) there may be value in not only including a diverse and relatively large group of experts, but also in using different methods to collect estimates.

1. Introduction

The economic practicality of paths towards a sustainable future depends crucially on the future costs of low-carbon energy technologies. The recently published 5th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), in its summary for policy makers, points to the fact that: "estimates of the aggregate economic costs of mitigation vary widely and are highly sensitive to model design and assumptions as well as the specification of scenarios, including the characterization of technologies and the timing of mitigation" [IPCC 5th AR, WG III, mitigation2014.org]. Indeed, total discounted mitigation costs (2015–2100) may increase up to 138% when some technologies are limited in their availability. It is expected that costs for most of these technologies will continue to fall, driven by various factors including research and development, economies of scale, and experience effects. However, the specific trajectories that costs may take in the future are highly uncertain. In the absence of a clairvoyant who can eliminate these uncertainties, policy decisions should be informed by the most credible judgments of technology costs available, and incorporate explicit estimates of the uncertainties. Given that society may not be able to fund every research direction to a level that would make a difference, effective policy

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decisions should include a probabilistic treatment of uncertainties over a large set of foreseeable scenarios using the best available information from technical experts at the time.

The 2010 InterAcademy Council review of the climate change assessment of the IPCC had only one substantive (rather than process-oriented) topic in its recommendations – the treatment of uncertainty:

“To inform policy decisions properly, it is important for uncertainties to be characterized and communicated clearly and coherently. … Quantitative probabilities (subjective or objective) should be assigned only to well-defined outcomes and only when there is adequate evidence in the literature and when authors have sufficient confidence in the results. … Where practical, formal expert elicitation procedures should be used to obtain subjective probabilities for key results” (Council, 2010).

Similarly, the National Research Council (NRC, 2007) recommends that the U.S. Department of Energy use probabilistic assessment based on expert elicitations of R&D programs in making funding decisions. Thus, despite the inherent subjectivity of expert elicitations, they are the primary means for forecasting the implications of Research and Development, and are of growing interest.

On December 2–3, 2010, the Department of Energy's Office of Policy and International Affairs sponsored a two-day workshop on energy RD&D portfolio analysis. This workshop concluded that (1) the large and growing elicitation data sources need to be integrated with each other and with other relevant data on technology supply, and (2) that the integrated data needs to be communicated in ways that are useful to a variety of users, including both government decision makers and researchers who require expert technology supply information for their research (Clarke and Baker, 2011).

This paper outlines the results of three major expert elicitation efforts carried out independently by researchers at UMass Amherst (Baker and Keisler, 2011; Baker et al., 2008, 2009a, 2009b), Harvard (Anadón et al., 2012, 2014a; Chan et al., 2011), and FEEM (Bosetti et al., 2012; Catenacci et al., 2013; Fiorese et al., 2013). Each of the three groups covered many of the most promising future clean energy technologies [IPCC 5th AR, WG III, mitigation2014.org]: liquid biofuels, electricity from biomass, carbon capture (CCS), nuclear power, and solar photovoltaic (PV) power. The surveys varied considerably in terms of quantities elicited, projected dates, funding assumptions, types of questions, and modes of survey administration. These differences make the comparison challenging, but also allow us to span a variety of different assumptions and detect whether there are robust insights to be drawn by these exercises taken together.

1.1. *Current state of knowledge on expert elicitations for energy technologies*

There exist a number of expert elicitation studies on energy technology projects and programs. Table 1 summarizes the studies to date that focus expressly on eliciting probability distributions over parameters of energy technologies. The EERE division of the USDOE has also performed a number of elicitations, but they are not publicly available.

These studies were performed independently across organizations (and sometimes within) and often are very difficult to compare, due to their structural differences. See Table 2 for an example of the range of studies on CCS (Carbon Capture and Storage). Among these studies, the potential futures are assessed at different target years, ranging from 2022 to 2050; they assess

Table 1
Summary of existing expert elicitation studies on energy technologies

Organization	Technologies: CCS	Solar	Biomass	Nuclear	Storage/EV	IGCC
UMass	(Baker et al, 2009a; Jenni et al., 2013)	(Baker et al, 2009b)	(Baker et al., 2011)	(Baker et al., 2008)	(Baker et al., 2010)	
Harvard	(Chan et al., 2011)	(Anadon et al., 2014b)	(Anadon et al., 2014b)	(Anadon et al., 2012)	(Anadon et al., 2014b)	
FEEM	(Ricci et al., 2014)	(Bosetti et al., 2012)	(Fiorese et al., 2013)	(Anadon et al., 2012)	Catenacci et al., 2013	
Carnegie Mellon	(Rao et al., 2008)	(Curtright et al., 2008)		(Abdulah et al., 2013)		
NAS, Duke	(NRC, 2007; Chung et al., 2011)					NRC, 2007

Key: UMass (University of Massachusetts, Amherst, Mechanical and Industrial Engineering Department); Harvard (Harvard University, Belfer Center for Science and International Affairs, John F. Kennedy School of Government); FEEM (Fondazione Eni Enrico Mattei, Milan Italy); EERE (Office of Energy Efficiency and Renewable Energy); NAS (National Academy of Science).

Table 2
A comparison of CCS studies

Group	Endpoint year	Format	# of experts	Technology	Endpoints
UMass	2050	Survey, mixed	4	Pre, post, chem looping	Various technical and cost
UMass 2	2025	F2F	11	Pre, post, alt	Energy penalty
Harvard	2030	Survey	13	General (different experts assessed the technology they considered most-commercially viable)	Capital cost, efficiency, capacity factor, and book life
FEEM+UMass	2025	Web survey	TBD	Pre, post, alt	Energy penalty
Carnegie Mellon	2030, 2050	F2F	12	Absorb (post-C)	Various technical
Duke	2030	Survey, follow-up	11	Amines, chilled ammonia, oxy-combustion	Energy penalty
NAS	2022	Panel F2F	12	General	LCOE

Key: see Table 1 for group abbreviations; F2F – face to face; pre – pre-combustion; post – post-combustion; alt – alternative combustion.