Non-Energy Benefits from Energy Productivity Improvements: A Cobb-Douglas Approach to Measuring Impact on GDP[1]

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ABSTRACT

This paper examines the impacts of energy efficiency measures and productivity improvements on GDP. Energy efficiency measures often yield significant energy savings that are accurately measured. In many cases, energy efficiency measures also generate important non-energy benefits that are not systematically represented in most models or M&V protocols. Productivity improvements lead to better or greater production, which is also well quantified. However, productivity improvements often result in energy savings, which are rarely captured either. Because non-energy benefits are not always captured the impact of energy efficiency on GDP growth is often understated. Because energy savings from productivity improvements are not often measured, the impact on GDP growth from such improvements is incomplete.

To better explore the large-scale economic benefits of energy efficiency, we detail the types and scale of non-energy benefits resulting from implementation of energy efficiency measures and energy savings that stem from improvements to production equipment. The data is then analyzed using a Cobb Douglas model to show the impact on GDP from such measures. The model shows that when non-energy benefits from energy efficiency measures and energy savings from productivity improvements are captured, positive impacts on GDP growth result. The inclusion of non-energy benefits in such a model provides a more accurate assessment of the impact of energy efficiency on GDP. By integrating such benefits systematically in economic models, energy efficiency and investments in production equipment can become more compelling.

Introduction

For the past two decades, a growing body of literature has demonstrated that positive externalities result from the implementation of energy efficiency measures across industrial, commercial and residential sectors. More recently, several reports have discussed unanticipated energy savings that were recorded when investments in productivity were made. Most payback models and M&V protocols assess the impacts of such projects based solely on the energy cost savings from energy efficiency and production increases from productivity investments. This

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leads to overly modest performance metrics and an imperfect understanding of the full impact of the respective investments in energy efficiency and productivity.

Several analyses have used modeling frameworks that incorporated the impacts of non-energy benefits from energy efficiency investments. These analyses show that when such benefits are systematically included, the returns on investment are significantly higher than when they are omitted. This should make investments in energy efficiency more compelling for homeowners, companies, manufacturers, and institutions. At the same time, including energy savings from productivity improvements in performance metrics can improve the return of productivity in those investments. In addition to making the business case of energy efficiency more compelling, integrating non-energy benefits of energy efficiency and energy savings of productivity investments can yield more accurate estimates of GDP growth.

In this paper we use a three-factor Cobb-Douglas production model to demonstrate the impact of non-energy benefits and energy savings on GDP growth. We also examine the impacts of such benefits and energy savings on climate change as one important non-energy benefit of energy efficiency is the reduction in greenhouse (GHG) gases. Analyzing such benefits in this and, similar frameworks can more accurately reveal the full impacts of energy efficiency and productivity improvements. Such analyses can also deliver important policy insights for government officials, corporate officers and homeowners.

We begin with a definition of energy efficiency, a literature review of non-energy benefits from energy efficiency and show how such benefits amplify the impact of energy efficiency. We then discuss studies showing that energy savings are often recorded when productivity improvements are undertaken. Next, we present the Cobb-Douglas production model and the three-factor version used in this analysis. We show how energy savings from efficiency and productivity improvements affect the energy shift parameter and the impact on GDP growth. We also discuss their impact on climate change. We conclude by discussing how non-energy benefits can be used in performance models and M&V protocols to improve the business case of energy efficiency. We also present some recommendations for raising awareness of non-energy benefits and their impact within the educational and professional infrastructure that is involved in evaluating energy-saving and productivity-enhancing activities.

Literature Review

For many observers, energy efficiency measures involve installing or replacing discrete technologies or equipment with new, similar technologies that are capable of reducing energy use. This is because there is an assumption that factories and commercial facilities operate as technologically efficiently as possible since they are profit-oriented (Browning & Zupan 1999). As a result, implementing energy efficiency measures is thought to require large capital outlays and significant amounts of time, which can interrupt production (McKane, Pye, Laitner 1999). However, it is important to understand that energy efficiency involves proper engineering in addition to installing or replacing existing technologies with new ones. In many cases, significant energy savings and other benefits were achieved through proper engineering measures alone (Lung, McKane, and Olszewski 2003). Often, investments in energy efficiency measures involving proper engineering require minimal investment and, therefore, have short returns.

When factored into the mix of energy efficiency measures, those characterized by re-engineering of existing equipment hold significant promise in terms of cost and performance.

Several studies show than when non-energy benefits of energy efficiency investments are quantified and integrated into evaluation models the return on investment increases significantly (Worrell et al. 2003; Lung et al. 2005; Pye, McKane, Laitner 1999). In one study of 52 industrial efficiency upgrades (Worrell et al. 2003) the non-energy benefits were sufficiently large that they lowered the aggregate simple payback for the energy efficiency measures from 4.2 years to 1.9 years. Another study comprised of 81 separate industrial energy efficiency projects (Lung et al. 2005) showed an aggregate simple payback from energy savings alone of less than 2 years. When non-energy benefits were factored into the analysis, the simple payback fell to slightly under one year, indicating annual returns higher than 50 percent.

Other studies have quantified or reported links between non-energy benefits and energy efficiency measures in commercial and residential settings. One study found that up to 55% of efficiency improvement projects in commercial buildings yielded non-energy benefits and that the magnitude of such benefits to energy savings averaged 30% (Birr, 2008 p. 15). In several studies of energy efficiency improvements in residential buildings, non-energy benefits have been calculated to represent between 10 to 50 percent of the household energy savings from those measures (Amann 2006). Another study assessed the value of non-energy benefits for residential buildings and found that their value outweighed the value of the energy savings (Smith-McClain, Skumatz, Gardner, 2006). These studies demonstrate that when the positive externalities of energy efficiency investments are captured in conventional performance models, they make such investments more compelling.

In addition to increasing the attractiveness of investing in energy efficiency, non-energy benefits can amplify the macro-economic impacts of energy efficiency measures. This can happen by improving a shift parameter of a macro-economic growth model. In the case of a two-factor Cobb-Douglas model capital (K) is made more productive by some amount of energy efficiency. This augments the value of the capital parameter, yielding greater GDP growth. Energy savings from productivity improvements can also be captured. In a three-factor Cobb-Douglas model with an energy (E) parameter, reductions in energy consumption lower the weight of E in the model, yielding greater GDP growth.

Some studies have estimated increases in output and employment from energy efficiency improvements. One study by Imbierowicz, Skumatz & Gardner calculated that energy efficiency measures yielded economic output multipliers that ranged from 74 to 320% (Imbierowicz, Skumatz & Gardner 2006). This study also examined several other analyses of job creation from investments in energy efficiency yielded a range of job creation of 5.6 to 71 jobs per million dollars of energy efficiency investment. Integrating non-energy benefits from energy efficiency measures and energy savings from productivity improvements, can lead to more robust macro-economic growth models.

Non-Energy Benefits and Business Case for Energy Efficiency

Historically, energy and energy cost savings from energy efficiency measures have served as the prime technical and financial justification for implementing energy efficiency projects. This approach was logical and readily possible due to the availability of energy use and cost data. In addition, a wide variety of audiences including consultants, vendors, managers, academia and homeowners believed that energy savings were the only reliably quantifiable result of energy efficiency measures (Pye, McKane & Laitner, 1999). Because energy was relatively inexpensive, energy costs were considered hidden or a small part of overall production costs and, therefore, returns from energy efficiency measures based solely on energy savings were not highly significant (Bonneville, 2005). Also, since companies, individuals and institutions had limited resources, energy efficiency projects were often postponed in favor of projects having greater returns or that were perceived to be more valuable.

Such an approach does not enable stakeholders from understanding the ‘big picture’ of energy efficiency. When quantifiable non-energy benefits related to energy efficiency implementation have been integrated in financial models to evaluate energy efficiency investments, greater returns (lower paybacks) from such measures have been realized (Worrell et al. 2003; Lung et al. 2005; Pye, McKane, Laitner 1999). However, the systematic incorporation of quantifiable non-energy benefits to evaluate the performance of energy efficiency measures has yet to occur.

Another barrier to implementing energy efficiency measures is the idea that the implementation of such measures requires new equipment that is very costly and time-consuming to install. While it is true that newer, more sophisticated process and support equipment is generally more efficient, installing such equipment is not the only way to achieve energy efficiency. In the industrial sector, energy efficiency projects using best practices in engineering and maintenance can go a long way in reducing energy consumption and achieving strong returns (Lung, McKane, and Olszewski 2003). Between 2006 and 2009, approximately 40 percent of energy efficiency recommendations in 100 assessments of papermaking machines could have been implemented with no capital costs (Reese 2009). In several cases, the papermaking efficiency recommendations could have also improved the machines’ productivity and reduced their water consumption.

Non-energy benefits can improve the business case for energy efficiency investments across industrial, commercial and residential sectors, thereby making such investments more compelling. Numerous examples of greater returns from incorporating non-energy benefits in performance models abound in the industrial sector. In the iron and steel industry, the simple payback for 52 projects fell from 4.2 years to 1.9 years when non-energy benefits were included (Worrell et al. 2003). Another analysis of energy efficiency projects in a broad cross-section of industrial plants showed that the inclusion of non-energy benefits reduced the aggregate simple payback from slightly more than 1.5 years to less than 1 year (Lung et al. 2005). Because management in corporations need to be mindful of the bottom-line impact of their decisions, it is imperative to include non-energy benefits in the evaluation of energy efficiency projects in order to factor all of the potential savings and other benefits that a manufacturing plant will attain by implementing energy efficiency measures.

In the residential sector, non-energy benefits are harder to quantify than for the industrial and commercial sectors. However, studies have shown that when non-energy benefits are estimated and included, they increase the value of energy efficiency improvements to homeowners and occupants (Smith-McClain, Skumatz and Gardner 2006; Amman 2006). Some researchers have used survey data to determine dollar values of perceived non-energy benefits such as better house aesthetics, greater occupant comfort, health and productivity, and lower maintenance costs (Smith-McClain, Skumatz and Gardner 2006). In one study the value of non-energy benefits from upgrading insulation and retrofitting HVAC systems consistently outweighed the value of energy savings (ibid). Another study of residential retrofit programs in the U.S. found that quantified non-energy benefits were estimated to be worth between 50% and 300% of the energy savings from the retrofit projects (Amman 2006). This study also examined certain cost-effectiveness tests and found that when such tests incorporated non-energy benefits, the cost-benefit ratios rose by as much as 100%. These results show that non-energy benefits may be more attractive than the energy savings from energy efficiency measures. This could encourage greater numbers of homeowners to implement energy efficiency measures.

In the commercial sector, non-energy benefits have not been systematically quantified for many reasons. The single largest reason is data collection; the baseline and post-implementation data of non-energy systems is not readily available and acquiring this data is considered excessively time-consuming. One additional barrier to acquiring this data is a short-term focus by many managers that obviates proper evaluation of the impact of energy efficiency (Birr 2008). Because some non-energy benefits take longer to be realized after energy efficiency measures are implemented, this short-term focus forestalls the approach needed to monitor and quantify such benefits (ibid). One survey of institutional and commercial buildings that did attempt to capture O&M savings in the wake of energy efficiency projects, found that O&M savings were reported in 26% of municipal and healthcare facilities, and 55% of federal government buildings (Birr 2008).

In addition to the savings and other benefits that commercial and institutional buildings can derive from energy efficiency measures, utilities can benefit significantly from energy conservation efforts by such customers. This is because reduced energy demand and consumption by large commercial and institutional customers lowers the cost of service for electric utilities (Birr 2008; Lovins 2002). Avoided utility system costs, which include avoided costs of transmission, distribution and generation capacity, can be significant when energy and demand savings are realized by many large customers. As a result, energy efficiency measures that reduce demand and consumption create value for utilities. One study estimated that if all utility system cost reductions from commercial customer energy efficiency measures was quantified, such avoided costs could represent as much as 30% of the value of annual energy savings (Birr 2008). The savings from avoided utility costs can be passed on to all consumer classes through lower average electric bills and reduced risk of brownouts or outages.

Energy Savings from Productivity Improvements

Recently, several studies have analyzed improvements to plant processes and production equipment that have yielded substantial energy savings. As energy prices have risen to historically high levels, energy savings can provide additional incentive for implementing productivity improvements. One analyst, B. Oppenheimer, estimated that as many as half of all productivity improvements in manufacturing plants generate significant energy savings (LaPalme et al. 2007). Other studies have used techniques to disaggregate plant energy use from production-dependent energy use and have estimated reduced energy intensities stemming directly from process and productivity improvements (LaPalme 2007; Seryak 2007). In one study of 22 manufacturing plants that implemented process improvements, output increased by 90% per month and energy intensity per unit declined by 47% (LaPalme et al. 2007). Another study reviewed several manufacturing processes that underwent Lean Manufacturing events (Seryak et al. 2007). This study found that such productivity improvements can yield greater production and improved process energy efficiency at production rates that were higher than the maximal production rates in effect before each event (ibid). These improvements in energy intensity ranged from 1.5% to 12.5% (ibid).

The installation of emerging technologies has significant energy savings potential. One study of four emerging industry-relevant technologies in the food processing sector (energy-efficient blanching, pulsed electric field (PEF) pasteurization, radio frequency (RF) drying, and evaporator fan controllers for refrigerated cold storage) estimated the technical potential for annual energy savings from those four technologies at 2.22 TBtu and 186 million kWh (Lung 2006). Several instances in which these technologies were installed showed either strong energy savings or improved production. In the case of the energy efficient blancher, energy costs and energy consumption decreased by 4% and 10% respectively in one plant and in another, production increased 300% (ibid). The installation of a radio frequency dryer at a bakery resulted in a 30% increase in production, a reduction in annual purchased energy equivalent to 600 barrels of oil, and annual O&M savings of $715,000 (ibid). Another study of 54 emerging industry-relevant technologies estimated the technical potential for primary energy savings for all 54 technologies at approximately 3.54 Quadrillion Btu, representing 8.4% of the assumed 2015 industrial energy consumption (Laitner et al. 2003). This same study estimated an economically achievable potential of 2.66 Quadrillion Btu based on energy prices in 2015 as forecasted in the 2002 Annual Energy Outlook (ibid).

In addition to energy savings that are immediately apparent in the wake of measures intended to improve production, such measures often create opportunities to achieve greater savings in other areas. When production equipment is replaced with newer equipment or when processes are reconfigured there is often an opportunity to downsize crosscutting supporting systems. When a manufacturing plant is built the crosscutting systems that deliver steam, fluids, air, etc. are sized to support the production processes and equipment in place at that time. When production-related processes and equipment are retrofitted with less energy-intensive equipment the crosscutting systems in the plant can often be downsized without negatively affecting production. Several examples across multiple industries have been highlighted in case studies produced by the U.S. DOE’s Industrial Technologies Program. In 1999, a new printing machine at the John H. Harland Corporation’s Atlanta, Georgia, facility significantly increased the site’s compressed air demand. By reconfiguring the new printing machines to require less compressed air, the company avoided purchasing $500,000 in additional air compressors, which would have consumed 2.9 million kWh and cost more than $200,000 annually[2]. At Visteon's Nashville, Tennessee, glass plant the pumping system serving the cooling processes was left unchanged while production equipment was made smaller over several decades. When that pumping system was evaluated, the plant found that it could operate with fewer pumps. The resulting project yielded annual energy cost savings of $288,000[3].

While quantified energy savings from productivity improvement projects are an unanticipated benefit for the plants that achieve them, such savings can have important implications for macro-economic models of energy usage. Studies have shown that models of energy production and consumption have often over- and under-estimated national energy production and consumption level in the U.S. (Laitner 2003). In some cases, incorrect estimates by energy models have been severe (Ibid). These varying results can also have consequences for policy-making. In 1996, the Annual Energy Outlook (AEO) forecast of U.S. energy consumption in the year 2000 was significantly lower than the actual energy usage for that year. The data from that AEO estimate was the most recent forecast available to U.S. officials leading up to the 1997 Kyoto summit that determined the greenhouse gas emission reductions protocol. This forecast gave the negotiators an overly negative expectation of the U.S.'s future energy use, which could have affected the flexibility they had and the objectives they pursued (Laitner 2003).

The results of such imprecise models can have important repercussions for forecasts of GDP growth and economic policy. Over-estimates of energy consumption can lead to overly modest estimates of GDP growth and excessively low estimates of energy usage can result in exaggerated estimates of GDP growth. Energy models that take account of energy savings resulting from productivity improvements can become more properly characterized and can therefore, provide more exact and robust estimates of energy production and consumption.

Three-Factor Cobb-Douglas Production Model

The Cobb-Douglas production model is one of the most widely used economic models for representing the relationships between inputs and the level of output. This group of functions generally takes on the form $Q = AL^aK^b$, where Q signifies output, A is the constant and L and K are the production factors representing labor and capital, respectively. The exponents in the model represent the output elasticities of labor and capital, respectively. The output elasticities measure the sensitivity of output to a change in levels of the inputs, which in most cases is either labor or capital. The sum of the output elasticities determines the returns to scale of the production factors. The Cobb-Douglas model assumes constant returns to scale, so the output elasticities sum to one ($a + b = 1$). This means that if each of the inputs increases by 10%, output increases by 10%. If the output elasticities in a Cobb-Douglas function sum to less than one, then the returns to scale will be decreasing (a 10% increase in inputs will yield an increase in output of less than 10%). If the output elasticities sum to more than one, the function will have increasing returns to scale, i.e., a 10% increase of inputs yields an increase in output greater than 10%.

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[2] http://www1.eere.energy.gov/industry/bestpractices/pdfs/bp_cs_harland.pdf

[3] http://www1.eere.energy.gov/industry/bestpractices/pdfs/gl_cs_visteon_nashville.pdf

Historically, most economic production models have focused on capital and labor as the main inputs and have not specified energy as a relevant production factor (Buenstorf 2004). One possible reason is that many production models often focus on factor costs and the share of energy as a cost of production has historically been small in relation to inputs such as capital and labor (ibid). When energy has been considered in economic production models, it has usually been within the context of studies of exhaustible natural resources and economic growth (ibid). Such research has generally found that indefinite positive consumption without technological improvement depends greatly on the elasticity of substitution between a finite resource and reproducible capital (ibid). If this elasticity is greater than one, production can continue without the use of this resource, allowing for continued consumption and positive economic growth (ibid).

However, in one study Robert Solow found that a positive level of consumption, and therefore growth, can occur indefinitely if the output elasticity of production capital exceeds the output elasticity of a given finite resource used by the capital (ibid). This finding satisfies the requirement that constant elasticity of substitution be greater than one for the Cobb-Douglas framework. In another study, Joseph Stiglitz used the Cobb-Douglas model to show that positive per-capita consumption can be maintained if the rate of resource-augmenting technological change is at least as high as the population growth rate (Stiglitz 1974). This body of research demonstrates that if energy is treated as a proxy for finite resources it can be integrated as a parameter in a Cobb-Douglas production model used for estimating economic growth.

For this paper, we use a 3-factor Cobb-Douglas model that includes energy as a production factor. We assert that GDP is a function of Labor non-energy, Capital non-energy, energy used plus the difference between energy used in production and imported energy. The model takes the form $Q = AL^aK^bE^c + (E\ prod - E\ imp)$ where Q is GDP, A is the constant, L is labor, K is physical capital, E is energy used, E prod is the energy used in production, and E imp is imported energy. By using energy as a production factor, this model also turns energy into a shift parameter so that changes to energy use, holding the other factors constant, cause a shift in GDP. The output elasticities a, b and c sum to one, signifying that the model assumes constant returns to scale.

The model uses a number of assumptions:

- Energy intensity reduction of 30% between 1990 and 2030
- Energy cost of $12.95/MMBtu calculated from the 2009 AEO deflated to 2000 dollars
- Energy use of 113.6 exajoules projected by the 2009 AEO as implied total primary energy use in 2030
- Median labor wages of $65,000/year
- A labor force of 164.4 million employed workers
- A 10% return on the rented price of capital
- A capital stock valued at $60 trillion in 2000 dollars

Two scenarios in addition to an initial ‘business as usual’ scenario were run through the model that could yield an energy intensity reduction of 30% between 1990 and 2030, a price shock and a productivity-led scenario. The initial scenario in which no reduction in energy intensity occurred yielded total annual value of energy used of $1,474 billion, potential GDP of $20.1 billion and energy intensity of 5.65. The price shock scenario, in which the price of energy rises 30%, resulted in total annual value of energy used of $1,030 billion, potential GDP of $20.2 billion and energy intensity of 3.93. With the productivity-led scenario, in which a net productivity improvement of 2.2% reduces energy intensity by 30%, the total annual value of energy used falls to $1,030 billion, potential GDP rises to $20.4 billion and energy intensity declines to 3.90. In both the price shock and productivity scenarios, energy intensity declines vis-à-vis the initial scenario by 30.35% and 30.92% respectively. This is shown below in Table 1.

Table 1. Scenarios Highlighting GDP Changes from Changes in Energy Efficiency

	Business as Usual	Price Shock Only	Percent Change	Productivity-Led	Percent Change
Constant	2.648	2.648	0.00%	2.669	0.80%
Capital Non Energy	6,000	6,293	4.90%	6,293	4.90%
Labor Non Energy	10,755	10,901	1.40%	10,901	1.40%
Energy Used	1,471	1,030	-30.00%	1,030	-30.00%
Non Energy Output	20,555	20,525	-0.10%	20,689	0.70%
Non Energy GDP	19,084	19,495	2.20%	19,660	3.00%
Energy Production	1,029.60	721	-30.00%	721	-30.00%
Energy Imports	441	309	-30.00%	309	-30.00%
Potential GDP (billion 2000 $)	20,114	20,216	0.51%	20,380	1.32%
E/GDP	5.65	3.93	-30.35%	3.9	-30.92%

Both the price shock and productivity scenarios assume that the reduced energy production frees up labor for use in non-energy output, which yields the increase in GDP. The output elasticities of labor, capital and energy are 0.61, 0.32 and 0.07 respectively. The impact of both the price shock and the productivity increase yield significant reductions in energy intensity. If increased energy efficiency yields a positive change in productivity of capital, positive GDP growth could be significant. With a productivity-led scenario, in which energy efficiency causes a net productivity improvement of 20% and reduces energy use by 30%, the total annual value of energy used falls to $1,030 billion, potential GDP rises to $21.9 billion and energy intensity declines to 3.63. This shows that small improvements in energy efficiency, shift parameter (E), can yield larger impacts on GDP growth. These results are shown in Table 2.

Table 2. Impacts from Improved Assumptions about Energy Efficiency Dynamics

	Business as Usual	Price Shock Only	Percent Change	Productivity-Led	Percent Change
Constant	2.648	2.648	0.00%	2.868	8.30%
Capital Non Energy	6,000	6,293	4.90%	6,293	4.90%
Labor Non Energy	10,755	10,901	1.40%	10,901	1.40%
Energy Used	1,471	1,030	-30.00%	1,030	-30.00%
Non Energy Output	20,555	20,525	-0.10%	22,232	8.20%
Non Energy GDP	19,084	19,495	2.20%	21,202	11.10%
Energy Production	1,029.60	721	-30.00%	721	-30.00%
Energy Imports	441	309	-30.00%	309	-30.00%
Potential GDP (billion 2000 $)	20,114	20,216	0.51%	21,923	8.99%
E/GDP	5.65	3.93	-30.35%	3.63	-35.78%

Climate Change

One additional impact of reduced energy use stemming from economy-wide gains in energy efficiency is the potential for reductions in Green House Gas (GHG) emissions that could mitigate climate change. Since total GHG levels are linked to total energy expenditures, decreases in energy consumption could lead to decreases in total emissions (Laitner 2009). As an example, the industrial sector accounts for almost 40% of total global primary energy use per year and a corresponding amount of global CO2 emissions related to such energy consumption (Welsch 2008). According to both the International Energy Agency (IEA) and the Intergovernmental Panel on Climate Change (IPCC), potential reductions in CO2 from implementing energy efficiency measures for five energy-intensive industrial subsectors ranges from between 10% and 40%, depending upon the sector (ibid). In addition, the IEA has estimated that the technical potential to reduce total energy-related CO2 emissions by 2030 is approximately 50% depending on the type and amount of implemented energy efficiency measures (ibid).

Other forecasts reveal potentially significant GHG emissions reductions from the implementation of energy efficiency measures. One recent analysis estimated that energy efficiency could yield primary energy savings of 18.4 quadrillion Btu by 2020 with corresponding decreases of 1.1 gigatons of CO2 (McKinsey & Company 2009). Another study projected energy use, GDP growth and GHG emissions to 2050 (Laitner 2009). This analysis used a reference case in which no energy efficiency implementation, an assessment with typical modeling procedures, a scenario with high efficiency factors typically omitted in many models, and an analysis that includes the third scenario and the purchase of international offsets. This study projects that total GHG emissions for both energy-related CO2 emissions and all other non-energy related emissions increases 23% from 7,119 million metric tons of CO2 (MMTCO2e) in 2010 to 8,739 MMTCO2e by 2050 in the reference case (ibid). The typical modeling assessment shows a decrease of 3,277 MMTCO2 by 2050, the high efficiency scenario shows a decrease of 7,167 MMTCO2 by 2050 and the fourth scenario shows a decrease of 6,167 MMTCO2 within the same timeframe (ibid). Just as significantly, the typical policy case shows that GDP is negatively impacted by costs of $700 billion to improve energy efficiency. However, both the high efficiency and the high efficiency scenario including international offsets show net negative costs for energy efficiency implementation (because energy efficiency produces downward pressure on energy costs), yielding positive gains to GDP of $456 billion and $276 billion, respectively (ibid).

Conclusion

Empirical evidence from almost twenty years of data collection and analysis by multiple researchers suggests that energy efficiency delivers more than reduced energy use and lower energy bills. Rather, expenditures in energy efficient practices and technologies are more akin to investments in economic productivity because the impacts of these expenditures frequently deliver positive benefits in production, maintenance requirements, emissions and numerous other categories. When such impacts are included in economic production models, the true impacts of such investments to the economy are captured, which deliver important insights to policymakers, corporate managers and homeowners. Understanding how energy efficiency investments add value for myriad stakeholders can serve to reduce and, eventually, eliminate significant and enduring barriers to implementing energy efficiency measures. Several steps can be taken to help to bring about greater awareness of the true impact of energy efficiency.

The first approach towards capturing the full impacts of energy efficiency across all economic sectors is to include measurement of non-energy costs in all pre-implementation baseline measurements and measurement and verification (M&V) protocols. Currently, most assessments of energy use include robust baselines of energy consumption and the corresponding M&V protocols capture changes in energy use once recommended energy efficiency measures are implemented. If such baselines were to include metrics of maintenance costs, ancillary equipment & materials, production levels, warranty claims, air quality, real estate values and personal comfort, then capturing non-energy benefits during the M&V process would be easy and meaningful since the baseline metrics would be uniform for all assessments. Energy management standards that integrate such measurements would be able to deliver even greater insights to multiple groups of stakeholders.

The second way to understanding the true economic impacts of energy efficiency is to include non-energy benefits from energy efficiency implementation and energy savings from productivity improvements into major economic and technical models. Numerous stakeholders including policymakers, researchers, students, and non-profit organizations depend on models such as the National Energy Modeling System (NEMS) and the Manufacturing Energy Consumption Survey (MECS) for a variety of needs. In fact, data from the NEMS model is used to generate the Annual Energy Outlook. Integrating all the impacts from energy efficiency implementation and energy savings from productivity improvements could increase the accuracy and robustness of such models, thereby increasing their value to their existing user base as well as newer groups of users.

The third method of expanding awareness about the complete impacts of energy efficiency is to include such impacts and ways to measure them in the educational curricula for individuals involved in energy-related endeavors. One of the largest barriers to implementing energy efficiency is the perception that energy efficiency is a luxury or that benefits from energy efficiency projects are minor compared with initiatives intended to improve production. This is partly because most evaluations of energy efficiency projects rely on the energy and energy cost savings alone to establish return on investment. However, there is also an assumption that because the private sector is motivated by profits, manufacturing plants and other corporate buildings and assets are operated as efficiently as possible. Not only does this place a premium on newer technologies to achieve energy savings, but it also obscures the reality in some cases that energy-using systems can be miss-specified or poorly maintained. Including non-energy impacts of energy efficiency in engineering, economics, and management curricula along with continuing education programs by corporations, trade associations, public sector and non-profit organizations can raise awareness within the energy community and lead to widespread inclusion in the analysis of energy-efficiency projects.

This paper has reviewed many studies and data of non-energy benefits that resulted when energy efficiency projects were implemented as well as energy savings that were recorded after improvements to production equipment were undertaken. Such information was applied to a

Cobb-Douglas production model to simulate the macroeconomic impact, specifically GDP growth that such activities can produce. The Cobb-Douglas model showed a positive impact on GDP growth when energy is treated as a production factor. By including data on non-energy benefits from energy efficiency measures and energy savings from productivity improvements in such models, more accurate and meaningful insights about investments in energy efficiency. This can have important consequences for policymakers, corporate managers and individuals as they decide how to allocate financial resources. If the benefits of energy efficiency and productivity investments are fully understood, such investments could become more compelling and could lead to a more productive economy and a healthier economic future.

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