The Energy Efficiency Benefits and the Economic Imperative of ICT-Enabled Systems

John A. "Skip" Laitner

Abstract. The global economy is not particularly energy-efficient. At current levels of consumption, we now waste about 86 percent of the energy now used to maintain economic activity. This magnitude of waste imposes huge costs that constrain the robustness of the world economy. At the same time, however, there is an array of untapped cost-effective energy efficiency resources that can restore both energy and economic efficiency. Information and Communication Technologies (ICT) may be the key to unlocking that potential.

Keywords: Information and Communication Technologies, Energy Efficiency, Energy Productivity

Introduction

In his speech "The American Scholar," philosopher Ralph Waldo Emerson noted an ancient oracle that said, "All things have two handles: beware of the wrong one" [1]. The continuing debate about ensuring an adequate supply of low-cost energy may be grabbing for the wrong handle. In a similar way, thinking about Information and Communication Technologies (ICT) merely as an emerging high tech market phenomenon may also be grabbing the wrong handle. It turns out that improvements in energy efficiency are critical drivers of a more robust and sustainable economy. At the same time, ICT devices, appliances, and networks may be the key to unlocking a more energy-efficient future.

All interactions of matter involve flows of energy. This is true whether they have to do with earthquakes, the movement of the planets, or the various biological and industrial processes at work anywhere in the world. Within the context of a regional or national economy, the assumption is that energy should be used as efficiently as possible. An industrial plant working two shifts a day 6 days a week for 50 weeks per year, for example, may require more than one million U.S. dollars (USD) per year in purchased energy if it is to maintain normal operations. An average American household may spend USD 2,000 or more per year for electricity and natural gas to heat, cool, and light the home as well as to power all of the appliances and devices within the house. And an over-the-road trucker may spend USD 1,500 on fuel to haul a load of freight 4,800 kilometers from Quebec to Los Angeles. Regardless of either the scale or the kind of activity, a more energy-efficient operation can lower overall costs for the manufacturing plant, for the household, and for the trucker. The question is whether the annual energy bill savings are worth either the cost or the effort that might be necessary to become more energy-efficient?[1]

In one sense of the word, the global economy is hugely energy inefficient. At current levels of consumption, for example, the U.S. economy converts only 14 percent of the total energy it uses into economic activity. This means that the United States is now wasting 86 percent of its available energy resources [2].[2] With a similar level of energy intensity as the U.S. now maintains, the world economy is an anemic14 percent energy efficient. Drawing from the international energy statistics published by the U.S. Energy Information Administration (EIA) [4], the working estimate for Europe and Japan suggests that they are only marginally better at 18 to 20 percent energy-efficient. That means, they continue to waste as much as 80 to 82 percent of all the energy that that they consume.

Because of that very significant level of inefficiency around the world, many in the business and the policy community increasingly look to energy efficiency improvements as cost-effective investments to reduce waste and cut costs. One current example of this win–win opportunity is the advent of energy service companies (ESCO's) that save energy for clients, but at no upfront cost to the clients, while making a profit for themselves. As an example, the International Energy Agency (IEA) reports levels of ESCO spending that have grown from USD 1 billion in 2000 to USD 7 billion in 2011. This is an average annual growth rate of 20 percent. Indeed, ESCOs are now active in close to 50 countries globally [5].

Perhaps more interesting, according to the IEA the annual routine investments for building and industry energy efficiency improvements are up to USD 300 billion globally in 2011. The IEA indicates this magnitude of annual spending on energy efficiency upgrades is at a scale that is similar to renewable energy and fossil fuel power sector investments. The reduced energy demand stemming from energy efficiency over the past decades is larger than any other single supply-side energy source for a significant share of IEA member countries. This, the IEA suggests, is driving energy efficiency to be our "first fuel" [5].

1 Historical Impact of Energy Efficiency

In many ways energy efficiency has been a continuing but also a seemingly invisible resource. Unlike a new power plant or a new oil well, we do not see energy efficiency immediately at work. A new car that uses 9.4 liters per 100 kilometers (25 miles per gallon), for example, may not seem all that much different than a car that requires only 4.7 liters/100 km (50 miles per gallon). And yet, the first car may consume ~250 gallons of gasoline to go 10,000 kilometers in a single

[1] The mentioned examples of energy expenditures are derived from several calculations by the author.

[2] Laitner [2] builds on an updates work published by Ayres and War [3].

year while the second car, depending on how it is driven, may need only half that amount. In effect, energy efficiency in this example is the energy we do not use to travel 10,000 kilometers per year. More broadly, energy efficiency may be thought of as the cost-effective investments in the energy we do not use either to produce some amount goods and services within the economy. Within that context we can ask how energy efficiency might compare to conventional energy resources.

Comparing economic activity over the period 1970 through 2010, the size of the global economy grew by about 3.9 times. Energy use, on the other hand, grew by only 2.4 times over that same period. In effect, the decoupling of economic growth and energy consumption was the result of increased energy productivity: in short, the ability to produce more goods and services, but doing so with less energy (and other resources). In a complementary analysis by the author, using a variety of IEA, EIA, and other available data, it appears that energy efficiency measures provided about one-half of the new demand for energy-related energy services over that 40-year time span. At the same time, analysis of 11 of the IEA member countries for which suitable data are available, indicates that between 1974 and 2010, energy efficiency was the single largest new energy resource that was brought online in that period (see Figure 1 below). [3]

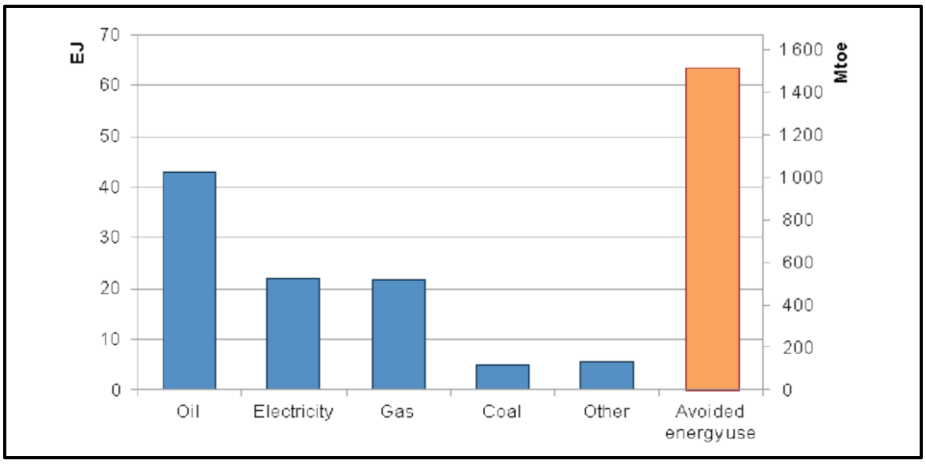

Fig. 1. The "first fuel": contribution of energy efficiency compared to other energy resources consumed in 2010 in 11 IEA member countries. Source: IEA [5]

According to the IEA assessment, the avoided energy over the 36-year period was equal to 65 percent of the total final consumption of energy in 2010. Over this time horizon, energy efficiency reduced growth in energy consumption to just 20 percent of the 1974 levels. Said differently, without energy efficiency improvements, energy consumption would have increased by 93 percent.

[3] The 11 countries are Australia, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, Sweden, the United Kingdom and the United States. Estimated energy use is calculated on the basis of how much energy would have been required to deliver the actual levels of activity reported each year for all sub-sectors had 1974 levels of energy use per unit of output persisted. "Other" includes biofuels plus heat from geothermal, solar, co-generation and district heating. Co-generation refers to the combined production of heat and power.

Having achieved these past gains, with an often ad-hoc approach to energy efficiency improvements, there is compelling evidence to suggest that even greater energy productivity benefits can be achieved. Moreover, the evidence suggests that significant gains are not only possible, but they will be cost-effective as well. And as we shall see, ICT can be a critical part of the story.

2 Cost-Effective Potential for Exploiting the Energy Efficiency Resource

Can the substantial investments that might be required in the more energy-efficient technologies save money for businesses and consumers? The *Efficient World Scenario* of the IEA *World Energy Outlook 2012* indicates that should policies remove market barriers and promote cost-effective energy efficiency measures, total primary energy supply could be reduced by an additional 900 million tonnes of oil (Mtoe) in 2020 beyond those reductions generated from current and announced policy interventions. This additional 900 Mtoe in avoided energy is equivalent to seven percent of 2010 global consumption, greater than the combined energy supply of Australia, Japan, Korea and New Zealand today. If achieved it would produce a corresponding reduction of USD 458 billion in consumer energy expenditures [6].

Lazard Asset Management [7] provides a detailed review of the various costs associated with electricity generation. They note, for instance, that meeting new energy demand by building new coal and nuclear power plants might cost an average of 6–15 cents per kilowatt-hour (kWh) of electricity generated. The costs for various renewable energy resources such as wind energy or photovoltaic energy systems (i.e. solar cells that convert sunlight directly into electricity) might range from 6 to 20 cents per kWh. In comparison, both Lazard and the American Council for an Energy-Efficient Economy (ACEEE) estimate a range of energy efficiency measures that might cost the equivalent of 3–5 cents per kWh of electricity service [8].

McKinsey and Company [9] in 2008 identified investments in energy efficiency that would generate at least a 10 percent annual return. When spread out over time, McKinsey suggested a global energy efficiency market on the order of USD 170 billion per year with an average 17 percent return. A subsequent McKinsey assessment stated that “energy efficiency offers a vast, low cost energy resource” in the United States [10]. If executed at scale, a holistic approach would yield energy savings worth more than USD 1,200 billion, well above the USD 520 billion needed through 2020 for upfront investment in energy efficiency measures. This is a sufficient costeffective opportunity to reduce the nation’s energy use in 2020 by roughly 23 percent from business as usual projections – should the U.S. choose to invest in the more efficient use of its energy resources.

Such investments can deliver dramatic reductions in pollution. The Union of Concerned Scientists [11] recently published a detailed portfolio of technology and program options that would lower U.S. heat-trapping greenhouse gas emissions 56 percent below 2005 levels in 2030. Their analysis indicated an annual USD 414 billion savings for U.S. households, vehicle owners, businesses, and industries by 2030. After subtracting out the annual USD 160 billion costs of the various policy and technology options, the net savings are on the order of USD 255 billion per year. Over the entire 2010 through 2030 study period, the net cumulative savings to consumers and businesses were calculated to be on the order of USD 1,700 billion under their recommended scenario (with all values in 2006 dollars).

More recently, Laitner et al. [12] documented an array of untapped, cost-effective energy efficiency resources roughly equivalent to 250 billion barrels of oil. That is a sufficient scale to enable the United States to cut total energy needs in half compared to business-as-usual projections for the year 2050. Capturing this energy efficiency resource could generate from 1.3 to 1.9 million jobs while saving all residential and business consumers a net USD 400 billion per year, or the equivalent of about USD 2,600 per household annually (in 2010 dollars).

At the international level, Copenhagen Economics [13] suggests that energy efficiency improvements in buildings alone, throughout the European Union, might lower total energy use by 8 to 12 percent by 2030. This would require gross annual investments of 41 billion euros to 78 billion euros per year, but those investments would also deliver ongoing annual returns of 104 billion euros to 175 billion euros.

Pushing an innovation-led investment strategy, Nord-Pas de Calais, a former coalmining and still heavy industrial region of 4 million people in northern France, accepted a Third Industrial Revolution Master Plan that, if successful, would reduce final energy use by as much as 60 percent by 2050. As the plan laid it out, renewable energy technologies would power all remaining energy needs, also by 2050 [14]. The preliminary estimate of the total investment needed to drive the energy efficiency/renewable energy transition is on the order of 210 billion euros (in constant 2005 euros) over the period 2014-2050. This averages to a little more than 6 billion euros per year, or about 5 percent of the region’s GDP over that 37-year period. The substantial economic returns to Nord-Pas de Calais—including both the lower costs of energy and a more robust economy—would be about 1.7 times the total cost of the upfront investment. And the combination of investments and energy bill savings would generate an average 100,000 new jobs for that region with as many as 165,000 new jobs by 2050. In other words, the improved productivity, supported by the Third Industrial Revolution Master Plan, would measurably strengthen the region’s overall economy.

There is a further aspect that merits a brief review—the non-energy benefits that typically accrue to energy efficiency investments. When energy efficiency measures are implemented in the industrial, commercial, or residential settings, several nonenergy benefits such as maintenance cost savings and enhanced productivity benefits can often result—in addition to the anticipated energy savings. The magnitude of nonenergy benefits from energy efficiency measures is significant. In one study of 52 industrial efficiency upgrades, all undertaken in separate industrial facilities across a number of different countries, Worrell et al. [15] found that the non-energy benefits were sufficiently large that they lowered the aggregate simple payback for energy efficiency projects from 4.2 years to 1.9 years.

Another study for 81 separate industrial energy efficiency projects showed that the simple payback from energy savings alone was less than 2 years, indicating annual returns higher than 50 percent. When non-energy benefits were factored into the analysis, the simple payback fell to just under one year [16]. In residential buildings, nonenergy benefits have been estimated to represent between 10 and 50 percent of household energy savings [17]. Unfortunately, these non-energy benefits from energy efficiency measures are often omitted from conventional performance metrics. This leads, in turn, to overly modest payback calculations and an imperfect understanding of the full benefit of additional efficiency investments.

With this backdrop we can return to the report by Copenhagen Economics which actually decomposes the annual building energy efficiency benefits into a broader category of impacts. They include reduced air pollution, improved health benefits, and annual improvements of public finances as fewer long-term subsidies are needed. In fact, Copenhagen Economics actually broke down the economic returns—the previously referenced annual benefit to society of €104-175 billion in 2020— into those same three major categories: (i) €52-75 billion from lower energy bills, (ii) at least €9-12 billion from the co-benefits of reduced outlay on subsidies and reduced air pollution from energy production; and (iii) €42-88 billion in health benefits from improved indoor climate. If investments are continued after 2020, they noted, the annual benefits could be doubled by 2030.

3 The ICT Contribution

How might we think about the ICT-enabled contributions to the energy efficiency potential? First, we might simply step back and imagine how much easier it might be to move electrons around than to ship people or goods over long distances. Or to move information that can be acted, but using less energy. Hence, the more we can do to substitute the flow of information for goods that should lead to a reduction in the use of energy and materials. As an example, Cisco estimates there will be the very large sum of 830 exabytes of data that will flow through a variety of communication tools in 2014 [19]. Adding up all the incredibly light electrons that will be needed to hold all those bits of information in place, we might suggest a weight of only 3.4

millionths of an ounce. Yet, if we printed all of that information on paper, it might require, instead, more like 165 billion tons of paper.[4]

Many of the assessments to date tend to focus on the direct energy requirements associated with different aspects of ICT-enabled systems. Coroama and Hilty [20], for example, provide a thoughtful overview of studies along these lines. As they properly note, assessing “the average energy intensity of Internet transmissions is a complex task that has been a controversial subject of discussion.” They document estimates published over the last decade “which diverge by up to four orders of magnitude — from 0.0064 kilowatt-hours per gigabyte (kWh/GB) to 136 kWh/GB” [20].[5]

Laitner et al. [21], on the other hand, note that energy intensity appears to be coming down as projected by the EIA’s *Annual Energy Outlook*. Looking at the year 2030, as an example, the *Annual Energy Outlook 2008* was forecasting that, in the United States, ICT-related activities might require 8.6 percent of all electricity needs in that year. In the most recent 2014 projections, however, total demands in 2030 are down to just 2.8 percent—even as total electricity consumption itself is now forecast to be 11 percent lower than was previously estimated for 2030. The former reduction appears to be related to greater efficiencies in the equipment while the latter impact may be a greater rate of unexpected efficiency gains. That, of course, may well be driven, in turn, by the so-called substitution effect—or substituting the greater uses of electronics and ICT technologies and networks for primary energy.[6]

Evidence of this latter impact comes from a report sponsored by the Global-e Sustainability Initiative (GeSI). In 2012 Laitner, Partridge, and Vittore [22] explored the micro-level of energy efficiency associated with increased adoption of ICT and broadband services at the residential level. They examined eight consumer activities enabled by the development of broadband technology: telecommuting, use of the Internet as a primary news source, downloading video/music, online banking, online auctions/purchases, online education, use of digital photography, and use of e-mail. Assuming an upper end of reasonable adoption of all eight residential activities, the study found the U.S. could generate an annual net energy savings of about 336 million barrels of oil, equivalent to 2 percent of total U.S. energy consumption. In a comparable finding, the five EU nations of France, Germany, Italy, Spain and the U.K would be

[4] As a further insight, the 830 exabytes will be up significantly from 523 exabytes recorded in 2012, and heading for 1448 exabytes or 1.4 zettabytes by 2017. That will translate into an average annual compound growth rate of 23 percent over the period 2012 to 2017 [19].

[5] An update on the state of research in Internet energy intensity is provided in two later chapters of this book [37-38].

[6] The calculations in this paragraph exclude televisions and related equipment as among the ICT-related technologies.

able to save an annual net energy savings of 164 million barrels of oil, equivalent to 2 percent of total energy consumption in those countries.[7]

While primarily focused on reducing greenhouse gas emissions, two complementary GeSI studies point the way to significant gains in energy efficiency. In 2008 the Global e-Sustainability Initiative (GeSI) demonstrated how ICT is making the world's energy infrastructure more efficient and concluded that smart grids, buildings and transport along with travel substitution could reduce global carbon emissions by a net 15 percent and save up to €600 billion by 2020 [23]. Most recently the GeSI *Smarter 2020* study found that the total abatement potential of ICT-enabled solutions in 2020 was about 9.1 gigatons of carbon dioxide equivalent ($GtCO_2e$), a savings of about

16.5 percent of global GHG emissions by 2020. This is roughly equivalent as USD

1.9 trillion in gross energy and fuel savings and a savings of 21.6 billion barrels of oil [24]. Figure 2 on the following page shows the various mechanisms that helped achieve the overall savings.

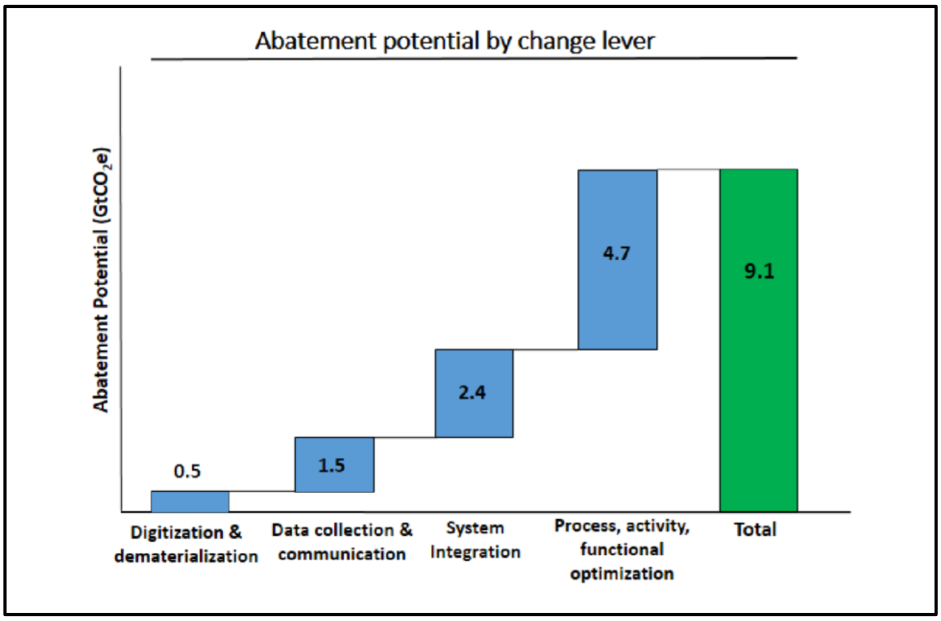

Fig. 2. Mechanisms of Greenhouse Gas Emissions Reductions. Source: GeSI 2012 [24]

Digital and dematerialization, relying primarily on existing technologies that substitute or eliminate the need for a carbon intensive product, were shown to achieve 0.5 $GtCO_2e$. The use of social media and networking (data collection and communication) were shown to reduce emissions by 1.5 $GtCO_2e$. [8] Systems integration— primarily building or industrial management systems and

[7] The emphasis here and elsewhere is on net energy savings. That is to say, the studies cited here reflect both the energy necessary to build, operate and maintain ICT-related technologies as well as the energy displaced by the use of those technologies.

[8] Related to the social media and networking mechanism is the role of consumer feedback. In a 2010 detailed review of 57 multi-continent studies over a 30-year period, EhrhardtMartinez et al. [25] showed that feedback initiatives – including real-time Web-based or inhome feedback devices and enhanced billing approaches–reduced individual household electricity consumption an

the use of less-carbon intensive, renewable energy technologies—were shown to save 2.4 $GtCO_2e$ while the use of intelligent simulation, the automation of infrastructure, and industrial processes more broadly, were shown to save 4.7 $GtCO_2e$.

Using a top-down assessment, Laitner [26] reported that the deployment of semiconductor-enabled technologies since 1976 generated a sufficient energy productivity benefit across the entire U.S. economy to reduce total electricity consumption by 20 percent compared to an economy without the benefit of those technologies. In other words, the family of semiconductor technologies now at work within the economy appears to have amplified the productivity of buildings and equipment, labor, and energy resources well beyond normally expected returns.

Although the impact of energy productivity has been significant, a further analysis indicated that a policy-driven semiconductor-enabled efficiency scenario (SEES) might stimulate an average annual investment of about USD 22.5 billion over the period from 2010 through 2030. More interesting, the findings also suggested an average electricity bill savings on the order of USD 61 billion during that same period of analysis. Even if the assessment includes program and administration costs necessary to drive that result, the net savings were still more than twice the total cost of the scenario. Perhaps an even more compelling outcome is the impact on employment. The working analysis suggested that, because energy-related expenditures are so much less labor intensive than almost all other consumer expenditures within the economy, the energy bill savings would support a net increase of about 553,000 jobs over that same 20-year period. This suggests an important additional benefit from the deployment of ICT-related technologies.

4 Overcoming Barriers to Improving Energy Efficiency

There is a range of market imperfections, market barriers, and real world behaviors that leaves substantial room for public policy to induce behavioral changes that produce economic benefits. One classic example is the misaligned incentive that exists for those living in rental units when the renter pays the energy bills but the landlord purchases the large appliances such as refrigerators and water heaters. In this case, the purchaser of the durable good does not reap the benefits of greater energy efficiency. The Market Advisory Committee of the California Air Resources Board [27] provides a nice short overview of key market failures.[9] A deeper exploration

---

average 4 to 12 percent. Huber and Hilty [39] provide a brief overview of eco-feedback systems and related approaches in their chapter about gamification in this volume.

[9] Following are examples of three important market failures and suggested remedies: (1) stepchange technology development in which there may be many uncertainties about appropriate technologies, as well as both market, and policy risks. Temporary incentives might be used to encourage companies to deploy new technologies at sufficient scale in ways that benefit the public good. Other remedies might include energy efficiency resource standards, energy or fuel performance standards and low-carbon fuel standards. (2) Fragmented supply chains – where economically rational investments (for example, energy efficiency in buildings) are not executed because of the complex supply chain. Examples of remedies are building codes or incentives for performance upgrades. (3) Consumer behavior where individuals have demonstrated high discount rates for investments in energy efficiency. Examples of remedies are vehicle and appliance efficiency standards and rebate programs [27].

of the types of market barriers is beyond the scope of this paper, but others have done work to map this terrain [29-34].

The importance of reflecting policies that might be directed at market failures was explored, in part, by Hanson and Laitner. In one of the few top-down models that explicitly reflects both policies and behavioral changes as a complement to pricing signals, they found that the combination of both price and non-pricing policies (e.g., performance standards, eco-labeling, and product information more broadly) actually resulted in a significantly greater level of energy efficiency gains and a lower carbon permit price to achieve the same level of emissions reductions [35].

One critical comment on the rebound effect may be appropriate at this point.[10] Lower energy prices and a positive income effect are likely to follow these energy efficiency improvements. These, in turn, may erode some of the net energy savings as lower prices and a slightly higher income encourage more energy use. But as Ehrhardt-Martinez and Laitner point out [36], this rebound effect is likely to be limited to 10–30 percent of the initial energy savings in the short term. Moreover, just as we learn how to manage efficiency improvements, we can also learn over time how to mitigate the rebound effect with improved resource management strategies and people-centered energy initiatives. On balance, the net ICT energy savings and benefits are likely to remain significant – if we choose to pursue the full set of energy efficiency opportunities.

References

1. Emerson, R. W.: The American scholar. In Nature addresses and lectures, Vol. 1. New York: Wm. H. Wise 1923, pp. 81–84 (1837)
2. Laitner, J.A.S.: Linking Energy Efficiency to Economic Productivity: Recommendations for Improving the Robustness of the U.S. Economy. ACEEE Report E13F. Washington, DC: American Council for an Energy-Efficient Economy.
3. Ayres, R.U., Warr, B.S.: The Economic Growth Engine: How Energy and Work Drive Material Prosperity. Edward Elgar Publishing, Cheltenham, UK and Northampton, MA, USA (2009)
4. EIA, United States Energy Information Administration: International Energy Statistics. Washington, DC: U.S. Department of Energy (2013) http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm. Accessed 31 May 2014
5. International Energy Agency: Energy Efficiency Market Report, OECD/IEA, Paris, France (2013)

[10] Gossart [40] provides an overview of the literature on rebound effects in an ICT context later in this volume.

6. International Energy Agency: World Energy Outlook, OECD/IEA, Paris, France (2012) 7. Lazard Asset Management: Lazard's Levelized Cost of Energy Analysis: Version 7.0. New York, NY: Lazard, Ltd (2013)

8. Elliott, R.N., Gold, R., Hayes, S.: Avoiding a Train Wreck: Replacing Old Coal Plants with Energy Efficiency. American Council for an Energy-Efficient Economy, Washington, DC (2011)

9. McKinsey & Company: The Case for Investing in Energy Productivity (2008). http://www.mckinsey.com/insights/energy_resources_materials/the_case_for_investing_in _energy_productivity. Accessed 31 May 2014

10. McKinsey & Company: Unlocking Energy Efficiency in the U.S. Economy. McKinsey & Company (2009) http://www.mckinsey.com/client_service/electric_power_and_natural_gas/latest_thinking/ unlocking_energy_efficiency_in_the_us_economy. Accessed 31 May 2014

11. Cleetus, R., Clemmer, S., Friedman, D.: Climate 2030: A National Blueprint for a Clean Energy Economy. Union of Concerned Scientists, Cambridge, MA (2009)

12. Laitner, J.A.S, Nadel, S., Elliott, N., Sachs, H., Khan, S.: The Long-term Energy Efficiency Potential: What the Evidence Suggests. American Council for an EnergyEfficient Economy (ACEEE), Washington, DC (2012)

13. Copenhagen Economics: Multiple Benefits of Investing in Energy Efficient Renovation of Buildings, Brussels, Belgium: Renovate Europe (2012)

14. Rifkin, J., Prunel, B., Bastie, S., Hinterman, F., Laitner, J.A.S., Moorhead, S.: Nord-Pas de Calais Third Industrial Revolution Master Plan – 2013. Bethesda, MD: Foundation on Economic Trends (2013)

15. Worrell, E., Laitner, J.A.S., Ruth, M., Finman, H.: Productivity benefits of industrial energy efficiency measures. Energy 28, 1081–1098 (2003)

16. Lung, R.B., McKane, A., Leach, R., Marsh, D.: Ancillary benefits and production benefits in the evaluation of industrial energy efficiency measures. In: Proceedings of the 2005 Summer Study on Energy Efficiency in Industry, American Council for an EnergyEfficient Economy, ACEEE, Washington DC (2005)

17. Amann, J.: Valuation of Non-energy Benefits to Determine Cost-effectiveness of Wholehouse Retrofit Programs, Report No. AO61. American Council for an Energy-Efficient Economy, ACEEE, Washington, DC (2006)

18. Ryan, L., Campbell, N.: Spreading the Net: The Multiple Benefits of Energy Efficiency Improvements. International Energy Agency, Paris, France (2012)

19. Cisco: VNI Forecast Highlights, Cisco Systems, San Jose, CA (2014) http://www.cisco.com/web/solutions/sp/vni/vni_forecast_highlights/index.html. Accessed 31 May 2014

20. Coroama, V.C., Hilty, L.M.: Assessing Internet energy intensity: A review of methods and results. Environmental Impact Assessment Review 45, 63–68 (2014)

21. Laitner, J.A.S., McDonnell, M.T., Ehrhardt-Martinez, K.: The Energy Efficiency and Productivity Benefits of Smart Appliances and ICT-Enabled Networks: An Initial Assessment. American Council for an Energy-Efficient Economy, ACEEE, Washington, DC (2014, forthcoming)

22. Laitner, J.A.S., Partridge, B., Vittore, V.: Measuring the Energy Reduction Impact of Selected Broadband-Enabled Activities within Households. ACEEE Report E128. American Council for an Energy-Efficient Economy, Washington, DC (2012)

23. GeSI. 2008. Smart 2020: Enabling the Low Carbon Economy in the Information Age. Brussels, Belgium: Global e-Sustainability Initiative.

24. GeSI. 2012. SMARTer 2020: The Role of ICT in Driving a Sustainable Future. Belgium: Global e-Sustainability Initiative.

25. Ehrhardt-Martinez, K., Donnelly, K., Laitner, J.A.S.: Advanced Metering Initiatives and Residential Feedback Programs: A Meta-Review for Household Electricity-Saving Opportunities, ACEEE Research Report E105, American Council for an Energy-Efficient Economy, Washington, DC (2010)

26. Laitner, J.A.S.: Semiconductors and Information Technologies: The Power of Productivity, Journal of Industrial Ecology 14(5), 692–695 (2010)

27. California Air Resources Board, Market Advisory Committee: Recommendations for Designing a Greenhouse Gas Cap-and-Trade System for California, (2007). http://www.energy.ca.gov/2007publications/ARB-1000-2007-007/ARB-1000-2007007.PDF. Accessed 31 May 2014

28. Sathaye, J., Murtishaw, S.: Market Failures, Consumer Preferences, and Transaction Costs in Energy Efficiency Purchase Decisions, Repory No. CEC-500-2005-020. California Energy Commission, Public Interest Energy Research Program, Sacramento, CA

29. Murtishaw, S., Sathaye, J.: Quantifying the Effect of the Principal-Agent Problem on U.S. Residential Energy Use, Rep. No.LBNL-59773. Lawrence Berkeley National Laboratory, LBNL, Berkeley, CA (2006)

30. Levinson, A., Niemann, S.: Energy use by tenants when landlords pay for utilities. Resource and Energy Economics 26 (1), 51–75 (2004)

31. Levine, M.D., Koomey, J.G., McMahon, J.E., Sanstad, A.H., Hirst, E.: Energy efficiency policy and market failures. Annual Review of Energy and the Environment 20, 535–555 (1995)
32. Brown, M.A.: Market failures and barriers as a basis for clean energy policies. Energy Policy 29 (14), 1197–1207 (2004)
33. Geller, H.S., Harrington, P., Arthur, H., Satoshi Tanishima, R., Unander, F.: Policies for increasing energy efficiency: Thirty years of experience in OECD countries. Energy Policy 34, 556–573 (2006)
34. Brown, M.A., Chandler, J., Lapsa, M.V., Ally, M.: Making Homes Part of the Climate Solution: Policy Options to Promote Energy Efficiency, Rep. No. ORNL/TM-2009/104. Oak Ridge National Laboratory, ORNL, Oak Ridge, TN (2009)
35. Hanson, D.A., Laitner, J.A.S.: An integrated analysis of policies that increase investments in advanced energy- efficient/low-carbon technologies. Energy Economics 26, 739–755 (2004)
36. Ehrhardt-Martinez, K., Laitner, J.A.: Rebound, technology and people: mitigating the rebound effect with energy- resource management and people-centered initiatives. In: Proceedings of the 2010 ACEEE Summer Study on Energy Efficiency in Buildings, American Council for an Energy-Efficient Economy, Washington, DC (2010)
37. Coroama, V.C., Schien, D., Preist, C., Hilty, L.M.: The Energy Intensity of the Internet: Home and Access Networks. In: Hilty, L.M., Aebischer, B. (eds.) ICT Innovations for Sustainability. Advances in Intelligent Systems and Computing. Springer International Publishing (2014)
38. Schien, D., Coroama, V.C., Hilty, L.M., Preist, C.: The Energy Intensity of the Internet: Edge and Core Networks. In: Hilty, L.M., Aebischer, B. (eds.) ICT Innovations for Sustainability. Advances in Intelligent Systems and Computing. Springer International Publishing (2014)
39. Huber, M.Z., Hilty, L.M.: Gamification and Sustainable Consumption: Overcoming the Limitations of Persuasive Technoloiges. In: Hilty, L.M., Aebischer, B. (eds.) ICT Innovations for Sustainability. Advances in Intelligent Systems and Computing. Springer International Publishing (2014)
40. Gossart, C.: Rebound Effects and ICT: A Review of the Literature. In: Hilty, L.M., Aebischer, B. (eds.) ICT Innovations for Sustainability. Advances in Intelligent Systems and Computing. Springer International Publishing (2014)