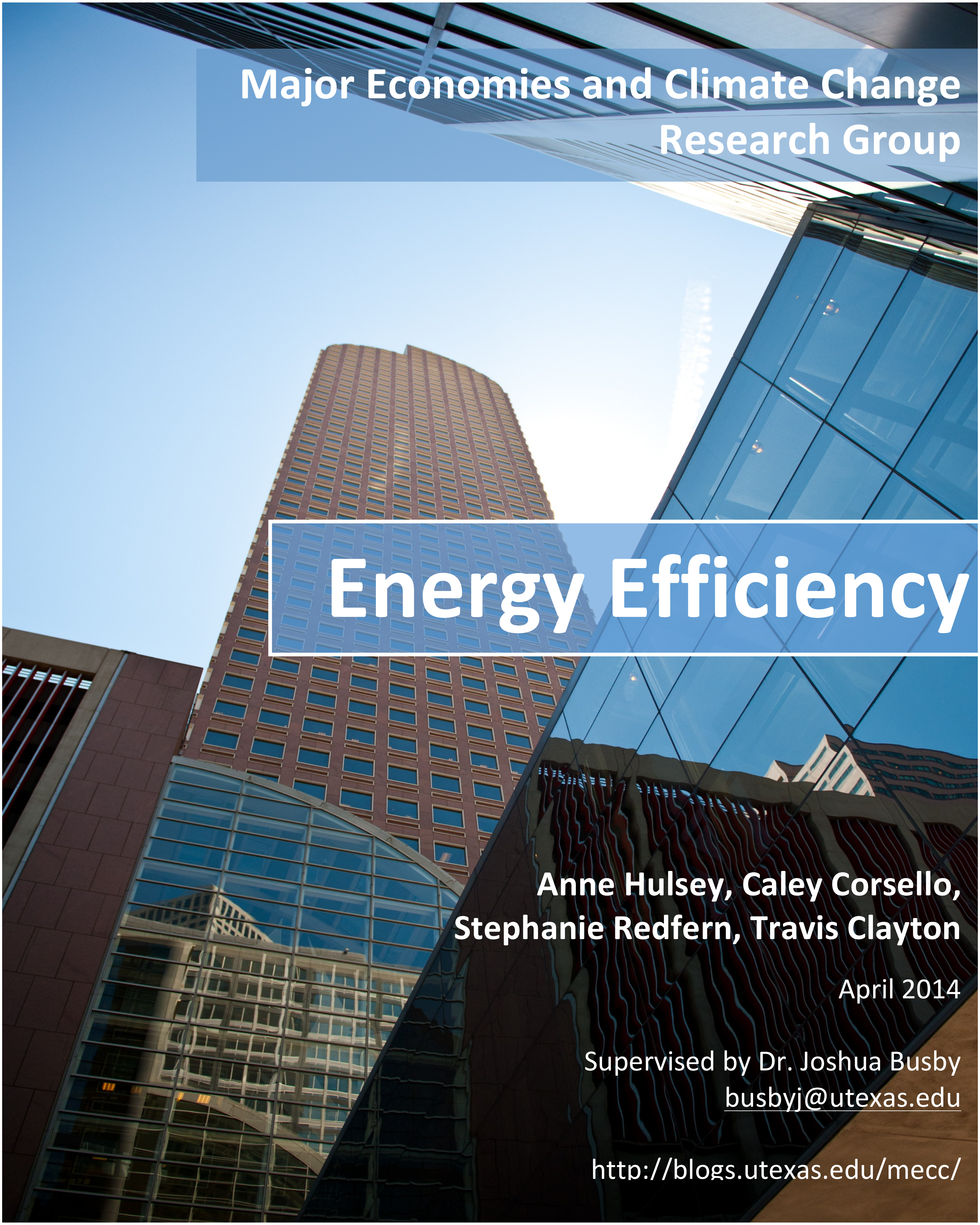

Major Economies and Climate Change Research Group

Energy Efficiency

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April 2014

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ACRONYMS AND ABBREVIATIONS

BAU	Business as Usual
BECs	Building Energy Codes
BREAM	Building Research Establishment Environmental Assessment Method
CCS	Carbon Capture and Sequestration
CHP	Combined Heat and Power
DRI	Direct reduced iron
DSMs	Demand Side Management
EJ	Exajoules
EPRI	Electric Power Research Institute
EV	Electric Vehicle
GtCO2e	Gigatonne of Carbon Dioxide equivalent
GtCO2e/year	Gigatonne of Carbon Dioxide equivalent per year
IEA	International Energy Agency
LEED	Leadership in Energy and Environment Design
OECD	Organization for Economic Cooperation and Development
PNNL	Pacific Northwest National Laboratory
PV	Photovoltaic
SMEs	Small – Medium Enterprises
T&D	Transmission and Distribution
UNEP	United Nations Environment Programme

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EXECUTIVE SUMMARY

Energy efficiency is a promising venue for greenhouse gas emissions reductions, especially given its appeal based on economic benefits. Potential for efficiency reductions is best quantified through current emissions and future projections data for sectors such as building and industry, which have significant opportunity for efficiency measures. Another avenue for increasing efficiency is smart grid infrastructure, through which monitoring can both allow for more efficient generation/dispersion of electricity and inspire conservation among consumers.

(1) Building Sector

The building sector accounts for a fifth (19%) of current global emissions, with the U.S., E.U., and China contributing over half (57%) of the sector emissions. Though the McKinsey Business as Usual (BAU) scenario predicts a 26% (2.4 $GtCO_2e$) global increase by 2030, additional abatement measures could reduce that growth by 3.0 $GtCO_2e$. The abatement potential in these three countries/regions alone would eliminate 14.5% of the world's BAU building emissions. Effective abatement tools include appliance standards, energy certification, and building codes.

Barriers

- Fragmentation of stakeholders: split incentives among various parties
- Payback delay: long payback periods for upfront costs deter investments
- Lack of information: inability to quantify current energy use
- Lack of awareness: misunderstanding or ignorance of energy efficiency options
- Secondary political priority: economic growth take precedence
- Insufficient building codes: status quo is maintained over efficiency innovations
- Enforcement challenges: inability to effectively enforce building codes

Recommendations

- Adopt and enforce stringent building codes based on certification systems
- Commission city-wide review of existing building codes
- Require use of appliance energy labels
- Focus on public-private partnerships to finance energy efficiency investments

(2) Industry Sector

A third (32%) of current global emissions comes from the industry sector. Chemicals, iron and steel, and cement are the largest subcategories, accounting for 57% of total industry emissions. The 2030 McKinsey BAU scenario predicts a 56% (8.6 $GtCO_2e$) increase, with the majority of emissions coming from China (3.5 $GtCO_e2$) and India (1.7 $GtCO_2e$). Global abatement potential is 6.9 $GtCO_2e$, with 3.7 $GtCO_2e$ in China alone. Potential abatement techniques are common among all three large industries: implementing the latest technology, switching feedstock, combining power and heating processes, recycling, and carbon capture and sequestration.

Barriers

- Payback delay: though overall costs may be negative, initial investment is high
- Complex markets: global markets for some industries, highly localized for others
- Link to developing economies: aversion to risking growth of critical industries
- Resistance by population: to alternative fuels such as solid waste
- Ambiguity in regulatory authority: overlapping/conflicting regulations
- Demand from other sectors: demand for CO_2 heavy ammonia in biofuel production

Recommendations

- Develop technological standards and incentives for standardizing equipment
- Adopt energy efficiency labels such as Energy Star
- Facilitate energy efficient technology transfers to developing countries
- Support international ventures to reduce evasion of regulation through outsourcing

(3) Smart Grid

Finally, the smart grid offers a way to transform power distribution and set in motion efficiency opportunities across many sectors. By facilitating dynamic consumer price schemes, the smart grid prompts a flatter demand curve that reduces the need for fossil fuel-fired peaking power plants. Smart grid infrastructure will also facilitate the spread of new efficiency programs, distributed renewable energy generation and widespread integration of electric vehicle interfaces. Even in rural areas of undeveloped countries, the smart grid offers a viable power system option due to its adaptability as local, modular grids that can not only be integrated as they grow but also deliver rapid returns on investment.

Barriers

- Upfront costs: high initial investments are a significant obstacle
- Uncertainty of customer participation: unsure how well customers will respond to dynamic pricing and the smart grid
- Opposition to smart grid: concerns over privacy, security, health risks, costs/benefits
- Need for regulatory policies: new types of data collection require new policies
- Appliance interoperability: need set of international standards for smart systems

Recommendations

- Establish international protocols and standards for equipment, data collection etc.
- Develop policy for regulating privacy
- Invest in marketing, R&D and pilot programs to build trust in scheme
- Implement educational programs
- Encourage renewable energy growth and enable dynamic electricity pricing

In sum, these three levers – building efficiency, industry efficiency, and the smart grid – have the potential to greatly reduce CO_2e emissions, while simultaneously enhancing cost effectiveness.

ENERGY EFFICIENCY

There are a handful of promising venues for reducing global emissions, one of which is energy efficiency. Much of the appeal of energy efficiency is that, in addition to enabling emissions reductions, finding ways to do more with less energy also has economic benefits. However, "efficiency" is a hard concept to quantify, given the fact that it is by nature a change in status quo as opposed to a tangible source of emissions. That is, there is no efficiency sector (such as the power generation sector) that emits a certain amount of greenhouse gas per year. It is instead a matter of negative space: determining what future emissions can be "unemitted" by preemptively employing efficiency measures.

In order to address such an intractable issue, this analysis considers two sub sectors, building and industry, which do have quantifiable yearly emissions that can be lessened through efficiency measures.[1] In addition to considering energy efficiency indirectly through the building and industry sectors, smart grid technology will also be addressed as a newly appearing but highly promising way to make the power grid itself more efficient.

The analysis for the building and industry sectors is based on the Climate Desk by McKinsey & Company. This tool is based on both collected data and future projections. For several sectors, including efficiency's building and industry, the emissions data is separated as being either "direct" or "indirect." Indirect emissions are due to the use of energy that is produced outside of the sector. McKinsey separates direct and indirect emissions in order to avoid double counting when summing the energy production sector with other end use sectors to calculate total global emissions. When evaluating individual sectors, however, McKinsey includes both direct and indirect emissions. This analysis does the same, based on the fact that improved efficiency in buildings and industry would require less energy, eliminating the emissions that would have resulted from its production.

The building and industry sectors were chosen based on both their significant contribution to total global emissions and on the abatement potential that they offer. The building sector is responsible for 19% of 2010 emissions while industry contributes 32% of the total. Additionally, much of the emissions due to buildings and industry are concentrated in a few select regions, offering the potential to address much of the issue among a small cohort of interested parties.

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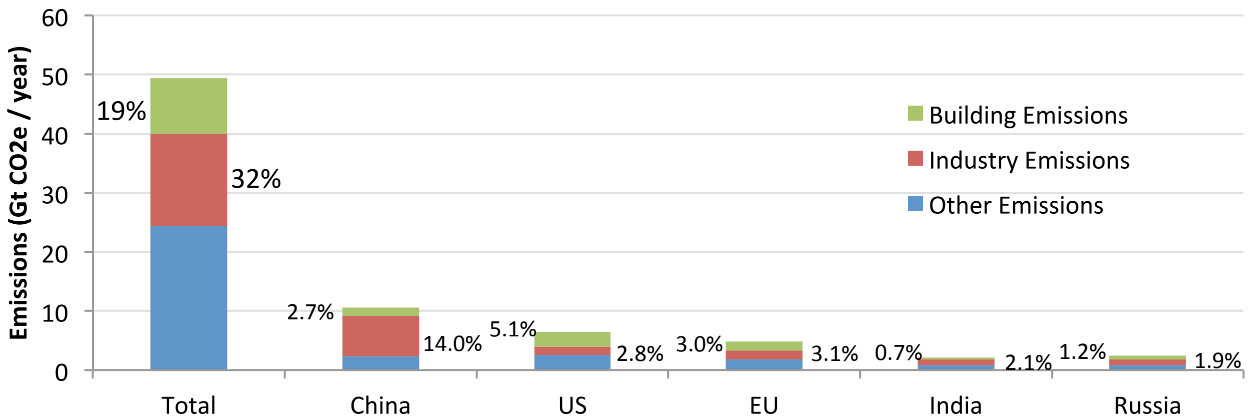
[1] Though transportation is widely recognized as an area for improved efficiency, it will be considered separately as

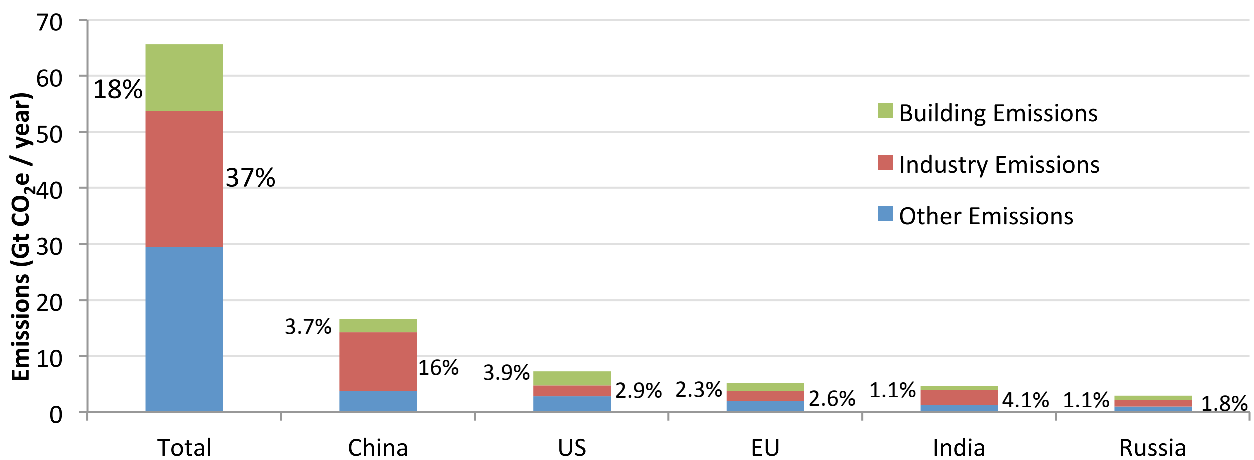
Figure 1. Building and Industry Emissions as Proportion of Current Total Global Emissions



Source: McKinsey Climate Desk

This trend continues in 2030 projections under the Business as Usual (BAU) scenario. Buildings will retain roughly the same proportion of total emissions while industry emissions will increase to 37%.

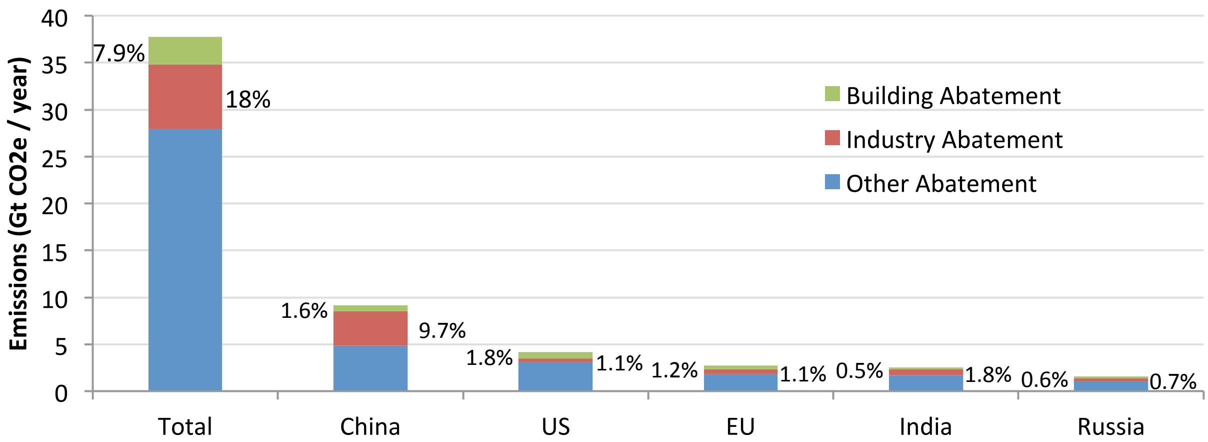
Figure 2. Building and Industry Emissions as Proportion of 2030 Total Global Emissions



Source: McKinsey Climate Desk

Though the building and industry sectors' contribution to global abatement potential is not as large as their portion of global emissions, they still represent a significant opportunity for emissions reductions. Buildings represent 8% of potential abatement while industry can deliver 18% of possible reductions.

Figure 3. Building and Industry Abatement Potential as Proportion of Total Global Potential



Source: McKinsey Climate Desk

The smart grid, as a relatively new technology enabled by developments in wireless and IT, differs quite a bit from the traditional energy efficiency subsectors of buildings and industry. It includes updates to the electricity transmission and distribution infrastructure that increase overall system efficiency, prompt demand response behaviors that enable more efficient consumption, and improve ease of renewable generation integration. Essentially, aside from facilitating minor gains in the power grid itself, the smart grid lays the foundation for a number of improvements in other areas of energy production and consumption.

Because smart grid is still in its infancy, much research still needs to be done to determine its exact emissions reduction potential. Countries are rolling out pilot projects, but many regional results remain unpublished. Therefore, the smart grid analysis in this paper will differ from that of buildings and industry. Total global potential for reduction (including uncertainty) will be discussed, but the analysis will remain fairly qualitative.

BUILDING SECTOR

Use of McKinsey's Climate Desk analysis tool identified the countries/regions that are major emitters in the building sector, by both their current (2010) emissions and their BAU trajectory for 2030. The BAU scenario assumes the implementation of no additional abatement measures. The 2030 abatement potential is outlined by comparing the BAU to the Full Technical Potential scenario, which assumes full realization of these measures. The abatement potential of specific measures is also discussed, as are some of the implementation challenges faced by governments and decision makers worldwide.

CURRENT EMISSIONS

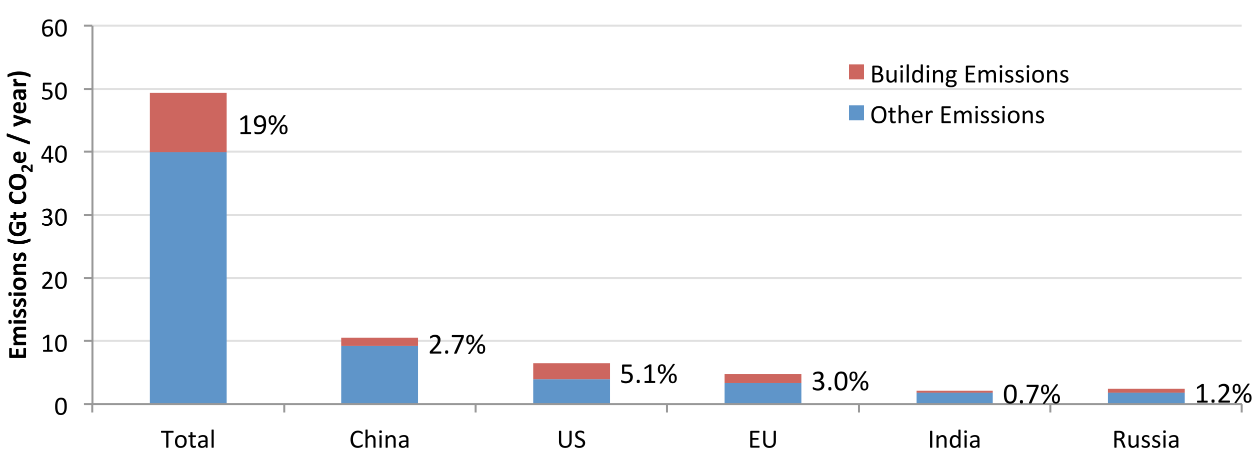
The regions whose building sectors currently have the highest levels of greenhouse gas (GHG) emissions include the United States (U.S.), 2.5 gigatons of CO_2 equivalent ($GtCO_2e$)/year; China, 1.3 $GtCO_2e$/year; and the European Union (E.U.), 1.5 $GtCO_2e$/year.

Table 1. Building Sector Emissions in 2010

	Total	China	US	EU	India	Russia
$GtCO_2e$/year	9.4	1.3	2.5	1.5	0.33	0.62
% sector		14	27	16	3.5	6.5

Source: Based on data from McKinsey Climate Desk

Figure 4. Building Emissions as Proportion of Total Global Emissions



Source: McKinsey Climate Desk

PROJECTIONS

Under the BAU scenario, global emissions produced by the building sector are expected to increase by approximately 2.4 $GtCO_2e$ (a 24% increase), totaling 11.9 $GtCO_2e$ by 2030. The

U.S. building sector is expected to remain roughly the same at 2.5 $GtCO_2e$, as is the E.U.'s at 1.5 $GtCO_2e$. Conversely, China's building sector emissions are projected to nearly double from 1.3 to 2.4 $GtCO_2e$ by 2030. It is also worth noting that while India's current building sector emissions are comparatively low (0.33 $GtCO_2e$), they are expected to more than double under the BAU scenario, resulting in sector-wide emissions of approximately 0.73 $GtCO_2e$ by 2030.

Table 2. Projected BAU Increase in Building Emissions

$GtCO_2e$/year	Total	China	US	EU	India	Russia
2010 level	9.44	1.343	2.54	1.499	0.331	0.615
Increase	2.42	1.1	-0.002	-0.016	0.396	0.107
2030 BAU	11.85	2.443	2.538	1.483	0.727	0.722
2030 % global	18	3.7	3.9	2.3	1.1	1.1

ABATEMENT POTENTIAL

In total, the building sector offers an emission abatement potential of 3.0 $GtCO_2e$. The U.S. is capable of providing 22% of that total, followed by China at 21% and the E.U. at 15%. The following table summarizes the emissions abatement potential of the top five emitters.

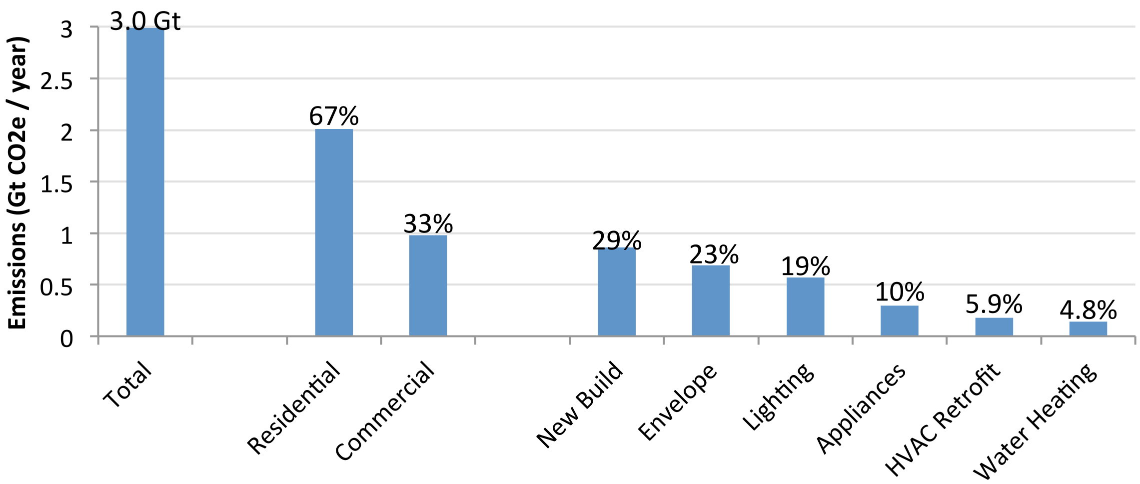
Table 3. Emissions Abatement Potential in Building Sector

	Total	China	US	EU	Russia	India	Top 5
Gt CO2e/year	2.99	0.618	0.669	0.438	0.22	0.181	2.126
% sector abatement		21%	22%	15%	7.4%	6.1%	71%
% total abatement	7.9%	1.6%	1.8%	1.2%	0.6%	0.5%	5.6%
% sector BAU emissions	25%	5.2%	5.6%	3.7%	1.9%	1.5%	18%
% total BAU emissions	4.6%	0.9%	1.0%	0.7%	0.3%	0.3%	3.2%

Building emissions abatement potential can be further decomposed into specific areas within the sector. For example, the potential for residential buildings is approximately 67% (2.009 $GtCO_2e$) of the sector's total abatement potential by 2030, with commercial buildings contributing approximately 33%.

The 2030 abatement potential for various energy efficiency measures is as follows:

Figure 5. Emissions Abatement Potential by Lever



Source: McKinsey Climate Desk

Table 4. Emissions Abatement Potential by Lever (McKinsey Climate Desk)

	Total	Res.	Comm.	New Build	Envelope Retrofit	Lighting	Appliances	HVAC Retrofit	Water Heating
Gt CO2e	2.99	2.01	0.98	0.864	0.686	0.568	0.296	0.177	0.143
% sector abatement		67%	33%	29%	23%	19%	10%	5.9%	4.8%
% total abatement	7.9%	5.3%	2.6%	2.3%	1.8%	1.5%	0.8%	0.5%	0.4%

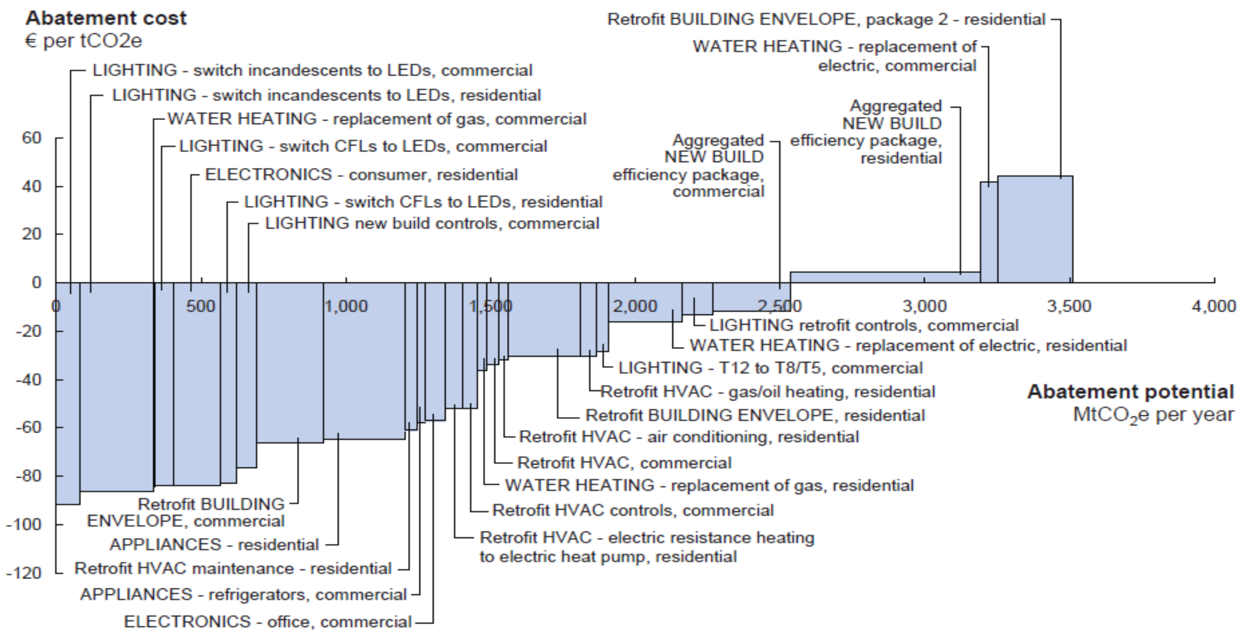
Again, when considering these potentials according to their proportion of total global abatement potential, new building efficiency packages constitute approximately 2.3%, followed by envelope retrofits (1.8%), lighting (1.5%), appliances (0.8%), HVAC retrofits (0.5%), and water heating retrofits (0.4%).

RATIONALE

With an abatement potential of 3 $GtCO_2e$ by 2030, the building sector is a significant arena for reducing global GHG emissions. Greater than half of the abatement potential within the building sector is available in only three regions: the U.S., China, and the E.U. Hence, a closer examination of current and potential energy efficiency policies and measures within these regions is warranted.

Although there are often upfront costs associated with improvements in the building sector, these measures will result in cost savings in the long term (sometimes resulting in net negative costs). This is because most of the improvements are efficiency-related and therefore reduce operating costs alongside the overall levels of GHG emissions. According to the McKinsey GHG abatement cost curve, some of the areas with the highest abatement potential and lowest cost are to be found in the residential area (lighting and appliances) and with the retrofit of commercial buildings.[2]

Figure 6. Global GHG Abatement Cost Curve for the Buildings Sector



Source: McKinsey 2009

The most effective abatement solutions in this sector depend largely on each region's current status of development. Abatement potential in the form of new building efficiency packages is particularly significant in developing countries, given the recent building booms in nations such as China.[3] From a financial standpoint, the relatively low cost associated with implementing energy efficiency measures in new buildings presents an attractive alternative to executing more expensive retrofits in later years. On the other hand, many of the buildings that will be operating in 2050 in regions such as the U.S. and E.U. have already been constructed, meaning that retrofits could be a more viable option for potential emissions reductions.[4]

The instruments available for unlocking the abatement potential within the building sector can be categorized by their overall effectiveness and cost-effectiveness. According to the UNEP report titled *Buildings and Climate Change: Summary for Decision-Makers*, instruments with a "high" level of effectiveness and "high" cost-effectiveness include appliance standards, energy efficiency obligations and quotas, and demand-side management programs (DSMs).

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[2] McKinsey, 2009.
[3] Amecke et al., 2013.
[4] UNEP, 2013.

The report identifies labeling and certification programs as highly cost effective, with a medium to high level of overall effectiveness.[5] Energy certification can be applied to both new and existing buildings, and can be either mandatory or voluntary.[6] A primary benefit of energy certification programs is that they increase awareness among building owners, tenants, and the general public. This can serve as an incentive for builders to construct more energy-efficient buildings and for tenants to accurately align their energy usage with the associated costs.[7]

Additionally, building codes and mandatory energy audits are listed as having a "high" level of effectiveness, accompanied by a "medium" level of cost-effectiveness. Many developed and developing countries have some form of Building Energy Codes (BECs), and studies have shown that mandatory BECs are more effective than voluntary codes.[8] However, only three countries (Denmark, France, and Tunisia) have the most advanced type of code (performance-based BECs), and only China and the remaining EU member states have mandatory BECs that apply to their entire building stock.[9] Moreover, the enforcement of building codes can be challenging in both developed and developing countries, especially within smaller cities and rural areas.[10]

BARRIERS TO IMPLEMENTATION

There are various barriers to implementing energy efficiency measures in the building sector, several of which are outlined in UNEP's *Buildings and Climate Change* report.[11] While the following barriers are applicable to both developing and developed countries worldwide, specific examples are provided within the context of the two countries with the greatest abatement potential in the building sector: the U.S. and China.

MARKET BARRIERS

A primary challenge to implementing energy efficiency measures in the building sector is the fragmentation of its stakeholders. Due to the typically long life cycle of a building, decisions made during the construction phase can have significant implications for the building's ability to meet certain energy efficiency targets during its operational phase. However, a lack of coordination among the various stakeholders can result in missed opportunities for emissions reduction through energy efficiency measures. [12]

For example, a common issue in the U.S. building sector is referred to as the "tenant/landlord" or "split incentive" problem. This occurs when landlords or builders are faced with the challenge of accurately quantifying the value of their energy-efficient investments and are forced to make a decision on behalf of the future tenants who will ultimately reap the

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[5] UNEP, 2013.
[6] OECD/IEA, 2010.
[7] Ibid. p.16.
[8] OECD/IEA, 2013.
[9] Ibid. p.99-100.
[10] UNEP, 2013.
[11] Ibid. p.12.
[12] Amecke et al., 2013.

benefits of these investments. Because much of the true value of such investments is "hidden," landlords' or builders' decisions are largely influenced by energy prices and final construction tactics are often not as energy efficient as they could have been.[13]

Furthermore, upfront costs and a delayed payback period are challenges in both developed and developing countries. In general, payback periods that exceed two years deter consumers from investing in energy efficiency measures (even if the upfront cost is minimal).[14] Hence, policy instruments such as tax rebates could help individuals and groups overcome some of the financial barriers associated with energy efficiency measures in the building sector.[15]

INFORMATION BARRIERS

A major barrier to the realization of energy efficiency in the building sector is that all too often, the perceived costs of energy efficiency measures in building projects are inflated.[16] As noted earlier in this report, there are several areas (such as lighting and appliances) that require minimal investment and provide substantial energy savings over the long term. Increasing awareness of these issues would help to address some of the behavioral challenges associated with the building sector, and likely incentivize stakeholders to take more aggressive steps toward realizing a more energy efficient future.

Additionally, there is a lack of awareness regarding current energy use, the potential benefits of investing in energy efficiency, and the various low-cost efficiency measures that are widely available within the building sector. Building owners and tenants should be given access to clear standards that allow them to assess and compare their energy usage and costs, since this information is integral to the justification of investment in energy efficiency measures.

While access to such information is crucial to the realization of energy efficiency measures in the building sector, there are often complex barriers that prohibit this. For example, since buildings in Northern China are largely served by district heating systems, measurement of actual heat consumption in individual buildings is not currently possible. Hence, energy pricing is not a viable tool for implementing energy efficiency measures in this region.[17]

In the U.S., imperfect information related to energy efficiency continues to be a major barrier to advancement in this arena. This relates specifically to the challenge of accurately quantifying savings from the use of specific appliances, as well as measuring current energy consumption.[18] Confusion surrounding actual energy savings and use can lead to inaccurate assumptions about the value in energy efficiency investments, therefore impeding progress at both the individual and the aggregate level.

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[13] David, 2012.
[14] McKinsey, 2009.
[15] UNEP, 2013.
[16] Ibid., p.15.
[17] Amecke et al., 2013.
[18] American Council for an Energy-Efficient Economy, 2011.

REGULATORY BARRIERS

Regulatory barriers to the implementation of energy efficiency measures in the building sector can arise as a result of enforcement shortfalls at the federal and local levels. For example, China's energy efficiency policies are designed and orchestrated at the federal level but implemented at the provincial and municipal level.[19] Enforcement at the local level is provided by Environmental Protection Bureaus, which rely on provincial governments for financial support. Given that economic growth is, and is likely to continue to be, provincial governments' top priority, lack of funding and political support impedes the Environmental Protection Bureaus' ability to adequately enforce energy efficiency policies.[20]

In the U.S., regulatory uncertainty within building codes themselves can create a barrier to the realization of energy efficiency measures. Contractors are unlikely to risk installing technologies or products that are not included in the building code. This is because during the permit approval process, inspectors are forced to use their own judgment if there is no official regulation in place to which they can refer. The majority of contractors would rather avoid this risk, thereby sacrificing an opportunity to improve energy efficiency.[21]

Finally, the enforcement of building codes is crucial to ensuring that buildings are energy efficient, particularly in their construction phase. This is a particularly relevant in China, where accelerated economic growth and urbanization have resulted in unprecedented demand for new buildings.[22] While China has made considerable strides in enforcing its building codes over the last several years,[23] enforcement of building codes in smaller towns and rural areas remains a challenge. This is primarily due to a lack of capacity and infrastructure for enforcement in these areas, as well as the predominance of single-family homes (China's current building codes are not tailored to address energy usage in small buildings).[24]

RECOMMENDATIONS

The following recommendations address some of the most pressing issues described in the above sections, and are applicable to policymakers in both developed and developing countries worldwide:

1. **Develop Certification Systems:** Governments should adopt and enforce stringent building codes based on certification systems (similar to LEED in the U.S. and

[19] Amecke et al., 2013..
[20] Busby, 2010.
[21] Stover et al., 2013.
[22] Amecke et al., 2013.
[23] Evans et al., 2010.
[24] Ibid.

BREEAM in the UK) for new buildings, and continually update current codes to ensure effectiveness. This is particularly important in developing countries where there is a need for increased government oversight of the building sector as well as government-backed support of implementing energy efficiency measures within the sector.

International development institutions could help meet this need by increasing public awareness within developing countries. For example, the World Bank is working to increase energy efficiency in India's power sector through its project called "Financing Energy Efficiency at SMEs." Similar initiatives could be tailored to specifically increase developing countries' understanding of the benefits of energy-efficient buildings, as well as the importance of government support in implementing various measures.

2. **Review Building Codes:** City leaders should follow in the steps of the New York City Council and, where, possible, commission a thorough review of their city's building codes in search of opportunities for increased sustainability.[25]

3. **Create Energy Consumption Labels:** Governments should require the use of appliance energy labels (such as to Energy Star in the U.S.) to increase knowledge surrounding current energy use and potential savings through energy efficiency measures.[26] As noted in the first recommendation, lack of public awareness is a significant roadblock to the countrywide implementation of energy efficiency measures. By providing building tenants and homeowners with an accurate way to measure their own energy consumption (and consequently modify their behavior), governments can create another avenue to increasing energy efficiency on a widespread scale.

4. **Continue Private-Public Partnerships:** There should be a continued focus on the use of public-private partnerships to finance energy efficiency measures within the building sector. China's use of subsidies to increase consumption of energy efficient light bulbs is an example of a successful public-private partnership in this arena.[27] International development organizations can work with governments to understand the benefits of public-private partnerships, and provide examples of where such partnerships have been successful. Organizations such as the International Energy Agency (IEA) could possibly help provide targeted guidance to governments looking to enter into public-private partnerships to finance energy efficiency projects in the building sector.

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[25] Stover et al., 2013.
[26] International Energy Agency, 2011.
[27] Farrell and Remes, 2009.

CONCLUSION

In sum, the building sector provides significant abatement potential in terms of overall global greenhouse gas emissions reductions. The U.S. and China are capable of the greatest abatement potential within the building sector by 2030, through the use of various energy efficiency mechanisms. However, decision makers must first address the various implementation barriers in these regions and others worldwide. A comprehensive approach to these challenges, including the necessary technological components and properly enforced policy measures, is essential to the building sector's ability to reach its full emissions reduction potential.

INDUSTRY

Analysis of industry emissions within the energy efficiency sector focuses on the three industries with the highest energy savings potential from the adoption of best available technologies: chemical, iron and steel, and cement.[28] Emissions among these industries result directly from chemical feedstocks, iron reduction, and the calcination process, and indirectly through the localized energy production in these industrial processes. McKinsey research projections indicate the greatest growth in industry emissions by the developing countries, China and India, due to increased urbanization and development. Among OECD countries, the U.S. is projected to remain the largest industrial CO_2 emitter. With the adoption of energy efficient technology and practices, promoted through government-supported incentives and supports, the industry sector can achieve the projected CO_2 abatement potential in the industry sector.

CURRENT EMISSIONS

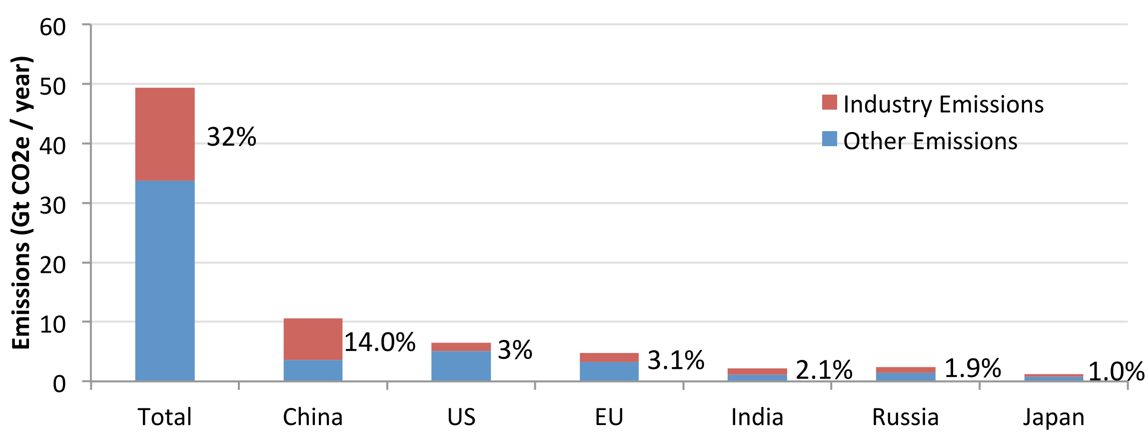
The regions whose total industry sector GHG emissions are highest in 2010 include China, 6.9 $GtCO_2e$; the E.U., 1.5 $GtCO_2e$; and the U.S., 1.4 $GtCO_2e$.

Table 5. Industry Sector Emissions in 2010

	Total	China	EU	US	India	Russia
$GtCO_2e$/year	15.6	6.9	1.5	1.4	1.0	1.0
% sector		44	9.7	8.9	6.6	6.1

Source: McKinsey Climate Desk

Figure 4: Industry Emissions as Proportion of Total Global Emissions



Source: McKinsey Climate Desk

[28] IEA, 2009.

Within industries, however, the chemical industry's current emissions are the most equally distributed among countries, with a total of 2.8 $GtCO_2e$. The highest emitters are China, 0.8 $GtCO_2e$; the U.S., 0.6 $GtCO_2e$; and the E.U., 0.4 $GtCO_2e$.

Current emissions by the iron and steel industry total 3.3 $GtCO_2e$, but are distributed mostly among the developing world. The iron and steel industry's highest emitters are China, 2.0 $GtCO_2e$; the E.U., 0.3 $GtCO_2e$; and India, 0.2 $GtCO_2e$.

Current emissions from the cement industry total 2.8 $GtCO_2e$, and are distributed similar to the iron and steel industry. The cement industry's highest emitters are China, 1.6 $GtCO_2$; the E.U., 0.2 $GtCO_2e$; and India, 0.2 $GtCO_2e$.

PROJECTIONS

Under the BAU scenario, global GHG emissions produced by the industry sector are expected to increase by 8.6 $GtCO_2e$, a 55.4% increase, totaling 24.3 GtCO2e by 2030. China's industry emissions are expected to increase the most, by 3.5 $GtCO_2e$, a 52.4% increase. India's industrial emissions are expected to increase by 1.7 $GtCO_2e$, a 165.2% increase. The U.S.'s industrial emissions are expected to increase by 0.5 $GtCO_2e$, a 34.5% increase.

Table 6. Projected Business as Usual Increase in Industry Emissions

$GtCO_2e$/year	Total	China	India	US	EU	Russia
2010 level	15.6	6.9	1.0	1.4	1.5	0.95
Increase	8.7	3.5	1.7	0.48	0.20	0.24
2030 BAU	24.3	10.5	2.7	1.9	1.7	1.2

Source: McKinsey Climate Desk

Emissions from the chemical industry are projected to increase the most (2.3 $GtCO_2e$—an 81.8% increase), totaling 5.1 $GtCO_2e$. China's chemical industry's emissions are expected to increase the most, by 1.1 $GtCO_2e$, a 126.0% increase. The U.S.'s chemical industry's emissions will grow the second greatest, by 0.4 $GtCO_2e$ (64.0%).

Emissions from the iron and steel industry are forecasted to increase by (2.2 $GtCO_2e$—a 66.9% increase), totaling 5.5 $GtCO_2e$. China's steel industry's emissions are forecasted to increase the greatest, by 0.9 $GtCO_2e$, a 45.9% increase. India's steel emissions are forecasted to increase the second most, by 0.4 $GtCO_2e$, a 264.4% increase.

The cement industry's emissions are expected to increase by the least of the industries, by 1.1 $GtCO_2e$, a 38.9% increase, totaling 3.9 $GtCO_2e$. India's cement industry emissions are projected to increase the most, by 0.5 $GtCO_2e$, a 298.3% increase. The U.S.'s cement industry emissions are projected to increase by 0.05 $GtCO_2e$, a 58.5% increase. China's projected BAU cement emission reductions are projected to fall by 0.1 $GtCO_2e$, an 8.2% decrease.

ABATEMENT POTENTIAL

In order to succeed in industrial GHG abatement, the focus must be on the following processes:

1. **Energy Efficiency Improvements:** the development and deployment of more energy efficient technologies to replace older factory equipment.
2. **Fuel and Feedstock Switching**: Industrial processes could switch from more GHG-emitting fuels such as coal and oil to natural gas, biomass, geothermal, or solar heat.
3. **Co-generation or Combined Heat and Power (CHP):** On-site generation of electricity and energy naturally produces heat as inefficiency, which can be used for heat-intensive production techniques, such as clinker production for cement, iron reduction for steel, and chemical distillation.
4. **Recycling and Recovery**: Used steel and plastics can be economically recycled, generating fewer emissions than the original production process.
5. **Carbon Capture and Sequestration (CCS):** CCS can remove a portion of emissions from both local generation of energy and from the carbon-emitting industrial processes themselves.[29]

In total, the application of these five methods provides a 2030 emissions abatement potential of 6.8 $GtCO_2e$, representing 18% of global total abatement potential. Abatement potential from the chemical industry constitutes 27% of total industry abatement potential, iron and steel industry, 35%, cement industry, 15%, and all other industries not specified by McKinsey Climate Desk (e.g., paper and pulp, aluminum), 23%.

Table 7. Emissions Abatement Potential in Industry Sector

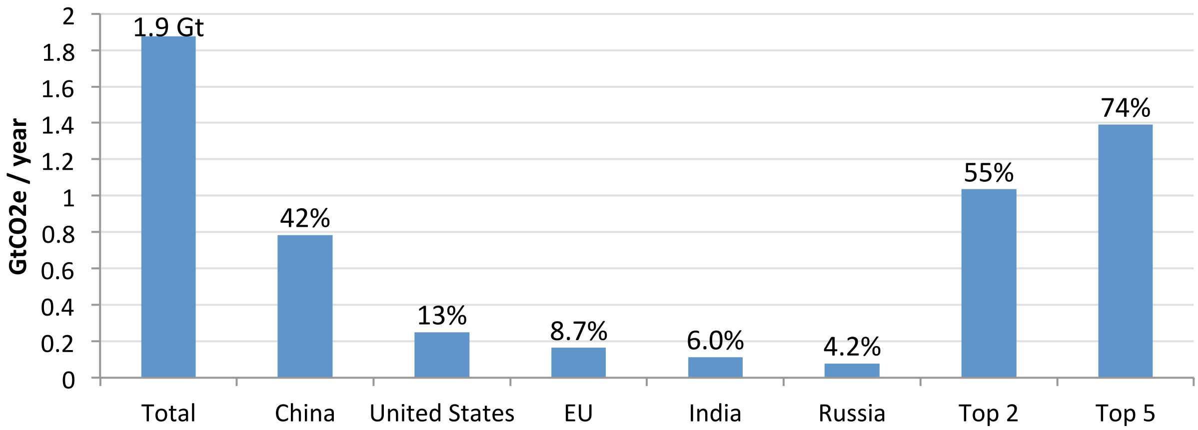
	Total	China	India	EU	US	Russia	Top 5
Gt CO2e/year	6.875	3.672	0.67	0.43	0.425	0.269	5.466
% of sector abatement		53%	10%	6%	6%	4%	80%
% of total abatement	18%	10%	2%	1%	1%	1%	14%
% of sector BAU emissions	28%	15%	3%	2%	2%	1%	23%
% of total BAU emissions	10%	6%	1%	1%	1%	0%	8%

Source: McKinsey Climate Desk

[29] This will be accounted for further in the Energy Production sector.

Among the individual industries, GHG emissions abatement potential can be further divided among the top emitting countries:

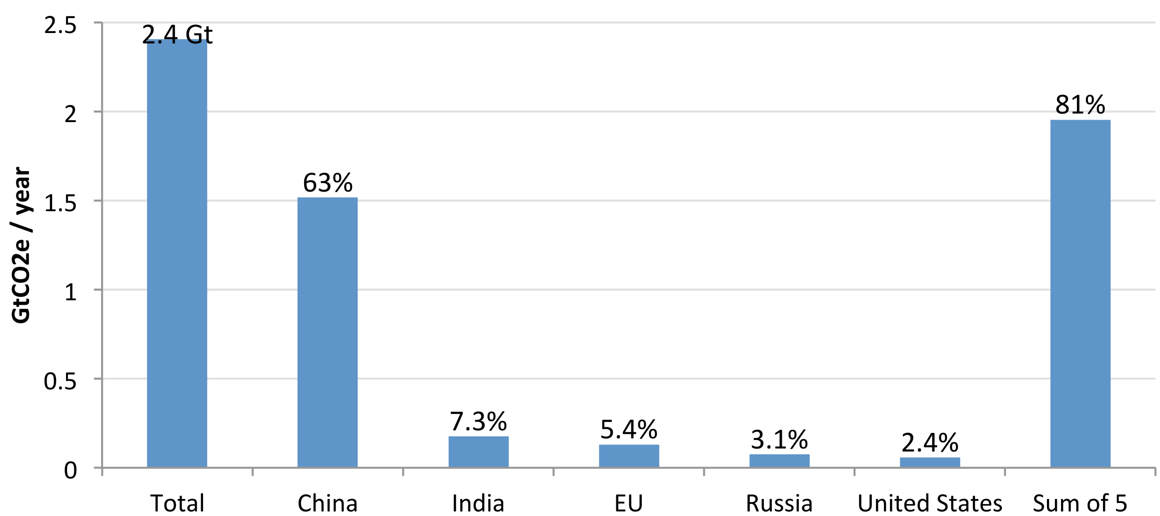
Figure 8. Chemical Industry Abatement Potential



Source: McKinsey Climate Desk

The two countries with the highest abatement potential in the chemical industry are China and the U.S., totaling 1.0 $GtCO_2e$.

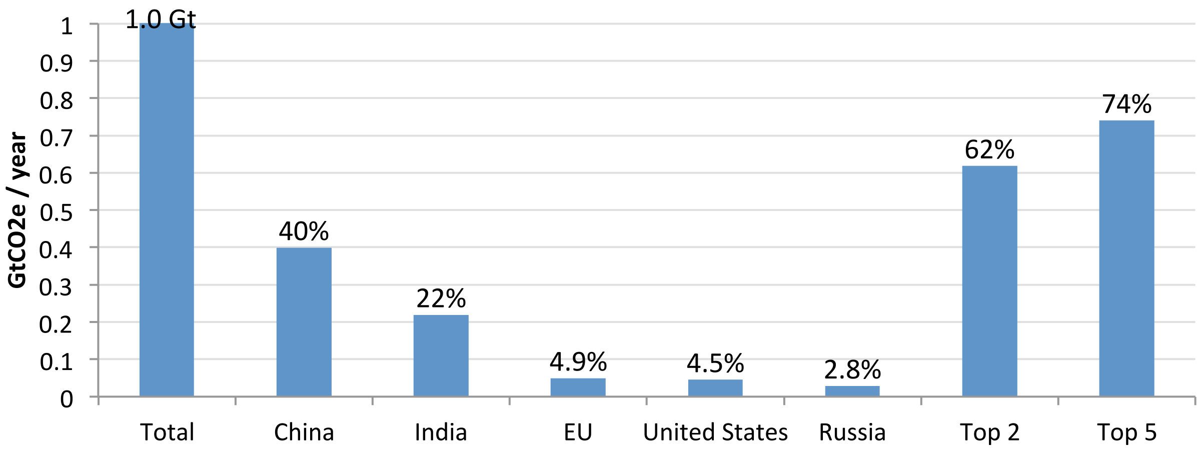
Figure 9. Iron and Steel Industry Abatement Potential



Source: McKinsey Climate Desk

Total iron and steel industry emissions abatement potential are highest in China and India, totaling 1.7 $GtCO_2e$.

Figure 10. Cement Industry Abatement Potential



Source: McKinsey Climate Desk

Again, China and India are the countries with the highest abatement potential, totaling 0.6 $GtCO_2e$.

RATIONALE

Because the industrial sector represents an abatement potential of 6.9 GtCO2e by 2030, it carries significant potential for reducing global GHG emissions. As each individual industry's abatement potential is dominated by a couple of countries—chemical by China and the U.S., iron and steel by China and India, and cement by China and India—interventions for the industry sector are dependent upon these specific countries. China and India's positions in this sector are unique because, unlike other developing countries, both have greater access to capital to finance high capital costing energy efficiency projects but net negative costs over the payback period. However, these industries all have long plant lifetimes and difficulty in retrofitting older plants, necessitating prompt action in order to lock in energy efficient technologies rather than lock in high emissions.

CHEMICALS

China and the U.S. lead current chemical emissions abatement potential. Feedstock switching from coal to natural gas or biogas could reduce CO_2 emissions, particularly in China where ammonia and methanol production is mostly coal-based.[30] Abatement can also be accomplished through process integration—utilizing waste heat and using by-products as raw materials—and process intensification. CHP can also be further employed at the chemical plant level. Currently, CHP provides 10% to 25% of energy demand in the chemical and petrochemical sector, but in countries with more favorable CHP policies, such as the Netherlands and Canada, CHP provides as much as 70% and 90%.[31] Primary energy savings

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[30] Industrial Efficiency Technology Database, http://ietd.iipnetwork.org/content/ammonia#technology-resources.
[31] Energy Technology Transitions for Industry, 117.

potential from the recycling of plastics, rather than landfilling, is estimated at 2.4 EJ (exajoules) annually.[32] Furthermore, CCS would be well adapted for capturing CO_2 in the ammonia and ethanol product processes, with an estimated abatement cost of less than $50/t CO_2.[33]

The chemicals industry is the fastest growing sector within industry.[34] Investments in best practice technology are required in the present to preclude the lock-in of relatively inefficient capital. Much of the existing stock in industrialized countries, such as the U.S., is undermined by depreciated facilities and lack of space, making energy efficient retrofitting more difficult compared to new construction. Indeed, the average age of chemical plants in Europe and North America is more than 20 years, compared to just 10 years in China, with Middle Eastern and African plants ranging somewhere in between.[35]

IRON AND STEEL

China and India have the greatest abatement potential in the iron and steel industry, having relatively greater energy savings potential from blast furnace improvements.[36] New blast furnace technologies that could reduce China and India's iron and steel emissions include new coal-based processes such as the FINEX smelting reduction process, which is only 80% of the investment costs of a traditional blast furnace and also reduces both production costs and CO_2 emissions.[37] The gas-based direct reduced iron (DRI) also presents an opportunity for steel producers to reduce emissions. In the DRI process, natural gas can be used as a reducing agent for iron ore, replacing coke as a cleaner ingredient in steel production. In regions of China and India where natural gas is cheaper than coke, deployment of DRI technology could cut emissions. Furthermore, waste plastic can be substituted as the reducing agent to reduce CO_2 emissions, and is currently employed by Japan, Germany, and Austria.[38] Possible emissions reductions in emissions from CCS are estimated at 75% of total process emissions and are compatible with traditional blast furnace and FINEX processes. Finally, scrap steel recovered from previous use can be melted in an electric arc furnace and reused with the same quality. Greater steel recycling thus eliminates the CO_2 emitting reduction process, while simultaneously satisfying demand.[39]

CEMENT

Greatest emissions abatement potential in the cement sector can be found in China and India, where urbanization and economic growth has spurred the recent expansion of the industry. Energy consumption in the cement industry is partially determined by the kiln design used. Wet kilns, which can more easily control the calcination reaction, require much more

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32 Ibid., 118.
33 Ibid., 130.
34 EIA, 2013.
35 Energy Technology Transitions for Industry, 118.
36 Ibid., 54.
37 *FINEX: a New Iron-Making Technology*, POSCO, 6, community.sk.ru/press/m/wiki/4417/download.aspx
38 Energy Technology Transitions for Industry, 69.
39 Carbon Trust, 2011.

energy (5.9-6.7 GJ/t clinker) than dry kilns (3.3 GJ/t clinker).[40] Asia's shares of kilns usually run on the dry design, unlike North America's, which indicates that China's and India's large abatement potentials are due to other sources or to the sheer size of the industry.

Fuel switching to natural gas can also reduce CO_2 emissions. In addition to natural gas, alternative fuels can be easily adapted for cement production. These options include waste tires, plastics, chemical waste, waste pellets, wood waste, and sewage sludge. Currently, the replacement potential of these alternative fuels rather than fossil fuels is estimated to be 12%.[41] However, cement producers in Europe have been able to achieve substitution rates between 7% and 43% using these alternative fuels.[42] In addition, cement clinker can be substituted with blast-furnace slag (a waste product from the steel industry), fly ash (a waste product of coal energy production), and natural pozzolan (volcanic ash) reducing CO_2 emissions and in some cases, cement costs. Furthermore, deployment of CHP and CCS for post-combustion capture in cement production could contribute to abatement. However, CCS for cement kilns is less economical than CCS for the chemical and iron and steel industries. Similar to the other industries discussed, the cement industry exhibits a low rate of capital stock turnover. The average cement plant can last up to 50 years and as it ages is less suitable to retrofitting.[43] This necessitates the adoption of best available technology during the plant's construction phase.

BARRIERS TO IMPLEMENTATION

Although the industry sector contains numerous methods for GHG emissions reduction through energy efficient technologies, fuel switching, cogeneration, recycling, and CCS, many barriers exist which can hinder the realization of these abatement measures. Primarily, market barriers can prevent these industries' investment in these abatement measures. Additionally, cultural barriers can stall intervention, and regulatory barriers can reduce each specific country's capability to support abatement potential.

MARKET BARRIERS

Within the industrial sector, short investment payback thresholds, risk, and limited access to capital could stymie possible investment planning. In the case of CHP, fuel switching to natural gas, and clinker substitution, overall GHG abatement costs among industries are negative, offering incentives to firms to adopt these techniques. Many energy efficiency measures, which range from 10% to 15% of total energy costs, can be captured with paybacks in less than two years.[44] However, in the case of CCS, which has both high capital costs and positive abatement costs, other incentives will be required to push for industrial adoption.

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[40] Energy Technology Transitions for Industry, 80.
[41] Zhu, 2007.
[42] Energy Technology Transitions for Industry, 84.
[43] IEA, 2009.
[44] McKinsey, 2009.

Furthermore, each industry's different market structure influences global abatement potential from individual country actions. Within the chemical industry, access to shipping has made it economical to import chemicals from less energy efficiency conscious regions with lower fuel and feedstock prices due to energy subsidies. Therefore, actions taken by the U.S. and China to reduce energy use by their chemical industries could shift production to other regions. The steel industry also relies on international shipping. However, in the case of steel, steel exports are dominated by China, which in 2012 exported 54.8 million tonnes and imported 14.2 million tonnes, while India and the U.S. are all net importers.[45] Therefore, Chinese iron and steel abatement potential is reliant upon demand by foreign importers. Unlike the chemical and iron and steel industries, however, cement is largely a local industry with little to any access to international shipping. Thus, solutions for cement emissions should rely on domestic action, while solutions for chemical and iron and steel emissions can rely on a combination of domestic and international interventions.

CULTURAL AND INFORMATIONAL BARRIERS

Some constituents within the countries seeking abatement potential might oppose these measures for cultural reasons. Significantly, the iron and steel industry is typically seen as having a role in national security as a measure of economic development. Therefore, if constituents believe energy efficiency measures could harm the international competitiveness of this industry, policymakers might choose not to pass legislation encouraging long-term energy efficiency in the steel sector in order to maintain the short-term production capacity. As China and India are both developing countries, this nationalistic inclination could prevent government action. Moreover, the steel industry in China alone provides 4.1 million jobs and in some cities equals 79% of the workforce.[46] As steel is a major source of employment, government action on iron and steel emissions abatement must be portrayed as beneficial to domestic employment, as should action on the chemical and cement industry's emissions.

Moreover, some might oppose the use of alternative fuels such as solid waste in the cement industry due to a perceived health risk. However, studies show that in general, air pollutants, nitrogen oxides, and sulfur dioxide emissions are reduced when cement kilns switch from fossil fuels to municipal solid waste.[47]

REGULATORY BARRIERS

In the U.S., emissions regulations and energy efficiency standards are set by the Environmental Protection Agency. However, due to China and India's recent liberalizations of key industries in the past two decades, the industrial regulatory systems have changed drastically. In some cases this has caused ambiguity in how policies are implemented. For example, China's energy efficiency policy is regulated not only by the National Development and Reform Commission, but also by the Ministry of Industry and Information Technology, the

[45] World Steel Association, 2013.
[46] World Steel Association, n.d.
[47] Network for Business Sustainability, n.d.

Ministry of Land and Resources, and the Ministry of Environmental Protection.[48] Because of the overlapping responsibilities of these regulatory bodies, conflicts sometimes arise in decision making, contributing to a stalemate. In the case of India, the regulatory scope of various agencies is more clearly defined, with the Ministry of Steel determining steel investments, and the Central Pollution Control Board deciding efficiency standards for the iron and steel and cement industries. However, in both China and India, regional resources are also required to enforce these regulations, which some provinces and states lack.

In addition, current regulatory campaigns for the development of biofuel stocks require continued access to ammonia fertilizers obtained from the chemical sector, despite the fact that the production of a tonne of ammonia releases an estimated 1.6 to 3.2 tonnes of CO_2 into the atmosphere.[49] In the U.S., biofuels account for 7.1% of total transport fuel consumption and are argued to be a means to reduce the transport sector's carbon footprint.[50] Additionally, China, which seeks to reduce its petroleum dependence and emissions, has set a goal to double its use of biofuels in the current 12th Five-Year Plan.[51] Actions designed to attain abatement potential within the chemical industry must account for the relative loss of abatement potential from the transport sector.

RECOMMENDATIONS

Since energy efficiency payoffs from these technological improvements can be unclear to the industry sector, government assistance can help provide incentives and information. Therefore, in order to capitalize on these technological opportunities, the following initiatives are recommended for implementation or maintenance:

1. **Create Standards:** Technological standards and incentives should be enacted when the need for equipment standardization or economic barriers vindicate government arbitration. Furthermore supportive measures should exist to provide domestic industries with energy-efficient technologies.

2. **Adopt Domestic Efficiency Programs:** Governments should adopt domestic programs like Energy Star which assist leading manufacturers in energy efficient management, evaluate performance, and provide resources for electricity demand forecasting.

3. **Engage in Multilateral and Bilateral Technology Programs:** Governments should establish bilateral or multilateral venues, similar to Japan's Green Aid Plan with China, which facilitate energy efficient technology transfers to less energy efficient countries. In particular, venues between the United States and either China or India hold potential. As China has accelerated its efficient technology deployment, this could

[48] Wall Street Journal, 2013.
[49] IPCC, 2006.
[50] USDA, 2014.
[51] Renewable Energy World, 2012.

significantly reduce China's emissions and can provide a model for technology transfers to India.[52]

4. **Provide support:** Supportive measures to promote low-carbon chemical and steel joint ventures between industries in both developed and developing countries should be adopted. International business integration in key industries will facilitate technology transfers and reduce the emissions effects of outsourcing which result from access to shipping.

CONCLUSION

The chemical, iron and steel, and cement industries produce a significant source of potential greenhouse gas emissions abatement, largely centered in the U.S., China, and India. While each of the targeted industries' abatement solutions—use of best available technology, fuel and feedstock switching, cogeneration, recycling, and carbon capture and sequestration—are implemented at the firm level, government decision makers can accelerate adoption by providing technical information, supportive measures, and incentives. However, barriers within the industry sector present a roadblock to the adoption of energy efficient practices. If policy makers want to achieve their goals of reducing industrial greenhouse gas emissions, they must incorporate these barriers into decision making and offer better policy regimes to these industries.

[52] WRI, 2010.

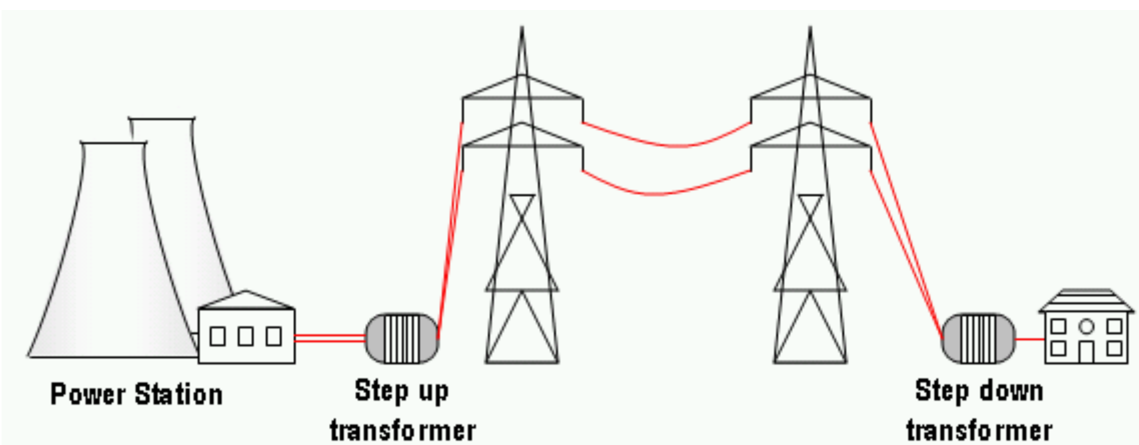
SMART GRIDS

A third, high-potential intervention for the energy efficiency sector is the global deployment of a smart grid infrastructure. Unlike the building and industry focuses, the smart grid is less of an end-product solution than it is a framework for other reduction areas. The smart grid lays the foundation upon which other solutions may be built; without it, integrating variable generation technologies and promoting electric vehicle (EV) adoption would be more difficult and diffusion of these technologies would not spread as rapidly. By updating electricity transmission and distribution systems to conform to the smart grid vision, not only will there be efficiency gains in the electricity sector, but also spin-off effects such as an increase in consumer conservation, greater distributed renewable energy generation, and increased facilitation of EV deployment.

SMART GRID BASICS

The traditional electricity grid is a relatively straightforward system of power transmission, from the point of generation to the point of consumption. Generators produce electricity from primary energy sources, which is then transferred to consumers via power lines. Transformers and substations step voltages up for low-loss transmission, then down for safe consumption. Because electricity is dynamic and current storage technologies for electric energy are poor, the amount of power end-users demand must continually be met through real-time generation. Grid operators are tasked with the responsibility of maintaining this balance between producers and consumers.[53] Figure I illustrates the typical layout of a power grid.

Figure 11. Traditional power grid setup[54]

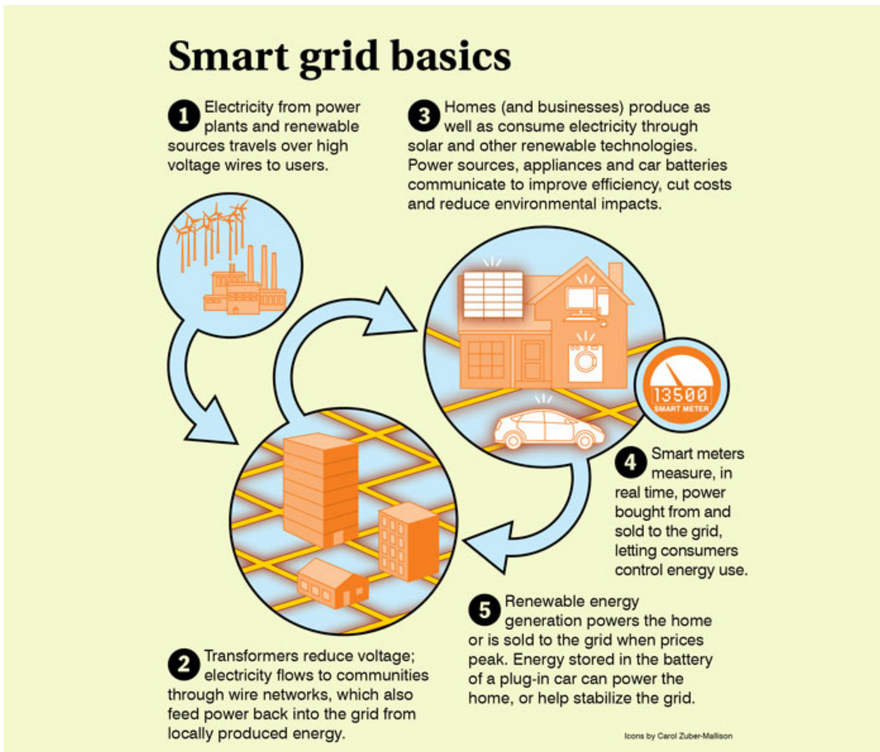


The smart grid builds upon this conventional power system setup by integrating information technology into the infrastructure. This comprehensive monitoring allows

[53] Brain, n.d.
[54] Wikimedia, n.d.

operators to react quickly to power losses and fluctuations in demand, thus providing more efficient grid management services. More advanced smart grid arrangements also incorporate plug-and-play interfaces for EV charging, energy storage, and distributed renewable energy generation. Additionally, smart grids are generally coupled with a dynamic pricing scheme that more accurately represents market rates (which fluctuate regularly). All of these components prompt behavior changes that reduce carbon and GHG emissions from the electricity sector.[55] See Figure 12 below for a visual representation of these smart grid updates.

Figure 12. Smart grid basics[56]



One of the most integral components of a smart grid system is the smart meter, which is deployed to end-users and displays their real-time consumption, total consumption, cumulative costs for the month, and (ideally) spot electricity prices. This gives consumers new insight into exactly how much energy they are consuming at any point in the day. Additionally, with real-time electricity pricing, consumers will know precisely how much they are paying for the energy they use. Smart meters help promote energy conservation and peak-flattening demand response (relieving grid stress and reducing the need for new generation investment).[57]

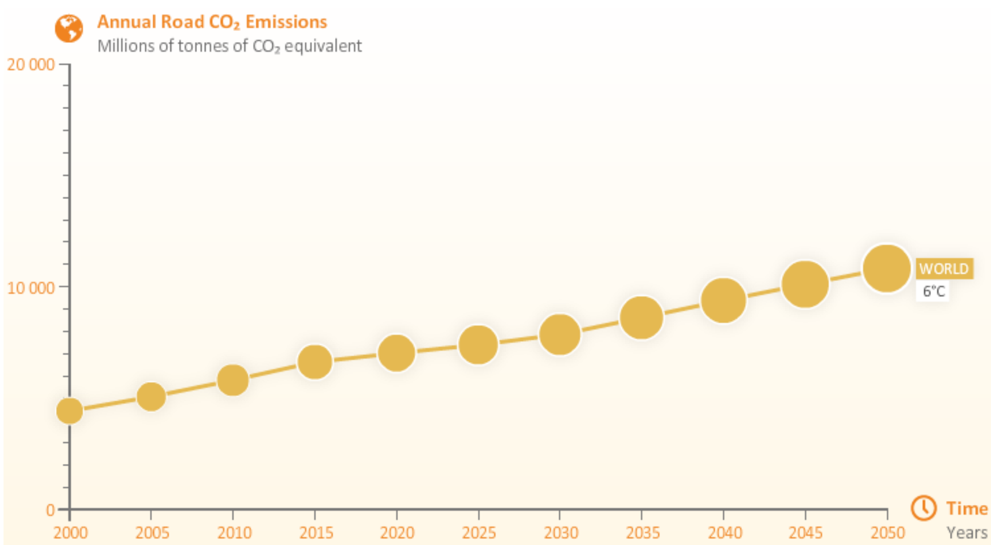
CURRENT EMISSIONS

[55] IEA, 2011.
[56] EDF, n.d.
[57] IEA, 2011.

Because the smart grid would affect a variety of areas, several sectors' current emissions and BAU projections must be examined for us to understand what type of abatement potential exists within this subsector. Transportation, electricity production, and transmission & distribution (T&D) must each be studied, because a smarter grid would result in more efficient electricity transmission, higher integration of cleaner energy production technologies, the potential need for fewer fossil-fuel fired peaking plants, overall higher levels of conservation, and a possible reduction in transport sector emissions. The lowered transport emissions depend on the rate of EV uptake and electricity source—clearly, if the power plants in the area are primarily coal-based, then there may not be much benefit realized even with a radical shift to electric vehicles in the region.[58]

Figure 13 depicts 2011 emissions for electricity production and anticipated emissions under a new policies scenario, as outlined by the IEA. Using the 2011 emissions intensity and projected 2035 electricity demand, BAU projections of generation emissions can be estimated at 21.3 $GtCO_2$ in 2035. Figure 14 shows the BAU emission curve for the transport sector, based on current CO_2 levels and expected increases in demand. Under this scenario, emissions from transportation are predicted to be 8.6 $GtCO_2e$. Additionally, Figure 15 illustrates the size of carbon dioxide emissions directly attributed to T&D losses in 2010 by country of interest.

Figure 13. Annual CO_2 emissions projections, Transport Sector[59]



[58] Alternative Fuels Data Center, n.d.
[59] IEA, 2012

Figure 14. Global CO_2 emissions from the electricity sector, 2011 and 2035[60]

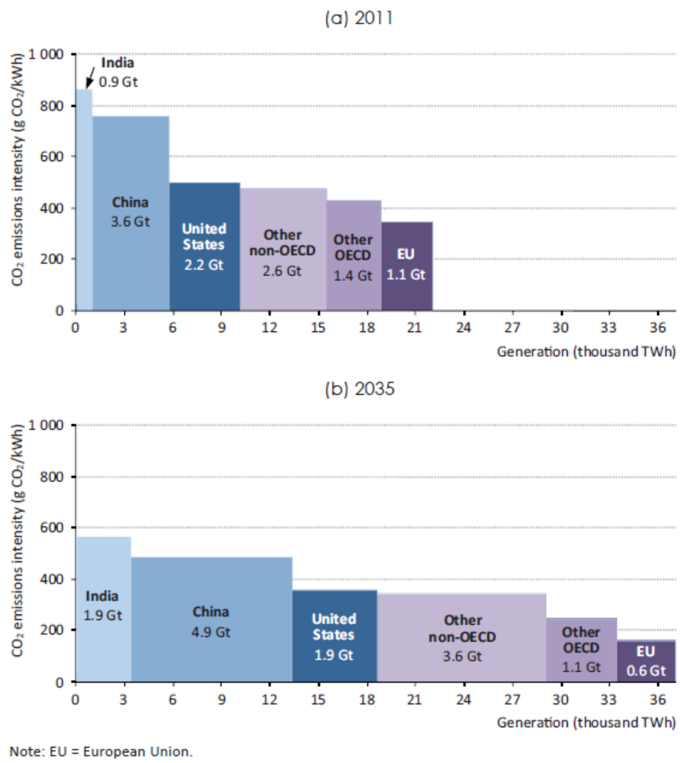
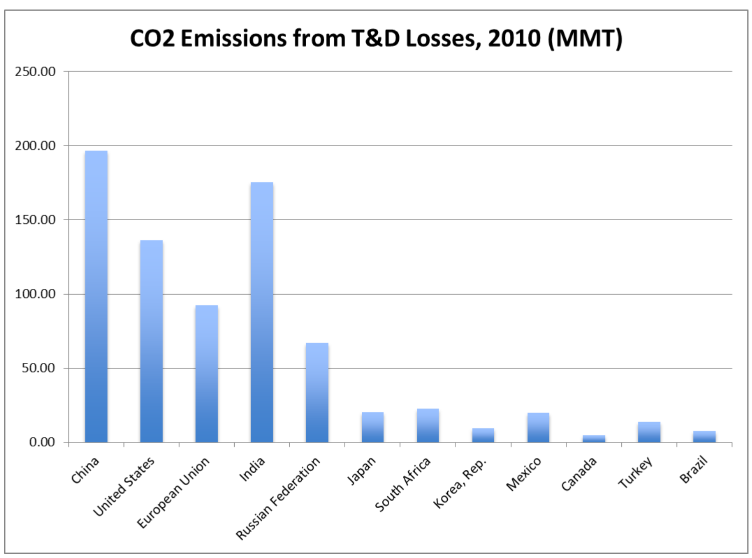


Figure 15. CO_2 emissions from T&D Losses by Country, 2010[61,62]



[60] IEA, 2013.
[61] IEA, 2012.
[62] World Bank, n.d.

ABATEMENT POTENTIAL

A smart grid rollout throughout the OECD nations, as well as China and India, could have a sizeable impact on GHG emissions reduction efforts in the sectors mentioned above (see Table). Direct impacts include energy savings that arise from better peak load management (via the aforementioned demand response resulting from smart meter installations); accelerated deployment of end-use and system energy-efficiency programs, resulting in general overall conservation; and reduced system losses, due to more efficient and responsive grid balancing. Indirect impacts include emissions reductions stemming for greater investment in distributed, renewable electricity generation (e.g., residential solar PV arrays) and the facilitation of EV investment.[63]

According to studies done by the IEA, Pacific Northwest National Labs (PNNL), and the Electric Power Research Institute (EPRI), there is a wide range of potential abatement estimates that could result from global smart grid adoption over the next few years or decades. These reductions will be spread throughout the electricity production sector, the transportation sector, and electricity transmission and distribution. Because they have been determined and reported in a lump sum—global projection—parsing them out into sectoral and country potential is not possible (aside from the U.S. capacity, which has been estimated through two country-focused studies, shown in Table 5). Some general regional numbers are presented in Figure 16, but these values have not been broken down into a national analysis. Therefore, the best that can be asserted at this point is that these projected abatement numbers will reduce the BAU projections shown in Figures 16 and 17 should impact the annual losses attributed to transmission and distribution, but by an indeterminate amount in each sector.

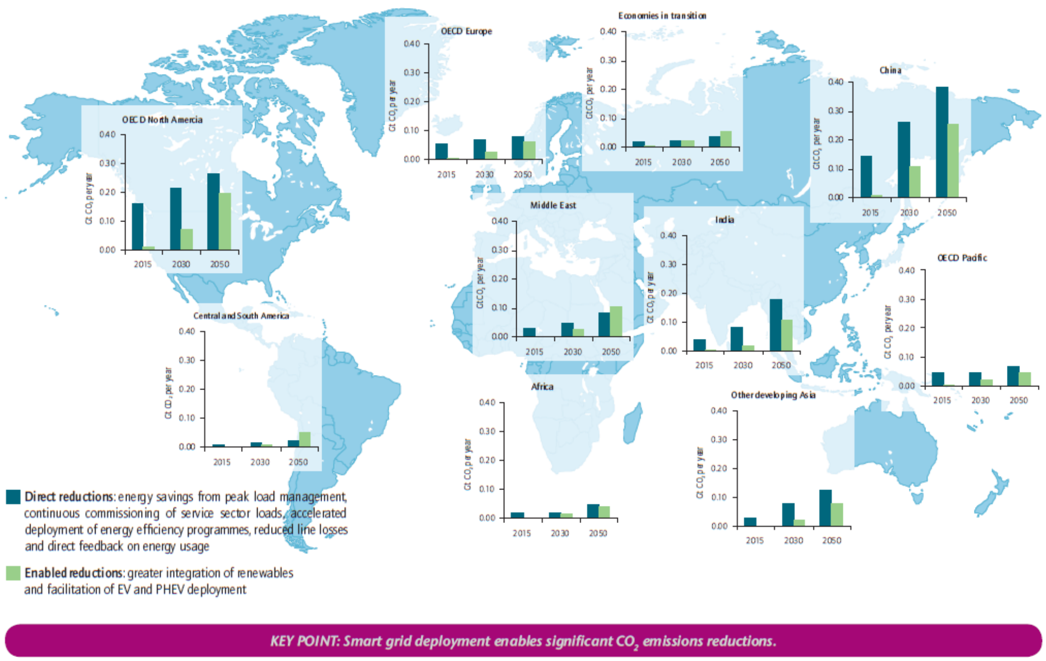
Table 5. Abatement Potential by source and region[64] [65] [66] [67]

Amount Reduced	Type of GHG	Target Year	% Reduction from Projected Global Emissions	Source	Area	Report
60 – 211 MMT/yr	CO_2	2030	0.23 – 0.85%	ERPI	U.S.	The Green Grid
277 – 359 MMT/ yr	CO_2	2030	1.07 – 1.38%	PNNL	U.S.	PNNL Smart Grid: Estimation of Energy and CO_2 Benefits
0.7 – 2.1 Gt/yr	CO_2	2050	4.38 – 13.13%	IEA	World	IEA Smart Grid Technology Roadmap
0.2 – 0.5 Gt/yr	CO_2	2020	0.59 – 1.47%	IEA	World	IEA TCEP

[63] IEA, 2013.
[64] Balducci et al., 2010.
[65] EPRI, 2008.
[66] IEA, 2011.
[67] IEA, 2013.

The impacts on the transportation sector emissions are highly dependent on region of implementation and the development of that region's electricity production sector in the upcoming years. Nations like India and China, which are currently highly dependent on coal for power generation, could actually see an increase in GHG emissions with an increase in electric vehicle adoption.[68] If the IEA 2DS[69] guidelines are followed, however, these nations will be simultaneously investing in a cleaner energy production infrastructure, and the transition would therefore likely result in a decrease in carbon dioxide emissions.[70]

Figure 16. Regional Smart Grid deployment potential



RATIONALE

The deployment of a smart grid infrastructure is extremely important for the success of other sectors' abatement potential. Because it lays such a solid foundation for distributed renewable generation, EV deployment, automated and comprehensive demand response, and overall conservation potential, it can be viewed as a framework for the future. In light of the world's expected growth in electricity demand—a projected increase of 150% over 2010 numbers under the IEA Baseline Scenario[71]—and the effects already brought on by climate change, the peak demand management measures and enablement of easy distributed renewable

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[68] Doucette and McCulloch, 2011.
[69] 2DS is the most ambitious mitigation scenario that IEA explores.
[70] IEA, 2012.
[71] IEA, 2011.

generation are essential. Otherwise, the necessitated construction of new fossil fuel-fired peaking power plants heightens the risk of significantly increasing global GHG emissions.

Additionally, the adoption of smart grid technologies in developing nations (particularly those in Sub-Saharan Africa)—on a modular, microgrid scale—could be a cost-effective way of bringing electrification to the rural areas of these countries. Under a smart grid system, these households could build their way up from battery-based and single-household, distributed generation to local, regional, and national connections as the nation and its economy develops.[72]

The smart grid also addresses opportunities for improvement throughout all levels of the value chain. Consumers benefit from fewer and shorter outages, since grid operators can more effectively balance load fluctuations and isolate areas of failure. They also have the opportunity to enter the market as a power provider, should they choose to invest in residential generation. Operators see gains because they have fewer losses and can more efficiently balance their supply and demand. Power generators have better insight into their expected demand due to the IT feedback from smart meters and mass data collection. And finally, utilities, too, have a better picture of their consumer profiles, and can tailor their offerings to fit specific consumer demands.[73]

With all of these functional benefits in mind, it is also important to understand that smart grid technologies are quite cost-effective emissions reduction solutions—for all areas of the world. The investment's monetary benefits exceed the costs, and this payback occurs concurrently with investment. Essentially, as a nation is building out its grid infrastructure, the benefits are realized almost immediately (see Table 6 for more details). Smart grid projects running in the United States have already demonstrated this payback trend. In March 2012, the US government had invested $2.96B in smart grid development, and had already seen an economic benefit of $6.8B.[74]

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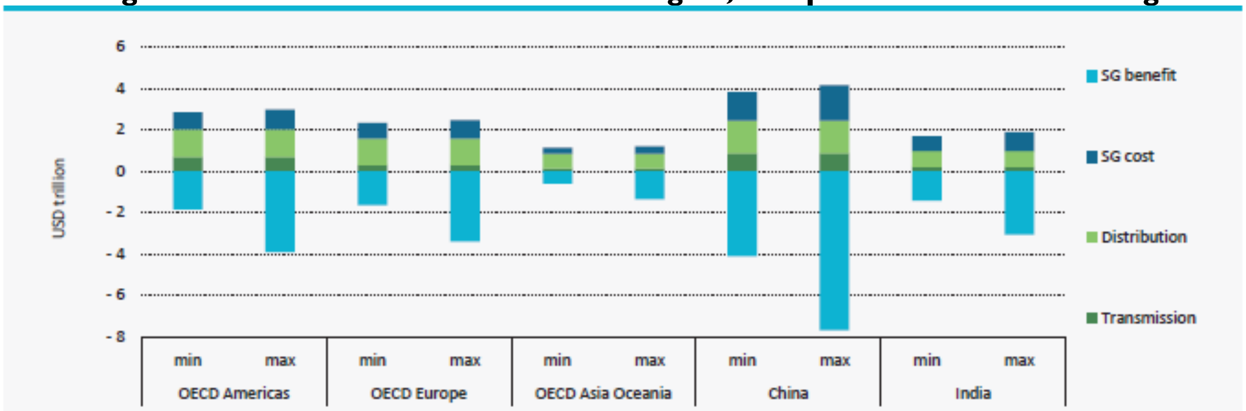
[72] Ibid.
[73] Clastres, 2011.
[74] "Smart Grid Economic Impact," *Electronic Perspectives* 38, no. 3: 14.

Table 6. Costs vs. benefits of smart grid technology under IEA 2DS deployment plan[75]

USD Billions		2010 – 20		2020 – 2030		2030 - 2050	
		Cost	Benefit	Cost	Benefit	Cost	Benefit
OECD Europe	Min/max	124 – 143	430 – 730	169 – 197	320 – 856	468 – 565	882 – 1820
OECD Americas	Min/max	126 – 248	461 – 820	183 – 215	360 – 948	507 – 600	1019 – 2138
OECD Asia Oceania	Min/max	54 – 61	305 - 452	73- 85	59 – 340	176-205	232 – 564
China	Min/max	177 – 239	483 -786	278 – 351	736 – 1632	908 – 1121	2893 – 5261
India	Min/max	113 – 147	264 – 391	134 – 173	112 – 516	475 – 486	1035 - 2150

When compared with the build-out of our conventional power grid system, the costs are also favorable. A traditional grid does not elicit efficiency savings like the smart grid does, so there is essentially no payback on investment. While the upfront costs are higher, as shown in Figure 1, this extra cost for upgrading the grid under smart parameters is actually always outweighed by the benefits, no matter how extensive the implementation scenario is.

Figure 17. Costs and benefits of smart grid, compared with traditional grid[76]



BARRIERS TO IMPLEMENTATION

While the smart grid does offer up a great deal of potential for GHG emissions reductions, cost savings, consumer entry to the electricity market, and reliable electricity transmission, there are a number of obstacles currently blocking this technology from taking off

[75] IEA, 2012.
[76] IEA, 2012.

on a global (or even a widespread, national) scale. Despite its quick and sizable payback, the costs of rolling out a new smart grid infrastructure are still quite high. Additionally, there are market barriers preventing utilities and transmission organizations from investing, cultural barriers preventing consumers from embracing the smart meter, regulatory barriers exposing vulnerabilities to the system, and general questions about how effectively the smart grid prompts adequate demand response. Additionally, utilities must be open to the possibility of purchasing power from their consumers (those with EV storage or distributed generation). As of now, this prospect is met with mixed reactions from some, since they view such a requirement as damaging to their profit margins.[77]

FINANCIAL BARRIERS

As has been discussed, the upfront cost of rolling out a widespread smart grid infrastructure in any one nation is quite high. While this may be a deterrent for developed nations, it can act as an all-out roadblock for developing countries. For example, even though modular microgrids are an effective solution for nations trying to electrify their rural areas, the initial capital costs of smart grid development, particularly those looking to integrate renewable technology, can be prohibitively expensive.[78] For developed nations, the investment in communications hardware and other upgrades is also high, and therefore justifying such an expense can be difficult.[79]

MARKET BARRIERS

Currently, the costs required to construct a successful smart grid are spread out among the electricity distribution system actors—meaning, the grid operators, utilities and paying consumers. However, the benefits that result from a smart grid implementation are distributed throughout the entire electricity sector (for example, to generation facilities, which do not have to bear the burden of grid upgrade investment).[80] As a result, there is disparity between who pays and who gains. For smart grid infrastructure investment to be successful, there must be a fair distribution of costs and benefits, which will only happen if governments establish regulations tailored specifically to address this issue with the smart grid.

Furthermore, there is uncertainty in the regarding consumer response to smart grid development; specifically whether or not they will they embrace their new roles as influential members of the electricity infrastructure. The IEA has determined that regional marketing approaches are needed for each area of the smart grid rollout, in order to ensure that consumers adopt their new roles successfully. This bit of uncertainty is critical, as demand response, investment in residential and commercial renewable generation, and overall energy conservation account for a large portion of the emissions reductions gained by smart grid. There is need for further research and pilot programs to effectively demonstrate the cost savings and positive environmental impacts that smart grids will bring. Further collaboration

[77] Pierobon, 2013.
[78] Clean Energy Ministerial, 2013.
[79] World Economic Forum, 2009.
[80] IEA, 2013.

among various research groups, both domestic and international, would help the evaluation and distribution of best-practice advice.[81] All of this, however, takes time.

INFORMATION & CULTURAL BARRIERS

Additionally, some consumers are strongly opposed to the smart grid. There is a small yet furtive worldwide cultural movement—seated primarily in more developed nations like the U.S. and Europe—to ban the distribution and installation of smart meters in residences. Some are wary of how smart meter-enabled data collection may infringe upon their privacy rights, while others don't like the idea of anyone—utility company or not—knowing when they are home and when they are away (by tracking energy consumption). Another set of opposition groups are concerned about the potential health impacts of wireless data transmission from their at-home smart meters back to the grid operators. They claim the radiation will have long-term, damaging effects to household occupants, and cite cell phone radiation as a similar issue (although the link between cell phones and cancer is still unproven).[82] Others do not like the idea of utility workers tromping through their yards and gardens to install the meters. And, finally, some consumers are not open to the notion of the increased costs they will face to foot the bill of a smart grid.[83]

REGULATORY BARRIERS

Cybersecurity is a significant concern that has many alarmed consumers voicing negative opinions about the smart grid. Currently, the electricity sector needs more standards, regulation and best practice policies to ensure that under a smart metering infrastructure, consumers' information and data is adequately shielded from potential threats. Policies must be developed to guarantee that consumer security is standardized and enforced throughout the entire industry. These regulations and protocols must address vulnerabilities in equipment, the transmission of data, and data storage.[84]

Another regulatory barrier is the lack of policies regarding interoperability.[85] There should be an international set of standards regulating the interfacing of various grid components with one another, as well as grid components with other "smart" components, such as EVs, distributed generation, and smart appliances. Without these interoperability regulations, consumers may face issues with compatibility and grid operators may run into issues related to technological obsolescence and expanding/scaling up their metering. Additionally, lack of interoperability standards may also open the door for cyber vulnerabilities.[86]

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[81] Ibid.
[82] NIH. n.d.
[83] Penn Energy, 2012.
[84] IEA, 2011.
[85] Ibid.
[86] IEA, 2013.

RECOMMENDATIONS

Smart grids have considerable potential for prompting more efficient energy consumption, but it is clear that enabling the adoption of this infrastructure will require the help of new policies. To bring down some of the barriers highlighted above, the IEA recommends that policymakers consider the following:

1. **Establish Legalities:** Establish "protocols, definitions and standards for equipment, data transport, interoperability, and cyber security;"[87]

2. **Collaborate:** Collaborate with other nations to spread best practices and set international standards;

3. **Develop Policies:** Develop new policies to regulate privacy and alleviate concerns related to smart metering;

4. **Invest in Knowledge:** in marketing, R&D and working pilot programs that involve a wide array of participants and which may serve to build trust in the smart grid infrastructure and dynamic pricing scheme; and

5. **Educate:** Implement education programs to relieve culture barriers associated with the smart grid infrastructure.[88]

Additionally, drawing upon the above recommendations, policymakers may also want to consider the following:

1. **Dynamically Price:** Encourage and establish policies that enable dynamic pricing schemes throughout the electricity sector;

2. **Supportive Regulation:** Develop regulatory mechanisms and policies (such as renewable portfolio standards) to ease and encourage the transition to higher integration of renewable energy technologies into the grid;

3. **Design Business Models:** Encourage business model development and microfinancing arrangements that enable developing nations to invest in micro smart grids as they expand electrification.

Of course, comprehensive acceptance of a smart grid infrastructure will take time, as all major changes do. Hopefully, through the implementation of recommendations such as those outlined above, the length of this adjustment period, one characterized by high tensions and resistance, will be reduced.

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[87] IEA, 2011.
[88] Ibid.

CONCLUSION

The smart grid is a unique area of energy efficiency, because it is an effective enabler for larger-reaching greenhouse gas emissions reduction potential spanning from energy production to transportation. The direct environmental gains achieved through a smart grid infrastructure are large; the indirect gains, too, are significant. While this technology is still being researched and developed, initial studies have shown that despite its high upfront costs, the smart grid can enable sizable financial benefits—and not just in developed nations. If the various barriers barring the path of widespread deployment can be overcome, smart grid has the potential to lay the foundation for more efficient and effective electricity generation for years to come.

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