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Key challenges to expanding renewable energy

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HIGHLIGHTS

- Integration of intermittent renewables with existing power grids.
- Renewable ramping and over production issues.
- Renewable caused system costs.
- Energy poverty circumstances and consequences.

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ABSTRACT

The key advantage of renewables is that they are free of direct pollution and carbon emissions. Given concern over global warming caused by carbon emissions, there are substantial policy efforts to increase renewable penetrations. The purpose of this paper is to outline and evaluate the challenges presented by increasing penetrations of renewable electricity generation. These generation sources primarily include solar and wind which are growing rapidly and are new enough to the grid that the impact of high penetrations is not fully understood. The intrinsic nature of solar and wind power is very likely to present greater system challenges than "conventional" sources. Within limits, those challenges can be overcome, but at a cost. Later sections of the paper will draw on a variety of sources to identify a range of such costs, at least as they are foreseen by researchers helping prepare ambitious plans for grids to obtain high shares (30–50%) of their megawatt hours from primarily solar and wind generation. Energy poverty issues are outlined and related to renewable costs issues.

1. Introduction

The purpose of this section is to outline and evaluate the challenges presented by increasing penetrations of renewable electricity generation. These generation sources primarily include solar and wind, which are growing rapidly and are new enough to the grid that the impact of high penetrations is not fully understood. The challenges associated with solar and wind will be examined qualitatively, and to the extent possible, in terms of the costs that might impact the system over and above the costs associated with deploying and operating electrical generation equipment. Hydropower is generally well integrated into existing operations, but has much less potential for growth. Tidal, wave, run-of-river hydro and geothermal sources are currently much more limited in both quantity and growth (EIA, 2015). Energy efficiency is sometimes considered an energy "source," but is not usually combined with renewables; nonetheless, it is discussed below because the potential for more efficiency would to some extent obviate the need for renewables (or for more nuclear). Special challenges posed in developing countries are presented as well.

The intrinsic nature of solar and wind power is very likely to present greater grid system challenges than "conventional" sources. See "Power System Fundamentals," Section 2 below for explication of the unique challenges presented by renewables. Within limits, those challenges can be overcome, but at a cost. Later sections of the paper will draw on a variety of sources to identify a range of such costs, at least as they are foreseen by researchers helping prepare ambitious plans for grids to obtain high shares (30–50%) of their megawatt hours from primarily solar and wind generation.

Since a primary policy rationale to including renewables in the system is reduction of carbon emissions, prospects for high (30–50%) penetrations of renewable power will be a key focus, even though they may require significant technology improvements such as renewable cost reduction and widely available low cost energy storage. There is hope that areas unusually endowed with renewable resources can achieve these reductions given current trends (Brinkman et al., 2016).

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These issues also raise the question of what role is appropriate for nuclear power (a non-CO2 power source whose capacity can be expanded) in helping integrate renewables into grid operation.

2. Some power system fundamentals

Modern electric power grids are really a technological marvel, even if routine. Electric power, delivered as needed on demand is a priceless resource for industry, commerce and everyday household life. In addition to the simple availability of easy-to-use energy, its value is much increased by the reliability and the "quality" of supply. Power must be supplied to users within voltage tolerance limits, and rigidly maintained frequency (60 Hz in the US).

Power systems are typically very large networks drawing on many generating sources of power and dispatching that power to many loads. This involves large-scale "transmission" of power to nodes and "distribution" of power to users who range from very large industrial complexes to ordinary homeowners and everyone in-between. These systems are extensively thought-out and planned.

The degree of difficulty for maintaining such a system is substantially exacerbated by the fact that power flows are virtually instantaneous and that power storage opportunities are very limited. Thus, any upsets in the system (large power plants or industrial users tripping offline, transmission line breakdowns, etc.) must be offset on the order of seconds. Further, like any mechanical equipment, power plants must be periodically shut down for planned maintenance and reserve power must be available during these periods.

The two most basic measures of electricity are megawatts (MW), which connote the flow rate of power or capacity of generation, and megawatt hours (MWh), which indicate energy usage.

Costs associated with power sources occur at three levels. First, there are the costs of the generation facility itself. These are capital costs for land, equipment and construction, and ongoing operating and maintenance costs. The given facilities must be connected to the grid, and the grid must be capable of carrying sufficient power to desired nodes which gives rise to additional capital and operating costs. Finally, all power systems have substantial infrastructure whose primary purpose is to maintain grid stability and reliability. This need is acute because, at least for now, the possibility of storing electricity is cost-effective only in limited cases.

Solar and wind power are fundamentally different in character from traditional fossil fuel sources, nuclear and hydro. Such "conventional" facilities are normally described by their capacity for power production in terms of MW. That capacity is generally available on a dispatchable basis for the system operator. Fuel (coal, oil, reservoir water, uranium) is stored on site or piped in (natural gas). While breakdowns do occur, they are rare.

Solar and wind are also rated according to capacity. However, these ratings are based on specified conditions: 1 kW/square meter insolation (intensity of sunlight) and 12 m/s wind, for example. However, these conditions are not achieved at the discretion of the operator, but rather are subject to nature.

Consequently, both solar and wind energy present intermittency issues to system operators. These are time of day, seasonal and even idiosyncratic. Solar and wind produce energy from available sunshine and wind. Either of those can change very suddenly. But power demand doesn't fall, so the shortage situation must be dealt with. Wind availability may not correspond to time of day or seasonal power needs. In addition, both solar and wind at utility scale require substantial expanses of land for deployment and good insolation or wind availability. Thus, these sources may require substantial transport of power from locations not convenient to the grid. Conventional sources have similar problems, but face fewer location constraints since their fuel is more transportable or ubiquitously available.

Up to a certain level of penetration, these issues associated with intermittent renewables don't present unique challenges for grid operators. While rare, breakdowns from conventional power generation equipment certainly occur and variations in load occur frequently. Operators have developed a number of tactics for dealing with these. Spinning reserves, for example, can be brought online very quickly to offset power sags or meet load coming onto the system. Power is already transported long distances in particular circumstances.

However, these tactics come at a cost. Currently such costs are often subsumed into aggregate system operation costs. Since renewable sources tend to draw more heavily on these resources, they are in effect subsidized by grid operation. (They can be charged directly for such services, but currently, given their small portion of total supply, this is not often done.) This implicit subsidy is in addition to direct subsidies currently provided renewables (Poser et al., 2014; OECD/NEA, 2012).

As the proportion of solar and wind power to conventional power grows, the operational realities of these issues become clear. To the extent possible, some exemplary costs imposed by renewables will be evaluated. A number of European nations are planning for substantial increases in solar and/or wind shares for their power sources. The California grid currently provides excellent examples, which will be explored. Further, as current energy policy, particularly in California, dictates unprecedented shares of renewable power for future years within utility planning horizons, the ultimate limitations of such power are being investigated and will be examined here and in Chapter Five (OECD/NEA, 2012). See Section 6 "Low Carbon Grid Study" for a counter example of California with relatively well situated resources.

3. System costs versus facility costs

All large power plants require substantial capital investment for site locations, structures and equipment. "Conventional" power plants (coal, oil, natural gas, hydro and nuclear) turn some sort of turbine attached to generation machinery. The capital investments associated with conventional power plants are usually expressed in terms of dollars per MW. These generators produce alternating current power. That power must be conditioned and transferred to the grid. Critically, all of these spinning generators must be synchronized, i.e., spin at the same speed.

Except for hydro, conventional plants have fuel costs. All have operating costs similar to what would occur in any factory and require significant periodic maintenance.

3.1. Connection

Solar and wind power installations require high capital expenditure per MW of rated power which as mentioned above does not have the same connotation as conventional plants. Solar photovoltaic (PV) power requires specific equipment to "condition" produced power to convert direct current to AC, increase voltage and maintain grid synchronization. Additional steps are required to ensure solar PV installations meet grid requirements for upset conditions. On the demand side, grid operators prefer that wind farms install additional equipment to support grid interaction, providing, for example, the ability to curtail wind output.

3.2. Transmission

Large scale power facilities transmit produced power to the grid for ultimate delivery to system nodes and then distribution among users. Such transmission costs tend to be higher for solar and wind relative to their rated capacity because of location limitations cited above, and because relative to their rated power, they have relatively low load factors. Generally, transmission is sized to accept the highest output likely from such facilities. This is especially true when plans for renewable energy set ambitious goals for production. Higher per MW costs spread over relatively fewer MWh means higher cost (OECD/NEA, 2012). Nuclear facilities also often bear relatively high transmission costs. For safety considerations, they have a redundancy in connection to provide greater assurance for cooling water pumps. This is in addition to onsite backup diesel or other power.

3.3. Balancing and adequacy of supply

Over and above facilities costs, power grids require system infrastructure to maintain continued operation and stability. While solar and wind inherently place disproportionate demands on this infrastructure, they are not different in kind from conventional sources.

Solar and wind power availability may tend to vary on a predictable daily and/or seasonal cycle. Solar especially can be expected to have a daily cycle. During any off cycle, if power demand doesn't fall in concert (the solar cycle tends to almost coincide with peak daily power demand), standby power must be available (at least according to most current standard practice). This same requirement applies to conventional power which needs backup power ("reserve") for maintenance cycles. Conventional sources must be ramped down as solar and wind are ramped up to keep the system in balance. Some baseload facilities, coal and nuclear primarily, have historically run more or less continuously at full power in most systems. System goals set for renewable power generation, e.g., California's goal of 33% of electricity retail sales from renewables by 2020, but to a greater extent 50% which is under consideration, require displacing power from these facilities.

Further, solar and wind have inherently more volatile output than conventional sources whose uncontrolled variability is tied basically to relatively rare breakdowns. For solar and wind respectively, sunlight may be obstructed, and wind may stop blowing. There may be some warning, but these events are akin to breakdowns in mechanical equipment. The problem is exacerbated in that these events may impact a range of solar installations or wind farms.

The principal means of meeting power generation shortfalls is spinning reserve, usually gas turbines, intentionally running at less than full capacity. These may be ramped up or down very quickly to respond to very short term situations.

With greater warning provided by weather forecasts in the case of renewables, maintenance planning and equipment monitoring, reserve facilities can be fired up and brought online to fill-in gaps in demand. Again, these are typically gas-fired fossil fuel plants or hydro. Simple cycle gas turbines are used for spinning reserve because they have lower capital costs than most other capacity options.

4. Flexibility

The flexibility of the contribution of new renewables to the electricity supply varies. Hydroelectricity is generally reliable and provides flexible supply (except in periods of prolonged drought). Operators can also store huge amounts of water/power to be used when necessary. This advantage is enhanced by pumped hydro storage, which involves pumping water uphill into the reservoir at off-peak and then releasing it when needed. Biomass (subject to land and water availability, and food requirements) and geothermal can provide reliable renewable sources. However, other new renewables (particularly solar and wind) present formidable challenges to the transmission supply operators due to their intermittency and unpredictability from changing meteorological conditions.

The flexibility of national electricity grids to accommodate variable power sources is enhanced by achieving geographic and technological diversification of variable energy sources, improving local energy management, the increasing prospects of energy-storage schemes, and also by trading with other electricity grids.

Nuclear plants pose other types of system challenges because they most often dispatch power below cost when power demand is low. They need some time to ramp up and down their load and follow system. Some light-water reactor (LWR) plants have limited ability to significantly vary their output to match changing demand. Pressurized water reactors (PWR), CANada Deuterium Uranium (CANDU) and boiling water reactors (BWR), have load-following capability which allows them to fill more than baseload generation needs. Some newer reactors also offer some form of enhanced load-following capability. For example, the Areva EPR™, a PWR, can slow its electrical output power between 990 and 1650 MW at 82.5 MW per minute. However, the great capital expense of nuclear facilities militates against such routine use. Their low marginal cost of production tends to dictate baseload operation, and high utilization helps amortize capital cost.

In the generation dispatching schedule, renewables production is "free," and it is a "must dispatch" source of generation. This is followed by nuclear. Correspondingly, if the system has minimum load, e.g., during weekends, and a surge of wind occurs, renewables and nuclear output may exceed demand. It is not easy to ramp down load on nuclear quickly or shut down other dispatchable facilities in the generating system. These events lead generation to significantly exceed load. If there are enough regional interconnections, neighboring systems can accommodate some of this excess generation (as regularly happens with Denmark's wind energy generation). But what happens if those systems have the same problem? For example, offshore North-West Europe periods of calm quite regularly coincide across a wide area of ocean.

The least-cost solution is to offer consumer incentives to take more load by various means including negative pricing. This means that nuclear output is not only offered free, but consumers are actually paid incentives to take it. We are not talking hypothetically here, but of actual incidents experienced by the European system in recent years. In other cases, the power output of these plants is simply curtailed. If new renewables, particularly the wind component, are increased, then this dispatching problem is going to become more acute. It remains to be seen whether these scenarios lead to an increase in the disadvantages and costs of nuclear generation or to the fuller exposure of the frailties of new renewables to the advantage of nuclear. Given a need for nuclear across such an area during wind lulls, it may be preferable to provide incentives for consumers to take excess power during wind peaks rather than cycle nuclear facilities. This sort of load shifting is considered in the "California Low Carbon Grid Study" addressed below in Section 6.

5. System cost and renewable share

A number of countries and states in the US have advanced very ambitious goals for the share of power provided by renewable sources. California calls for 33% electricity retail sales from renewables by 2020 (originally 20% by 2017), not including hydro. Finland, France, Germany, Republic of Korea, and the UK have

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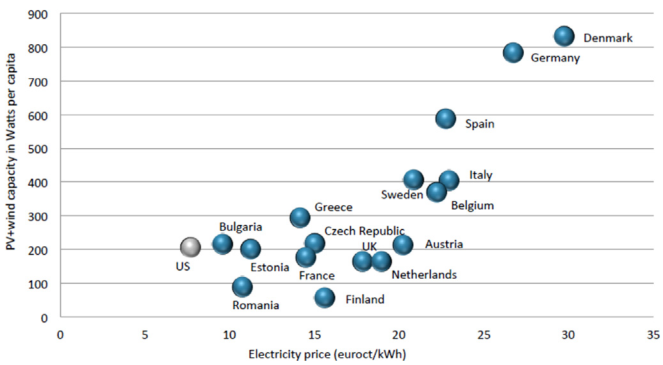

Fig. 3.1. Comparison of the amount of wind and solar capacity and electricity prices, selected countries, 2012.

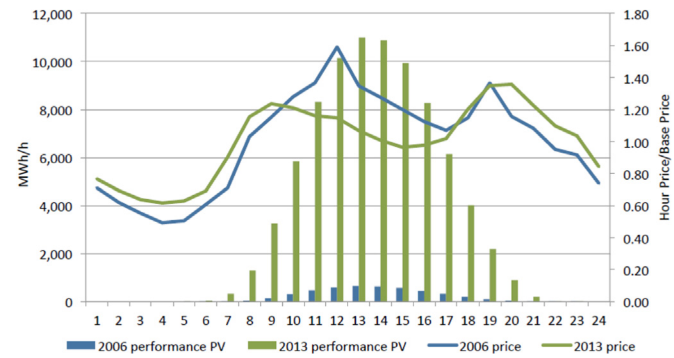

Fig. 3.2. Yearly Performance of PV and Electricity Tariff (standardized). (Poser et al.).

ambitious goals as well. Denmark is already deriving 30% of its power production from wind, and exports power to nearby countries in times of surplus. Maine, Massachusetts, New Hampshire, New York and Maryland have already cut their power sector emissions by 40% with renewables and gas.

Much study and planning have been undertaken to understand the consequences of these goals. They are potentially two-fold. First, total cost of power per MWh increases (on a fully allocated cost basis which includes the cost of capital) because renewable generation is now relatively expensive, and because system costs per MWh increase as the share of renewables increases (OECD/NEA, 2012). System costs increase because proportionately more balancing and back-up resources are required to compensate for the intermittency of increased renewables.

The second concern is the extent to which there is a limit to the share of renewable power, at least as provided by wind and solar, that can't be dealt with without some dispatchable fossil fuel power in the system.

A recent study illustrates these factors specifically with respect to Germany and presents data across nations. This is summarized in Fig. 3.1.

As can be seen, there appears to be a strong positive correlation between consumer power costs and the percentage of solar and wind penetration. A more subtle insight is that the cost impact from penetration will vary by system (Poser et. al., 2014, p. 33).

In Germany this situation has also reduced revenues for "traditional" fossil fuel operators. On a real time basis, grid power is priced on the basis of what is in effect an essentially continuous auction based upon marginal generation costs. Solar and wind have zero marginal cost or are designated as "must run" facilities (perhaps for this reason). The availability of substantial "free" resources lowers prices overall. And, in the case of solar, these reduced prices often coincide with peak power demand.

Given the nature of the auction, conventional suppliers bid their short run costs and don't generate unless these are covered and they are dispatched. However, they typically depend on "high" peak prices to make significant margins above cost in order to cover capital costs. These peak prices have been substantially reduced (Fig. 3.2).

The graph shows the fact that peak power prices have been driven down by peak solar power. These peak power prices are what suppliers of reserve power and spinning reserve depend upon to cover costs. The Applied System reference is Johansson et al. (2012).

"This situation is making cost recovery even more difficult. This means that the owners of the plants have to write-off the money they originally invested. RWE, a major German electric utility, recently announced a write down of €4.8 billion on assets, mainly power stations, and a net loss of €2.76 billion ($3.8 billion) on total sales of €54.1 billion, its first full-year loss since 1949…" (Poser et al., 2014, p. 33.) This situation is not unique to Germany. One of Australia's largest electric utilities, Energy Australia, also announced a significant write down due, in part, to gas-fired generators becoming uneconomic because of the rapid growth of solar power and the rapid increase of electricity prices for customers. Generators' financial difficulties have already translated into lower stock prices and credit ratings. In terms of the magnitude of share price reductions, power utilities have fared badly. According to the MSCI (Morgan Stanley) European utilities share price index, the top 20 energy utilities have lost more than half a trillion dollars since their peak in September 2008 (Yardeni Research, Inc., 2016).

Adding significant amounts of renewable power on grid have reduced wholesale power prices overall, and harmed the financial viability of utilities serving the grid. In the long run the insufficient revenue for backup generators would possibly be ameliorated by a rise in prices during periods (night time for solar dependent systems, for example) which are short of power sources. This would be an inversion of current market patterns which have peak prices during peak power demand periods. Alternately, grid operators can offer fixed payments for generators to stand by.

6. California low carbon grid study

However, these problematic results are not necessarily the end of the matter. More recently, and just in process of being completed, an impressive array of sponsors and participants have undertaken a "Low Carbon Grid Study: Analysis of a 50% Emission Reduction in California" (Brinkman et al., 2016). The studies reported in Chapter 5 of this special issue and results examined above might be characterized as "integrating renewables with the grid," meaning the grid as we know it today. The 50% reduction is targeted to be achieved by 2030. This goal is extremely ambitious.

California is a very large power market. Over the range of scenarios studied, in state and contracted sources, capacity ranges from 55 to 65 GW and consumption from 300 TWh to 350 TWh. Thus, the possibility that this very ambitious goal is presented as achievable by this very thorough study, sponsored in part by the National Renewable Energy Laboratory (NREL), is quite significant.

It is best to quote "Key Results" directly, and then subject the study (Brinkman et. al., 2016) to some examination.

This is possible with five key strategies:

- A focus on carbon during procurement and operation.
- A diverse portfolio of renewables and energy efficiency.
- Use of flexible load.
- Cooperation throughout the West.
- Efficient use of the natural gas fleet.

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California can cut electric sector emissions in half by 2030.

- Using proven technology.
- With minimal rate impact.
- Without compromising reliability.
- With minimal curtailment of renewables.
- With a stable gas fleet dispatched with minimum cycling.

California is interconnected with 11 Western states, 2 Canadian provinces and Baja California. The Study asserts that these results would be consistent across the entire Western Electricity Coordinating Council (WECC) interconnection, whose consumption is over 800 TWh. That is, California carbon reductions don't come at the cost of increases elsewhere. These strategies in part utilize these complexities to adapt the grid to renewables. Each is worth a bit of examination.

The analysis starts from behind, assuming that the Santa Nofre nuclear plant is closed down resulting in a loss of significant low direct carbon generation. The remaining sources are reformed and augmented. Obviously substantial renewable capacity is procured and installed in California. In addition, it is assumed that substantial renewable sources outside California are contracted for. This retires some coal generation outside California resulting in carbon reductions.

The California portfolio of incremental renewables includes customer rooftop solar, utility scale photo voltaic, concentrating (thermal) solar, wind, geothermal, biomass, and small hydro. (Large scale hydro is part of the California mix, but is not increased over the scenarios considered.)

Flexible load is moved from the highest peak periods to slightly earlier when solar production conditions are generally better. Given various scenarios this amounts to 2.5–5.2% of annual load. This helps reduce curtailment of available renewable power to the range of 1–4% depending on other assumptions. This means less solar capacity needs to be installed and that capacity is better utilized. The study also posits a substantial penetration of electric vehicles, both commercial and consumer. A portion of these is assumed to respond to "flexible" charging. This utilizes 2700 MW of solar power that would otherwise go underutilized during midday periods.

The Western interconnections allow California to import and export power depending on demand and supply conditions in the state. This would include imports of hydro, solar and wind (much of which is contracted for) when demand is relatively high and native supply too low. It also permits exports (including turning back contracted power) when demand is relatively low. Care has been taken in the study to assure that the other Western states benefit as well by these arrangements so that costs are not shifted out of California by assumption (which would be unlikely to occur in the real world). In addition, the study assumes that members of the Western grid can be expected to cooperate during difficult grid circumstances, reducing the likelihood and severity of outages.

Gas fired generation continues to be required to meet California power needs during particular times. Such generation capacity also aids grid stability in a variety of ways. Utilization of these facilities obviously increases carbon emissions, which are intended to be reduced. However, California's local generation rule requires 25% thermal and hydro generation in selected places. Allowing gas generators to run according to economic efficiency, that is, shutting down such units when very low marginal cost renewable power is available beyond the limits of these rules, avoids carbon emissions.

As mentioned above, this study is very thorough and considers a wide array of possible circumstances. As a consequence, a detailed critique is deserved but must be the subject of another effort. However, here, a high level caveat is appropriate. California is remarkably well situated to take on the challenge of carbon emissions reduction. It has ample wind and insolation resources within 100 miles of over 10 million people augmented by substantial high quality geothermal resources at both ends of the San Andreas Fault boundary. It also has access to non-carbon hydro power. Further, the state has access to the friendly Western US grid with which it can interact with mutual benefit. All of this is good for California in pursuit of carbon reductions, but much of the world does not enjoy these advantages and would likely have greater difficulty and more cost associated with such an effort.

A second and (potentially) unfair caveat is that decarbonization, if it is to occur, must be a long term process and a 50% reduction is not enough. It must be nearly 100% if the worst fears of climate change activists are correct (While the 50% reduction modeled here would be a remarkable achievement, it's clearly not a final goal for those concerned about global warming.)

7. Energy efficiency and energy poverty

Two issues tend to be correlative with renewable integration. These are "energy efficiency" and energy poverty. (In this context, energy efficiency means providing some energy driven services with less electricity.)

Obviously, if services are provided with energy saving technologies, less direct pollution and carbon are emitted thereby achieving carbon reduction goals. In addition, assuming such measures are cost effective, potential increases in power costs associated with renewable integration are ameliorated.

Energy poverty has a two edged relationship with renewables. One the one hand, renewables, especially solar PV, are available at very small scales and at tiny fractions of the cost of grid scale generation facilities. More, they can be deployed entirely independent of a main grid. This means capital costs, even if high per unit capacity, can be affordable, especially if supported by international aid efforts.

Access to a little bit of electricity can matter a great deal. A village solar facility can charge cell phone batteries and give even the poorest substantial communication capability. Batteries can be charged to provide pollution free night time illumination and even run TV's or radios. These high value services can improve lives and dramatically increase productivity.

On the other hand, should integration lead to much higher grid power prices such as in Germany and Denmark, a path out of poverty will face a roadblock.

7.1. Energy efficiency

Multiple studies show that energy efficiency could be the most important method to reduce greenhouse gas emissions while maintaining energy services provided consumers. Under the International Energy Agency (IEA) New Policies Scenario, 2013, total energy demand increases by one-third from 2013 to 2035, rather than 45% under current policies (see Fig. 3.3). Efficiency, especially in end-use sectors, accounts for three-quarters of that reduction. The IEA "Efficient World" scenario is even more aggressive, reducing global primary energy demand by 50% compared to the "new policies" case (IEA, 2013a, 2013b).

Both the IEA and International Institute for Applied Systems Analysis (IIASA) emphasize the importance of energy efficiency to reduce demand for new power generation. In IEA's "new policies" scenario, an additional \$3.4 trillion of cumulative investment through 2035 is projected to be made in energy efficiency compared to its "current policies" scenario (IEA, 2013a, 2013b). IIASA estimates that \$15 trillion will be needed through 2050 (Johansson et al., 2012). These investments produce an impressive payoff. IEA

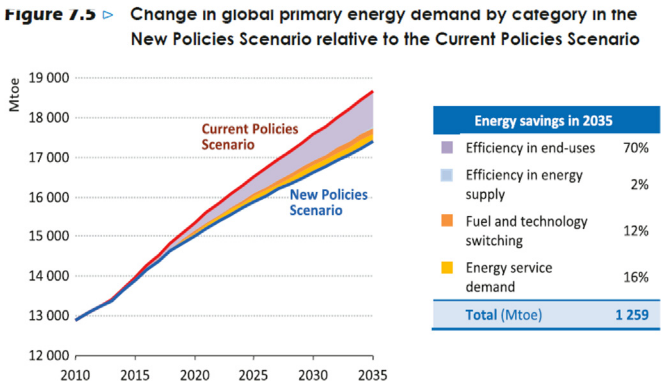


Fig. 3.3. Comparison of energy demand in IEA New Policies Scenario vs. Current Policies Scenario IEA (2013b), 2013 World Energy Outlook, pp. 226–227.).

estimates $6.1 trillion in energy savings and IIASA estimates $57 trillion in avoided heating and cooling costs alone. Nonetheless, as shown in Fig. 3.1, while energy efficiency investment significantly reduces the global growth in primary energy demand, significant overall global growth remains. The estimates of electric power demand growth cited above, account for investments in energy efficiency required by new energy policies.

Realizing this efficiency potential will require strong, sustained policies. The IIASA Global Energy Assessment suggests governments need to address split incentives, such as when energy users (tenants) and building owners have different time horizons for recouping investments, and recommends strong building and appliance standards coupled with information and awareness programs. Policies like these would help nations reduce future energy demand, with benefits including reductions in GHG emissions and other pollutants.

7.2. Challenges outside of the OECD

Outside the Organization for Economic Co-operation and Development (OECD), electrification started rather late, but is gaining momentum. The share of electricity in the Total Final Energy Consumption is 16% in 2011, which is expected to grow to 22% in 2035 according to the IEA New Policies Scenario. The annual growth rate of electricity demand between 2011 and 2035 is estimated at 3.3%, much higher than the growth rate of non-OECD Total Final Energy Consumption (2.0%).

Although energy consumption needs to grow at rates high enough to support economic development, rapid expansion of fossil fuel use will have deleterious effects on the environment. Therefore, in emerging countries, a major energy policy objective should be the "decoupling" of economic growth from fossil fuel energy consumption growth. Along with efforts to promote energy conservation and efficiency, clean energy supplies such as nuclear and renewables will be needed; gas is a cleaner-burning fossil fuel than coal, and will help reach Green House Gas (GHG) targets, but is not sufficient to decarbonize the electricity sector. However, there is uncertainty whether the electricity sector will attract enough investment to meet growing demand, especially in unstable countries. Business models as well as regulatory regimes tested and practiced in OECD countries will not necessarily be applicable to emerging economies due to the difference in not only developmental stages but also social, political and cultural backgrounds.

Energy subsidies, to help the poor or garner votes, present a particular problem as growing demand places burdens on national budgets and discourages energy efficiency. As several OECD energy companies have discovered, money will have to be found to fund new plants, and non-OECD countries in particular will be hard-pressed. Theft of power, corruption and other problems has caused several foreign power investments by independent power companies to fail.

7.3. Energy poverty

However, the largest challenge, which may even dwarf the challenges discussed above, will be the "eradication of energy poverty," especially electricity poverty, in the least developed countries and regions. This is an indispensable part of the efforts under the Goal 7, "access to affordable, reliable, sustainable, and modern energy for all" of Sustainable Development Goals UN 2016. There are several causes of energy poverty, the most obvious of which is living in a community having no, or very limited, access to electricity. Energy poverty can also exist in geographical regions that have inadequate electricity supplies, especially urban areas in less-developed countries. In these circumstances, the inability to afford electricity and associated end-use equipment are among the many consequences of poverty that cause suffering to hundreds of millions of people including malnutrition and preventable disease. These are problems that have existed throughout human history but are incongruous with the opportunities provided by today's technologically advanced economies. As Pope Francis said recently in Rio de Janeiro, "No amount of peace-building will be able to last, nor will harmony and happiness be attained in a society that ignores, pushes to the margins or excludes a part of itself."

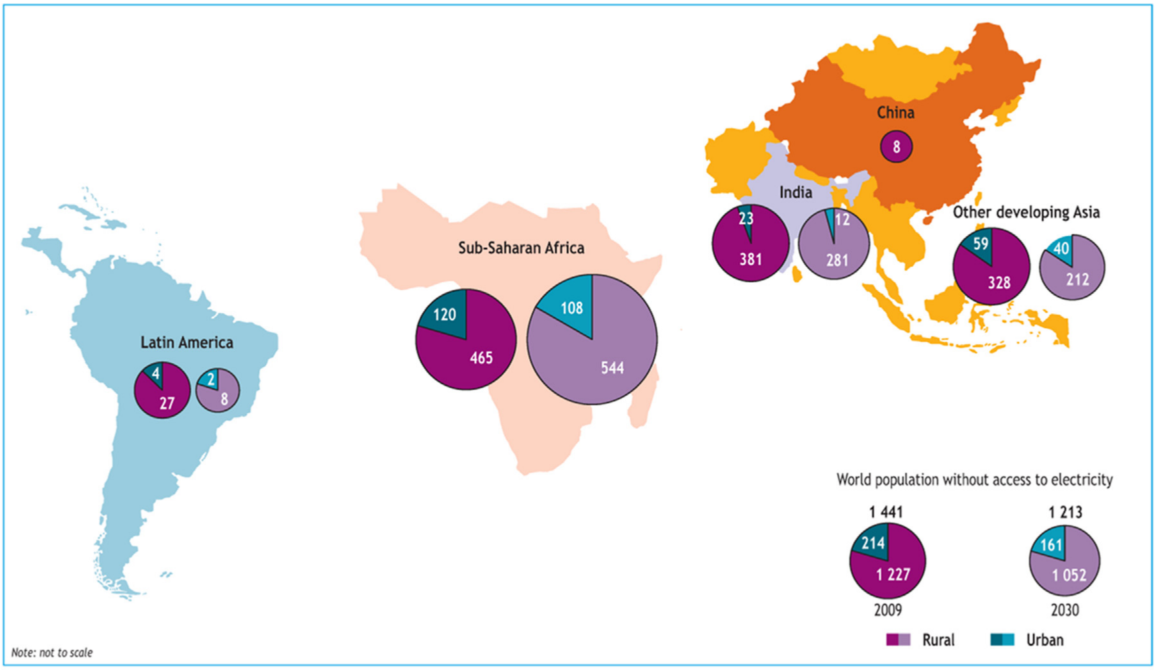
There are 1.4 billion people around the world that lack access to electricity, some 85% of them in rural areas (Fig. 3.4). In some countries, this problem is widespread. For example, 74% of the population in Myanmar lack access to electricity (OECD NEA, 2012). Because it is critical to the quality of human life, access to electricity should be facilitated above all else. Without electricity, the opportunity for education of younger generations will be reduced severely, with serious negative implications for on-going human capacity-building (IEA, 2010).

In this regard, a leapfrogging as seen in telecommunication (bursting into mobile phone bypassing the stage of landline phone) should be widely materialized by making the best use of renewables. Micro-grids using locally available energy sources, such as solar and wind power, will be an important option rather than waiting for the investment in large-scale generation and centralized transmission systems. Micro scale and therefore low capital cost, off-grid solar power, as seen in remote villages in India, is a good start. Even if the fully amortized kwh cost is high, the small amount needed to charge cell phones, or batteries to provide light at night is within reach of the poor. In a nutshell, every effort should be mobilized to overcome such chronic energy poverty as soon as possible though the particular combination of solutions relevant to each country will vary.

While renewable energy technologies, micro grids and interconnections to national power systems are able to provide electrical services to many communities that now do not have them, energy poverty will not be eliminated without outside intervention. Many governments are unable to finance these initiatives without outside aid. In addition, outside aid cannot solve problems in countries with corrupt governments or countries torn with ethnic or sectarian warfare, a condition too often present in communities that do not have access to electricity services.

It is beyond the scope of this paper to discuss the existing sources of funding for energy poverty projects, such as the World Bank's Global Environmental Facility and other institutions except to note that much work needs to be done to finance energy poverty projects. We only note that renewable energy technologies have features that make them especially valuable for application in remote communities and to power micro grids.

However, if renewable driven grids yield very high power



The boundaries and names shown and the designations used on maps included in this publication do not imply official endorsement or acceptance by the IEA.

Fig. 3.4. Number of People without Access to Electricity in Rural and Urban Areas in the IEA New Policies Scenario (unit: millions of people).

prices in the long run, this will create a substantial barrier to emerging into economic prosperity.

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