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International Journal of Ambient Energy

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/taen20

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To cite this article: I. Vinoth Kanna & D. Pinky (2020) Solar research – a review and recommendations for the most important supplier of energy for the earth with solar systems, International Journal of Ambient Energy, 41:8, 962-968, DOI: 10.1080/01430750.2018.1472658

To link to this article: https://doi.org/10.1080/01430750.2018.1472658

Published online: 25 May 2018.

INTERNATIONAL JOURNAL OF AMBIENT ENERGY
2020, VOL. 41, NO. 8, 962–968
https://doi.org/10.1080/01430750.2018.1472658

Solar research – a review and recommendations for the most important supplier of energy for the earth with solar systems

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ABSTRACT

Many energy-industry observers consider solar energy a theoretically elegant but unrealistic solution to the imminent gap between global energy supply and demand. Everyone agrees that clean, limitless, free energy from the sky sounds ideal, but more practical considerations such as relative cost and the sheer scale of the current energy infrastructure seem to doom solar energy to follower status for years to come. Other sources of energy, both conventional and renewable (including wind, geothermal and biomass), appear to be cheaper, easier to deploy and better funded and currently enjoy popular support in the media and renewable-energy advocacy circles. In addition, memories of false starts and unfulfilled promises during the twentieth century have tempered general optimism about solar energy's potential. This credibility gap exists not only among members of the conventional energy-industry fuel providers, electric utilities and all other interested parties – but also among a larger group of environmentalists and solar-energy system installers. The memory of this disappointment lingers, promoting scepticism solar could be a viable economic energy solution without substantial government subsidies. In this manuscript describes solar energy and its future.

ARTICLE HISTORY
Received 28 March 2018
Accepted 30 April 2018

KEYWORDS
Energy; solar energy; renewable energy; government subsidies

1. Introduction

The future of the global-energy industry can be understood only through examining the industry's history and current configuration is examined as well as the critical moments in history during which energy sources failed. Though seemingly unrelated, events as varied as the establishment of the earliest societies, the fall of Rome, England's early lead in the industrial revolution, and the outcome of World War II were all directly and powerfully influenced by those societies' intimate relationship to energy. Understanding the fundamental role energy plays in our collective well-being provides a basis for exploring the modern industrial world's total dependence on continued access to energy and highlights the precarious nature of the status quo (Green 2000).

Long before humans walked the planet, the life that makes up the earth's biological systems relentlessly pursued two interrelated goals developing effective methods to attract and absorb adequate supplies of energy (in the form of food) and avoiding being eaten as a source of energy by anything else. From simple cellular creatures to large complex mammals, the very nature of life is to repeat the process of energy absorption and conversion for growth, procreation, and self-preservation, and these behaviours have been deeply embedded into the DNA of organisms through millions of years of Darwinian evolution. From the beginning of life in heated ocean vents, ever greater numbers of more complex life forms appeared and pursued these goals with increasing skill and precision – first single-celled organisms, then small multicellular organisms, and eventually plants and animals. As life forms increased in size and mass, they acquired more advanced neural structures and complex behaviours (International Energy Outlook 2005). This added size and awareness enabled and motivated these organisms to seek out and absorb greater and more efficient quantities of energy. At every level of development, however, one basic need remained constant – the requirement to absorb sufficient amounts of basic energy to stay alive, develop and flourish.

The first law of thermodynamics, also known as the law of energy conservation, is an ever-present constraint in the struggle to access energy sources. This law states that energy – or rather, matter/energy, for the two turn out to be interchangeable cannot be created or destroyed; it can only be converted from one form to another. For example, burning wood does not create energy but converts energy stored in chemical bonds within the wood into heat and light. Similarly, when animals digest food, their digestive systems break down and convert the chemical energy latent within the food into alternate forms that are in turn used throughout the body to drive various chemical, electrical and mechanical processes (Global Population Profile 2002). At every stage, existing energy is transformed into more useable forms, usually with some degree of loss or waste but never changing the total amount of energy.

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So if energy cannot be created or destroyed, what is the original source of energy with which life can flourish?

All energy that can be effectively harvested and used by living organisms comes in the form of light, heat, or chemical energy. Of these, the primary sources are light, originating exclusively from the sun, and heat, primarily resulting from accumulated absorption of sunlight by the atmosphere of the earth. These primary energies nourish and sustain the planet's creatures, and all fundamental organic processes were derived from them. The remaining forms of chemical energy that are useful to sustain organic life often appear as simple or complex derivatives of light and heat and are formed from other dead organic matter. Consequently, nearly all energy available today – whether in the form of food, fuel, or direct solar energy – originated from the light of the sun. And the techniques that organisms and societies have developed to power themselves rely almost exclusively on a base of stored solar energy in the organic materials of the planet.

As higher-order organisms on earth developed, they generally fell into one of two broad categories – plants (which absorbed their energy directly from the sun through the process of photosynthesis) and animals (which absorbed their energy from eating some combination of plants and other animals). For hundreds of millions of years, this cycle of life continued as plants and animals absorbed sunlight or each other and converted this food to energy. Larger numbers and types of plants and animals adapted to specific local conditions, which allowed for the creation of a wide variety of complex and robust ecosystems both on land and in the sea, with each generation serving as the food and energy source that fed and nourished the next generation. Over hundreds of millions of years, these ecosystems developed complex interrelationships and webs of life built on the soil and organic material of millions of years of ancestry.

As ages passed and geologic conditions changed, some of these ecosystems were lost, covered over by sediment from rivers and oceans or from the debris of volcanic eruptions. Some of these remnants of long dead ecosystems and their captured solar energy (the ones with the right combination of geologic features and temperature) were transformed through a process of oxidation and decay over millions of years to become the fossil-fuel deposits that our modern world relies on today. Aside from those gradual geological shifts, the growth of life was also occasionally interrupted on a global scale by some cataclysmic event that disrupted the balance of energy and limited organisms' ability to continue to collect or concentrate vital energy.

One of the best known of these mass extinctions, though not the most devastating, is thought to have occurred during the Cretaceous period around 65 million years ago by what scientists now generally believe was an immense meteor strike in the area of the Yucatan peninsula. This meteor strike threw globe-encircling clouds of dust and sulfur into the atmosphere, effectively blocking out the sun for decades. The resulting reduction in available plant life led to an extinction of many of the animal species on the planet, including the largest, most complex and highest on the food chain – the dinosaurs. Though this was one particularly devastating event, it is by no means unique in history (Vinoth Kanna, Vasudevan, and Subramani 2018). By studying the geologic record of fossils, scientists have identified five of these mass extinctions in the last 500 million years, each of which eliminated from a sixth to a half of the existing families of plants and animals in the world at the time. The fossil record shows that a number of lesser reductions in both the quantity and diversity of life on earth have occurred over the last half billion years, and nearly all of them can be attributed to volcanic activity, meteor strikes, or other global geologic events, such as rapid climate change.

2. The field of alternatives

As the previous chapter explored, the growing mismatch of supply and demand of energy and the increasing external costs of current energy practices are providing economic, environmental, and social pressures to develop alternate supplies of vital energy. Many argue that economic pressures can be mitigated by increasing the efficiency of energy use in everything from vehicles to light bulbs to appliances and by reducing energy losses in homes and offices through the more effective and widespread use of insulation in building materials. Increased energy efficiency will, indeed, play a major role in reducing the costs and risks of the global energy infrastructure, and it is often the cheapest and most effective method of addressing such issues in the short run until widespread deployment of alternatives can occur (Devaraj et al. 2017). For instance, the global transportation infrastructure and the existing stock of cars, trucks, ships, and planes (and the petroleum infrastructure necessary to manufacture and fuel them) is so vast that more efficient use of remaining petroleum reserves represents the only viable method of addressing increased energy costs and dwindling supplies in this sector for the next few decades. In the end, however, efficiency can be only a portion of a new energy solution because efficiency alone cannot solve the problems of both keeping the price of declining energy stocks in check while also providing opportunities for growth in wealth and prosperity for the billions of people beyond the industrialised countries. Simply put, increasing global population, growing industrialisation, and declining resource availability are (as they have been since the beginning of the industrial revolution) more powerful pressures than efficiency alone can withstand. Efficiency can and will help to address issues in global energy supply, but vast new sources of energy will eventually have to be deployed to avoid both punitive economic changes and a declining standard of living for fossil-fuel-importing nations. This chapter begins with a review of potential new energy sources that are geared primarily toward generating electricity.

(Direct solar technologies are left aside, to be explored in more detail in chapter 5.) As many of these alternative sources of energy are best suited to the generation of electricity, many of the solutions that will eventually arise to meet the energy needs in transportation and heating applications are likely to be direct or indirect applications of electricity (Statistical Handbook of Japan 2005). As a result, harnessing sufficient local renewable sources of electricity becomes the necessary first step to address the balance of all global energy issues. The second half of this chapter examines hydrogen fuel-cell technology in terms of both its promise and challenges – how it can be used for both stationary and motive purposes and how it may bridge the gap between electricity and today's fuel-based applications (Bird and Cardinal 2004)

2.1. Renewable-energy-generation technologies

In reviewing the field of alternative renewable technologies (including nuclear, hydroelectricity, wind, geothermal and biomass), each has advantages, limitations, and unique economic considerations that determine its value in providing energy for specific applications and locations. Businesses and economies will pursue the alternative renewable technologies that they are best suited for by natural-resource endowment and that they can develop the necessary expertise for quickly and at the lowest cost. This section asks relevant questions about each energy technology: how is it currently being employed, what role does it serve, what type of power does it cost-effectively supply, and what natural limits exist to its growth and deployment? Each of these technologies needs to be exam mined not as one class but on its own merits. All of these technologies will have a role in the aggregate energy system of the future because each is better suited than others to meet specific energy needs. Disaggregating these technologies and looking at the costs and benefits of each individually are critical to informed forecasts and decisions about the future of the energy system. Because technological progress, research, and development continue to push, back technical boundaries and may change the relative economics and viability of each technology, no technology should be dismissed, even when the initial answers are unclear or a given solution appears to be limited. The most important element for analysis is the expected cost of each technology among its likely applications, and it is no simple matter to make these comparisons. Various methods of production, use, and financing can affect the analysis and are often hard to estimate reliably. It is even more difficult to project many of these variables over the long life of an energy investment, injecting added risks into any such calculation. The true cost of many of these technologies is further obscured by the absence of many social costs in their final energy price. Just as a portion of the cost of securing oil supplies in foreign countries is paid not at the pump but in taxes, many of the hidden costs of nuclear and hydropower are not paid for in the market price of the electricity they deliver. These direct and indirect economic dimensions are examined for each alternative energy technology below.

1. Hydroelectric dams
2. Nuclear power
3. Wind power
4. Biomass
5. Geo thermal
6. Ocean power
7. Fusion
8. Solar

3. Solar Energy

Many energy-industry observers consider solar energy a theoretically elegant but unrealistic solution to the imminent gap between global energy supply and demand. Everyone agrees that clean, limitless, free energy from the sky sounds ideal, but more practical considerations such as relative cost and the sheer scale of the current energy infrastructure seem to doom solar energy to follower status for years to come. Other sources of energy, both conventional and renewable (including wind, geothermal and biomass), appear to be cheaper, easier to deploy, and better funded and currently enjoy popular support in the media and renewable-energy advocacy circles. In addition, memories of false starts and unfulfilled promises during the twentieth century have tempered general optimism about solar energy's potential. This credibility gap exists not only among members of the conventional energy industry – fuel providers, electric utilities and all other interested parties – but also among a larger group of environmentalists and solar-energy system installers. Many of these people invested time and money to promote solar energy in response to the first OPEC oil shocks of the 1970s, only to be abandoned after 1982 by the national governments that had supported them. The memory of this disappointment lingers, promoting scepticism that solar could be a viable economic energy solution without substantial government subsidies. Rapid changes in the photovoltaic industry, technology, and institutional players over the last decade have dramatically altered PV's economic viability, and fundamentally transformed the competitive landscape of the energy industry. Today, solar energy and photovoltaics comprise a global, multibillion-dollar industry providing cost-effective energy to millions of people worldwide in many large and growing markets. As with most technologies, the cost-benefit calculation varies by each potential user and application, making simple generalisations difficult. As a result, the largest remaining obstacle to continued adoption of solar energy is the lack of reliable and current information about its true economic characteristics. This chapter puts this growing global industry in perspective by highlighting its history – its roots, its driving forces and characteristics, the current state of its development, and methodologies for estimating how the cost of producing PV will change as the industry matures and grows.

4. Types of solar energy

Typically, an informed discussion about solar energy is limited by various and confusing notions of what the term solar energy actually describes. Broadly, speaking, solar energy could be used to describe any phenomenon that is created by solar sources and harnessed in the form of energy, directly or indirectly from photosynthesis to photovoltaics. Many of today's environmentalists use the term solar energy in its most comprehensive sense to include certain new renewable-energy technologies such as wind power and biomass, arguing that these sources derive energy from the sun, however, indirectly. More conservative uses of the term, such as the one that this book employs, discuss direct only solar sources, whether active, passive, thermal or electric that is, sources of energy that can be directly attributed to the light of the sun or the heat that sunlight generates. This more restrictive classification is useful because a more general characterisation of solar energy that includes wind and other technologies tends to obscure various isolated trends within the broader renewable energy industry.

Many renewable-energy technologies sometimes lumped under solar energy have very different economic characteristics, making it difficult to draw meaningful conclusions about them. Since the economic drivers discussed in the second half of this book do not apply to all technologies equally, it is helpful to be precise when analysing specific industrial transformations and the markets in which they will occur. Understanding direct solar energy requires examining three key continuums in the methods of harnessing it:

(1) Passive and active,
(2) Thermal and photovoltaic and
(3) Concentrating and non-concentrating.

Every solar-energy technology features some combination of these characteristics to harness sunlight. Passive solar energy requires a building design that is intended to capture the sun's heat and light. In passive solar design, heat and light are not converted to other forms of energy; they are simply collected. This is done through various design and building methods. The simplest conceptualisation of passive solar-energy design for the building is in a greenhouse, a design that allows solar light to pass into the interior and then captures the heat it generates inside to maintain year-round growing conditions. Passive solar features some of which have been used in the building. Passive solar is an elegant way to harness the sun's energy, but it usually has to be designed into the original building plans to be made cost-effective. Once a building design has been finalised with siting, orientation, and structural elements, it is often prohibitively expensive to change or retrofit the facility to capture additional passive solar-energy benefits.

Active solar energy refers to the harnessing the sun's energy to store it or convert it for other applications. These applications include capturing heat for hot water that can be used for cooking, cleaning, heating or purification; producing industrial heat for melting; or generating electricity directly or through steam turbines. The common characteristic is the active and intentional collection and redirection of the solar energy.

These active solar solutions can be broadly grouped as either thermal or photovoltaic according to the method by which they generate energy for transfer or conversion into other useful forms. Thermal applications include all uses of the sun's energy in heat-driven mechanisms, such as heating water or some other conductive fluid, solar cooking and agricultural drying, or other industrial heat-collection applications – for processes as varied as water treatment or hydrogen generation through water decomposition. The most powerful solar thermal applications are used to superheat water and convert it to steam, which is then used to power a conventional steam engine for thermal electricity generation.

Prior to the middle of the twentieth century, all industrial applications of solar energy were thermal in nature, and many of the simplest and most widely used remain so today, including the millions of rooftop solar water-heating systems installed around the world. Solar photovoltaic is the state of the art in active solar electricity generation. By capturing the photonic energy of light on materials of a specific molecular structure, direct electric current is produced. The photoelectric effect (the description of which won Albert Einstein his Nobel Prize in physics in 1921 and which he believed to be more valuable than his work on the theory of relativity) allows an electric charge to be created on a semi conductive substrate that has been doped with chemical additives to create opposing positive and negative layers. Photons of sunlight striking this surface facilitate an electron moving from the positively charged layer to the negative, creating an electrical current. This shifting of electrons in photovoltaic energy generation occurs without the need for moving parts and in proportion to the amount of light striking the surface. Land-based applications based on silicon material for PV cells are often warrantied by manufacturers for 25 years or more, although the expected useful life is much longer.

The final distinction in solar applications is concentrating and non- concentrating. Concentrating solar applications use mirrors or lenses to focus sunlight. Concentration can significantly increase light intensity in the focus area, similar to the way in which a magnifying glass burns a hole in a leaf. Industrial-scale concentration can be achieved by the trough method, in which a long, trough like parabolic mirror focuses sunlight along the length of a fluid-filled pipe suspended above the mirror.

Large-scale concentration can also be created via an array of sun-tracking mirrors arranged to focus sunlight on a central point for thermal or photovoltaic use. Arrays of lenses can concentrate energy on photovoltaic cells, which tend to operate more efficiently (that is, convert more of the sunlight that strikes them into electricity) when the light is brighter. Concentrating systems are, by their nature, more complicated to build and manage than non-concentrating systems and contain equipment with moving parts that suffer wear and tear as well as problems relating to the significant heat generated by them. Non-concentrating systems, which allow the sunlight to fall on their energy-gathering parts without concentration by lenses or mirrors, are usually simpler and therefore less expensive maintain; however, they achieve correspondingly lower intensities and temperatures. Non-concentrating systems include those that use direct sunlight to heat close-set pipes (as in a domestic hot water system) or open water (such as a swimming pool), as well as most PV panels commonly seen on the roofs of houses and in stand-alone signs and lighting. Figure 1 shows the breakdown of modern active forms of harnessing solar energy, both thermal and photovoltaic, among the various sizes of the generators used. The size classifications (centralised, large distributed, and small distributed) correspond to the different types of users that can use the amounts of power generated (utilities, commercial users, and residential users respectively). These distinctions will be examined in later chapters to discuss the evolving economic decisions that each of these potential users of solar energy face.

5. Future transformations

As it has throughout most of our history, the demand for the services that energy and electricity provide is likely to continue to grow in a global economy that encompasses hundreds of millions of industrialised consumers who have expectations of future prosperity and billions who aspire to industrialised levels of prosperity in developing countries. People will continue to demand more lights, more cars and trucks, and more computers along with other modern amenities. (EIA, Electric Power Monthly (October 2003).

To meet these needs, existing sources of energy will have to be spread further and used more efficiently, and additional

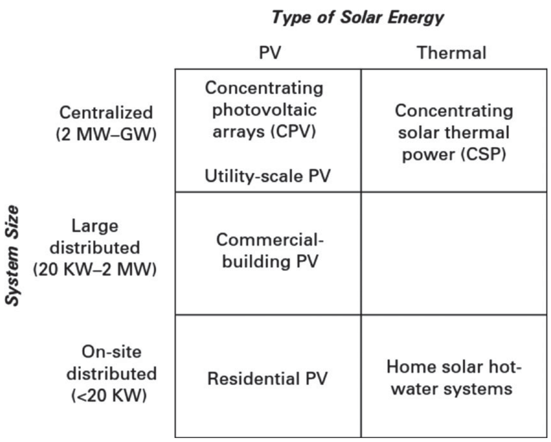

Figure 1. Today's mix of active solar-energy technologies by size and type.

sources of energy will have to be deployed. Effective and coordinated government policy might be able to meet this rising demand by aggressively pursuing efficiency improvements and disseminating 'best practices' of energy generation and use to growing nations and economies. However, we do not live in a world of effective, coordinated government policy, particularly when resource hunger drives short-term decision-making. Historically, improvements in the efficiency of energy use have not been able to stop the need to acquire new energy sources to satisfy increasing demand, and it will not likely do so in the future either (EIA, Electric Power Monthly (October 2005).

Currently, the modern world almost totally depends on the stored solar energy embedded within fossil fuels for transportation, heat and electricity. In the broadest sense, modern industrial capacity has been created specifically by and for the exploitation of this form of fuel-based energy, and all business-as-usual forecasts implicitly assume that the global economy will continue to be fuelled in a reliable and cost-effective way. Nevertheless, the world's oil and natural-gas deposits cannot provide a constant energy output over the next few decades, much less an increasing one. Coal is the only remaining fossil fuel available to supplement the difference, but the environmental impacts of current coal energy-generation technologies are generally considered unacceptable. As the need for industrial energy continues to outpace supply, the inelastic nature of demand for these energy resources will drive increases in the prices of gas, oil, and coal. For both environmental and economic reasons, large quantities of the alternative sources of energy described in the last two chapters will need to be harnessed to make up the difference. When selecting additional sources of energy to use in electricity generation, utilities have a portfolio of choices including nuclear energy, wind power, and solar energy. An examination of the costs of generating electricity by each of these methods as well as the type of power they provide shows that solar energy can already cost-effectively supply a portion of utilities' needs for daytime electricity, currently the most expensive form of electricity for utilities to produce. Using the tool of experience curves discussed in the last chapter shows that the relative competitiveness of solar electricity for a utility-scale generation will continue to grow.

6. Solar electricity in the real world

The prior chapter discussed how the evolving cost-effectiveness of photovoltaic electricity technology is poised to transform the economics of the energy industry in the next decade. However, many additional determinative variables such as public awareness, the effects of volatile fuel and energy prices, and the political will to support the deployment of any energy or electricity technology are not predictable or even always quantifiable. Choosing to install PV happens at the individual level of households, businesses, or utilities. When these decision makers are going through the process of evaluating and deciding to install PV electricity, adoption is driven partly by economics and partly by other factors, including an awareness of PV as a potential solution, the time required to become comfortable with the new technology, an assessment of the risks created by switching from a current type of electricity to PV, and an assessment of the risks of not doing so. Access to the credit needed to finance these systems is also important, particularly in the credit-starved areas of the developing world (Bird and Sweezy 2003). As in every industrial transformation, businesses will emerge to provide information about PV and to simplify ancillary financing, maintenance and risk-mitigation services for PV adopters. As the electricity and broader energy industries transform, both winners and losers will emerge, creating many social and exogenous benefits but also threatening many aspects of the existing global economic system. Some of the most commonly perceived likely losers in the shift to solar energy, existing fossil-fuel providers and utilities, still have a robust opportunity to respond to future changes in the energy economy and to participate in and benefit from the transition a move that some are already beginning to make (Maycock 2005)

6.1. Forecasting future energy prices

Many ways of forecasting energy supply and demand are used today by governments, research labs, and consultants. These range from highly technical economic models to scenario analysis of possible future worlds.

Some of the most widely used figures come from the US Department of Energy's Energy Information Agency (EIA), which publishes an annual forecast of world energy use – the International Energy Outlook (IEO) – and a similar projection that includes expected future world prices of fossil fuel and electricity – the Annual Energy Outlook (AEO). The EIA projects a number of future scenarios in these reports, but the one cited most often is the Reference Case, the one asserted by the EIA to be the most likely to occur.

The 2005 IEO Reference Case's forecast to 2025 for global energy forecasts that world energy demand will grow at 2% per year from 411 quadrillion British thermal units (Btu) in 2002 to 644 quadrillion Btu in 2025. This projected increase in energy supply is forecast to be met by all energy sources – coal, natural gas, oil, and nuclear energy. Under this forecast, natural gas will grow faster than all other fuels, supplying a higher share of energy demand in 2025 than today, and nuclear will grow the slowest, as many plants constructed in the 1970s and 1980s are decommissioned over this period when they reach the end of their fi40–50-year useful life. Figure 2 shows the breakdown of

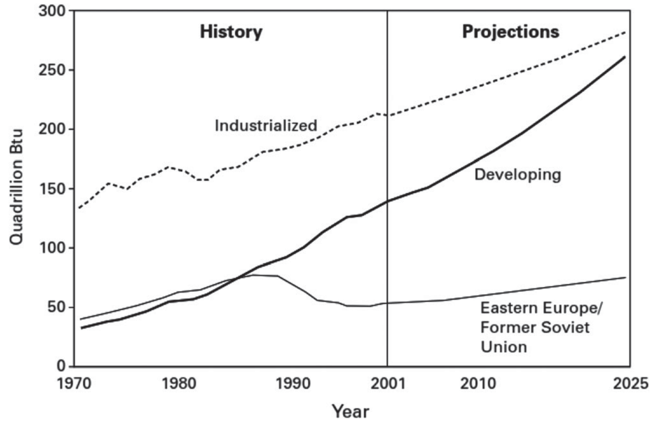

Figure 2. World energy consumption by region from 1970 to 2001 with forecasts through 2025 (quadrillion Btus).

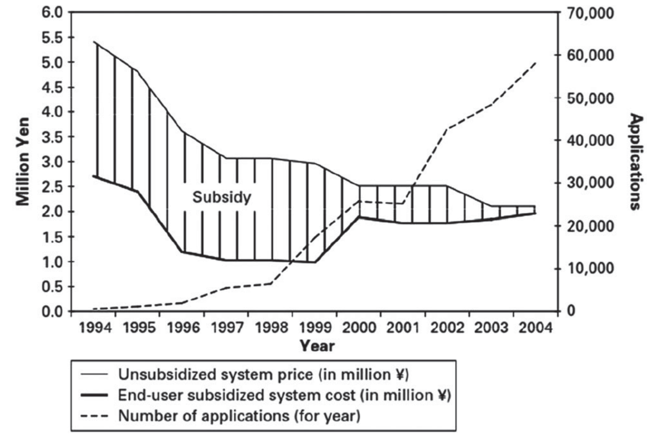

Figure 3. Subsidised and unsubsidised PV system costs in Japan and annual applications for rebates, 1994–2004. Soure: Vinoth Kanna, Devaraj, and Subramani (2018).

projected energy demand by region, divided into industrialised nations, developing nations, and the former Soviet Union. As the graph shows, the bulk of the growth in energy demand will come from the developing world (particularly in China and India, which together contain more than one-third of the world's population) as rapid industrialisation absorbs tremendous amounts of additional energy. However, the industrialised world and countries of the former Soviet Union are also expected to experience increased energy demand.

The EIA updates its forecasts annually and compares current-year forecasts to those of prior years to show the trends in its own projections. However, with something that has the complexity and long time horizon of global energy supply and demand, it is necessary to look at the results of any forecast to see if the combined outputs of the projection models can be realistically achieved. Doing this for the IEO projections.

7. Research and development

Aside from directly affecting system costs and revenues through subsidies and tax breaks or adding additional cost to competitive polluting fossil fuels, the method most commonly used by governments to support new energy technologies is research and development funding (R&D). In the United States, the Department of Energy spent $212 million in 2004 for renewable-energy R&D primarily through the National Renewable Energy Laboratory in Golden, Colorado. R&D funding by industrialised countries' governments for renewable energy is crucial for market growth because it helps to resolve a commonly observed market failure in economics that is, businesses collectively underinvest in R&D and basic science compared to what a socially optimal level would be. To compensate, governments of industrialised nations often support basic research on promising technologies. Energy R&D investments, in particular, yield benefits far in excess of their cost. A study by the US Congressional Budget Office shows that over a 22-year period $7 billion in US Department of Energy investments in more efficient use of energy generated some $30 billion in benefits. However, despite the clear payoff from R&D investments in efficiency improvements and renewable energy, annual global energy R&D spending dropped by almost two-thirds between 1979 and 1996, disproportionately in renewable-energy R&D, due to low fossil-fuel prices and changing geo-political priorities (Figure 3).

8. Conclusion

Economics is driving the energy and electricity industries to develop more renewable-energy technologies, which will also create ancillary wealth, security and environmental benefits around the world. These social benefits are potentially vast and should be encouraged through progressive government policies as well as coordinated industry efforts. Thoughtful investments in attention and money made today by industry and government are highly likely to accelerate this change and bring dramatic financial and social returns.

Various policy tools have been created and used at all levels of government from local to international to help accelerate the adoption of renewable-energy technologies, including PV. Without the implementation of such policy tools in Japan and Germany over the last decade, the PV industry would not be enjoying its current rapid growth and market opportunities. Today, social and political pressures coupled with rapidly rising fossil-fuel prices are increasing the motivation for most jurisdictions around the world to evaluate additional solar-energy industry support programmes, including rebates, feed-in tariffs and R&D support programmes. In addition, the private sector is developing coordinated and collaborative efforts by industry players to standardise equipment and connection methods, educate PV system installers and access capital markets, steps that all young industries take in their progression toward broad adoption and market growth. The solar energy is the best source to make a revolution in the energy field. The above review shows comfortable proof to make that revolution in energy.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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References

Bird, Lori, and Karen Cardinal. 2004. *Trends in Utility Pricing Programs* (Report No. NREL/TP-620-36833), p. 1. Golden, CO: National Renewable Energy Laboratory.

Bird, Lori, and Blair Sweezy. 2003. *Green Power Marketing in the United States: A Status Report* (6th ed.) (Report No. NREL/TP-620-35119), p. 1. Golden, CO: National Renewable Energy Laboratory.

Devaraj, A., Vinoth Kanna, I., Manikandan, K., Jishuchandran. 2017. "Impact of Engine Emissions from HCCI Engine: An Overview". *International Journal of Mechanical and Production Engineering Research and Development* 7 (6): 501–506.

Energy Information Administration (EIA). 2003 October. *Electric Power Monthly*, 85.

EIA. 2005 October. Electric Power Monthly, 2.

Green, Martin. 2000. *Power to the People: Sunlight to Electricity Using Solar Cells*. Sydney: University of New South Wales Press.

International Energy Agency (IEA). 2005. *Key World Energy Statistics 2005*. Paris: IEA. http://www.iea.org/bookshop/add.aspx?id = 144.

Maycock, Paul. 2005 July–August. "Market Update: Global PV Production Continues to Increase." *Renewable Energy World* 8 (4): 86–99. 92, 96.

Statistics Bureau, Japan Ministry of Internal Affairs and Communications. 2005. *Statistical Handbook of Japan 2005*. Tokyo: Statistics Bureau. Chapter 2. http://www.stat.go.jp/english/data/handbook/c07cont.htm

Vinoth Kanna, I., A. Devaraj, and K. Subramani. 2018. "Bio Diesel Production by Using Jatropha: The Fuel for Future." *International Journal of Ambient Energy*. doi:10.1080/01430750.2018.1456962.

Vinoth Kanna, I., A. Vasudevan, and K. Subramani. 2018. "Internal Combustion Engine Efficiency Enhancer by Using Hydrogen." *International Journal of Ambient Energy*. doi:10.1080/01430750.2018.1456961.