Progress of renewable electricity replacing fossil fuels

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Abstract: Dramatic fall in costs of renewable energy in the last 24 months has not only accelerated the replacement of fossil fuels by renewable energy in electricity generation. The low cost renewable electricity is now starting to replace fossil fuels in other sectors.

One reason is that renewable electricity is now cheaper per unit energy than oil, about the same price as fossil methan but, still, more expensive than coal. Another reason is that electricity often offer other opportunities, such as cheaper transport, better control, higher energy efficiency in final production of energy services and lower local environmental costs.

Keywords: Industrial learning, Renewable energy, Fossil fuel substitution.

1 Introduction

In the short term, minimising the direct price of energy is seen as the target of an individual customer. However, aiming at creating wealth for all people, ambitions must be higher. From a resource perspective, the supply system should not deplete the resources it relies on, making future economic development more difficult when scarcity increases resource costs. Further, environmental costs, in particular negative health effects of toxic or radioactive emissions should not be allowed to counteract the benefits of energy utilisation.

Some individual thinkers have contributed to the development of sustainable energy strategies, based on efficient end-use and renewable energy supply. Notably Lovins [1], Brundtland [2] and Johansson et al [3].

Understanding the relevance of the renewable energy industrial learning is a key insight to understand the opportunities for global economic development.

Electricity from fuel based thermal power has little potential of becoming cheaper anymore as learning has gone on for long and opportunities are largely exhausted. Instead, with increasing rates of fossil fuel consumption, costs tend to increase due to resource scarcity. With increasing standard of living, the power plants becoming more expensive due to societal demand of improved safety and reduced pollution. When relying on non-renewable energy supply, successful economic development would raise prices and make further economic development more difficult.

Renewable electricity does not face such cost driving factors. Instead, learning by experience brings costs down. Thus, when utilising renewable energy, successful economic development makes further economic development easier, as costs of energy decrease. Even if the renewable electricity was initially more expensive, with accumulating experience they are becoming efficient enough to outcompete non-renewable sources.

This understanding was clearly described in a book by Wene published by the OECD in 2000 with the title "Experience Curves For Energy Technology Policy" [4].

The Asian economic development accelerated during the end of the 20th century, led by China. Energy supply, as a result, became an urgent global issue, and leaders in Asia have come to use a scientific approach, based on global expertise, to design a strategy to make further economic development an opportunity for all.

From the beginning of 2016 until today, reports have appeared showing a fast decrease in prices achieved in tendering processes around the world, now reaching below the cost of thermal electricity. For on-shore wind prices 30 USD/MWh was reached already in early 2016, [5]. In northern Europe, off-shore wind prices were reported

Received: 7 November 2017 /Accepted: 18 December 2017 /Published: 25 January 2018

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at 70 EUR/MWh in July 2016 [6], at 60 EUR/MWh in September [7] and below 50 EUR/MWh in November 2016 [8]. Solar PV reached 50 USD/MWh in Latin America in the spring of 2016 [9,10]. Then Dubai, Chile and Abu Dhabi reached prices around 30 USD/MWh [11]. During the 2017 prices kept falling toward 20 USD/MWh in Mexico and Chile[12,13], while Saudi Arabia reached offers of solar electricity at 17.9 USD/MWh in October 2017, and 17.7 USD/MWh was the lowest bid in Mexico reported in November [14, 15].

These prices, reported from tendering, are in most cases still only bids. It is not certain that they can be built at these costs, but there are strong economic incentives successful bidders not to fail in completing the projects.

It appears as if we have reached the point, at least in most parts of the world, where renewable power is outcompeting all other sources of electricity when new capacity is needed. This is also the result of a comprehensive study for the United States by Lazard [16].

Since long, solar and wind power is outcompeting all other sources of electric power among existing power plants on short-term costs. As they do not require any fuel consumption their marginal cost is zero, while generation of electricity from fuels always come at the marginal cost of the fuel consumed.

Further replacement of fuels with renewables will follow as when there is overcapacity, fuel based plants will be closed, while renewable sources will be competitive on a short term marginal cost basis. When new capacity is needed, renewables will offer lower total cost options and be the economic choice.

Already, new solar and wind is cheap enough to outcompete oil- and some gas-based generators. When coal and nuclear plants face the need of major investments for repair or upgrades then also repair renewables may prove a better option.

Thus the replacement of non-renewable energy in the electricity production sector is starting. The question addressed below, however is what the conditions for the next replacement – the use of renewable electricity to replace fossil fuel in other sectors – look like after the recent fall in costs of renewable electricity.

2 Comparing the prices of different energy carriers

2.1 Units of energy

When comparing the prices of energy carriers like coal, methane gas, oil and electricity you are faced with the tradition of using different units for the energy content.

Public data is often provided in USD per barrel of oil, USD per million British Thermal Units, BTU, for methane gas, or USD per ton of coal. This makes the comparison with the energy price of electricity, usually given as USD per MWh difficult. As a consequence, the competition and substitution opportunities are more difficult to see than necessary.

The prefix “M” usually represents Mega or million, that is 1000 000, and used as such in the using MWh, being 1000 000 Wh. However, in combination with BTU the prefix “M” has the meaning 1000. A million BTU is written MMBTU, for reasons not easily explained.

Despite the exclusive and unclear terminology in these industries, the relationship in each case is a simple factor. Applying that factor and calculating the relationship make visible that the next stage of development, the replacement of fossil fuels by renewable electricity in other sectors, is becoming feasible.

2.2 Renewable electricity vs oil

Oil is the first fossil fuel to be outcompeted in electricity generation because it has the highest price and value of the three main fossil fuels. As a liquid it is the easiest of the three to store and transport. It has a relatively high energy density in the form where it is easily stored and handled.

Oil is now mainly used in the transport sector after refining crude oil into different fuel qualities.

In Fig. 1, the relationship between the oil and electricity price units is illustrated. The current oil price as this is written is 65 USD/barrel which is equivalent to 40 USD/MWh as there is 1.6 MWh in a barrel of oil.

The important observation is that renewable electricity from new solar and wind power plants is now cheaper per unit energy than crude oil. This comparison shows that the replacement of oil by renewable electricity is

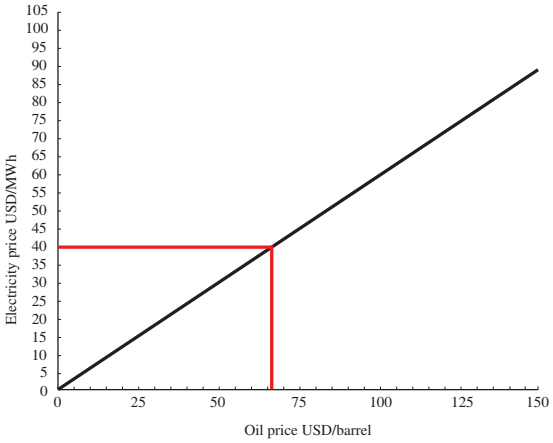

Fig. 1 The relationship between the energy price of oil and electricity

clearly possible. As a result we see a rapid transition in the automotive industry. Electric road vehicles are increasing, the first electric ferries are in use and even some small airplanes are using electricity instead of oil based fuels. In the heating sector fuel oil is replaced by electricity often using energy efficient heat pumps.

2.3 Renewable electricity vs fossil methane gas

Fossil methane, or natural gas, is often considered the least damaging fossil fuel. With its chemical structure, containing only one carbon atom, it is easily burned without particle emissions and the relatively large share of energy from oxidising hydrogen compared to carbon make combustion produces less carbon dioxid per unit energy released compared to coal or oil. However, if methane leaks from gas systems the advantage from a greenhouse gas perspective is easily lost as methane itself is a much more effective greenhouse gas than carbon dioxide.

Gas prices vary significantly depending on where it is traded in relation to sources and infrastructure.

Producing electricity from methane is still common as combustion technology is low cost because gas is easy to burn. Many gas fired electricity plants in the world have low capacity factors and are used only during peak price periods.

The import of Liquified Natural Gas, LNG, is expensive in countries like Japan. As shown in Fig. 2, the reported prices are around 8 USD/MMBTU which is already above the levels of the best solar and wind power costs in the world. Elsewhere the prices are lower, 5-6 USD/MWh in Europe and well below 5 in the areas where gas is extracted.

But the idea of producing gas from renewable electricity is pursued in some cases. First, the economic case for such processes comes from the opportunity created during periods of more power from solar and wind being available than there is demand within reach in the grid.

Combining these observations power company Nuon, and fule companies Gasunie and Statoil has set out to convert a gas fired power station in Groningen, Netherland, to use hydrogen[17].

This peak price plant will produce electricity when electricity is expensive using hydrogen gas produced from electricity when the electricity is cheap. The system will contribute more to balancing solar and wind power than a gas plant burning fossil gas as it will both consume and produce electricity.

2.4 Renewable electricity vs coal

Coal is still a dominating source of energy for electricity production in most electricity markets in the world. Thus, the price of coal per unit energy is necessarily lower than the price of electricity in these markets, as shown in Fig. 3. Thermal power plants have an efficiency of typically 40%, and the fuel energy used to produce electricity is therefore 2.5 times the amount of electrical energy delivered. Only as long as the value of the electricity is at least 2.5 times the price of coal will these plants be operated.

One may expect that with coal still being so cheap per unit energy compared to renewable electricity the substitution will not occur. Still for most applications, other than large scale generation of electricity and heat, coal implies costly logistics and coal combustion is relatively difficult to control, both regarding power output and pollution. Thus, other uses are now mainly in industries, in particular in the steel industry.

Some steel processes have since long been increasingly

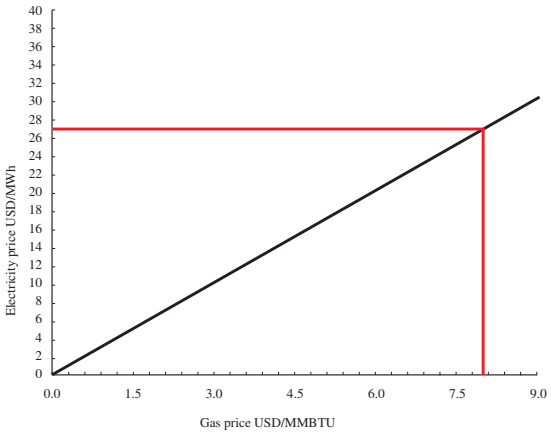

Fig. 2 The relationship between the energy price of methane gas and electricity

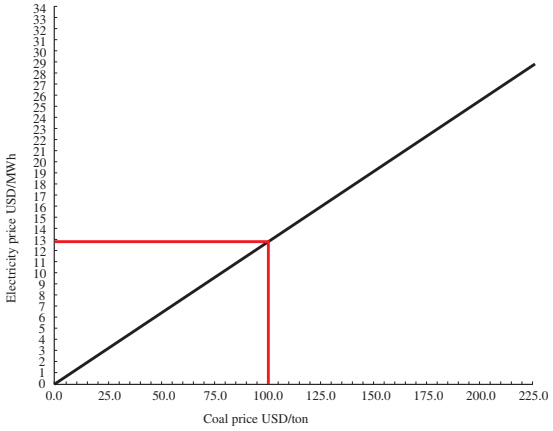

Fig. 3 The relationship between the energy price of coal and electricity

electrified. But now, there are attempts to replace coal with hydrogen. The techniques are developed in Korea [18] in the Swedish Hybrit joint venture company [19] as well as in a similar Austrian project [20].

None of these project have expressed claims that the hydrogen based process will be immediately profitable. However, there are two trends making future commercial success likely. One is that renewable electricity is going to get even cheaper. The other that the costs of carbon dioxide emission will increase as a result of ambitions to ensure that rate of climate change will be manageable.

3 Discussion

Making the world independent of limited fossil fuels will be realised only when renewable energy is replacing fossil fuels for electricity generation and for other purposes. The comparisons of energy prices of renewable electricity and the different fossil fuels are not the only factor that decides the success of this second replacement.

Electricity can outcompete oil for heating at a higher price as electric heating may be achieved by heat-pumps providing 2-5 energy units of heat per unit electricity, while producing heat by burning oil will produce just a little less than one unit heat per unit oil energy.

In the transport sector electric motors are more efficient than fuel using internal combustion engines, ICE. On the other hand, ICE after decades of industrial development, are produced at low cost while batteries still have to go through a period of industrial learning an increasing economy of scale to come down in price.

So, this article is not saying that comparing the cost of energy is the sole criteria of competitiveness. But as Electricity in many cases offers other advantages to fuels, the comparison, after recent dramatic decrease in costs of renewable electricity, is an important indication of the opportunities created.

4 Conclusion

Renewable electricity replacing non-renewable sources of electricity is going on all over the world.

While obscured by exclusive units in the markets for different energy carriers, it is shown that falling costs of renewable electricity have made electricity competitive with fuels per unit energy. This makes it possible to start a second replacement process, where low cost renewable electricity replaces oil, fossil gas and even coal in other sectors.

Oil is clearly outcompeted on price already, and fossil gas is challenged. Coal is still cheaper per unit energy, but with technical advantages or carbon emission pricing schemes may be outcompeted by renewable power. With continued reduction in renewable electricity costs or increased carbon dioxide pricing the replacement will accelerate also for coal.

Some industries have discovered these opportunities. Others should, as the transformation, once started, may be rapid.

References

[1] Lovins AB (1977) Soft Energy Paths: Toward a Durable Peace, Penguin Books

[2] Brundtland GH (1987) Our Common Future, Report of the World Commission on Environment and Development. http://www.un-documents.net/our-common-future.pdf

[3] Johansson TB, Bodlund B, Williams RH (1989) Electricity: Efficient End-Use and New Generation Technologies and Their Planning Implications. Lund University Press

[4] Wene C-O (2000) Experience Curves for Energy Technology Policy. OECD Paris. http://www.wenergy.se/pdf/curve2000.pdf

[5] GWEC (2016) New Low for wind Energy Costs: Morocco tender averages USD 30/MWh. http://gwec.net/new-low-for-wind-energy-costs-morocco-tender-averages-us30mwh/

[6] Darby M (2016)Two 350MW arrays in the Netherlands will supply power at €87/MWh, beating the next cheapest project by miles. http://www.climatechangenews.com/2016/07/06/dong-passes-offshore-wind-cost-milestone-three-years-early/

[7] Gosden E (2016) New record for cheapest offshore wind farm. http://www.telegraph.co.uk/business/2016/09/14/new-record-for-cheapest-offshore-wind-farm/

[8] Vattenfall (2016) vattenfall wins tender to build the largest wind farm in the nordics. https://corporate.vattenfall.com/press-and-media/press-releases/2016/vattenfall-wins-tender-to-build-the-largest-wind-farm-in-the-nordics/

[9] Lindon H (2016) Tremendously Low 4.8¢/kWh Solar Price In Peru, Unsubsidized. https://cleantechnica.com/2016/02/25/tremendously-low-4-8¢kwh-solar-price-in-peru-unsubsidized/

[10] Greentechmedia (2016) Solar Stuns in Mexico's First Clean Energy Auction: 1,860MW Won at $50.7 per MWh. https://www.greentechmedia.com/articles/read/solar-stuns-in-mexicos-first-clean-energy-auction-1860-mw-won-at-50-7-p

[11] Bloomberg (2016) solar developers undercut coal with another record set in dubai. https://www.bloomberg.com/news/articles/2016-05-03/solar-developers-undercut-coal-with-another-record-set-in-dubai

[12] LÓPEZ BD (2017) Mexico signs lowest-price solar contracts to date. https://www.pv-magazine.com/2017/02/06/mexico-signs-lowest-price-solar-contracts-in-the-world-to-date/

[13] Parkinson G (2017) Chile solar auction sets new record low for solar PV. http://reneweconomy.com.au/chile-solar-auction-sets-new-record-low-for-solar-pv-85114/

[14] Graves L (2017) World's cheapest prices submitted for Saudi Arabia's first solar project. https://www.thenational.ae/business/

energy/world-s-cheapest-prices-submitted-for-saudi-arabia-s-first-solar-project-1.663842
[15] Weaver JF (2017) UPDATED: Cheapest electricity on the planet is Mexican (actually) wind power at 1.77¢/kWh. https://electrek.co/2017/11/16/cheapest-electricity-on-the-planet-mexican-solar-power/
[16] Lazard (2017) Lazard's Levelized Cost of Energy Analysis–Version 11.0. https://www.lazard.com/media/450337/lazard-levelized-cost-of-energy-version-110.pdf
[17] Institute for Sustainable Process Technology (2017) Nuon, Statoil and Gasunie join forces using hydrogen in future CO2-free energy plants. http://www.ispt.eu/nuon-statoil-gasuni-join-forces-use-hydrogen-co2-free-energy-plants/
[18] Reuters (2016)posco aims to halt co2 via hydrogen steelmaking. https://www.reuters.com/article/posco-carbon/posco-aims-to-halt-co2-via-hydrogen-steelmaking-idUSSEO205120091127
[19] SSAB (2016) SSAB HYBRIT A Swedish prefeasibility study project for hydrogen based CO2 free ironmaking. https://carbonmarketwatch.org/wp-content/uploads/2016/04/SSAB-HYBRIT-A-Swedish-prefeasibility-study-project-for-hydrogen-based-CO2-free-ironmaking.pdf
[20] Felsbach P(2017) voestalpine, Siemens and VERBUND are building a pilot facility for green hydrogen at the Linz location. http://www.voestalpine.com/group/en/media/press-releases/2017-02-07-voestalpine-siemens-and-verbund-are-building-a-pilot-facility-for-green-hydrogen-at-the-linz-location/

Biography

Tomas Kåberger received a MSc in Engineering Physics, a PhD in Physical Resource Theory, and Docent in Environmental Science at Chalmers. He is currently Professor of Industrial Energy Policy at Chalmers University of Technology and serves as Distinguished Visiting Expert of bio-energy technology at Zhejiang University in Hangzhou. He also serves as Senior Advisor for Global Energy Interconnection Development and Cooperation Organisation, GEIDCO. He spends a third of his time in Japan as Executive Board Chairman of the Renewable Energy Institute based in Tokyo.

(Editor Shuo Feng)

Economic analysis of solar energy development in North Africa

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Abstract: The economic analysis of solar energy development is the basis of promoting the solar energy planning in north Africa and realizing the clean energy power transmission among continents. In this paper, the cost development trend of photovoltaic(PV) power and concentrating solar power(CSP) generation is analyzed, and the levelized cost of energy (LCOE) of solar power generation is forecasted. Then, taking the development of Tunisian solar energy as an example in the context of transcontinental transmission, PV power with energy storage and PV-CSP power generation are given as two kinds of development plan respectively. The installed capacity configurations of the two schemes are given with production simulation method, and comprehensive LCOE are calculated. The studies show that based on the LCOE forecast value, the LCOE of PV-CSP combined power generation will decrease when the annual utilization hours of transmission channel is increased. It can be chosen as one of important mode of the North Africa solar energy development.

Keywords: North Africa, Photovoltaic power generation, Concentrating solar power, Energy storage, Technical and economic.

1 Introduction

The global high level of solar irradiation intensity region mainly concentrated in the 10°north latitude to 35°north latitude, and the annual solar irradiation intensity is between 1800kWh/m^2 to 2600kWh/m^2. Hence, the resource of solar energy is rich in North Africa, and the potential is quite large to build solar power generation base in the most of North Africa region countries, such as Morocco Tunisia, Algeria, Egypt[1]. In recent years, North African economy is continued to grow steadily and energy demand is accelerated. But the existing energy and electric power situation in this region cannot adapt to the development state. The research of solar energy technical status, development trend and technical route will help solar power generation to be developed orderly in the world, especially in North Africa. The scheme of developing large scale solar energy resource in North Africa, and transmitting clean energy power through transmission channel between North

Received: 20 October 2017 / Accepted: 15 December 2017 / Published: 25 January 2018

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