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FACULTY OF ECONOMICS

MASTER'S THESIS

MOVING AWAY FROM CONVENTIONAL ELECTRICITY GENERATORS TO RENEWABLE RESOURCES – PHOTOVOLTAICS ON ITS WAY TO GRID PARITY

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INTRODUCTION

In ever-evolving global economies the demand for electricity is steadily increasing. Industries as well as households consume more electricity than ever before. Global consumption is approaching the point where conventional energy sources (oil, coal and natural gas) are becoming scarce and the cost of its production and distribution to the main consumer is increasing at a fast pace. Most importantly, the global growth of industry increases the demand for electricity with the consequence of increasing the threat to the environment.

Governments are aware of the need to broaden their portfolio of electricity generators in order to reduce their dependence on the insecure raw materials supply which heavily affects the market price of electricity. For instance, the UK expects a shortage in electricity supply by 2020, which will be caused by a lack of generating capacities and tightness of the gas supply, expected to peak in 2015 (Constable & Sharman, 2008, p. 30). There is a continuously growing trend of rising prices in the global electricity market; in the last 20 years the electricity prices in the United Kingdom have increased by ca. 75% (National Grid, 2011, p. 16).

The above given reasons, as well as the binding energy generation policies to reducing carbon dioxide emissions, enforced by the international organizations, are pivotal reasons for a gradual move towards low carbon technologies. However this shift in international mind set demands some further thorough reforming, liberalization and decentralization of the electricity production and distribution systems. Governments are intensively subsidizing particularly the renewable energy generation technologies, clearly showing that the renewable technologies have been taken very seriously indeed. This encouragingly indicates we can expect tectonic changes in the energy generation and distribution sector in the next two decades, where renewable energy generators will become a big contributor to the global energy mix.

Electricity production utility managers and power plant developers already consider making land marking decisions by including renewable generators in the energy utilities' portfolios, which shows the big potential of the alternative energy sources, photovoltaics in particular (Berry, 2008, p. 5). Until recently, conventional generators have been the main choice of Utilities, but today there are many upcoming technologies being significantly less raw material – intensive, equally or more cost efficient and more sustainable than ever before.

The UK Government has, as many other countries in the EU, launched support schemes with a main purpose of incentivising low carbon renewable generators i.e. wind, solar and hydro powered power plants. These technologies, being in an incumbent phase not more than five to ten years ago, and far off from being commercially attractive enough, were in serious need of government support in order to accelerate its market penetration.

The Photovoltaic technology is swiftly moving towards being a prevailing renewable technology in the UK (as well as the rest of EU countries) due to its versatility, applicability and low-risk. Renewable technologies are, due to the favourable government' subsidies, experiencing a significant growth in the global markets and are expected to continue this trend in the future. In 2011, 9.5% of electricity was produced by renewable generators in the UK, which is a 2.7% increase from 2010. In the last two years photovoltaics has been the fastest growing segment amongst all renewable technologies (DECC, 2012, p. 45).

Increased growth in the last couple of years has caused a fierce increase of competition within the PV industry which has encouraged a faster technology evolvement and a significant price decrease. Subsequently, the gap between the photovoltaic and conventional generators has started to narrow, i.e. the generation cost of electricity produced from PV is starting to approach the levels of generation costs of conventional electricity power plants. According to Kaminska (2012), PV technology is becoming less reliant on financial supports and will gradually start to present a head-on competition to conventional generators globally.

The cost of electricity production for PV generators (so-called LCOE "levelized cost of electricity") is in some countries/regions already in line with the LCOE of utility generators (Germany, South of Italy). This so called "Grid Parity" process is increasingly gaining on its relevance also in the UK Energy Market.

LCOE is the main driver and indicator that serves us as an effective tool for determining the feasibility of implementation and development of power generation projects and enables a direct comparison of electricity production costs of different generators.

Thesis objectives. Several studies on the world's energy markets indicate the increasing global demand for electricity. Due to the scarcity of energy resources, the cost of electricity production as well as the transmission and distribution costs is rapidly increasing, which all reflects in the rise of electricity prices, eventually transferred to the consumer via the electricity bill. These trends have now given a "push" and are opening new routes to alternative energy resources, which have now, with the extensive help of the governments, found their way and are further strengthening their position within the global energy mix. Hereby my main goal of this research will be to:

- present the Scholars' and Industry's view on the energy markets and the photovoltaic industry within it, with the main focus on United Kingdom,

- elaborate on the main traits of a photovoltaic generator, its current position and prospects in the UK electricity market,
- analyse the financial plans of comparable-sized conventional and photovoltaic electricity generators in order to acquire comparable data on projects' feasibility,
- produce comprehensible results based on the above "Case study" which will help me to confirm or further question my hypothesis in relation to the current views on the discussed matter,
- correlate my main findings and assumptions regarding the competitiveness of PV's and apply them to the Grid parity notion.

To undertake this task in the most representative and direct manner possible, I will make a hypothesis based on my concrete assumptions which are a fusion of my experience and acquired knowledge about the PV industry in the UK.

Research hypothesis

"Solar electricity in the UK will reach Grid Parity by 2020. However, considering the fact that electricity supplied to a residential market is more expensive (cost of transmission and grid maintenance costs) compared to the industrial segment, therefore my assumption on the 2020 mark applies mainly to the industrial/commercial sector and general power generation level. On the residential front, my assumption is that the grid parity with the cost of electricity supplied to residential market will be reached earlier, in 2018."

To clarify what stages of Grid parity we know, NEDO ("The New Energy and Industrial Technology Development Organization") defined three main types of Grid parity (NEDO, 2009, p. 4):

- 1st phase grid parity: residential grid-connected PV systems.
- 2nd phase grid parity: industrial/transport/commercial sectors.
- 3rd phase grid parity: general power generation.

Considering the fact that the PV module prices are dropping at a faster pace than the electricity costs are rising, I can confidently assume that the UK solar residential market is fairly close to the 1st stage of the grid parity already – or it might even be there (i.e. the levelized cost of electricity is the same or lower than the LCOE of producing electricity from conventional centralized generators). However, an important factor that still remains a challenge is the lack of energy storage technology. To explain this better, almost half of the electricity generated from a residential PV system (a typical UK household) is exported, and therefore not used in the household. This means that at the time when the majority of electricity is produced (during the day), the electricity consumption requirements are the lowest, so instead of storing and using the electricity when needed (and not selling it back to the grid at the lower rate than buying it later on from the grid), means lowering the returns of the residential PV power plant.

Industrial/commercial and utility sectors are a harder nut to crack. Even though the prices of silicon modules are in a significant decrease, the economies of scale (as well as lower transmission and procurement costs) are at this point still ahead of the larger scale renewable generators. This will, however, eventually change considering the ever-growing maintenance, decommissioning costs and risks related to the operation of the power plants, whereas solar is increasingly gaining on its returns and by becoming a low risk investment it is also more attractive for the investors and financiers.

My main three conditions when argumenting the above hypothesis:

- An existence of a predictable and sustainable governmental policy (as existing or more transparent and sustainable) encouraging the market competition, technology evolvement and applicability.
- To at least maintain or preferably reduce the legislative and administrative barriers for implementing the renewable (solar) projects.
- Costs of conventional electricity will unavoidably increase at a pace predicted by latest industry researches (scarcity of raw materials, grid maintenance cost, rising fuel costs, etc.).

Research methodology. I intend to divide the research into two main parts; theoretical and empirical.

The first, theoretical part will descriptively present the fundamental findings of a rather new and increasingly evolving Photovoltaic technology, focusing particularly on the last ten years since technology has become vastly commercialized on a global scale. In relation to the uptake of the Photovoltaic Industry the essential notion of the electricity market presents a context on which the Photovoltaic Industry is heavily reliant. A particular region or country's energy market traits are essential to address prior and during discussion of the development of the Photovoltaic Industry. Being based and working in the United Kingdom for the last couple of years, I became very much familiar with the UK Energy market, its traits, pitfalls and potential. Being actively involved in the Photovoltaic sphere since its very first debut in Great Britain, I have observed and experienced the PV industry's development and eventually standing firmly its ground towards the heavily regulated UK energy utility market. To give my research a broader context and a proper benchmark I will also look further afield, within Europe's more mature markets.

The second, analytical part will substantiate and complement the theoretical part by comparing the financial model of conventional electricity generators, particularly the coal-fired power plant, and the photovoltaic power plant. The reason for choosing the coal-fired plant generator as a direct cost/performance comparison is that it is the most common type of conventional electricity generator worldwide at present. Financial plans will include projected cost structure and revenue streams, allowing me to acquire comparable results showing the cost effectiveness and returns on investments for both technologies. This will be on an empirical basis allowing me to provisionally confirm or discard both the scholars' and the industry assumptions of PV technology's move towards increasing competitiveness to conventional energy sources.

1 ABOUT PHOTOVOLTAICS

Photovoltaic (hereafter referred to as "PV") technology allows us to generate electricity in a clean, quiet and renewable way. It utilises the most abundant and non-exhaustible energy source on the planet – the sun, without releasing any harmful carbon dioxide (CO_2) emissions, one of the main gases affecting climate change.

1.1 What is Photovoltaics and how it works

The PV process enables the conversion of sunlight, the most abundant energy source on earth, into direct electricity (DC) current. This is done by utilizing a PV cell, made from a semi-conducting material, most usually silicon. The sunlight hits the surface of the photovoltaic cell where it creates an electric field across the layers of the cell, giving opposite charges – one positive and one negative. This creates an electron imbalance between the front and back of the cell and causes electricity to flow. The greater the irradiation of solar intensity, the higher electricity output of the solar cell/panel.

The power generated from a PV cell is measured in kilowatts peak (hereafter referred to as »kWp«). This is the rate at which the photovoltaic cell/module generates energy at peak performance in full direct sunlight during the summer. PV modules which combine a bigger number of photovoltaic cells come in a variety of shapes and sizes and are appropriate for roof-mounting or ground-mounting. Many new technologies allow greater possibilities of different applications, as well as efficiency levels (from space satellites to solar calculators, watches, street lightning, etc.).

1.2 How it all started

Photovoltaic technology is today at the forefront of the increasingly developing renewable sector. Its earliest start goes way back to the 1870s, when photovoltaic effect was first discovered and researchers found that certain materials produce small amounts of electricity current when exposed to light.

Three decades later, after some intensive research in solids, selenium solid was found as the key element which increased the efficiency of photovoltaic cells. Soon after that selenium was adopted for use in light-measuring devices.

In 1916, a Czochralski process was developed for producing highly pure crystalline silicon. Armaou & Christofides (2001) define Czochralski process as a method of crystal growth used to obtain single crystals of semiconductors, salts, and synthetic gemstones. The process is named after Polish scientist Jan Czochralski, who discovered the method whilst investigating the crystallization rates of metals.

Soon after that, in 1954, Bell Laboratories developed crystalline silicon photovoltaic cell, utilizing a Czochralski process.

First practical applications of photovoltaics have been made by NASA to power orbiting satellites and space crafts. Later on, in the 1970s the technology slowly started to be applied in terrestrial application by US Government and slowly started to commercialize. In 1983, the world PV production exceeded 9.3 Megawatts (hereafter referred to as “MW”). All the way up to 2011 when we can say the PV technology is in the upturn and starting to become an important player in the electricity’s energy mix and moving to become a direct competition to conventional electricity generators.

1.3 Where do we stand today

In the beginning of 2012, PV segment was in certain countries on the verge of becoming independent from the government. I am thinking about mature markets such as Germany and Italy, where installed capacities have reached several Gigawatts (hereafter referred to as “GW”) to date and where the scale of installed projects presents a significant contribution to the governments’ energy generation mix (DECC, 2011b, p. 14). In 2011, Italy represented 28% of all globally installed capacities (9.3GW) followed by Germany accounting to more than 25% (7.5GW) installed PV capacities globally (EPIA, 2012, p. 5). We can see that the European markets are moving towards maturity where growth in installations is going to slow down and settle due to the market saturation as well as the thoroughly reduced governments’ incentives, which will fall by approximately 5% on an annual basis (IHS iSuppli, 2012).

The intensive growth in photovoltaic industry will move towards developing markets. IMS Research (2012) points out in their report that the American and Asian markets are to become the two most prospective regions and will contribute for more than 85% of the global total growth of PV installations in 2013 whereas Europe’s share of installed capacities will fall by more than 50%. This is already creating challenges for the PV manufacturers who will have to diversify and expand their presence to several different markets and approach different sales’ channels in order to stand out.

2011 has been a very shaky year for European PV markets. Two main reasons for this are definitely related to the government's decrease in subsidising the renewable technologies and the increased competition in the world's PV market which puts a tremendous pressure on the PV manufacturers (especially European ones) who are facing big reductions in profit margins due to the on-going "price battle" (PVmarketresearch.com, 2012).

In terms of installed PV capacities, 2011 brought a slight turnaround whereby Italy "took the lead" to Germany with more than 7 GW installed. Germany, the world's biggest PV market in terms of total numbers of installed capacities, has recorded a slump in the installed volumes especially in the fourth quarter of 2011 due do its radical reduction in 'feed-in-tariff'. Global installed capacities reached more than 24 GW which was up 34% from a 17.7 GW total in the 2010 (IHS iSuppli, 2012).

The top six countries in respect of installed PV capacities in 2011 were; Italy, Germany, United States, China, Japan and France, respectively. Up-and-coming Middle, Far East and the Americas present for the majority of the growth in 2012 and have somewhat balanced out sluggish growth in the EU PV industry growth (IHS iSuppli, 2012). One of the biggest emerging markets, already showing its first big signs of a growth potential is China, which has also launched its FIT framework scheme, hence kicked off the PV industry in its own region (Pinelli et al., 2012, p. 3).

1.4 Photovoltaic technologies and its market penetration

There are many technologies in the market available today, however only some are financially viable and cost efficient enough to be commercially attractive and to make investment worthwhile.

As mentioned in the previous chapters, governments globally are using different leverages to give the PV industry a "push" in order to find its own ground and reach a point of being an easily financeable and worthwhile investment. This is also how governments encourage a competitive and evolving market where the demand will push the development forward and allow the price to drop and performance efficiency will increase what will effectively lead to the increase in competitiveness and consequently wider application of PV in the market.

1.4.1 Crystalline silicon technology

Crystalline silicon technology (in short: c-Si) is currently a prevailing technology in the global PV market and it accounts for about 90% of the whole photovoltaic market today (IEA & OECD, 2010b, p. 7).

Crystalline silicon cells are produced out of thin slices extruded from a single crystal of silicon (Monocrystalline) from a block of silicon crystals (Polycrystalline). Currently, efficiency ratings of crystalline silicon technology range from 11–19%.

Three prevailing types of crystalline silicon cells are (IEA & OECD, 2010b, p. 7):

- Monocrystalline (Mono c-Si),
- Polycrystalline (also called the multicrystalline, multi c-Si),
- Ribbon sheets (ribbon-sheet c-Si).

1.4.2 Thin film technology

The second technology already penetrated the market is thin film. This type of technology is made-up by depositing very thin layers of photosensitive materials on to a low-cost backing of glass, stainless steel or plastic (IEA & OECD, 2010b, p. 24). Production costs of thin film technologies are lower as opposed to the c-Si Technology, which is a more material-intensive technology. The price is counterbalanced by the lower performance figures (typically from 4 to 11%).

There are currently four prevailing types of thin film technologies in the market (IEA & OECD, 2010b, p. 24):

- Amorphous silicon (a-Si),
- Cadmium telluride (CdTe),
- Copper Indium/gallium Diselenide/Disulphide (CIS, CIGS),
- Multi-junction cells (a-Si/m-Si).

1.4.3 Concentrated PV technology

Another promising PV technology is the concentrated PV technology (hereafter referred to as “CPV”) which, unlike the flat panel solar solutions, utilizes direct sunlight by concentrating it through optical means (usually lenses or small mirrors) and concentrates it to small areas via highly efficient PV cells. This saves on the cost of PV and increases the power plant’s efficiency. However, this highly efficient PV process has been subject to intensive research due to its attractiveness. This PV application requires much smaller surface areas. Low and medium-sized concentration systems work with high efficiency silicon solar cells. For the higher concentration levels beyond 500 suns, III-V compound semiconductors are being used for the CPV cells where efficiencies beyond 40% have been achieved (IEA & OECD, 2010b, p. 26).

1.4.4 Other technologies

Photovoltaics is an incredibly fast-developing industry where new technologies are arising rapidly. Some of them are considered to become the leading PV technologies in the future, however at the moment not yet commercially as attractive as crystalline silicon (c-Si) technology.

Some of the perspective upcoming technologies are:

- Concentrated photovoltaics (as discussed above),
- Flexible cells,
- Dye sensitized photovoltaics.

The PV Industry is one of the fastest evolving industries. Due to its growth rate and applicability it is at this point comparable to the crude oil and mobile phone industries (Breyer & Gerlach, 2010, p. 4). One of its biggest advantages is definitely its modularity and scalability; this means that there are many possibilities of applying the technology on different scales (Breyer & Gerlach, 2010, p. 4). Current needs for sustainable energy are driving PV into a mass-commercialised technology with its huge growth and cost reduction potential (IEA & OECD, 2010b, p. 31).

1.5 Learning curve of Photovoltaics

Immense growth rate, hence technology advancement and consequentially its cost reduction potential puts PV industry amongst those with the highest learning curve rate of ca. 20% as opposed of the learning curve of the renewable sector as a whole, which is about 10% (Breyer & Gerlach, 2010, p. 3).

Margolis (2012, p. 3) describes the “learning curve” as a rate of a marginal labour cost decline with cumulative production for a given manufactured good and firm. Learning curves reflect a process of learning-by-doing or learning-by-producing within a factory or a market setting.

High learning curves can be seen in faster improvements in efficiencies and cost reduction as well as in enrolments of new PV technologies with better efficiencies, low light performance, temperature coefficients and longer life-span which allow shortening the energy payback time (“EPBT”)[1]. These will all contribute to lowering the levelized cost of electricity (“LCOE”)[2] as well as lowering the greenhouse gas emissions by increasing the amount of produced units of electricity per capacity (Breyer & Gerlach, 2010, p. 3).

According to Breyer and Gerlach (2010, p. 3), the semiconductor industry and the photovoltaic sector within it has experienced a 20% learning curve growth in the last twenty

[1] Energy input during the module life cycle which includes the (energy requirement for manufacturing, installation, energy use during operation, and energy needed for decommissioning) and the annual energy savings due to electricity generated by the PV module (Nieuwlaar & Alsema, 1997)

[2] Stands for the “Levelized cost of electricity”. Its definition is presented in Chapter 3.4.1.

years, which brought a 70% price reduction in the global photovoltaic market. European Photovoltaic Energy Association – EPIA (2011, p. 15) forecasts a further decrease in prices of PV by ca. 36–51% by 2020, but this can easily be achieved even earlier. This pace also depends upon the efficiency of the government's mechanisms which drive the photovoltaic industry forward as one of the leading ways of meeting the binding carbon reduction targets. The existing trend definitely shows a positive progress towards grid parity.

1.6 Development prospects of Photovoltaics

The trend is moving towards pushing the technology development in order to improve efficiencies, lower the production costs and reduce the price of the panels (IEA & OECD, 2010b, p. 35). There is always a question of commercial attractiveness which is a basic cost-benefit equation and is reflected in a simple return on investment calculation ("ROI"). Crystalline silicon technologies currently reach efficiencies of up to 20% (EurObserv'er, 2011, p. 169), which under current market conditions and level of support schemes in the UK can bring realistic returns of about 12% annually.

The analysts estimate that, at this pace of industry progress, the commercially available flat-plate module technology is to achieve up to 25% efficiency increase by 2030, 40% by 2050 for monocrystalline silicon technology, and 21 and 35% increase in efficiency for polycrystalline, respectively. Meanwhile, an entrance of new technology being commercially as attractive at that point is also expected (IEA & OECD, 2010b, p. 22).

If we sum up the main developments expected in the upcoming decades, considering the crystalline silicon technology, we can observe and predict the following trends.

1.6.1 Crystalline silicon technology

The expected efficiency levels for commercially available crystalline silicon technologies are (IEA & OECD, 2010b, p. 24):

- By 2015: Multicrystalline – 17%, Monocrystalline – 21%,
- By 2020: Multicrystalline – 19%, Monocrystalline – 23%,
- By 2030: Multicrystalline – 21%, Monocrystalline – 25%.

From the **manufacturing aspect**, the consumption of silicon per gram/watt will decrease to less than 5, to less than 3 and less than 2 until 2015, 2020 and 2030, respectively.

From the **research and development aspect**, the new silicon materials and new processing procedures are to emerge, as well as new cell contacts, admitters and passivation processes and improved device structures, which will allow higher productivity and cost optimisation in production. The latter are expected to come into the forefront by 2020. By 2030, major shifts in wafer equivalent technologies and new device structures are anticipated (IEA & OECD, 2010b, p. 24).

1.6.2 Thin film technology

Thin film technology is at this point still one step behind the crystalline silicon technology. This is primarily due to their efficiencies and, effectively, its cost/performance ratio. With the development and progression of the thin film technologies as well as its introduction to the market, this will eventually reflect in the advancements in the manufacturing process which will allow lowering the costs and increase of efficiencies. The main drawback of thin film compared to crystalline silicon technology is the lack of real life testing due to its rather incumbent phase (IEA & OECD, 2010b, p. 25).

When we are discussing the commercial modules the following improvements and advancements in thin film technologies are to be expected (IEA & OECD, 2010b, p. 25):

- Thin film to reach 10% efficiencies by 2015, 12% by 2020 and 15% by 2030,
- Copper iridium gallium diselenide (CIGS) technologies to reach efficiency of 14% by 2015, 15% by 2020 and 18% by 2030,
- Cadmium-telluride (CdTe) technology to reach efficiency of 12% by 2015, 14% by 2020 and 15% by 2030.

From the **manufacturing aspect**, by 2015 all the technologies will improve in terms of growing rate of high deposition, advancements in roll-to-roll manufacturing and packaging techniques. By 2020 major changes in simplifying the production processes, lowering the costs of packaging and improved management of toxic materials are also expected. By 2030, we can expect major shifts in the development of large high-efficiency production units as opposed to decreasing availability of manufacturing materials. Great emphasize is put on module recycling notion (IEA & OECD, 2010b, p. 25).

From the **research and development aspect,** a large area deposition process and improved substrates and transparent conductive oxides are expected to increasingly develop by 2015. There are also improved cell structures and deposition techniques expected, as well as advancements in materials and new concepts development (IEA & OECD, 2010b, p. 25).

Great importance is put on development and commercialisation of inorganic thin film technologies (SiG, CIGS), which have been the most massively produced amongst all thin film technologies. According to the industry, the SiG technology has an energy payback period of less than eight months which makes it a technology with the best EPBT in the industry. The reason why this technology is still not at the forefront is its high manufacturing cost compared to the CdTe cells. Today CdTe cells are in a prevailing position amongst the thin film due to its cost per watt (IEA & OECD, 2010b, p. 25).

1.6.3 Concentrated PV technology

According to the IEA Technology Roadmap (2010b, p. 26), CPV technology is moving towards its commercialisation in the commercial-scale applications. There is a further research and development needed for the optical systems, module assembly, tracking system, high-efficiency devices, manufacturing and installation. There is, however, huge potential for CPV and other novel technologies in years to come.

1.6.4 Other technologies

There are many new innovative technologies in the development stage, such as inorganic thin film technologies (SiG, CIGS – mentioned above), as well as the organic cells (IEA & OECD, 2010b, p. 26). These have potentially low cost implications, hence are expected to approach niche markets soon. However, they are still less efficient in terms of power output and their versatility in its application is still to be further researched, therefore their future prospect is still yet to be proven.

Yet another interesting PV technology approaching its market penetration point is thermo-photovoltaic. It works as a combination of PV cells combined with the radiation source and is intended to be used with future concentrating solar technologies.

All new technologies are striving towards achieving higher energy yields through higher efficiency solar cells, utilizing the active layers which best match the solar spectrum or which modify the incoming solar spectrum (IEA & OECD, 2010b, p. 26). Both approaches are built on the progress of nanotechnology and nanomaterials. Quantum wells, quantum wires and quantum dots are examples of structures within the active layer. Further developments are focused on the collection of the charge carriers – hot carrier cells, and the formation of intermediate band gaps. These technologies are still in their first phase of research.

Whether all these technologies will eventually become marketable and commercialized, will very much depend on whether they can be combined with existing technologies or if these will lead to the development of new cell structures and processes. Should the latter happen, then the time-frame is expected to occur mid-to long-term.

1.7 Challenges

As mentioned in the previous chapters, photovoltaics is one of the fastest developing industries at present. There is an on-going improvement, development and evolvement of new technologies through improving efficiencies and discovering new ways of applying the photovoltaics.

However, within the future developments of emerging technologies we can expect the following challenges (IEA & OECD, 2010b):

When considering the development of cell types there are still effectively rather high cost implications as well as higher efficiency expected for CPV technology whereas the emerging technologies will strive towards the lower cost of production, hence also its moderate performance. Therefore the biggest challenge will be to improve the efficiencies as well improving its applicability and at the same time as lowering the price, in order to stay competitive towards industrial applications.

In terms of the **technologies' potential**, CPV can currently deliver up to 23% system efficiency with the potential to reach 30% and above. Emerging technologies are at the moment still very much in their testing phase (dye-sensitized PV, Printed CIGS, etc.) and still not fully commercialised. The first serious commercial applications of these technologies are happening for now only in the niche markets. There is however a wide range of new conversion technologies in the development stages with a big breakthrough potential once fully marketed.

Considering the **research and development** side, CPV is likely to achieve extremely high efficiencies in the future, up to 45%. However the industry, on the other hand, strives towards reducing the costs in order to achieve the most cost efficient solution for optical concentration and tracking. The same goes for the other emerging technologies, where there is an on-going improvement of efficiency in order to bring the technologies to the level where these will be suitable for the first commercial applications. In the case of novel technologies, proof-of-principle of new conversion concepts are expected to be established as well as new processing, characterisation and modelling of especially nano-structured materials and devices. Encapsulation of organic-based concepts will also come in the forefront (IEA & OECD, 2010b, p. 26).

1.8 PV and CO_2 reduction potential

CO_2 presents the main cause of global warming. It is a by-product of the fossil fuel combustion process and in more than 50% of cases it is caused by human activities.

Electricity generated from renewable resources, particularly photovoltaics, is non-polluting, at least not when in operation. However, we are not taking into account the CO_2 emissions occurring in different stages of equipment's manufacturing process, transport and decommissioning at the end of their lifecycle.

According to World Nuclear Association – WNA (2011) the lifetime greenhouse gas emission intensity[3] of a photovoltaic system is ca. 85 grams of CO2/kilowatt-hour(s) (hereafter referred to as "kWh"). This number, however, depends on the PV technology. One of the cleanest electricity generators apart from PV is nuclear technology, but there are several significant safety and potential pollution issues, as well as the problem of storing nuclear waste. Natural gas powered generators are one of the lowest pollutants within the fossil fuel run generator technologies. However, this is not the case with the coal-fired power plant.

A coal-fired power plant emits on average ca. 891 grams of CO_2/kWh produced which is more than ten times that of the PV generator's emission figures (World Nuclear Association – WNA, 2011, p.6).

There is a very important notion that needs to be taken into consideration when calculating the reductions in CO_2 emission. Different electricity generators have different values of CO_2 emissions and therefore we have to note this when making a comparison of greenhouse gas emissions.

The UK's Energy Savings Trust (2010) came up with the CO_2 emission calculator, which represents the emissions of electricity produced and purchased from the electricity grid (hereafter referred to as the "grid"). It reflects the mix of fuels in energy generation (data from 2009). This includes nuclear, wind and other low carbon generation. This value is 0.544 kg CO_2/kWh.

For instance, a residential 4 kWp photovoltaic generator (16 PV panels, covering approximately 26 m^2 surface area) would in the United Kingdom (South of England, 30 degree roof pitch – south facing) generate up to 4000 kWh of electricity, this means a household would annually offset ca. two tons of CO_2.

EPIA and Greenpeace International (2008, p.10) claim that by 2030 solar photovoltaics could reduce the annual global CO2 emissions by more than 1.6 billion tones, which is an equivalent to the output of 450 average-sized coal-fired power plants. According to this scenario, the CO2 savings coming from PV generation could from 2005 to 2030 amount to an incredible 9 billion tones. This means, if the governments lead the renewable policies right, solar PV could seriously contribute to the CO2 emissions reduction in the forthcoming decades.

[3] Emissions of greenhouse gases over the complete life-cycle of a power source (World Nuclear Association-WNA, 2013)

2 PHOTOVOLTAICS AND THE UK ENERGY MARKET

In this part I intend to present the electricity generation and distribution system/infrastructure which heavily effects the development of PV industry by providing the infrastructure and the regulatory framework to alternative energy generators for production and distribution of electricity.

When we talk about the development of a certain technology in a particular market or region we need to closely correlate this to the energy market conditions and trends in that particular market/region. Therefore my main focus will be to explore and analyse the traits of the UK's energy market.

2.1 About the UK energy market

The electricity system in the United Kingdom has in the past been a state-owned asset in the form of regional monopolies which have later on eventually been transformed into one of the world's most liberalised systems with a well-established regulatory framework (HM Treasury & DECC, 2010, p. 11). A strong and independent regulation of this established framework hereby plays an important role in order to ensure the highest possible level of stability and security for consumers, whether it's for the businesses or individual households. The Government and the regulators (Office of Gas and Electricity Markets – OFGEM is government's appointed regulator for the UK's energy market) are both responsible for regulating monopolies in electricity transmission and distribution in order to assure and protect the interests of current and future consumers, as well as promoting competition at all times when and where this is possible.

The UK Electricity market is segmented as follows (HM Treasury & DECC, 2010, p. 11):

- Wholesale market – where the generators, suppliers and large customers buy and sell electricity),
- Transmission and distribution networks at national and regional level,
- Retail market – where suppliers sell and bill electricity to end customers/consumers.

Electricity companies are within these market segments taking decisions about investing in infrastructure and are responsible for ensuring that generation capacities are meeting the actual demand at all times. The network monopolies support a company's investment by ensuring the networks are developed in time as well as ensuring a reliable transmission and distribution. When liberalisation took place, several companies entered both the generation and the supply market which both became increasingly concentrated. The UK Electricity market is now dominated by six major energy companies also known as **"The Big Six"** which have a 99% share of domestic supply (HM Treasury & DECC, 2010, p. 11).

Due to new climate change objectives where the UK, as a member of European Union and a signatory of the Kyoto Agreement, had to adopt the carbon reduction commitments, there will be substantial investments in the UK electricity infrastructure and industry in general in order to decarbonise its energy production. The UK Government has committed themselves to legally binding targets of reducing the greenhouse gas emissions by 80% by 2050 (HM Treasury & DECC, 2010, p. 19). This, as mentioned, will take large steps in restructuring the system and regulatory framework in order to deliver these targets in time and accordingly.

Significant changes are needed to achieve the above targets (HM Treasury & DECC, 2010, p. 3):

- Technological changes where electricity markets will play a central role in reducing the carbon emissions.
- Changes in global markets and associated re-pricing of the risk which will affect the project financing notion.
- Businesses globally know more about both the challenges with building and operating current low carbon technologies and the possibilities of future technologies.

According to (HM Treasury & DECC, 2010, p. 3) the government needs to take further steps to ensure the electricity market framework can indeed effectively deliver secure supply. In order to achieve this, substantial low-carbon investments are needed to successfully tackle the long-term challenges beyond 2020.

New required investments present significant challenges in the four areas of the market framework and make new demands of the strategic approach:

- The economics of low-carbon generation,
- The finance requirements of low-carbon generation,
- Security of supply,
- Concerns about efficiency and fairness.

This clearly shows that the Government has indeed taken renewable policies very seriously. It also indicates that we can expect tectonic changes in the electricity production and distribution concept in 2030s. We are already witnessing part of these through the increasing role of the low carbon generators, especially PV, being an increasingly bigger contributor to the electricity mix.

Government uses several policy leavers to influence and control the evolvement and for delivering the planned outcomes of the electricity market. According to (HM Treasury & DECC, 2010, p. 4) these will be:

- Statutory regulation,

- Creating new markets,
- Price interventions,
- Changing the balance between the private and the public sector, using the balance sheet to support the financing of the investment.

We can categorize the above into the following groups of policies:

- To provide an additional payment to low-carbon generators (such as the “Feed-in-tariffs”[4] and other types of incentives, launched in the UK in 2010),
- To limit the investment of high-carbon generators,
- To provide a fixed revenue to low-carbon generators.

There are many other innovative ways of accelerating the growth of low carbon generation. One of them is definitely the Green Investment Bank, a funding scheme with the assigned task of attracting private funds for the financing of the British private sector's investments related to environmental preservation and improvement. Apart from this, there are more

varieties of incentives arising intended for other less “popular” renewable technologies such as Renewable Heat Incentive as well as the Green deal, which will all be presented more in detail later on.

All these notions within the low-carbon strategy are in line with the three main principles that the Government is striving towards:

- **Cost effectiveness** which implies that all the government’s objectives should be delivered as efficiently as possible. It also means that markets should function as effectively and dynamically as possible, allowing the creation of a competitive market and consequentially lower prices and better service.
- **Affordability** is apart from effectiveness a very important notion as all the Government’s interventions seriously affect the tax payers.
- **Stability and certainty** is crucial for maintaining consistent and sustainable reforms, and all that affects the credibility and trust in Government’s actions.

2.2 UK Electricity generation

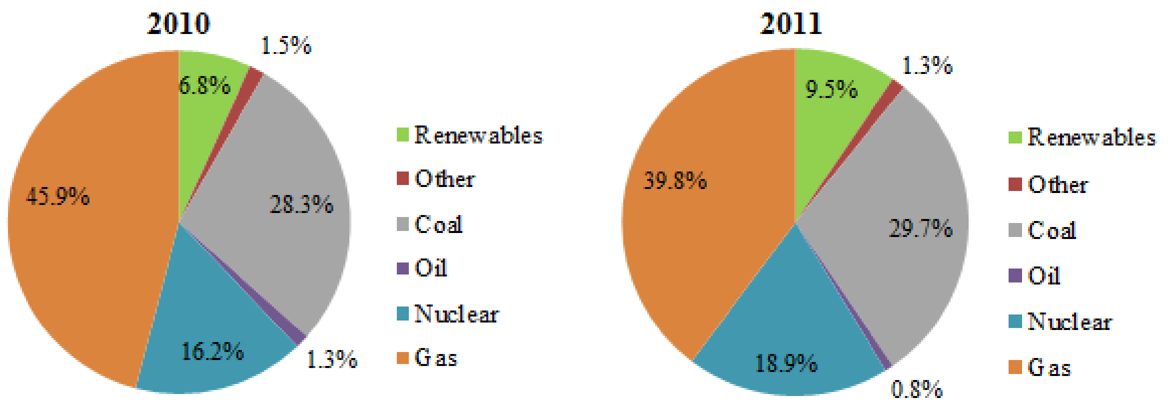
The United Kingdom is supplied with electricity from a portfolio of ageing conventional generators (DECC, 2012, p. 4) as well as an increasing number of low carbon and renewable generators:

- Nuclear power plants,

[4] Government’s incentive for uptake of electricity generating renewable technologies such as solar PV, described in Chapter 3.5

- Combined Cycle Gas Turbine (“CCGT”),
- Coal and oil refined steam power plants,
- Pumped storage power plants,
- A growing portfolio of renewable generators (Wind generators, hydro and solar PV generators).

Figure 1. Percentage of generated electricity by technology in 2010 and 2011



Source: DECC, *Energy Trends: March 2012, Section 5: Electricity*, 2012, p. 40, chart 5.2.

In 2011, total capacities of generated electricity reached 365 terawatt-hours (hereafter referred to as “TWh”) as opposed to 2010 volumes which amounted to 381 TWh, presenting altogether a 4.2% year-on-year decrease. On the other hand, the electricity imports in 2011 peaked at 6,222 gigawatt-hours (hereafter referred to as “GWh”) which is ca. three times more than imports in 2010 (2,663 GWh). Despite the fact that the consumption between both years has decreased (which is not a representative trend) as well as production, the numbers clearly show the increase in imports of electricity which is definitely related to the costs (DECC, 2012, p. 41).

2.2.1 Electricity price trends

There is a general awareness of a gradually increasing energy cost. All the indicators show that the energy market is moving towards the point where the UK’s energy situation will become underpinned by the price rise and the decrease in security of fuel supply (Constable & Sharman, 2008, p. 13).

Price levels are expected to steadily increase on average 2–6.7% per annum (EPIA, 2011, pp. 23–24). The main reasons for this are fairly obvious: raw material prices, network upgrade costs, political fixation costs and others. This increase will be transferred to the end consumer.

Due to the volatile macroeconomic situation it is difficult to predict the exact price movements however it is rather simple to make fairly realistic estimations of the future electricity prices using historical electricity price movements.

Firstly, it is essential to differentiate between the different market segments:

- Retail level (End customers),
- Wholesale level,
- Power Exchange level (Electricity market),
- Generation level (Electricity producers).

At the **retail level** residential customers (consuming ca. 2500–5000 kWh electricity annually) purchase electricity in the regulated environment from the local distributor system operators while businesses (commercial and industrial customers – consuming ca. 500–2000 MWh electricity annually) have a possibility of obtaining their supplier in the free market.

Wholesale level is known to be more open and competitive. The price of electricity is pushed to the marginal production levels that satisfy both sides the buyers and the sellers of electricity (Jamil & Fairuz, 2007, p. 9). In this case, the seller has a great manoeuvring space for profit margins which can be gained from bilateral trading. There is an important notion of bilateral trading and this is a balancing mechanism, whose purpose it is to balance the energy and the technical part of the power system. Balancing mechanisms have become a platform for the generators to generate their income (Jamil & Fairuz, 2007, p. 9).

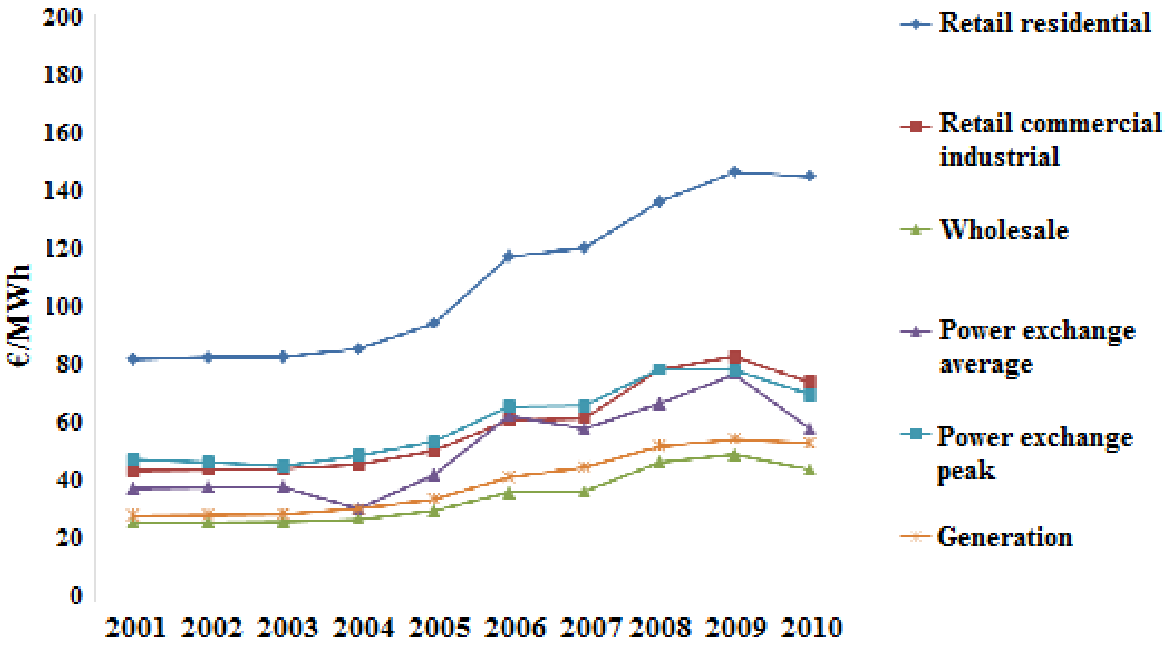
Short-term bilateral markets or **power exchanges** are sort of a “stock market” of electricity where all participants are in a “screen-based” trade standardised blocks of electricity, particularly focusing on the last 24 hours, for instance, where the delivery of a certain amount of MWh over a specified period of the next day is required. Power exchanges enable the sellers (generators) and buyers (suppliers) to negotiate and agree contract positions at the stage when their own demand and supply forecasts become more accurate and predictable (WIP – Renewable Energies, 2012, p. 10).

At the **generation level** the existing portfolio of high and low carbon electricity generators is responsible for generating the energy which gets then sent into the National Transmission Network and through to the regional distribution networks to the end consumers. For the purposes of analysis, the price of electricity is at this point replaced for electricity production costs, as the electricity production takes place at the first stage of the value chain.

The cost of electricity generated by a large-scale PV system will later be compared to the cost of electricity generated by a conventional power plant. Using the so-called levelized cost of electricity (hereafter referred as to “LCOE”) we will be able to position the PV generator on the PV grid parity curve, which will be discussed later on.

The graph below shows the evolution of the UK electricity prices in different market segments over a period of 10 years, from 2000 to 2010.

Figure 2. Evolution of UK electricity prices in different market segments from 2000–2010



Source: WIP – Renewable Energies, *Electricity prices scenarios until at least the year 2020 in selected EU countries*, 2012, p. 38, Figure 16.

Main observed trends will serve as a good basis for further analysis:

- 75% increase in price in residential retail electricity segment,
- 30% increase in price in the electricity generation segment (utilities).

When comparing the electricity prices in different market segments we can notice that at the generation level, the electricity price-cost is actually higher than at the wholesale level which does not make sense. This is due to the electricity generation companies which take into account the potential peak prices, whereas at the wholesale level the wholesalers can buy from generation companies producing at base load prices This is the main reason why the wholesale prices are the lowest levels followed by the generation prices-costs, then power exchange purchase, power exchange peak load, retail/commercial/industrial and retail electricity prices.

To get a better understanding of what the electricity unit price is comprised of, it is essential to analyse all the components included. This will give us a better understanding of what causes the energy price changes and to what extent.

Table 1. Breakdown of retail electricity prices for all market segments

	Average retail electricity price		**Average wholesale electricity price**	**Power exchange**	
	Residential	**Commercial**	**Commercial /industrial**	**Average purchase price**	**Average peak load price**
Procurement cost	47%	60%	80%	80%	80%
Network cost	33%	20%	0%	0%	0%
General system cost	10%	10%	10%	10%	10%
Taxes	5%	5%	5%	5%	5%
Value Added Tax (VAT) included?	Yes	Yes	Yes	Yes	Yes
Profit	5%	5%	5%	5%	5%

Source: WIP – Renewable Energies, *Electricity prices scenarios until at least the year 2020 in selected EU countries 2012*, p. 39, Table 14.

Weiss et al. (2011, p. 39) in PV Parity Project defines the main costs occurring in all four segment of electricity supply chain:

1. **Procurement costs** apply to electricity procurement and marketing activities.
2. **Network costs** apply to electricity transmission, distribution and metering.
3. **General system costs** apply to support schemes of renewable energy sources, decommissioning costs of nuclear thermoelectric power plants, social taxes for protected retail segment, cost for supporting research and development in the electricity sector and cost for enhancing energy efficiency in the electricity sector.
4. **Taxes and the VAT.** UK has the one of the lowest tax rates amongst EU countries compared to Italy, Austria, Germany, Netherlands, and Spain. Despite the fact that residential prices represent the largest portion of the UK electricity market segment, the relative amount of tax contribution for residential consumers is one of the lowest where only the VAT rate is applied to the basic price and no other taxes are applied (WIP – Renewable Energies, 2012, p. 39).

When discussing the electricity generation level there is an important notion that needs to be pointed out; the **base load** and the **peak load** electricity demand. Base load demand is the minimum amount of power that a utility or a distribution company must make available to the customers or the minimum amount of electricity needed to be available to meet some expected demand from the market. Peak load demand, on the other hand, presents a higher than usual level of demand for electricity and represents the highest point of customer consumption of electricity.

As most conventional generators have, due to their size, an amount allotted base load to handle, they get very rigid and expensive when it comes to covering the peak demands. Therefore smaller to medium sized generators, which are more flexible and responsive, are taking over covering the peak demands for electricity.

On the other hand, there are shortcomings of the PV generator's ability to supply a firm amount of power, due to the uncontrollable factors which refer to the solar irradiation at the particular time of the day, also known as the Time-Of-Day generation (hereafter referred to as "TOD"), it is harder to predict the amount of generated electricity in peak loads. For instance, a coal-fired power plant can provide a consistent amount of power at a certain time of the day, whereas solar plants cannot. This can be a significant driver of profitability as many power purchase agreements[5] (hereafter referred as "PPA") also include TOD factors which determine the effective revenue earned per kWh (Prior, 2011, p. 6).

A photovoltaic power plant performs best and produces the most electricity in the midday hours, at the time when demand for electricity is the highest and when electricity from conventional generators is most expensive. Therefore, the PV electricity generators are in a good position to become an alternative to existing small to medium scale conventional electricity generators and eventually pave their way towards the electricity generation market.

When discussing electricity prices at the base point and peak point it is important to highlight a very important factor that seriously affects the future electricity supply rate and its impact on the price; Generation Capacity Retirement. UK Government has somewhat underestimated the capacities that are obsolete or will need to be put out of order (Constable & Sharman, 2008, p. 1). For instance only EON and EDF, two of the "Big Six" electricity suppliers in the UK, see a total of 58 GW to retire by 2020.

UK government has, according to (Constable & Sharman, 2008, p. 1), also very much underestimated the impact of Large Combustion Plan Directive[6] as their portfolio of high-carbon generators is soon-to-be technically obsolete and inefficient which will seriously reduce the portfolio of their current coal-fired power plants.

[5] A contract for a large customer to buy electricity from a power plant. This is usually the most important contract underlying the construction and operation of a power plant (Financial Glossary, 2013).

[6] The purpose of LCPD is to reduce acidification, ground level ozone and particles throughout Europe by controlling emissions of from large combustion plants (LCPs) in power stations, petroleum refineries, steelworks and other industrial processes running on solid, liquid or gaseous fuel (What does the LCPD do?, DEFRA, 2013).

2.2.2 PV and its contribution to the UK's energy mix

Equipment price and installation cost of solar photovoltaic have dropped significantly in the last three years. Only since April 2011, PV module prices have fallen by more than 50% (Bloomberg Global Leaders Solar Index, 2012). The UK PV industry is now eighth in the world in terms of installed PV capacities, representing more than 2% of the global PV market. PV capacities installed under the feed-in-tariff scheme will generate more than 500 MWh per year and save 4.389 million tonnes of CO_2 over their lifetimes (Energy Savings Trust).

According to the Energy Savings Trust (2012), almost 11 million homes in the UK would benefit from having solar PV systems installed by end of 2011. By 2020, about three million of UK homes are expected to have installed more than 22GW of solar PV capacities, which is the equivalent of 10 large power stations (DECC, 2011b, p. 22).

2.3 Installed PV capacities and future predictions

In 2011, more than 658MW renewable generators had been connected to the UK electricity grid under the "Feed-in-tariff" scheme. Out of these, more than 593 MW were from photovoltaics, followed by wind with 34.7 MW installed (DECC, 2012, p. 48).

Cumulatively, almost 1.4 GW of solar PV capacity had been installed in the UK by December 2012 (DECC, 2013).

In 2008, the UK government and the National Grid made probable estimations and roadmaps of Electricity Generators' contribution of generated capacities. This included ca. 33 GW produced/contributed from the off-shore wind generators by 2020, which is still a very optimistic announcement considering the fact that wind is currently not even the main contributor of renewable energy to the Grid, but we will talk about this later.

A significant decrease in capacity margin of conventional electricity generators compared to the current levels is also expected (OFGEM, 2012, p. 1). This will cause a growth of suppliers' prices due to retaining of underused but indispensable conventional shadow capacity which will leave a wide gap for renewable power generation.

Due to PV's more favourable emissions profile compared with coal, and, especially the low capital cost of renewable generators, only gas (out of all of the conventional generators) has been brought forward in quantity in the period from 2008 to 2013.

However, global demand for gas is rising faster than global export production; therefore the competition for gas distribution will become even fiercer, with a consequent effect on the generation prices. There is a significant risk that gas may become physically unavailable and, in any case, very expensive as its price continues to converge with the price of crude oil. Constable and Sharman (2008, p. 30) predicts a tightness of electricity supply expected by 2020 caused by a lack of generating capacities and/or tightness of gas supply, which will peak in 2015. Therefore, already high prices are expected to rise due to scarcity of the commodity.

This fact talks in favour of renewable generators which will start to increase their share and contribute more to the UK energy generation mix. The pace and scale of this process is, however, at this point still very much dependent on the UK Government's ability to run the renewable policy effectively which means also "loosening" the rigid energy value chain in order to be able to act in a more commercial way and increase system's flexibility.

Another factor that will increase the competitiveness of renewable generators according to Constable & Sharman (2008, p. 3) is introducing the electricity storage capacities to the market allowing maximum generation volumes during the peak time of renewable generators (particularly solar PV) which will turn out to be extremely rewarding. All renewable generators will greatly benefit from this situation due to the increase of its capacity factors, hence improved utilization rate which effectively means lowering costs and increasing the competitiveness. In other words, renewable energy (wind, solar, hydro) will become cheaper to produce and therefore less vulnerable to the penalties introduced to carbon emissions.

In order to make some realistic assumptions about the future of PV development in a particular market, undertaking an analysis of the current situation is essential.

The United Kingdom, having more than 1 GW of installed PV capacity within the 2-year period, presents a very encouraging fact for the photovoltaic market and also gives us a good basis to analyse as well as a very good starting point for the future research where accordingly adapted prices and the green incentives will enable a continuous and sustainable market growth. My intention is to study the future growth trends through a case study i.e. analysing financial plans of two types of generators. This will serve as the most valuable basis that will prove the predictions discussed in the following.

Aanesen, Heck and Pinner (2012, p. 6) suggest the annual global installation volumes of photovoltaics could increase by 50 times by 2020 compared to 2005. This means at this point PV will seriously "threaten" gas, wind, hydro and even nuclear generators.

Aanesen, Heck and Pinner (2012, pp. 6–8) also point out the five main segments which will encourage the growth of the PV industry in the next 20 year period (applied to the UK electricity market):

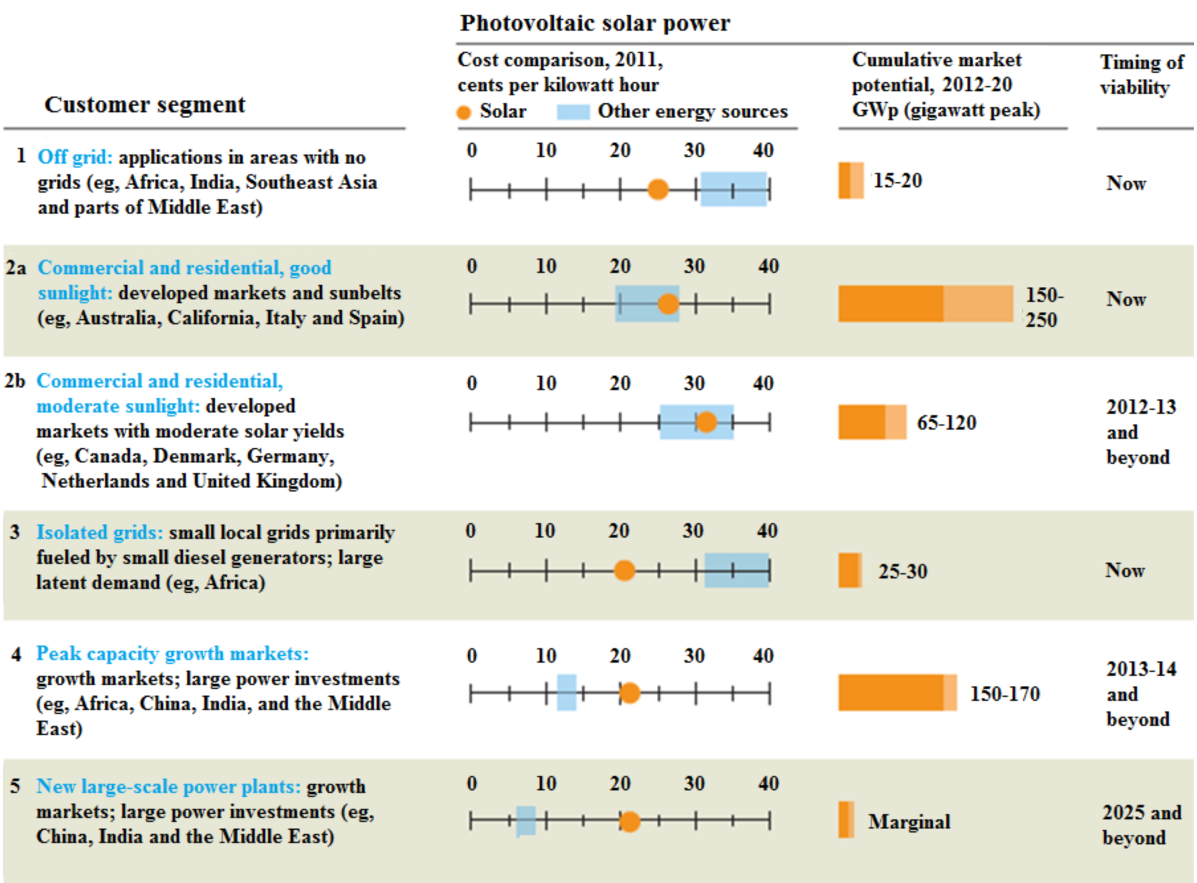
1. Residential and commercial retail customers in sunny areas where power prices rise steeply at times of peak demand (South of England).
2. Residential and commercial retail customers in areas with moderate sun conditions but high retail electricity prices (England on the whole).
3. New, large-scale power plants.
4. Isolated grids.
5. Off-grid segment.

The global potential for total installed solar PV could exceed 1 terawatt (hereafter referred to as “TW”) by 2020. This would also be the point where PV power plant’s LCOE would start to become comparable or even lower than the LCOE of the conventional power plant. However, there are certain barriers mitigating the uptake of PV such as:

- Regulatory environment,
- Access to financing sources.

Taking the above into account, the expected global installed capacity could reach 600 GW by 2020 (Aanesen, Heck and Pinner, 2012, p. 6).

Figure 3. Growth potential for different PV segments



Source: Aanesen, Heck and Pinner, *Darkest before dawn*, *McKinsey on Sustainability & Resource Productivity*, 2012, p. 4, 2012, p. 7.

The Deutche bank (2009, p. 20) stresses that the winners in the future PV “battle” in the increasingly competitive markets where the profit margins are fast decreasing will be the companies who will manage to achieve the most optimal LCOE price together with innovative approaches to financing and project implementation.

3 PHOTOVOLTAIC GENERATOR

A photovoltaic generator is a system utilizing solar panels to convert sunlight into electricity. This is done by using the photovoltaic module of different types and technologies, already introduced in chapter 1.4.

The remaining components of a PV system are also referred to as a BOS (balance of the system) which include:

- Inverter (the “brains” of the PV system, converting direct electricity current from PV panels to alternate current for purpose of usage),
- Generation meter (records the electricity generation),
- Other electrical equipment (Photovoltaic DC cable, DC isolator switches, AC isolator switches, other AC electrical material).

We can divide the photovoltaic system into three main categories, considering its:

1. Size:

- Residential photovoltaic systems (residential properties),
- Industrial and Commercial PV systems (industrial buildings, governmental facilities),
- Utility Scale power plants (solar parks).

2. Ways of applications:

- On-roof systems (installation on pitched and flat roofs),
- In-roof PV systems (building integrated photovoltaics; replacing the roof tiles or a façade),
- Ground-mounted PV systems.

3. Connection to the electricity grid:

- Grid-connected PV system (connected to the electricity network),
- Off-grid PV system (performing autonomously without grid connection, utilizing battery storage technology).

3.1 Performance

A photovoltaic power plant and its main components, solar panels, do not require direct sunlight to operate and can efficiently work in low-to-medium irradiation levels. Due to the amount of irradiation (daylight) it is obvious that a PV system produces more electricity in the summer months, however this does not mean it is useless in the winter months. It still produces generous amounts of electricity and this keeps improving with the increasing efficiency of solar modules.

Photovoltaic performs differently in different geographical areas with different irradiation levels. Its power output as well depends on the technology efficiency.

When designing a PV power plant we normally follow local regulations regarding performance estimation. In the UK, we particularly follow the Governments' Standard Assessment Procedure – SAP, a main tool to estimate the annual performance of the solar photovoltaic power plant.

Figure 4 shows the irradiation levels in the United Kingdom.

Figure 4. Solar irradiation levels in the United Kingdom

Source: *Photovoltaic Geographical Information System (PVGIS) tool, 2012.*

As seen in Figure 4, due to the climate variety in the UK, up to 1300kWh/m2 of electricity generation can be achieved in south west of the country. On the other hand, in the north the irradiation levels can be almost halved.

The main factors that determine the PV power plants output are:

- Array orientation – east /south-east /south /south-west/west,
- Tilt of the array,
- PV system size in kWp,
- Any potential shading or physical obstructions (trees, chimneys, surrounding buildings).

The following figure shows the percentage of the irradiation levels at varying orientations and angles of PV systems.

Figure 5. Energy yield levels at varying orientations and angles of PV systems

TILT (degrees)	WEST						SOUTH							EAST					
	90	80	70	60	50	40	30	20	10	0	10	20	30	40	50	60	70	80	90
0	87	88	90	91	92	92	93	93	93	93	93	93	92	92	91	90	89	87	86
10	84	87	90	92	94	95	95	96	96	97	97	96	95	94	93	91	89	87	84
20	82	85	90	93	94	96	97	98	99	99	98	97	96	95	93	91	88	84	81
30	78	83	87	91	93	96	97	98	99	100	98	97	96	95	93	89	85	81	78
40	75	79	84	87	92	94	95	96	96	96	96	95	94	92	90	86	82	77	72
50	70	74	79	83	87	90	91	93	94	94	94	93	91	88	83	80	76	73	70
60	65	69	73	77	80	83	86	87	87	87	88	87	85	82	78	74	71	67	63
70	59	63	66	70	72	75	78	79	79	79	79	79	78	75	72	68	64	61	56
80	50	56	60	64	66	68	69	70	71	72	72	71	70	67	66	60	57	54	50
90	41	49	54	58	59	60	61	61	63	65	65	63	62	59	60	52	50	47	44

Source: Energy Saving Trust, *Orientation and tilt table*, 2012.

Another important notion of the functioning of a photovoltaic system needs to be stressed; performance figures under different environmental conditions. Performance monitoring enables the owner of a PV power plant to monitor whether their solar PV panel installation is working to its potential and maximise the generator's output in terms of income and savings.

There are several ways of monitoring the system's performance as there are a number of ways the generation meters:

- Inverter display,
- Internet monitoring and portable/remote displays.

PV system performance monitoring is gaining on its relevance as large energy utility companies are starting to invest large amounts of money into the monitoring technology to receive and to analyse immense amounts of data in order to specify the customers consumption need and increase the consumption and generation visibility.

3.2 Cost structure

The main purpose of this chapter is to present the general cost structure trends of PV generators in the UK as well as globally. I do not intend to analyse all the factors of the PV power plant in-depth as I will do this in the financial plan analysis. I will therefore hereby reflect on the global trends in the PV Industry and apply them to the UK market, which is still a rather “virgin market” as opposed to the highly mature markets such as Italy and Germany.

I will hereby refer to a research, undertaken by Ernst &Young UK (2011) which closely relates to my views on the developments of the PV industry in the UK to-date and its future prospects. We have to note that it’s rather hard to provide the latest up-to date information which would even better present the current situation, due to the fast pace of PV market evolvement, which means working with the latest collected information which is about a year old. The target group includes the top ten UK PV developers representing an estimated 10% of solar PV capacity deployed in the UK to date, which will definitely present a substantial share of PV projects realised and will play a significant role in the future PV market in the UK.

The main finding referring to the 2011 situation is that the costs of PV in the UK are still above the mature markets such as in Germany and Italy. However, a further decline is expected beyond 2012 as prices will soon be in line with the mature market prices. Around 40% of the capital expenditure (hereafter referred to as “CAPEX “) on the project such as equipment, etc. are currently attributed to modules whose prices are expected to even further decrease (EPIA, 2011, p. 15).

There is an important notion of the UK’s ability to adopt the net metering concept[7] which would further encourage the uptake of the residential, as well as commercial PV project development. The main reason for this is that the excess electricity at the moment needs to be sold to the grid at an export rate and purchased back when needed from the electricity supplier at a regular rate.

Based on the above facts and figures, the PV industry in the UK is likely to reach grid parity with retail prices by 2020 without any subsidy for non-domestic, on-site installations. There

[7] Net metering is a system in which solar panels or other renewable energy generators are connected to a public-utility power grid and surplus power is transferred onto the grid, allowing customers to offset the cost of power drawn from the utility (Oxford Dictionaries, 2013).

is, however, still a very significant factor that keeps restraining the undisrupted market development and that is regulatory instability. The UK regulatory framework still causes high levels of insecurity in subsidies systems, which reflects in the enhanced risk of the investment, hence increasing the overall cost of financing of solar PV projects above the expected levels existing under a stable FIT regime.

Instability of the UK incentivising systems is still mainly due to the immaturity of the market and the lack of the governments' experience along with an inability to make firm estimations of the Industry market deployment.

There is a tremendous pressure on the market to reduce prices and improve efficiencies in order to make technologies more competitive. This trend has become even more apparent in the last year of PV development (2011–2012) when there has been a significant, more than 50% drop in PV panel prices (Bloomberg Global Leaders Solar Index, 2012). It is expected that the competition amongst the PV manufacturers will even intensify, however this will also apply to the downstream segments of the value chain. Upstream players, such as equipment manufacturers, will have to distinguish themselves by developing innovative, proprietary technologies whereas downstream players will need to focus on meeting the needs of particular market segments (Aanesen, Heck and Pinner, 2012, p. 12).

Key future success factors for upstream players:

- To develop own differentiated and scalable technologies,
- To drive operational excellence in manufacturing,
- To address balance-of-system (BOS) costs.

Key future success factors for downstream players:

- To develop targeted customer offerings,
- To minimize customer-acquisition and installation cost,
- To secure low cost financing.

3.3 PV business models

Until recently, the big energy utility companies have responded to the regulators who mainly provided help to the customers who wanted to purchase and own a PV system. Lately, the regulators are working very closely with the utilities in order to remove the barriers that hold back a more extensive PV deployment. Industry and the government are pivotally focusing on reducing administrative barriers by working closely with electricity companies to establish simplified interconnection standards and agreements (HM Treasury & DECC, 2010, p. 12). The role of the utilities, which has been very passive in the past, is now changing as PV is becoming a core business endeavour and concern as the PV electricity is becoming more competitive which increases the free competition in the market (Frantzis, Graham, Katofsky & Sawyer, 2008, p. vii).

Existing business models of PV power plants mainly revolve around the ownership of PV systems by individuals and increasingly by third parties, rather than by utilities (Frantzis, Graham, Katofsky & Sawyer, p. vii). At this point of market penetration, distributed and grid-connected PV is still not a main concern to most of the utilities. However, as the market share of the residential and commercial PV market, especially owned by the third parties will further increase, utilities will become critical stakeholders, driven primarily by concerns about grid operation, safety, and revenue erosion (Frantzis, Graham, Katofsky & Sawyer, 2008, p. vii).

The PV industry is moving away from the early approach in which the customer not only owned and financed the PV system, but also managed most aspects of installation. This approach is, according to Frantzis, Graham, Katofsky & Sawyer (2008, p. vii), referred to as the **Zero Generation PV business model**. Its attractiveness was very limited due to a relatively small group of so-called pioneers and enthusiasts who were committed to PV’s environmental, energy security, and self-generation benefits.

The PV industry has evolved to **1st Generation PV business model** in which the technology is more attractive and available to the broader market, mostly due to an existing government's support schemes which have encouraged the market development and emerging market of third parties solution providers, i.e. companies offering complete PV systems solutions as well as offering better access to financing, particularly important for industrial and commercial application. All these result in a bigger market uptake (Frantzis, Graham, Katofsky & Sawyer, 2008, p. viii).

The **2nd Generation business models** which is an evolving phase, is driving PV technology towards becoming a part of electricity supply and distribution infrastructure. 2nd Generation PV models are emerging in different variations – mainly evolving around ownership, operation and controls. In this phase, the big utilities are getting increasingly involved as the PV is becoming a more important electricity source, hence the PV products becoming increasingly commoditized.

3.4 Competitiveness of the PV Generator

The competitiveness of a PV generator is at the forefront of the grid-parity discussion. In order to find out at what stage of competitiveness PV generators are compared to the conventional generators, we need to analyse PV's generation costs in relation to its revenues, or in other words: **Dynamic grid parity** or/and compared to the generation cost of other electricity generators, or in other words: **Generation value competitiveness**.

The dynamic grid parity is defined as the point where, in a particular market segment in a specific country, the present value of the long-term net earnings (considering revenues, savings, cost and depreciation) of the electricity supply from a PV installation is equal to the long-term cost of receiving traditionally produced and supplied power over the grid (EPIA, 2011, p. 5).

Competitiveness of PV electricity for final consumers is defined as **dynamic grid parity**. Due to the different market conditions (different solar irradiance levels, market conditions in different market segments), dynamic grid parity will not happen simultaneously everywhere in Europe. Given the possible decline in generation cost, dynamic grid parity could be achieved as early as 2013 in Italy in the commercial segment and then spread all across the continent in the different market segments (EPIA, 2011, p. 5).

The generation value competitiveness is defined as the point where, in a specific country, adding PV to the generation portfolio becomes equally attractive from an investor's point of view to investing in a traditional and normally fossil-fuel based technology (EPIA, 2011, p. 5).

EPIA (2011) have based their assumptions on historical growth rates of the electricity prices as well as the PV equipment price movements. The bottom line is that the PV system prices are expected to halve in the next decade in all PV segments. Taking into account also the increase in technologies' efficiencies along with emerging economies of scale in increasingly developing markets, the PV will become cost competitive to conventional electricity sources before 2020.

The growth rate of PV competitiveness will however depend on the irradiation levels in certain geographical locations, electricity prices in those particular regions as well as the government's political commitment and support to development and maintaining sustainable regulatory frameworks and striving for the reduction of any market distortions.

The following part will focus on analysing the competitiveness factors from an end-user's, as well as from an investor's, point of view.

3.4.1 Levelized cost of electricity – LCOE

As already mentioned, LCOE is one of the main drivers and indicators that determines the feasibility of implementation and development of electricity generation projects. LCOE stands for "levelized cost of electricity" and is defined as a direct comparison to alternative energy production cost. This is usually expressed in currency/kWh. LCOE is the main calculation allowing us to measure and compare the cost of produced electricity by a conventional electricity generator and the renewable energy generator.

Campbell (2009, p. 140) defines LCOE as an analytical tool that can be used to compare alternative technologies when different scales of operation, investment or operating time periods exist. He defines the LCOE as a net present value of total life cycle cost of the project divided by quantity of energy produced over the system life.

Basic equation is as follows:

$$LCOE = \frac{CAPEX + NPV\ of\ total\ OPEX}{NPV\ of\ total\ EP} \tag{1}$$

Whereby:

- CAPEX stands for: Capital Expenditure i.e. investment costs of the project,
- OPEX stands for: Operations and Maintenance cost of the project,
- NPV stands for: Net Present Value,
- EP stands for: Electricity Production (in kWh).

3.4.1.1 Main drivers of LCOE

LCOE is a cover factor that consists of several components. Campbell (2009, p. 140) describes these components as “drivers” that determine and specify the PV power plant. He also stresses the impact that these drivers have on the PV power plant’s capacity factor.[8]

According to Campbell (2009, pp. 140–141), main inputs and drivers that determine LCOE are:

- Initial investment,
- Depreciation tax benefit,
- Annual cost,
- System residual value and
- System energy production.

Initial Investment. Initial investment represents and combines the total cost of a PV system along with the project and cost of construction financing.

The capital cost is mainly driven by:

a) Area-related costs that apply to the system size (PV module, mounting system, land, site preparation, field wiring and system protection).
b) Grid interconnection i.e. inverters, switching gears, transformers, interconnection relays and transmission upgrades.

[8] Capacity factor discussed in Chapter 3.4.2

c) Project-related costs i.e. general overheads, sales and marketing and site design (usually a fixed cost for certain-sized projects).

Depreciation tax benefit. Depreciation tax benefit is the present value of the depreciation tax benefit over a period of financed project's asset. Being allowed to be taken the depreciation tax benefit in the balance sheet as an accelerated depreciated asset, it significantly benefits the system's LCOE.

Annual costs. When calculating LCOE we also need to take into account the net present value of operation and maintenance throughout the life cycle of the PV power plant. These costs usually include inverter maintenance, PV module cleaning, site monitoring and insurance, land lease, financial reporting, overheads, field repair, data performance monitoring and additional reservations such as panel and inverter replacement, equipment replacement, etc.

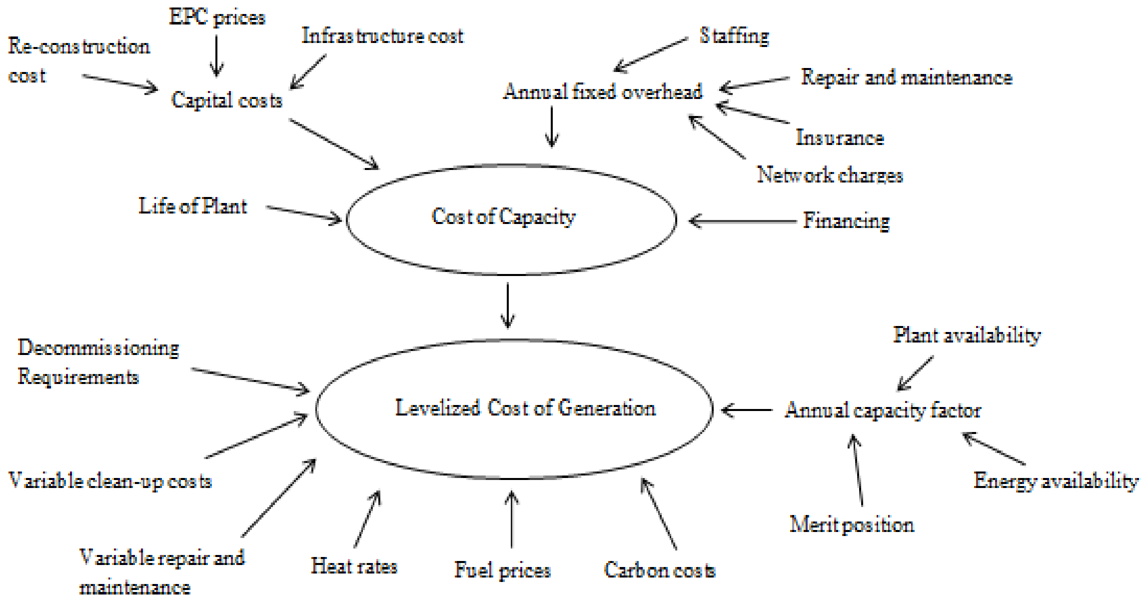
System residual value. The present value of the end-of-life asset value of PV power plant is deducted from the total life cycle cost in the LCOE calculation. As the life span of the solar photovoltaic modules is prolonging with the technology development, due to the financing models of 10 to 15 years, the residual value of the project can be significant.

System Energy production. The peak power output of a PV Power plant is usually determined by its DC – nominal power output expressed in kWh/kWp. The system's energy production rate is calculated based on its first year of electricity generation, which depends on the following factors:

- The amount of sunlight that the PV system receives in a geographical area where installed,
- The orientation and tilt of the PV mounting (south-facing, fixed tilt),
- Spacing between the PV modules expressed in the ratio of ground system coverage (GSC),
- System losses from soiling, inverters, cabling, etc.

Another important factor needed to be taken into account when defining the PV system's power output is the degradation rate. All systems degrade in performance by a rate of 0.2–0.5% annually. However, this depends on the quality of the solar module and other equipment. This is an important notion that needs to be considered and included in the future performance/cash flow estimations. The length of the project financed period significantly affects the finance cash flows and, of course, the system's residual value.

Figure 6. Drivers of levelized cost of generation



Source: Mott MacDonald, *Electricity Generation Costs Update: June 2010*, 2010, p. 3, Figure 2.1.

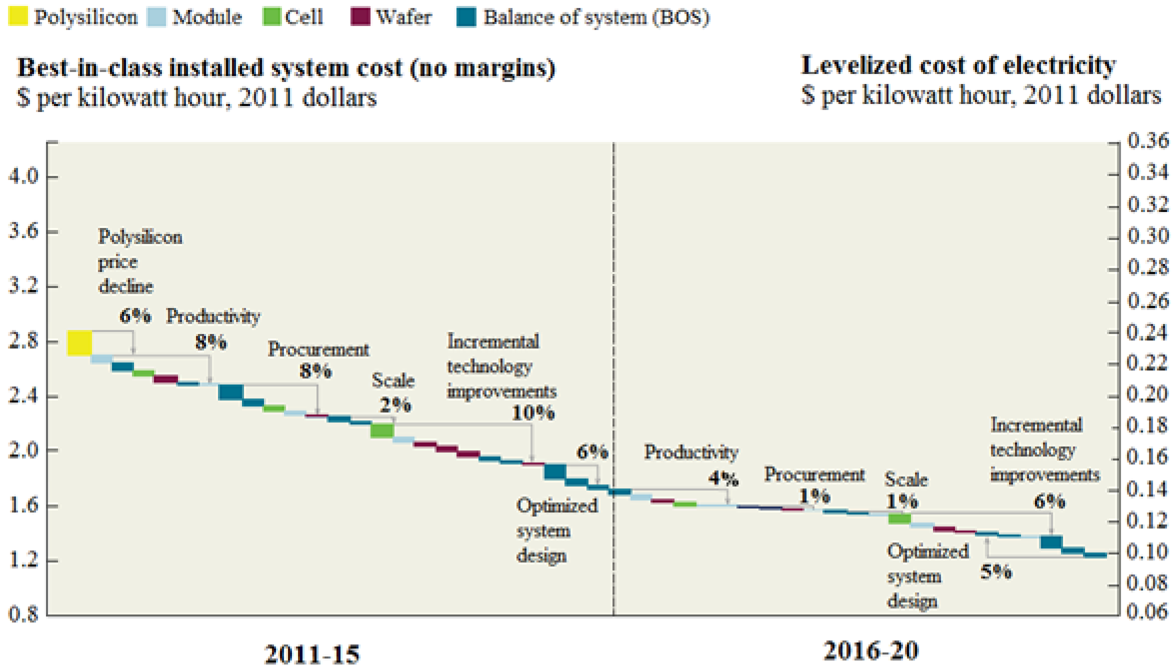
3.4.1.2 Expected future movements of LCOE

The future LCOE movements are a result of competitive hardware prices (modules, inverters, structural components) as well as competitive project development prices (including the margins for installers) of Project developers.

Graphs below show the generation costs assuming mature market prices, considering the global, European and UK environment. This will give us a good-enough benchmark to help us position the UK within the global PV development market.

- McKinsey & Co. (Aanesen, Heck and Pinner, 2012, p. 6) came up with the following chart which predicts a trend of LCOE movement of the photovoltaic power plant, globally, dropping from £0.164/kWh to about £0.063/kWh by 2020 which presents ca. 61% reduction.

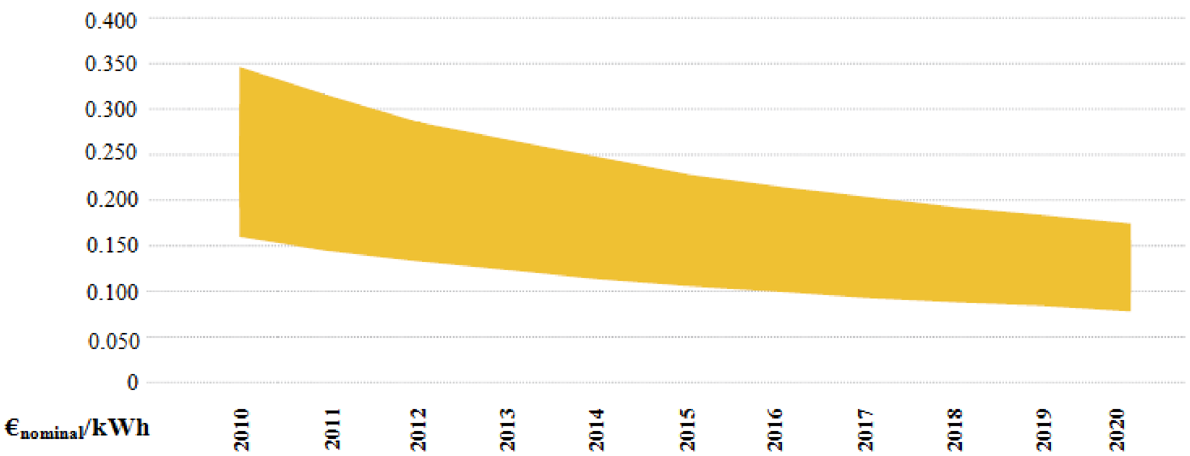
Figure 7. Projection of LCOE movement of PV globally from 2011–2020



Source: Aanesen, Heck and Pinner, *Darkest before dawn, McKinsey on Sustainability & Resource Productivity*, 2012, p. 4

- EPIA (2011, p. 1) predicts the European LCOE cost to drop from £0.192/kWh to about £0.064/kWh by 2020 which presents ca. 67% reduction.

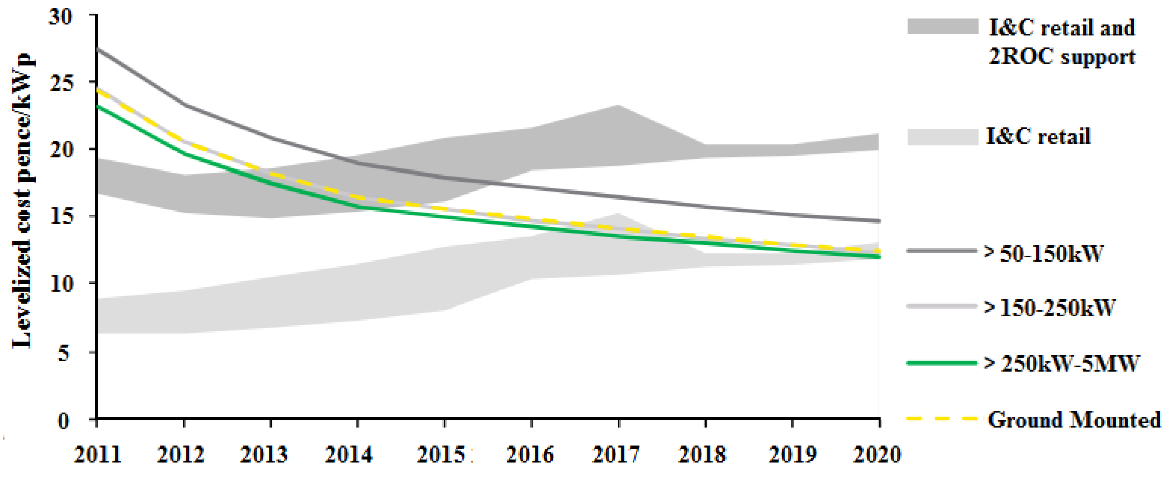
Figure 8. Projection of LCOE movement of PV in Europe from 2010–2020



Source: EPIA, *Competing in the energy sector – On the road to competitiveness*, 2011, p. 1, Figure 7.

- Ernst & Young UK (2011, p. 4) predict the LCOE in the UK cost to drop from £0.145/kWh to about £0.076/kWh by 2020 which presents ca. 48% reduction.

Figure 9. Projection of LCOE movement of PV in the UK from 2011–2020



Source: Ernst & Young UK, *Solar PV Industry Outlook. The UK 50kW to 5MW Solar PV Market*, 2011, p. 4.

As seen from the above charts, there is a stagnant more than 50% decrease in LCOE expected in all market segments throughout the EU and the UK by the end of the decade. However the areas with higher irradiation levels are the driving factor for lower generation cost, these figures show that the substantial decrease in LCOE can be achieved also in counties with lower irradiation levels, as the UK.

3.4.2 Capacity factor

Capacity factor is another indicator allowing us to measure the power output of a photovoltaic power plant. Capacity factor represents the ratio of the actual output of a power plant over a period of time and its potential output if it had operated at full capacity the entire time (Campbell, 2009, p. 142). This methodology is especially important for utilities in the energy sector as it enables them to measure the energy productivity of assets and is a leading method for assessing the power output for economical and finance modelling. The capacity factor's economic impact is substantial.

Net capacitor factor (AC power output after inverter, cabling losses and power plant own consumption) also enables us to calculate the LCOE of the electricity production for a particular type of generator.

The equation is as follows:

$$\textit{Net Capacity Factor (NCF)} = \frac{\textit{Net actual generation}}{\textit{Period hours x Net maximum Capacity x 100\%}} \qquad (2)$$

A PV power plant's net capacity factor is the function of the generator's most important properties as listed below (Campbell, 2009, p. 142):

- Insulation (irradiation) of the geographical location where the PV power plant is located,
- Performance traits of the PV modules,
- The orientation of the array (azimuth),
- System electrical efficiency,
- Availability to produce the power.

Capacity factor substantially contributes to the LCOE of the project. Financial calculation is most often based on the power plant's AC rating that means the kWh/kWp calculation is an AC output of the PV power plant (including all the losses caused by equipment and cabling), not the DC output.

The decline in capacity factor always needs to be in line with the prices of the equipment in order to generate sustainable and good enough returns to make the investment worthwhile.

There are several ways of improving the capacity factor of a PV power plant. One way is to utilize a tracking system, which maximises the PV system's power output by tracking the sun's movement. Therefore the PV system produces more electricity at all times during the day, which is especially important for covering the peak demands for electricity. The difference the tacking system brings in return to a PV power plant is substantial. However, due to the high set-up and maintenance cost, this type of application only comes into considerations in the geographical areas with high irradiation levels and high electricity costs. PV power plants with the tracker system can produce up to 30% more electricity on an annual basis as opposed to a fixed tilt PV power plant. That means a 38% and 24% capacity factor, respectively.

LCOE assigns more or less equal value to the electricity generated throughout the day, however we have to note that the peak electricity is the most valuable to the utilities.

There are several important notions needed to be discussed in relation to the capacity factor:

Land use. In most cases the land intended for large-scale PV power plants is rather useless, hence having little economic value and therefore low priced. Due to increasing demand for PV projects the prices of land of this type have started to rise drastically.

When it comes to the land usage in relation to the LCOE of the PV project there are two points we need to point out:

- Solar panel efficiency.

- Ground Coverage Ratio (GCR).

The efficiency of solar panels has already been discussed in previous chapters. This point highlights the importance of a panel's efficiency as it, in effect, determines the PV plant's ground coverage area.

Ground coverage ratio (hereafter referred to as "GCR") represents the PV array-to-land area ratio, in other words the percentage of land covered by PV array(s). For instance, a flat mounted PV system would maximise the land area but due to its lower capacity factor (result of lower output due to a non-optimal angle) would lower the overall PV system efficiency and subsequently cause an increase of LCOE. On the other hand, angled PV arrays have lower GCR, but due to a higher output (optimum angle) the capacity factor is appropriately higher, hence LCOE is lower.

In order to maximise the capacity factor and therefore lower the LCOE, there must be an optimal balance between the land size and system GCR (Campbell, 2009, p. 143). The latter also argues that by installing high-efficiency PV modules, we can reduce the size of the land needed by ca. 75%, and by installing the tracking system we can increase the capacity factor on the same sized land area by ca. 30%. However, this percentage does not really reflect the real market situation. Although the higher generation numbers and increased capacity factor talks in favour of a PV power plant on trackers, there is still a great on-going debate regarding cost-efficiency of the latter. Due to its high capital cost and rather low incremental increase in medium to low insulation geographical areas, the PV tracker is a viable solution only in high insulation areas (Campbell, 2009, p. 143).

Environmental Conditions. Irradiation levels, i.e. the amount of sun that panels can receive at a particular geographic location is, apart from the temperature and other weather conditions, the first decisive factor that affects the PV power plant's capacity. For instance, the desert's climate in Northern Africa can deliver almost double the irradiation levels than sites in Northern Europe. But usually higher insulation levels are most commonly related to higher temperatures, which has a negative effect on performance of photovoltaic technologies.

Operation and Maintenance. Compared to the conventional electricity generators, the operation and maintenance (hereafter referred to as "O&M") costs are relatively low due to the few moving parts in the generator (inverter) and no cooling system is required. According to Campbell (2008, p. 16) O&M costs generally scale with three factors:

- system peak power dominated by inverter maintenance,
- system annual energy production density,
- general site related items.

O&M costs can be lowered by increasing the capacity factor, i.e. through higher utilization of fixed assists (Campbell, 2009, p. 17). As already discussed above, a good example would be a tracker system with 30% higher capacity factor on the same surface area and only slightly more inverters than the fixed tilt PV modules. This brings a significant decrease to the percentage of the O&M cost in the overall investment cost.

To apply this notion to the fixed tilt system; increasing the capacity factor and reducing the O&M costs would mean utilizing higher performing modules as opposed to the lower performing modules at a lower cost. Significant costs apply also to the inverters and switchgears maintenance/ replacement.

Maximizing the capacity factor is essential in order to keep the LCOE as low as possible. For achieving that, the best proven performance PV technology is at this point the crystalline silicon technology with its life span of more than 30 years. However, the quality of the equipment is of paramount importance. To increase the capacity factor and lower the LCOE of the PV project there it is essential to source the most efficient panels with a low heat dissipation rate and long term durability. Due to the fact that the module's power output decreases by about 0.5% at every degree above the optimum 25ºC, we must realise that the only way to mitigate these losses is by choosing the highest quality components. The fast evolving PV industry is intensively working on increasing the efficiencies of the panels which is, along with the price decrease, rapidly steering the PV's LCOE "dangerously" close to the conventional energy generators.

3.5 Government's support schemes for PV generation

The UK Government has committed to legally binding targets in order to cut the greenhouse gas emissions in the UK by 80 % by 2050, which requires the electricity sector to largely decarbonise.

The UK, as a member of the European Union, is obliged to comply with the requirements of the new adopted and integrated climate and energy policy, which are setting the following goals planned to be achieved by 2020 by all European members (HM Treasury & DECC, 2010, p. 45):

- To reduce the greenhouse emissions unilaterally by 20% from 1990 levels,
- To ensure the renewable energy presents 20% share of all energy use, this applies to as much as 35% of electricity consumption,
- To reduce overall energy consumption by 20%.

The first two of these policies were detailed and endorsed by the European Parliament in 2008 and are now binding for all EU-member states being referred to as a “20/20/20” goals. They are underpinned by a broader EU policy rationale to:

- Promote environmental sustainability and tackle climate change,
- Increase security of energy supply,
- Support the EU economic competitiveness and the availability of affordable energy.

Throughout Europe these requirements are being implemented through different government support schemes, promoted under different names and various approaches. In the UK this was introduced as a “Feed-in-tariff scheme”.

3.5.1 Feed-in tariff scheme

The “Feed-in-tariff scheme” for renewable generators is currently the main support scheme in the UK, launched with the intention of compensating the difference in cost of electricity produced from the photovoltaic generator (or any other renewable generator) and the electricity produced from the conventional energy sources (occurred cost is later on transferred to electricity providers and consequentially to end users). In other words, feed-in-tariffs are a “boost” that helps the PV technology/industry to penetrate the market with the intention to reaching the stage where it will be able to compete for the market share with the conventional energy sources.

The feed-in-tariff scheme applies to most domestic PV systems and larger systems up to 5 MW in size that qualify for the scheme, as well as:

- Wind generators,
- Hydroelectricity generators,
- Anaerobic digesters,
- Micro combined heat and power plants (CHP).

Energy Saving Trust (2012) stresses the main principles of the feed-in tariff scheme:

- The electricity supplier pays the owner of a PV system for each unit of electricity it generates.
- The PV system owner can use the electricity generated which means no need to import it from the grid.
- The PV system owner exports the electricity back to the grid when it is not used and gets paid an export tariff.
- Electricity is imported from the grid only when additional is needed.

The feed-in-tariff payments are made by the UK “Big Six” energy suppliers, which are legally obliged by law to provide these payments to the energy producers. This cost is eventually transferred to the end users reflecting in the eventually higher electricity bill.

As soon as technology starts gaining its market share, this causes an increase of competition within the segment and eventually leads to the faster technology evolvement as well as the price decrease. As the gap between the renewable and the conventional generators is narrowing, the generation cost of electricity starts to decrease, therefore PV technology is progressively becoming less reliant on support schemes which will eventually lead to gradually phasing out this sort of incentives.

The speed of the PV industry approaching grid parity point very much depends on the external effects, i.e. government policies, economic conditions, which both determine the level of competition and therefore the scale of the push for technology evolvement and market growth. Once we achieve the PV competitiveness this won’t necessarily mean that all incentives will cease to exist. There will be a constant regulative support needed in order to preserve a reasonable balance of PV generation technology which will be vital for the UK Energy market (EPIA, 2011, p. 6).

PV is, within the renewable energy segment, the most perspective technology and will play an essential role in achieving the main goals the EU has set out, in order to guarantee the security of a safe and local energy supply. Ensuring the continuous growth of the photovoltaic segment is of the essence. In order to make this technology competitive enough, an appropriate regulatory framework is needed. This will allow the creation of a sustainable UK renewable industry with a promising future and therefore a significant potential to contribute to the global and local energy generation mix.

3.5.2 Other renewable schemes

Apart from the FIT tariff scheme, which is at this moment the paramount support scheme for alternative generators, there are also other schemes available.

3.5.2.1 Renewable Heat Incentive

The Renewable Heat Incentive scheme is quite similar to the Feed-in-tariff scheme. However, it only applies to the solar thermal technologies.

The concept is fairly similar with some exceptions:

- RHI Scheme is paid for by the UK Treasury not by energy users.
- There is no option of importing and exporting heat as is the case with the electricity.

3.5.2.2 Renewable Obligation Certificate scheme (ROCs)

Renewable Obligation Scheme (hereafter referred to as the "ROCs") is intended for larger PV electricity Generators. Usually, in cases where you produce larger amounts of electricity (for export i.e. sales purposes) ROCs can be a more cost-effective option.

For every MWh of produced electricity, a large scale PV generator sells under the ROC scheme, it receives:

- 2 x ROC units[9] (Renewables Obligation Certificate) for every MWh of clean energy produced, which then the owner of a PV generator sells to the electricity suppliers.
- Embedded benefits – usually as the generator's energy goes to local consumers, generators get more for reducing the transmission costs.

The downside of the ROCs scheme is the low level of income security. The main reason for this is the so-called "quota system", where prices for ROCs fluctuate depending on electricity supplier demand and supply. Therefore, potential investors must accept the risk of volatile ROCs prices.

3.5.2.3 The Green Deal

The Green Deal is an initiative triggered by the UK government. Its main purpose is to accelerate the uptake of renewable technologies amongst end-consumers as well as businesses. The main concept of the scheme is to provide green technologies with no upfront cost and allow the consumers to payback the investment through the electricity bill. The main advantage of this scheme is that the electricity bill will not work as a load but it will apply to the current owner of the property where the system is installed. The "golden rule" of the Green Deal is, however, that the financial savings coming from the green deal investment will need to be at least equal to or greater than the costs attached to the energy bill. The Government will attract private companies to participate in different segments of the initiative.

3.5.2.4 Green Investment Bank

The Green Investment Bank is one of the UK government's policies designed to help meet environmental objectives and promote economic growth in UK. Its main purpose is to provide financial solutions in order to accelerate the private sector's investment in the green economy.

With a budget of ca. £3 billion, it definitely plays an important role as a green investment development institution. It also helps address the market failures affecting green infrastructure projects in order to stimulate a step-up in private investment. It has a deep

[9] November, 2012.

expertise in financial markets and green investments, working towards achieving significant green impact and making satisfying financial returns.

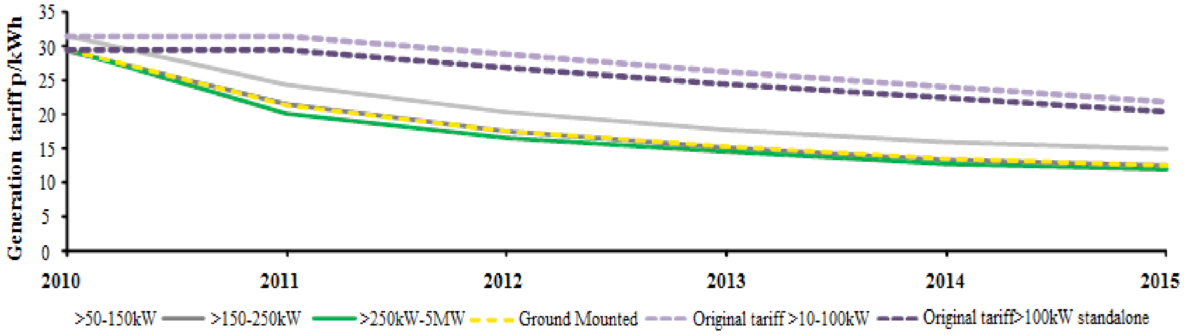
3.5.3 Future support levels

As we know the support levels for the PV generators are gradually decreasing due to

a) A rapid growth of PV industry and consequently the price decrease.
b) The Government's budgetary constraints.

The graph below shows the required trend of dropping tariffs in order to keep the pre- tax returns above 5 % (Ernst & Young UK, 2011, p. 15). This graph, however considers the export tariff to stay at the initial level of 3%. Since 2011 when the study was made, the support levels have been reviewed.

Figure 10. Predicted levels of support for the UK market (2011)



Source: Ernst & Young UK, *Solar PV Industry Outlook. The UK 50kW to 5MW Solar PV Market*, 2011, p. 15.

In 2012, the UK government established a more sustainable feed-in-tariff degression system which predicts a decrease of 3.5% every quarter if the installation volumes have reached an expected level of deployment. The scale of degression (between 0 to 3.5%) depends on the total deployment of PV systems within the certain tariff band during the three-month period ending four months before the degression rate.

This is definitely a more transparent and sustainable model which allows building firmer and more realistic business models and the time scale for their implementation. This will also serve me as a good basis for calculating the predicted returns of analysed PV and coal-fired generators.

3.6 Contribution of PV to the development of the UK energy market

The growing PV sector in the UK has come to a point where it already employs over 15,000 people and contributes significantly to the growth of the private sector as the number of registered solar PV companies has risen to 5,500 (UK Trade & Investment, 2012, p. 10).

Further shifts in employment rate are to be expected within the next 5 years in order to achieve UK renewable energy targets. There is also a very important notion to be considered when discussing the PV's contribution to the economy growth; Gross Value Added (GVA)[10] reflected in cost of carbon saved, income and corporation tax revenues and inbound investment opportunities by creating the new perspective markets and opportunities for product manufacturing.

The development of the PV market in Great Britain has brought many new players to the market, attracted some from abroad as well as encouraged existing companies to expand and diversify to the PV segment. This is creating a more competitive environment, not only in the PV segment but throughout the whole energy market. As the PV technology is considered as a fairly passive asset (Ernst & Young UK, 2011, p. 13), it is perceived as an attractive and low risk investment for asset-rich big energy utility companies. These have already started to modify their business plans by considering investment into large-scale PV generators, in order to respond to insecure and extremely competitive market conditions as well as at the same time tackling the environmental issues by lowering the carbon emissions and contributing a great deal to decarbonise their economies. For a sustainable and secure growth as well as attracting more capital in this segment, a stability of the existing support schemes is essential as it greatly affects the investment confidence.

An important role in the future uptake of PV will definitely present the availability of financial resources as well as innovativeness of financiers when offering financing of renewable projects. As PV is becoming considered as a low risk investment, financiers see it as a secure investment with attractive returns. However, for further uptake, there will also be significant investments required for new energy infrastructure that will enable the future growth of the PV industry.

Due to an increasing demand for electricity production, utility managers and power plant developers are the key decision makers in assessing the need for electricity generators (Berry, 2008, p. 5). In the past the conventional generators have been the main choice of electricity generators, but nowadays there are many technologies arising being significantly less raw material-intensive, equally more cost efficient and more sustainable than ever.

To showcase how the PV Industry will look like in the future and how close to the conventional fossil-fuels based generators it already is today, I will stress-out the following facts.

There are two main ways of comparing renewable and fossil-fuel energy:

1. The trend in installed power capacity,

[10] GVA measures the contribution to the economy of each individual producer, industry or sector in the United Kingdom (Guide to GrossValue Added- GVA, 2013)

2. Electricity generated.

Renewable power capacities (excluding hydro technologies) reached approximately 8 % of all installed electricity capacities in 2010. This was an increase from:

- 7% in 2009,
- 6% in 2008 and
- 5% in 2007.

In numbers, this would mean ca. 60 GW of new renewable capacities (excluding hydro technologies) added worldwide in 2010 (34% of the total installed electricity generation capacities), compared to 92 GW for conventional thermal (gas, oil), 5GW for nuclear and 24 GW for hydroelectric. All renewable capacities combined together accounted for almost 84 GW out of 180 GW (47%) of all net power additions in all technologies worldwide (McCrone et al., 2011, p. 25).

The above mentioned report shows that percentage of power generated from renewable generators globally rose to 5.4% in 2010, from 4.7% in 2009 and 4% in 2008. That presented 34.2% of overall capacity added worldwide in 2010 but smaller proportion of the total additional generation (McCrone et al., 2011, p. 25).

According to McCrone et al. (2011, p. 26), with the 954 TW added in 2010, we could meet the electricity demand of two Brazils or one India.

The total of £117 billion of asset finance invested in 2010 for renewable projects is very close to comparable capital spending in a new fossil fuel plants which amounted to £137 billion. This is a notably fast growth of investment in renewable low-carbon generators but it has still quite a lot to catch up. An important factor that also needs to be analysed is the net investment in fossil fuel plant as there is quite a significant portion of annual investment intended for replacing the plants that were decommissioned. Therefore realistically comparable net addition of fossil fuel capacities (as opposed to the gross addition) has amounted to 92 GW (128 GW gross), in capital terms that amounts to £98 billion, which is less that the net investments in renewable low-carbon generators.

Renewables are on the right way to shift the fossil-fuel investments to a different level. We also have to note that fossil-fuel investments include the up-stream activities (opening the coal mines, conventional and shale gas reserves), which brings the total investment to a whopping £293 billion mark (McCrone et al., 2011, p. 26). That puts renewables investments at only one sixth of the total investments in all energy sectors (£748 billion in 2010).

Investment in renewables today still presents a rather small percentage in comparison to all economic aggregates (£131 bio). This presented only 0.3% of the whole world's Gross Domestic Product (GDP) or 1.5% of the whole world's investment. Comparing the investment in renewables to investment in OECD Countries'[11] oil imports in 2010, those accounted only as one fourth of that (McCrone et al., 2011, p. 27).

If we have a look at the Global 500 League Table a list of 500 of the world's biggest companies by market capitalisation, we will struggle to find a company specialising in renewable technologies (apart from Iberdrola Renovables and some renewable energy divisions of utility companies such as Siemens, Eon, PetroChina). There are three main reasons for that (McCrone et al., 2011, p. 27).

1. The sector as a whole is out-of-favour with market investors and prices of shares were/are not in pace with the other market indices in 2010.
2. It is an extremely competitive sector where there is little room for high profit margins (unlike oil, internet, etc.).
3. The sector remains relatively un-concentrated (companies from EU, US and China are competing to hit the top 10 on the list of the biggest wind technology manufacturers). PV manufacturers are even more dispersed than the wind manufacturers.

4 PV vs. CONVENTIONAL ELECTRICITY GENERATOR

As presented in the theoretical part, the renewables sector is increasingly approaching the conventional electricity generation sector in terms of cost competitiveness and performance, even more in its accessibility for financing. The Government's backing and support to the renewable sector started to eventually reflect in lowering costs, increasing efficiencies, and outputs and, very importantly, increased willingness of the financiers to finance the solar PV projects due to its attractive returns, lowered risks relating to the project's life time operation and improved performance predictability.

Despite the fact that the UK does not receive the same amount of sun as the more southern countries, it is indeed a very prospective market where photovoltaic can prosper. If we just take Germany as an example, a country with similar climate/irradiation conditions, it is considered to be the most advanced PV market in the world.

Taking into account the on-going increase of electricity prices and gas supply insecurity in the UK, as well as the inability of existing electricity generation capacities to meet the peak load demands due to its high cost of operation at that time, peak load gap presents an immense opportunity for PV generators to enter a utility-electricity generation market and compete with small to mid-scale coal and gas-fired generators.

[11] 34 member countries (*List of OECD member countries*, 2013).

All this applies to the United Kingdom, which is, through adopting a rather strict EU environmental legislation, creating an encouraging environment for renewable technology to develop. In addition, they have started to penalize high carbon pollutants through carbon taxation, emissions trading ("cap-and-trade") system[12], as well as subsidizing other, low carbon generators.

The majority of renewable technologies are still, however, immature, although their capital costs are expected to decline over the next decade. We are already witnessing a strong trend of cost decrease in the PV sector, which will soon be in a good position to become a mainstream electricity generator.

I will highlight an overall feasibility of photovoltaic projects of different scales at residential, commercial and utility level. For the first two I intend to find out at what stage of approaching the dynamic grid parity are currently in. In other words, I will prove at which point the present value of the long-term net earnings (considering costs, performance and savings) of the electricity supplied from a residential and commercial PV power plant is compared to the cost of buying electricity from the grid (produced by conventional electricity generators).

By comparing the utility scale PV and the utility scale coal-fired power plant (with carbon capture and storage technology, as this is a regulatory demand for all OECD countries), I will hereby try to showcase at what point a PV power generator is at in terms of attractiveness from an investor's point of view for investment purposes. I will try to conclude whether is it already equally or even more sensible to invest in PV technology instead of a traditional fossil-fuel based technology, in this case a coal-fired power plant.

Table 2. PV competitiveness analysis- Overview

PHOTOVOLTAIC POWER PLANT- RESIDENTIAL	
Projected costs Projected output Electricity prices- retail level	**LCOE- Dynamic grid parity**
PHOTOVOLTAIC POWER PLANT- COMMERCIAL	
Projected costs Projected output Electricity prices- wholesale level	**LCOE- Dynamic grid parity**

(table continues)

[12] The cap-and-trade is a policy mechanism for managing and reducing industrial greenhouse gas (GHG) emissions (IEA, 2008, p.6).

(continued)

PHOTOVOLTAIC POWER PLANT- UTILITY-SCALE	**LCOE- Generation value competitiveness**
Projected costs Projected output	
COAL-FIRED POWER PLANT	**LCOE- Generation value competitiveness**
Projected costs Projected output Fuel and carbon cost	

4.1 Purpose and methodology of the analysis

I intend to undertake a comparison of project financial plans of a conventional and a photovoltaic generator. This will allow me to analyze and compare the capital investment cost and revenue streams which will allow me to calculate the LCOE and therefore position the PV generator on the PV competitiveness curve towards a conventional electricity generator. In addition, I will also take into account an important factor of risk.

4.2 PV power plant: Financial plan

My intention here is to undertake an in-depth analysis of comparable-sized PV generators in order to realistically showcase the current situation with regards to the electricity generation cost from a PV generator. In order to do this, I have classified the system according to its size into the below three categories:

- Residential PV power plant.
- Commercial and industrial PV power plant.
- Utility-scale PV power plant.

4.2.1 Residential PV power plant

A residential PV power plant is a small sized system usually installed on domestic premises. The modules are mounted onto the roof of the home for direct exposure to the sun light. The system size and its generation capacity usually reflect the annual electricity requirements of the household. In the UK, an average household consumes ca. 3,300kWh annually (OFGEM, 2011, p. 2), which is in effect the amount of electricity that a 4 kW system produces throughout the year. However, due to the production inconsistencies, i.e. the majority of electricity is generated during the day when the majority of electricity is not needed, it is therefore exported. The feed-in tariff in the UK breaks down the system sizes to different sizes; up to 4kWp, up to 10kWp, up to 50kWp, up to 100 kWp, up to 150 kWp, up to 250 kWp and up to 5MWp.

Tables 3 and 4 outline the financial calculation of a 4kWp-sized residential PV system. The calculation includes the initial capital cost, O&M costs, financing costs as well as the support levels for each unit of produced electricity. The project calculation will serve as a basis for the further analysis of revenue streams and the LCOE. We will compare the latter with the retail electricity prices today, as well as trying to find out the future movements of both, indicating the progress of residential PV towards the grid parity point.

Table 3. Project definition – Residential PV power plant

Project Definition	**4 kWp system**
General Information	Roof-mounted
Useful life (years)	35
Nominal power (kWp)	4
Annual Yield per kWp(kWh/kWp)	900
Degradation (%/year)	0.2
Feed-in tariff (£/kWp)	0.1544
Years	20
Installed system price (£ per kWh)	1600
Index linked	yes
Own consumption (kWh/year)	1800
Electricity price now (per kWh)	0.12
Energy Price Inflation (%/year)	3
Financing (%)	80
Own funds (%)	20

Table 4. Project summary and LCOE results- Residential PV power plant

Project Summary	
Nominal power (kWp)	4
Purchase value (GBP)	6,400.00
Own Funds (GBP)	1,280.00
Loan amount (GBP)	5,120.00
Present value of net income (GBP)	5,986.00
IRR [13](%)	19.2
WACC[14] (%)	6
Levelized energy cost (GBP/kWh)	**0.138**

Note. * Present value of net income: Present value of cash flows, i.e. the sum of discounted net income
– Loan (years) – 15

Source: Author and *PVCalc – The Return (ROI) Calculator for PV solar energy projects*, 2013.

[13] IRR (Internal rate of return) is a discount rate often used in capital budgeting. It presents the rate of growth a project is expected to generate (*Internal rate of return,* Investopedia, 2013).
[14] WACC (Weighted average cost of capital) is the average of the costs of sources of financing, each of which is weighted by its respective use in the given situation. WACC showes us how much interest the investor has to pay for every pound it finance (*Weighted average cost of capital- WACC,* Investopedia, *2013)*

4.2.2 Commercial and Industrial PV power plant

Commercial buildings like offices, production facilities, schools, clinics, community halls, hospitals etc. can also benefit from photovoltaics.

The industrial sector is another segment for PV application, in cases where smaller kW energy is required (TV and radio station, broadcasting towers, radio telephones). This applies also to the space industry (satellites), transportation signaling system (traffic signals, navigation systems, light houses in oceans, runway lights on airports, etc.). Other industrial applications where solar power is used are environmental, situation equipment and protection systems for well heads, bridges pipelines etc. In such applications where electricity load is high, solar power can prove cost effective by configure hybrid electric power systems, that joints photovoltaic solar power system with small generators that operates on fuel or natural gas.

My intention is to focus on the commercial scale applications i.e. system sized from 250kW–5MW which can in the UK generate substantial amounts of electricity, particularly needed in industrial premises, business buildings, production facilities, factories. The reason to emphasize this size and type of application is due to its nature of electricity consumption. Unlike residential systems, commercial systems provide electricity to entities during the time when it is most needed; therefore its return of investment is the highest. However, due to the lower cost of electricity for commercial purposes, the commercial PV applications are expected to reach the grid parity at the same time or later than residential system where the cost of transmission and grid maintenance costs are higher.

Tables 5 and 6 outline the financial calculation of a 1MWp-sized commercial PV system. The calculation includes the initial capital cost, O&M costs, financing costs as well as the support levels for each unit of produced electricity. The project calculation will serve as a basis for the further analysis of revenue streams and the LCOE. We will compare the latter with the wholesale electricity prices today, as well as trying to find out the future movements of both, indicating the progress of commercial PV towards the grid parity point.

Table 5. Project definition – Commercial PV power plant

Project Definition	**1 MWp system**
General Information	Roof-mounted
Useful life (years)	35
Nominal power (kWp)	1,000.00
Annual Yield per kWp (kWh/kWp)	900
Degradation (%/year)	0.2
Feed-in tariff (£/kWp)	0.071

(table continues)

(continued)

Project Definition	1 MWp system
Years	20
Installed system price (£ per kWh)	1,000.00
Index linked	yes
Own consumption (kWh/year)	720,000.00
Electricity price now (per kWh)	0.08
Energy Price Inflation (%/year)	3
Lease (GBP/year)	0
Insurance prem. (%)	0.5
Maintenance (%)	1.5
Inflation rate (%/year)	2
Financing (%)	80
Own funds (%)	20

Table 6. Project summary and LCOE results – Commercial PV power plant

Project Summary	
Nominal power (kWp)	1,000.00
Purchase value (GBP)	950,000.00
Own Funds (GBP)	190,000.00
Loan amount (GBP)	760,000.00
Present value of net income (GBP)	969,276.00
IRR (%)	18.3
WACC (%)	6
Levelized energy cost (GBP/kWh)	**0.087**

Note. * Present value of net income. Present value of cash flows, i.e. the sum of discounted net income
– Loan (years) – 12

Source: Author and *PVCalc – The Return (ROI) Calculator for PV solar energy projects*, 2013.

4.2.3 Utility-scale PV power plant

A utility scale photovoltaic power plant is also known as a photovoltaic solar park. This large-scale PV system is specifically designed and built for the supply of an investor's (merchant) electricity into the electricity grid. They are differentiated from most building mounted and other decentralized solar power applications because they supply power at utility level, rather than to a local user or users.

These sized systems are also referred to as solar farms, especially if installed in agricultural areas.

The purpose of analyzing the financial plan of large scale PV power plant is to acquire information about the capital cost, operational and maintenance costs, and most importantly find out the cost of electricity generation though time and try to find out when the electricity from this type of generator will be competitive to a conventional (coal-fired generator) with no subsidies, unlike the residential and commercial systems in whom calculation the government's incentives are included. The main difference of LCOE analysis between above two (residential and commercial generators) and the utility scale is that the cost of the electricity generation of the first two generators are compared to market electricity prices whereas the costs of utility scale electricity generator are compared to the generation cost of the coal-fired generator.

Tables 7 and 8 outline the financial calculation of a 359MWp-sized utility-scale PV system. The calculation includes the initial capital cost, O&M costs, financing costs as well as the export electricity price for each unit of produced electricity. The project calculation will serve as a basis for the further analysis of revenue streams and the LCOE. We will compare the latter with the cost of electricity produced by a comparable-sized coal-fired power generator. The LCOE calculation will allow us to find at what level of cost competitiveness the large-scale PV generator actually is at the moment, as well as allowing us to find out the future progress of utility-scale PV generator towards the conventional powered generator.

Table 7. Project definition – Utility-scale PV power plant

Project Definition	**359 MWp system**
General Information	Ground-mounted
Useful life (years)	35
Nominal power (kWp)	359,000.00
Annual Yield per kWp(kWh/kWp)	950
Degradation (%/year)	0.2
Feed- in tariff (£/kWp)	0
Years	35
Installed system price (£ per kWh)	850
Index linked	yes
Own consumption (kWh/year)	0
Electricity price now (£/kWh)	0.06
Export price of Electricity (£/kWh)	0.076
Energy Price Inflation (%/year)	3
Lease (£/year)	1,000,000.00
Insurance prem. (%)	0.5
Maintenance (%)	1.5
Financing (%)	80
Own funds (%)	20

Note. * Other additional costs included in the "Installed system price":

- **LEC's –** Electricity produced from designated renewable sources is exempt from the Climate Change Levy and is entitled to Levy Exemption Certificates (LECs) which can be bundled with the power when sold to a supplier.
- **GDUoS –** (Generation Distribution Use of System) charges are applied by your Distribution Network Operator (DNO) for the export power you have generated that is connected to their network. This may also include credits for the kWh you have generated.

Table 8. Project summary and LCOE results – Utility-scale PV power plant

Project Summary	
Nominal power (kWp)	359,000,000.00
Purchase value (GBP)	305,150,000.00
Own Funds (GBP)	61,030,000.00
Loan amount (GBP)	244,120,000.00
Present value of net income (GBP)	118,235,747.00
IRR (%)	9.6
WACC (%)	6
Levelized energy cost (GBP/kWh)	**0.079**

Note. * Present value of net income: Present value of cash flows, i.e. the sum of discounted net income
– Loan (years) – 25

Source: Author and *PVCalc – The Return (ROI) Calculator for PV solar energy projects*, 2013.

In this case, the PV project financial plan is solely based on the electricity export price, agreed in the PPA agreement. However there is an alternative support scheme available to large scale projects:

- **ROCs –** Renewables Obligation Certificates[15] are issued by the Authority to operators of accredited renewable generating stations for the eligible renewable electricity they generate. Operators can then trade the ROC with other parties, with the ROC ultimately being used by suppliers to demonstrate that they have met their obligation (OFGEM – Renewable Obligation explained, 2013).

4.3 Coal-fired power plant: Financial plan

In 2010, the total installed capacities of coal-fired generating technologies amounted to 29 GW (Kwok & Fineren, 2009). By 2016, these capacities are expected to increase by ca. 3.3GW (4%) to cumulatively more than 32GW in total. This statement was made in 2010

[15] Described in Chapter 3.5.2.2

and is definitely expected to change due to an increase in the competitiveness of alternative (renewable) generators, particularly photovoltaics.

The main reason for a successful uptake of coal-based electricity generators was in the coal's price competitiveness (in the absence of carbon pricing and disregarding the other environmental levies) due to its low price, usually as the coal-fired power plants were built close to the coal mines If proximity of the coal mine to the power plant is not the case, this significantly increases the overall electricity production cost due to higher transport costs, closely related to carbon costs.

Due to the rising CO_2 emissions, it is essential to mitigate greenhouse gas emissions in order to avoid the severe consequences reflecting in the climate change (Finkenrath, Smith & Volk, 2012, p. 22). Therefore the industry's main targets globally are to radically reduce the CO_2 emissions by decarbonizing fossil fuel usage, encouraging renewable and low-carbon generators.

The only existing technology that allows mitigating the GHG emissions from large scale fossil fuel usage is the CO_2 capture and storage (hereafter referred to as "CCS"). If adopted in full, it would be ca. 10% of the energy-related CO_2 emission reduction required to stabilize global warming (Finkenrath, 2011, p. 9). This shows us the potential of this technology which, however, it is not expected to play a pivotal role in the near future yet. The cost of adding the CCS to the new-build coal and gas-fired power plant would amount to £6–10 per MWh. Until a realistic number of demonstration plants with CCS technology have been in operation for worthwhile time frames, the total CCS costs will remain uncertain. However, CCS is starting to be seriously considered with new investments in the mid-term, as well as retrofitting the existing coal-fired power plants (Finkenrath, Smith & Volk, 2012, p. 10).

According to Blyth (2008, p. 10), there are two main ways of applying CCS to coal-fired power plants. The first one is to use the advanced version of the standard fuel cycle (advanced super-critical, ASC) in which the pulverized coal is combusted in a boiler to produce steam whereby electricity is generated from a steam turbine, here the CO_2 separation from other gases is relatively costly. The alternative way is to use different combustion technology – integrated gasification and combined cycle (hereafter referred to as "IGCC"), in which the coal is converted into a combustible gaseous form so it can be used as a gas turbine. Gas turbines generate electricity at a higher efficiency, and the concentrations of CO_2 in the fuel gas can be much higher, making separation of CO_2 more efficient and less costly. The latter alternative is less used and still at the beginning stages.

For the analysis I have decided to choose a small-to medium-scale supercritical (see below for explanation) type of generator with a 359 MWp output. The main reasons for this were:

a) Availability of information, and
b) Ability to analyze the most common type and sized generators currently in use.

The analysis will representatively showcase the comparable information needed for a detailed comparison.

Sargent & Lundy (2009, p. 1) divides Coal-fired power plant types in two groups:

1. PC (pulverized coal),
2. Integrated gasification combined cycle (IGCC) power plants.

Furthermore, coal-fired power plants differ according to their steam cycles (Sargent & Lundy, 2009, p. 1):

- Subcritical (subC),
- Supercritical (SC),
- Ultra-super critical (USC),
- Advanced (ultra)-super critical (AUSC).

Due to the above mentioned reasons, I have decided to analyze the Supercritical type of PC (pulverized coal) generator powered by a Powder River Basin (PRB) type of coal. The main characteristics of a Supercritical PC generator are (Studymode.com, 2010):

- A supercritical power plant operates at extremely high temperatures resulting in higher efficiencies – up to 46% for supercritical plants – and lower emissions than traditional (subcritical) coal-fired plants. The efficiency of the thermodynamic process of a coal-fired power describes how much of the energy that is fed into the cycle is converted into electrical energy. The greater the output of electrical energy for a given amount of energy input, the higher the efficiency.

- A supercritical power plant utilizes a turbine system which operates at 580ºC whereas subcritical plants operate at a lower temperature. The first one is much more efficient than a subcritical plant, producing more power from the less coal and with lower emissions.

Benefits of advanced supercritical power plants (Studymode.com, 2010):

- Reduced fuel costs due to the improved efficiency,
- Significant reduction in CO_2 emissions,
- Plant costs comparable with subcritical technology and lower than other clean coal technologies,
- Much reduced NOx, SOx and particulate emissions,
- Can be fully integrated with appropriate CO_2 capture technology.

Tables 9 and 10 outline the financial calculation of a 359MWp-sized coal-fired power generator. The calculation includes the initial capital cost, O&M costs, financing costs as well as the export electricity price for each unit of produced electricity. The project calculation will serve as a basis for a further analysis of revenue streams and LCOE. We will compare the latter with the cost of electricity produced by a comparable-sized utility-scale PV generator. This particular generator does not include the CCS technology, which could add up to ca. £6–10 per MWh.

Table 9. Project definition – Coal-fired power plant

Project Definition	
Unit size (MW Gross)	**400MW**
Unit size (MW Net)	**359MW**
Land and Land Rights (GBP)	not included
Structures and Improvements (GBP)	68,152,260.00
Boiler Plant (GBP)	337,149,800.00
Turbine Plant (GBP)	67,123,680.00
Misc. Power Plant Equipment (GBP)	7,154,800.00
Main Power System (GBP)	6,236,580.00
Auxiliary Power System (GBP)	8,432,000.00
Emergency Power System (GBP)	486,080.00
Electrical BOP (GBP)	38,297,400.00
Substation and Switchyard Structures and Facilities (GBP)	593,340.00
Substation and Switchyard Equipment (GBP)	5,611,000.00
Initial Fills (GBP)	288,920.00
Start-up Personnel- Craft Start-up Support (GBP)	2,667,860.00
Overtime Inefficiency & Overtime Premium Pay (GBP)	28,743,200.00
Per Diem (Subsistence) (GBP)	32,146,380.00
EPC Fees (GBP)	n.a.
Subtotal Direct Project Costs (GBP)	604,752,340.00
Indirect Project Costs (GBP)	45,139,720.00
Contingency (15%) (GBP)	97,483,840.00
Operating Spare Parts (1%) (GBP)	6,498,840.00
Escalation (4% Annual Rate) (GBP)	117,734,900.00
Subtotal Project Costs (GBP)	964,035,520.00

(table continues)

(continued)

Project Definition	
Unit size (MW Gross)	**400MW**
Unit size (MW Net)	**359MW**
Energy Price Inflation (%/year)	3
Financing (%)	80
Own funds (%)	20
Project cost (£/kW)	2,684.60
Predicted annual output (MWh/year)	2,828,000.00

Source: Sargent & Lundy, *New Coal-Fired Power Plant Performance and Cost Estimates*, 2009, p. 49, Table: Summary of Estimated Project Costs Based on PRB Coal.

Table 10. Project summary – Coal-fired power plant

Project Summary	
Unit size (MW Gross)	**400MW**
Unit size (MW Net)	**359MW**
OPERATING LIFE (years)	35.00
Fixed O&M cost	7,927,940.00
Variable cost	5,330,214.40
Fixed O&M costs/kW/year	22.09
Variable O&M costs £/MWh/year	1.88
Fuel-O&M cost (£/mmBtu)	0.87

Source: Sargent & Lundy, *New Coal-Fired Power Plant Performance and Cost Estimates*, 2009, p. 49, Table: Summary of Estimated Project Costs Based on PRB Coal.

Table 11. Project summary and LCOE calculation – Coal-fired power plant

Project Summary	
Nominal power (kWp)	359,000.00
CAPEX (GBP)	964,035,520.00
Own funds (GBP)	192,807,104.00
Loan amount (GBP)	771,228,416.00
WACC (%)	10
EP- MWh	27,275,851.51
Levelized energy cost (GBP/kWh)	**0.056**

Source: Author and *Levelized Cost of Energy Calculator, 2013*.

4.4 Cost structure analysis: PV vs. Coal-fired power plant

In this chapter I will elaborate on the project costing and showcase the main determinants that reflect the initial investment cost today and in upcoming years, as well as the recurring cost of the projects which are mainly related to the maintenance and operation.

Cost structure analysis will clearly indicate the volatility of the system cost and performance throughout its operating life and it will also give us an indication of future investment and operation costs of the power plants of both types.

When analyzing the coal-fired power plant's financial plan, great importance is put on the fuel/coal cost which will greatly affect the system operation and maintenance costs as well as its efficiency. But more about this is to follow.

4.4.1 Cost structure: PV power plant

The main components that determine the system's capital investment cost as well as its future revenue streams are as follows:

- Photovoltaic modules – up to 50% (of CAPEX),
- PV Inverter – up to 12% (of CAPEX),
- Mounting system – up to 12% (of CAPEX),
- Labour (mechanical installation, electrical installation DC and AC wiring and other equipment) – up to 10% (of CAPEX),
- Miscellaneous: (Transformers upgrade, site assessments, other administrative incl. land lease) – up to 14% (of CAPEX),
- Operation and maintenance costs – up to 2% annually.

This cost breakdown applies to a ground-mounted large scale system, as per the above financial plan. The cost ratio depends on the system size (smaller system means proportionally higher inverter cost compared to the module cost, the same goes for the understructure) and system type (Ground-mounted, roof mounted, building integrated etc.).

The main factors that will determine the future movement of LCOE of PV generator and therefore play a decisive factor in its competitiveness with the conventional generators are:

- Module price movement,
- Other component price movement,
- Government support scheme movement,
- Electricity price/costs movements.

These variables will allow me to create a trend (based on historical trends) that will help me position both conventional and the PV generators in the LCOE curve. This will allow me to come closer to my predictions regarding the grid parity, or in other words, where the PV and coal curves are going to "meet".

4.4.2 Cost structure: Coal-fired power plant

In order to present the cost structure of the coal-fired electricity generator in the most brief and representative way, I intend to breakdown the project cost into four main parts.

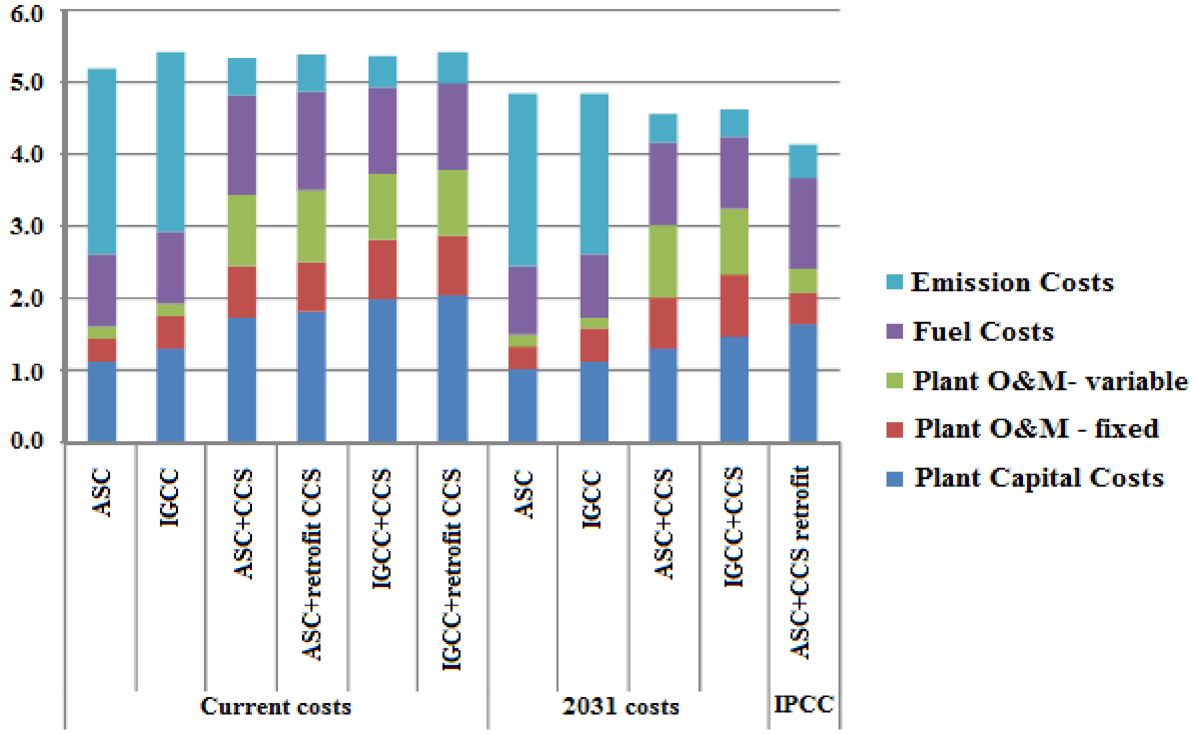
These are:

1. Initial capital costs (site analysis, construction costs, etc.);
2. Operational and maintenance costs, which consists of
   - Fixed O&M costs,
   - Variable O&M costs;
3. Fuel costs;
4. Carbon costs.

This breakdown will allow me to clearly showcase the cost sensitivity throughout the project life-time and will also help me to analyze the capital investment and operational costs of future coal-fired projects.

Figure 11 shows the breakdown of levelized costs (in p/kWh) in different technology – with and without CCS technology:

Figure 11. Cost breakdown of a coal-fired power plant with and without CCS



Source: W. Blyth, *The Investment Case for Coal-Fired Power Generation in the UK*, 2008, p. 10, figure 4.1.

For the coal-fired power plants that went live in operation in 2009, at 10% discount rate, the levelized generation costs ranged at around £37/MWh. Investment costs represent around 50% in most cases, O&M cost account for some 15% or the total and fuel costs for some 35%.

As we can see from the coal-fired power plant analysis that went into construction in 2006/7 and will be going live in 2012 or 2013, the projected cost generated electricity increased by about 51% than for the ones that went live at the beginning of the construction stage of these generators.

According to the U.S. Energy Information Administration- EIA (2010b, p. 119) for the projects that have been in the development phase since 2009, and that are planned to go live in 2016, the LCOE will increase by a further 30%.

As my main purpose is to analyze the LCOE movements in the following, I need to take into account the factors that will influence the LCOE movements the most and affect the competitiveness of a coal generator:

- Fuel costs,
- Operation and maintenance costs,
- Carbon emission cost (or alternative additional CCS technology).

These will be the factors that will determine the future capital and operational costs of the projects as well as heavily affecting the financial planning of projects in construction today. Therefore, a thorough analysis of future movements of these factors is essential when undertaking feasibility studies and deciding upon a project's implementation.

4.5 Revenue stream analysis: PV vs. Coal-fired power plant

My intention in this chapter is to briefly touch upon the revenue stream side of both types of investment. In general, there are two closely related ways of generating revenue from conventional and photovoltaic generators:

1. Electricity production and its sales and
2. Income generation utilizing the support schemes.

Both are closely related, however the income may apply to selling the electricity to the buyer on the energy markets. In the case of residential and commercial applications, investors benefit from direct income in the form of payment for every electricity unit the power plant generates.

The support schemes are expected to disappear by the end of the decade when the main revenue stream will be selling the electricity on the local/regional/global level, where electricity savings can be considered as an indirect effect of electricity generation.

4.5.1 Revenue stream analysis: PV power plant

When we are discussing the cash flows and revenue streams we need to note that these are closely correlated with the generator's performance.

The financial plans of residential and commercial power plants showcase the income from electricity generation throughout the 20 year period in which the UK government has subsidies the electricity generation for renewable generators. At the moment, the subsidy of up to 15.44p[16] for a residential system and up to 7.1[17]p for a commercial system is paid for every kWh of generated electricity from a PV array. In addition to the generation tariff, every generator gets up to additional 4.5[18]p for every kWh of electricity produced but not consumed and therefore exported to the electricity grid. In this case the system achieves a lower return on investment due to losing out on the "cheaper electricity" and exporting the surplus back to the grid as not needed and buying it back from the grid later on at the full market price.

Despite the fact that the 20 year operating period is taken into the account for the LCOE calculation purposes, with residential and commercial systems, a longer up to 35 year operating period is expected which would increase the LCOE rate as well as the return on the investment of the PV projects. As the government guarantees a 20 year support tariff for residential and commercial projects (as well as PV manufacturers offer a 25 year period), 20 years seems the most reasonable basis for calculation.

5.5.1.1 Residential PV power plant

For instance, a 4 kW system which costs £1600/kWp (as shown in financial plan-residential PV system), costs the investor ca. £6400 to install. At irradiance levels of 900kWh/kWp, the system would generate ca. 3600kWh of electricity annually, which is ca. 72MWh in 20 years. Considering the 50% consumption rate (the average amount of electricity produced and simultaneously consumed in an average household annually), the system would generate ca. £5,980.00 of net income in the 20 year period (discounted) and reach the breakeven point, **ROI in 5 years.**

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[16] November, 2012.
[17] November, 2012.
[18] November, 2012.

5.5.1.2 Commercial PV power plant

In the commercial PV segment, a 1MW rooftop system analyzed in chapter 4.2.2 system costs an investor ca. £950,000 to install. At irradiance levels of 900kWh/kWp the system would generate ca. 900,000kWh of electricity annually, which is ca. 18,000MWh in 20 years' time. Considering the 80% electricity consumption rate (the average amount of electricity produced and simultaneously consumed in the average industrial building annually), the system would generate ca. £969,270.00 of net income in the 20 year period (discounted) and reach the breakeven point – **ROI in ca. 5.5 years.**

5.5.1.3 Utility-scale PV power plant

A cash flow of a utility scale generator works on a slightly different principle, independent of any government support, however based on a PPA (power purchase agreement) between a power plant owner and a purchaser of electricity (electricity distributor, utility or any other entity).

The LCOE is, in this case, compared directly to the LCOE of a new-build conventional coal-powered electricity generator (as described in the financial plan in chapter 4.2.3). Here the costs and returns are different. The PV power plant's financial plan in 4.2.3 shows the breakdown of the costs and returns generated under the 950kWh/kWp irradiation levels. The main focus with the utility scale project is to find out the LCOE of a PV power plant which is a result of a capital cost, operation cost and the net present value of the electricity generated throughout the 35-year period. The operation period of 35 years is used for a returns and performance calculation due to the absence of any government support and better comparability of financial models to coal-fired power plants which have an operating life of 35 years.

A 359 MWp utility-scale PV generator costs ca. £305.15 million to build. If we assume the irradiance levels of 950kWh/kWp – due to the fact that the investor will look for geographic areas with highest irradiation levels in the UK. Here the system would generate ca. 341.05 TWh of electricity annually, which is ca. 11,930 TWh in 35 years' time. In case of utility scale PV power plant the own consumption rate would be zero as all the electricity would be directly exported/ sold to the user. At a 7.6p/kWh rate (as per PPA agreement, index linked) the PV system would generate ca. £ 118,235,700 of net income in its lifetime (discounted) and reach the breakeven point – **ROI in just over 10 years' time.**

For all the above mentioned PV power plants, a 6% WACC has been taken into consideration assuming the project would be financed 20% with investor's capital and 80 % with the financier's. As we know this the interest rates from lenders differ.

4.5.2 Revenue stream analysis: Coal-fired power plant

When it comes to a coal-fired generator, the performance/cash flow calculation differs from the PV power plant. The main costs of a PV project present the capital costs, operation and maintenance costs, whereas the substantial part in cost structure of a coal- fired power plant present also the fuel cost and the CO_2 capture cost.

Table 12. Estimated system performance

MW Gross (Btu/kW net)									
Plant size	**400**	**600**	**900**	**400**	**600**	**900**	**400**	**600**	**900**
Plant type			**Bituminous**			**PRB**			**Lignite**
subC	9,349	9,302	9,291	9,423	9,369	9,360	9,963	9,912	9,901
SC	9,058	9,017	8,990	9,128	9,080	9,057	9,647	9,603	9,576
USC	8,924	8,874	8,855	8,993	8,937	8,921	9,502	9,449	9,430
AUSC	8,349	8,305	8,279	8,414	8,363	8,341	8,882	8,834	8,808

Source: Sargent & Lundy, *New Coal-Fired Power Plant Performance and Cost Estimates*, 2009, p. 5, table 2-2.

In order to better explain the above performance estimation expressed as Net Heat Rate (Btu/kWh), U.S. Energy Information Administration – EIA's website (What is the efficiency of different types of power plants?, 2012) helps us define the **Heat Rate,** as a measure of generating station thermal efficiency, which is commonly stated as the British Thermal Unit (Hereafter referred to as: "Btu")[19] per kWh. Heat rate can be expressed as either gross or net heat rates, depending whether the electricity output is expressed in gross or net generation. Heat rates are typically expressed as net heat rates.

So, how much coal represents a Btu or, in other words, how much of it is used to generate one unit (kWh) of electricity?

The International Energy Agency has published the latest document stating the 2012 rates of average annual heat content of coal between 1973 and 2012. The latest value representing coal heat content is, according to the U.S. Energy Information Administration – EIA's website, 20.724 million Btu per short ton (Monthly Energy Review, 2013).

In the case of our analyzed supercritical type of coal-fired power plant, we see that its efficiency reaches ca. 37%, which means its power output peaks at 2.8 million MW, expressed in net heat rate this means it is able to produce 9128 Btu/kWh. Taking into

[19] The BTU (British Thermal Unit) is defined as the amount of heat required to raise the temperature of 1 pound of water by 1 degree Fahrenheit. One quadrillion Btu is 1015 Btu, or 1.055 exajoule (*Energy-Related Carbon Emissions Glossary,* 2013)

account the above mentioned value of coal heat content, a simple calculation shows us that the power plant uses ca. 0.43kg of coal for every produced kWh.

As the fuel cost is already included into the calculation as a variable O&M cost, the latter is discounted and added to a capital cost of £1.153.063.989 (£304.520.202 of this is O&M and fuel cost). A coal-fired generator would consume ca. 0.43kg of coal for every kWh as mentioned above, annually generating ca. 2.828.225.000 MWh of electricity. Selling the produced electricity at £0.076/kWh, it would amount to ca. £ 206,997,474.60 of revenue annually. LCOE amounts to a £56/MWh which is still much more competitive rate compared to a PV generator. However, we have not included all the carbon and other taxes which increase the LCOE price.

4.6 LCOE analysis: PV vs. Coal-fired power plant

The levelized cost of electricity (usually expressed in currency/kWh or currency/MWh) is the most important indicator allowing us to compare the cost of generated electricity from different power sources. LCOE is of special relevance to the project stakeholders. However, LCOE varies widely depending on a wider set of assumptions. It is widely based on geography and on the financial return requirements of investors, and does not allow for robust single-point estimates (Bazilian et al., 2012, p. 2).

As my main intention is to compare the competitiveness of both types of analyzed electricity generators, LCOE will give me a clear picture of the current status of both. In order to get the most realistic results, my LCOE will consider the initial capital investment, discount rates, discounted maintenance and operation costs as well as the electricity produced and income generated from the feed-in-tariffs for residential and commercial power plants.

Residential and commercial segment:

- Assumption 1: PV system price will decrease 6% annually,
- Assumption 2: Retail electricity price will increase 3% annually,
- Assumption 3: FIT rate will decrease 14% annually.

Utility segment:

- Assumption 1: PV system price will decrease 6% annually,
- Assumption 2: Price of coal will increase 1.5% annually, O&M costs will increase by 2% annually.

These cost and price movements will be the main determinants of the LCOE levels in the next 10–15 years, which is the period relevant to the analysis, however it can differ from the real values. These will depend upon the actual uptake of the PV market in relation to the incentive movement and other factors that affect the market development. However, the above estimations are in-line with the general industry estimations and predictions and therefore very likely to be achievable.

4.6.1 LCOE: PV power plant

My calculations of the current and future LCOE movements will be divided into three different segments:

1. Residential PV generators which will be compared to the costs of residential electricity. Retail electricity (to the end consumers) is the most expensive due to its transmission and procurement costs hence the residential PV systems are expected to reach grid parity earliest.

2. Commercial PV generators will be compared to the retail electricity segments at an industrial level, where the prices are lower due to the economies of scale, lower transmission costs and higher purchasing power of the electricity buyer. However, due to the nature of electricity consumption in this segment (largest amounts of electricity needed the most at the PV peak production hours) the generator is expected to reach grid parity fairly soon but later than the residential applications.

3. Third segment is the utility scale PV generation. Here I intend to compare the PV to the conventional generator and not to the electricity price levels. The grid parity point is expected to be rather late due lower prices of electricity, which are a result of economies of scale and market maturity of conventional electricity generation technologies. On the other hand, the cost of conventional electricity is steadily increasing due to the increasing prices of raw materials, high operation and maintenance costs, high decommissioning costs and the carbon prices- taxation policy frameworks governments have established to limit the toxic gases emissions into the environment.

Below are the main assumptions that will serve as a basis of my following estimations and calculations:

4.6.2 LCOE: Coal-fired power plant

Blyth (2008, p. 11) argues that the IGCC type of power plant, already utilising CCS (carbon capture and storage technology) is about 10% more expensive compared the analyzed type of coal run generator excluding the costs for emissions. The difference reduces slightly from when the emission costs are included due of the additional efficiency of IGCC (46.4%) compared to ASC (44.9%) and the analyzed SC type of generator (37%).

When we add the costs of CCS, the emission costs drop significantly, as 90% of the emissions is captured. Capital and O&M costs increase accordingly.

The capital costs of all types of coal-fired plants have increased dramatically in the recent years since the IPCC study has been carried out in 2008. Another important point arising from the above is that under these assumptions, retrofitting CCS at a later date is hardly any more costly than fitting it when constructing the generator, and this is the case for both ASC and IGCC technologies. This means that there are no penalties for companies building unabated coal generation plants now (whilst carbon prices are below the breakeven price for CCS), with a view to retrofitting the capture and storage plant should carbon prices rise sufficiently in the future. This flexibility provides companies with a valuable option for the future. CCS technology provides an important hedge against the risk of high future carbon prices, essentially reducing the risk of building coal plant.

4.6.3 LCOE Analysis: Results

After analyzing the financial plans of two main types of generators, I will now also analyze the outcomes of the LCOE analysis of existing and future projects and apply it to the grid parity notion. Before that, the main assumptions need to be stressed out yet again.

4.6.3.1 Main assumptions with regards to the LCOE analysis

Residential and commercial segment:

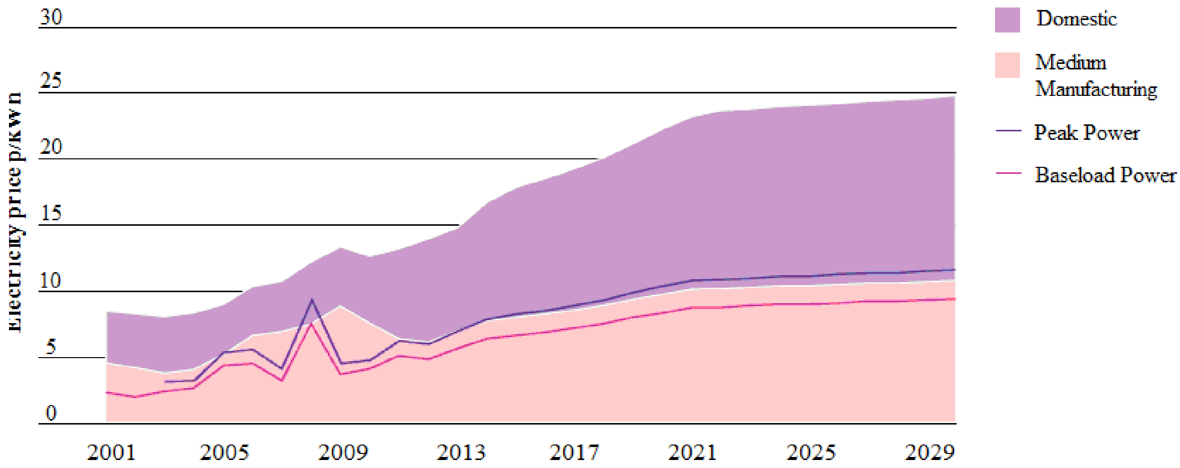
- Assumption 1: PV system equipment price will decrease 6% annually,
- Assumption 2: Retail/ wholesale electricity price will increase 3% annually,
- Assumption 3: FIT rate will decrease 14% annually.

Utility segment:

- Assumption 1: PV system price will decrease 6% annually,
- Assumption 2: Price of coal will increase 1.5% annually, O&M costs will increase by 2% annually,

The above assumptions are supported by the following Figure 12 and 13, which show us the increasing trend in electricity price movements in the 30 year-period in the UK market and, on the other hand, a continous decrease in prices of PV modules in the last four year period, globally.

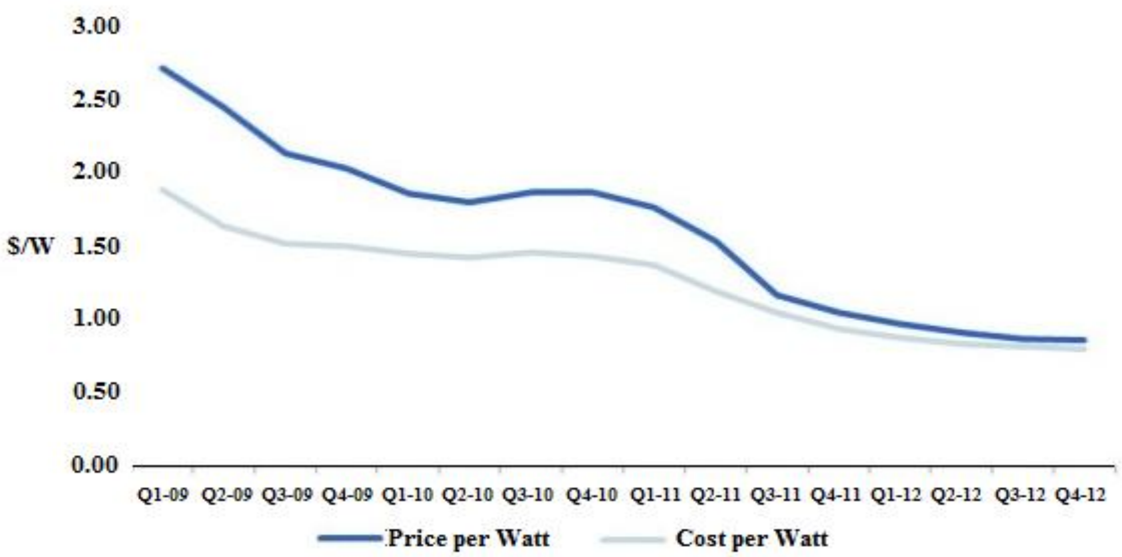
Figure 12. Estimated electricity prices by 2029



Source: *National Grid, UK Future Energy Scenarios: UK gas and electricity transmission*, 2011, p. 16, Figure 4.

Figure 13 indicates a price drop in PV module prices in a 4-year period.

Figure 13. PV price movements 2009–2012



Source: PVmarketresearch.com, *Crystalline PV Module Profits Fall to Single Digits*, 2012.

As seen in the Table 13, DECC predicts an overall increase in coal price however it estimates the price drop and its stagnation as of 2020 due to the decrease in demand and high carbon prices enforced by governments in order to meet the EU and OECD carbon targets

Table 13. Coal prices movements; three scenarios

Year ($)	Low ($)	Central ($)	High ($)
2010	93	93	93
2011	130	130	130
2012	124	130	137
2013	117	127	143
2014	112	124	144
2015	106	191	146
2016	96	119	147
2017	91	116	148
2018	85	113	149
2019	80	110	151
2020	80	110	152
2021	80	110	153
2022	80	110	153
2023	80	110	154
2024	80	110	154
2025	80	110	155
2026	80	110	155
2027	80	110	155
2028	80	110	155
2029	80	110	155
2030	80	110	155

Source: DECC, *Coal price projections*, 2011a, p. 20, figure 10.

Table 14 shows an estimated coal price movement throughout the 21 year period:

Table 14. Coal prices movements – Analysis

Year	Low ($)	Central ($)	High ($)	Average (£)	Change %
2010	93	93	93	57.7	0%
2011	130	130	130	80.6	40%
2012	124	130	137	80.8	0%
2013	117	127	143	80.0	-1%
2014	112	124	144	78.5	-2%
2015	106	191	146	91.6	17%
2016	96	119	147	74.8	-18%
2017	91	116	148	73.4	-1.9%
2018	85	113	149	71.7	-2.3%
2019	80	110	151	70.5	-1.7%

(table continues)

(continued)

Year	Low ($)	Central ($)	High ($)	Average (£)	Change %
2020	80	110	152	70.7	0.3%
2021	80	110	153	70.9	0.3%
2022	80	110	153	70.9	0.0%
2023	80	110	154	71.1	0.3%
2024	80	110	154	71.1	0.0%
2025	80	110	155	71.3	0.3%
2026	80	110	155	71.3	0.0%
2027	80	110	155	71.3	0.0%
2028	80	110	155	71.3	0.0%
2029	80	110	155	71.3	0.0%
2030	80	110	155	71.3	0.0%
		AVERAGE			**1.5%**

The price drop works in favour of coal-fired power plant technologies. However the pressure on the carbon reduction will demand constructing coal-fired generators with carbon capture technologies which increases the cost of the project but on the other hand also increase its competitiveness towards PV generators.

4.6.3.2 Cost of electricity produced from a residential PV generator vs. cost of electricity purchased from the retail market

Table 15 below is showing the LCOE throughout an eight year period inclusive of current and predicted future support levels (as of Q4-2012 a 14% drop annually, which is a 3.5% drop per quarter, planned for the UK feed-in-tariff scheme) for the residential sized PV generator installed on a residential roof with a peak power output of 4 kWp, taking into account the estimated future electricity price movements.

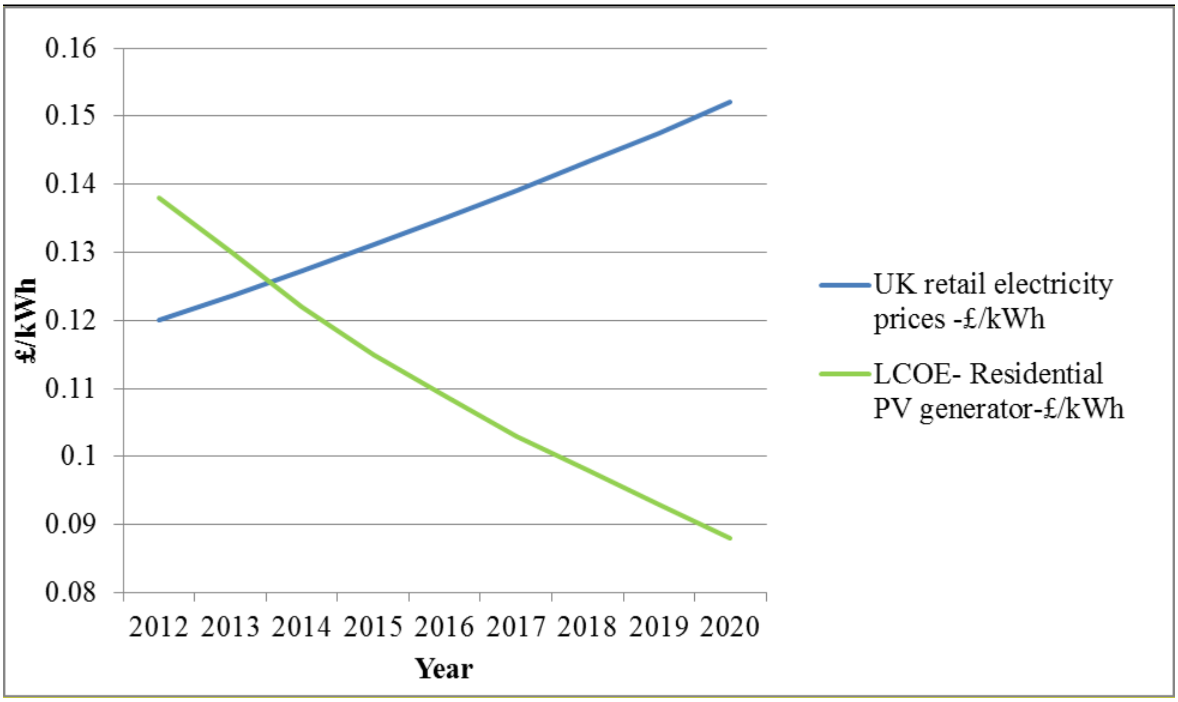
Table 15. LCOE movement analysis: Residential PV generator

Year	UK retail electricity prices -£/kWh	LCOE- residential PV power plant- £/kWh
2012	0.12	0.138
2013	0.124	0.13
2014	0.127	0.122
2015	0.131	0.115
2016	0.135	0.109
2017	0.139	0.103
2018	0.143	0.098
2019	0.148	0.093
2020	0.152	0.088

Source: Author and *PVCalc – The Return (ROI) Calculator for PV solar energy projects*, 2013

Figure 14 shows us the levelised cost of electricity generated from a residential PV generator taking into account the below assumptions. It will equal the cost of electricity purchased from the Grid by the beginning of 2014.

Figure 14. LCOE movement analysis: Residential PV generator



Assumption 1: PV system equipment price will decrease 6 % annually
Assumption 2: Retail electricity price will increase 3% annually
Assumption 3: FIT rate will decrease 14% annually

Source: Author and *PVCalc – The Return (ROI) Calculator for PV solar energy projects*, 2013.

An important notion that would even increase the returns and increase the competitiveness of residential PV generators would definitely be adopting the net metering concept, which would give consumers credit for the exported surplus of electricity which is not needed and can be taken back at no cost when needed.

4.6.3.3 Cost of electricity produced from a commercial PV generator vs. cost of electricity purchased from the wholesale market

Table 16 shows the levelized cost of electricity movement throughout an eight year period including the current and future predicted support levels (as of Q4-2012 a 14% drop annually, which is a 3.5% drop per quarter, planned for the UK feed-in-tariff scheme) for the roof-mounted PV generator installed on an industrial roof with a peak power output of 1 MWp, taking into account the estimated future electricity price movements.

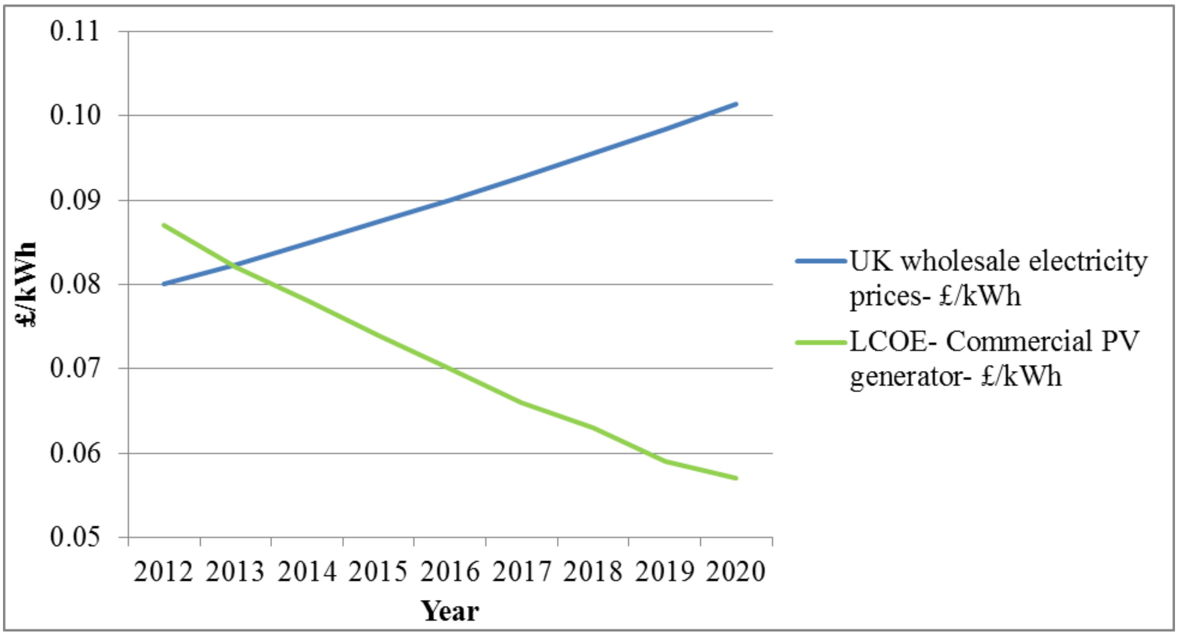
Table 16. LCOE movement analysis: Commercial PV generator

Year	UK wholesale electricity prices- £/kWh	LCOE- Commercial PV generator- £/kWh
2012	0.0800	0.0870
2013	0.0824	0.0820
2014	0.0849	0.0780
2015	0.0874	0.0740
2016	0.0900	0.0700
2017	0.0927	0.0660
2018	0.0955	0.0630
2019	0.0984	0.0590
2020	0.1013	0.0570

Source: Author and *PVCalc – The Return (ROI) Calculator for PV solar energy projects*, 2013.

Figure 15 shows us the LCOE from a commercial PV generator, which will equal to the cost of electricity purchased from the grid by mid- 2013, which is in even earlier than the residential PV market. Despite the very low price of electricity for businesses compared to the residential market as well as lower increases in prices throughout the time, the grid parity is expected very soon due to the greater return generated through own consumption for businesses (electricity consumption levels are the highest when the PV systems generates the most electricity – in the daytime). This offsets the lower wholesale electricity prices purchased from the grid.

Figure 15. LCOE movement analysis: Commercial PV generator



Assumption 1: PV system equipment price will decrease 6 % annually.
Assumption 2: Wholesale electricity price will increase 3% annually.

Assumption 3: FIT rate will decrease 14% annually.

Source: Author and *PVCalc – The Return (ROI) Calculator for PV solar energy projects*, 2013.

4.6.3.4 Cost of electricity produced from a utility scale PV generator vs. cost of electricity produced from a coal-fired generator

Table 17 shows us the direct comparison of the levelized costs of electricity throughout a 14-year period for a utility sized ground-mounted PV generator with a peak power output of 359 MWp. These take into account the predicted price movements of coal prices, based on historical movements, as well as the market estimations made by the industry's specialists.

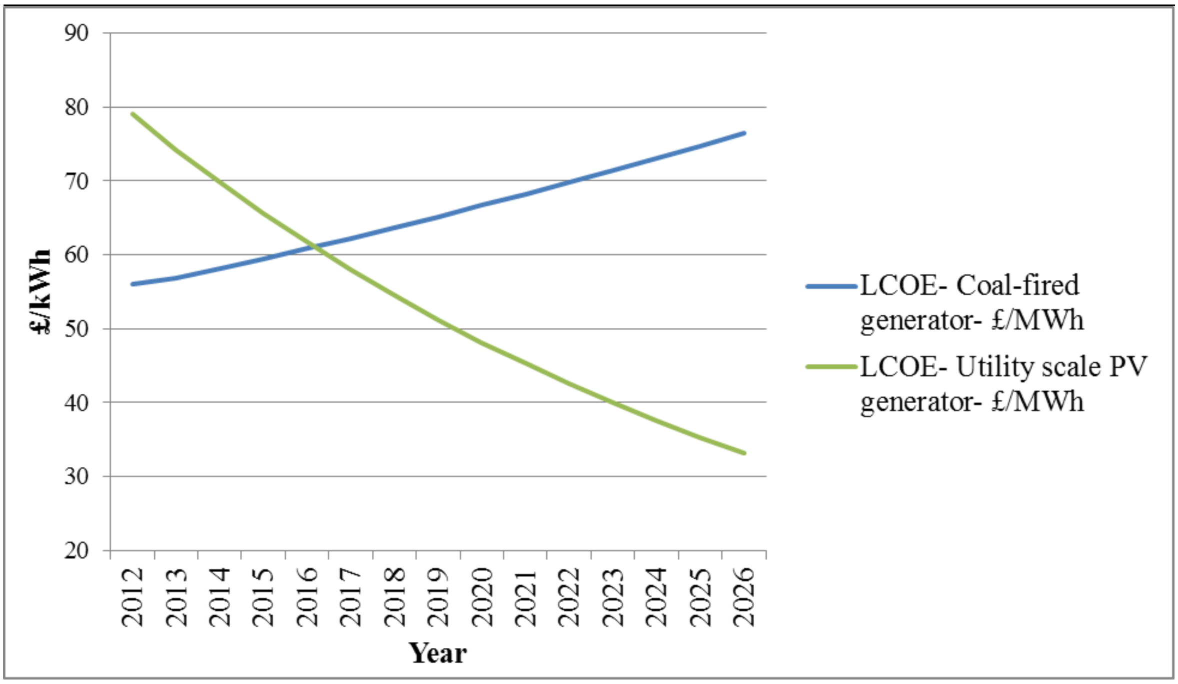
Table 17. LCOE movement analysis: Coal-fired vs. PV generator

Year	**LCOE- Coal-fired generator- £/MWh**	**LCOE- Utility scale PV generator- £/MWh**
2012	56	79
2013	56.84	74.26
2014	58.15	69.80
2015	59.48	65.62
2016	60.85	61.68
2017	62.25	57.98
2018	63.68	54.50
2019	65.15	51.23
2020	66.65	48.16
2021	68.18	45.27
2022	69.75	42.55
2023	71.35	40.00
2024	72.99	37.60
2025	74.67	35.34
2026	76.39	33.22

Source: Author and *PVCalc – The Return (ROI) Calculator for PV solar energy projects*, 2013.

Considering the assumptions stated at the beginning of the chapter, the utility-scale PV generator is according to my analysis expected to reach grid by the beginning of 2017, which a rather surprising outcome (shown in Figure 16). Furthermore, we need to note that this type of PV generator is not incentivized in any manner, i.e. exclusive of the governmental scheme which would otherwise generate additional revenue for every MWh of electricity produced. The revenues and returns are solely based on a PPA (power purchase agreement) made by both parties involved; the investor and electricity buyer. The PPA rate is based on current electricity trends and is linked to the future inflation movements.

Figure 16. LCOE movement analysis: Coal-fired vs. PV generator



Assumption 1: PV system equipment price will decrease 6 % annually.
Assumption 2: Coal prices will increase 1.5% annually, O&M costs will increase 2% annually.

Source: Author and *PVCalc – The Return (ROI) Calculator for PV solar energy projects*, 2013.

The coal-fired generator's LCOE calculations include the trends in coal price trends as well as the O&M cost movements. Future project costs also take into the account the costs of carbon capture systems as these are expected to be a mainstream in the project's financial models, due to the increasing carbon prices.

We can see that the LCOE curves meet at the beginning of 2017, which is much sooner than the industry's expectation.

4.7 Investments risks: PV vs. Coal-fired power plant

When making an investment decision of developing a conventional or photovoltaic generator there are several factors that need to be taken into consideration before going ahead with the project. The technical/performance part is subject to the upfront performance and cost estimations, which is fairly easy to assess due to its predictability and, in the case of coal-fired power plants, historical data available, which showcases the historical behaviour of the generators in operation today. The factors that increase risk and uncertainty are the environment, regulatory environmental politics and bureaucratic processes as well as the risks of corruption, changes and other unpredicted events that might not be directly related to the physical performance of the generators but can influence the project's feasibility (Bazilian et al., 2012, p. 3).

4.7.1 Risk and PV power plant

When discussing the large PV utility projects, we must realize that there are large capital investments involved and “high-rolling” investors and financial institutions get to participate in project development. Due to the high potential of investment risk related with these types of projects, mitigating the factors that increase the risk is of the essence. As financially powerful investors are increasingly getting involved with solar investments, they continue to demand better risk assessment methods/ perceived risk estimation in order to minimize the risk as much as possible beforehand.

Especially in the first stages of the PV investments, there has been too much focus on maximizing the risk adjusted NPV of the investment without taking into account the tax related risks, governmental changes, feed-in tariffs, technology evolvement, market conditions, expectation of future energy markets, proximity of power lines, possible political issues and end of life disposal costs of the PV power plant.

It is essential for PV system owners, investors and developers to eliminate risk exposure and maximize return on investment, thereby improving project finance ability to attract new capital. A variety of risks can impact upon a solar photovoltaic project’s financeability or bankability. To effectively manage them, it is crucial for PV system owners and investors to understand where the risks come from, and how they can affect the project’s return on investment.

Berry (2008) and Nergyos’ website (Main project stages exposed to risk, 2013) provide with the overview of the main project stages, the parties involved and those most exposed to the risk:

- Equipment & System,
- Electricity sales,
- Operations & Maintenance,
- Electricity Sales,
- Economic environment/regulations.

4.7.1.1 Equipment & System

- Mostly occurs as an upfront investment.
- Must keep assets running at highest performance level and without interruptions over the life time of project.
- Risk of losing out on incentives, tax benefits, and production revenues due to system failures and underperformance.
- Risk of losing warranties from equipment manufacturers due to failure of properly maintaining the system according to the warranty requirements.

4.7.1.2 Electricity sales

- The long-term revenue source.
- Must provide uninterrupted and guaranteed production of the PV system to the power plant owners/investors.
- Subject to risk of liquidated damages for non-delivery or under performance.
- Subject to loss of revenue and project internal rate of return.
- Electricity buyers create PPA contracts to insure against rising energy cost from utilities which can be therefore subject to risks of uncontrolled energy cost and spending.

4.7.1.3 Operations & maintenance

- On-going cost of operating and maintaining solar assets over life time.
- Must account for O&M cost upfront and operate within budget.
- Risk of potential cost overrun due to unforeseen failures, repairs and replacement, down time (biggest risk is the inverter failure).

4.7.2.1 Economic environment/regulations

- Government's incentives represent a large component in project's ROI.
- Financial plans are based on performance results including the feed-in-tariffs.
- Incentives are paid out each month upon submission of production reports meeting revenue-grade accuracy and scheduling requirements.
- Subject to risk of losing important revenue source and cash flow in case of retroactive changes.
- In cases when a project's business plan is based on selling on a project after a certain period of time the project could be at risk of recapture during the course of first five years as a result of non-operation or change of ownership – lower ROI than anticipated before assets are sold.
- Major part of loan payments from project owners over the multi-year financing terms.

When real exposures are identified, the appropriate risk mitigation and protection measures need to be undertaken in order to reduce or eliminate the exposure for increasing the project's profitability. This makes the project more attractive to investors and fundable to project lenders.

4.7.3 Risk and coal-fired power plant

The core principal of generating electricity by utilizing steam turbine run on coal is several decades already in use, therefore the historical information and operating power plants give us well proven empirical cases showcasing the "behaviour" of these generators in practice. This means, its operation is rather predictable, hence **technical risks** are very low.

The performance of the power plant depends on the particular type of coal that is in use with the generator (in the case of the analyzed coal-fired generator, a PRB – powder river basin is in use). This usually takes designing the generator around a particular type of coal, sourced from a few or a single source which can be quite risky. Therefore a reliability of a coal supply is of the essence (Berry, 2008, p. 10). Although there is a possibility of adapting the generator to a different type of coal later on, this is closely related to the cost increase. The ever increasing notion of carbon cost forces investor to seriously consider investing also in the emission – control systems, such as CCS technology (as described IGCC type of coal powered generator) which is still required by legislation; however it already offsets the carbon cost set by governments during the operation period of a generator. As mentioned, in some countries the environmental regulations are very strict, in the other countries the more stringent regulations are expected therefore the investors take this into account with most of newly designed coal-fired generators.

The bottom line is in order to assure a secure, relatively stable and predictable supply of fuel for at least 20 years is essential to reduce the risk of an investment in a coal-fired project. This was usually the case in the last 20 years. However, this may change in today’s volatile economic environments. Where there is an abundance of coal and where the latter faces the competition for natural gas, the fuel price movements are rather predictable, which allows a firm planning of life time fuel and other operating costs especially in cases when the generator exploits a local source of coal. As estimated above, the coal cost is even expected to lower and settle in the future due to the competition from other sources (particularly solar PV) however this could be counterbalanced by a lesser instability and insecurity of supply. Therefore, assuring a secure and stable fuel supply is essential from an investor’s point of view.

To conclude, coal seems to be a significantly more risky investment decision due to the possibility of significant losses occurring as a consequence of lower gas prices and higher carbon prices. On the other hand, this can be counterbalanced by possibilities of big gains, in the case of low prices and lower costs than expected (Blyth, 2008, p. 13).

At this point, coal is generating similar average returns as gas companies may be more concerned about the possibility of large losses than about the possibility of large gains (Blyth, 2008, p. 13). However, their risk analysis in practice is much more complex than that described.

5 MAIN FINDINGS

In this thesis I have undertaken comprehensive research into photovoltaic technologies, its market penetration and development in the UK market and globally. In the first part I have showcased a historical development, current situation and future prospect of PV technology, followed by a theoretical "case study" analysis of four financial plans, which I have undertaken in the second part; analysing the three photovoltaic and the one coal power plant business models, where I have compared the industrial-utility scale PV generator and the coal-fired generator, trying to find out whether a large-scale PV generation can compete towards a coal-fired generator in the electricity generation stage first in the value chain. After presenting the cost structure and performance estimation figures I have analysed the power plants' cost structure, revenue streams and investment risks. These gave me accurate enough figures to calculate the LCOE – levelized cost of electricity, an indicator that allows us to compare the cost of produced electricity from different generation sources and is a main decisive factor in the projects feasibility. Analysing the future movements of market electricity prices, fuel prices, equipment prices as well as government's regulatory framework indices, gave me a basis for estimating the future market movements which will affect the project's feasibility and therefore competitiveness.

Below, I have presented the main findings with regards to the competitiveness of a PV generator towards the conventional electricity sources.

5.1 Hypothesis evaluation

My main findings will be presented in a way of comparing my main hypothesis to the research results and applying it to the general market knowledge with regards to the movement towards the grid parity.

"Solar electricity in the UK will reach grid parity by 2020. However, considering the fact that electricity supplied to a residential market is more expensive (cost of transmission and grid maintenance cost) compared to the industrial segment, therefore my assumption on the 2020 mark applies mainly to the industrial/commercial sector and general power generation level. On the residential front, my assumption is that the grid parity with the cost of electricity supplied to the residential market will be reached earlier, in 2018."

5.1.1 Residential PV vs. Grid electricity prices: findings

According to my analysis, the levelized cost of electricity generated from a residential PV generator will equal the cost of electricity purchased from the grid by the beginning of 2014 which is fairly early. This showcases a faster uptake of PV and increased pace towards grid parity however the analysis is based on an "ideal scenario", i.e. sufficient uptake of installed volumes and equipment price drop in order to regularly reduce the FIT levels as planned and reach the required LCOE levels by 2014. Please note that an optimistic scenario (i.e. sufficient uptake in installation volumes for a maximum degression in FIT support levels quarterly-annual degression level) is taken in consideration, hence the actual uptake can differ rather significantly.

As mentioned in previous chapters, an important notion that would increase the competitiveness with electricity from the grid would be the “net metering” which would give consumers credit for the exported surplus of electricity which is not needed and can be taken back at no cost when needed.

5.1.2 Commercial PV vs. Grid electricity prices: findings

According to my analysis, the levelized cost of electricity generated from a commercial PV generator will equal the cost of electricity purchased from the grid by mid- 2013, which is way earlier than stated in my hypothesis (2020). However, the pace depends upon the “aggressiveness” of the market growth which will reflect in the government’s support levels. Again, an optimistic scenario (i.e. sufficient uptake in installation volumes for a maximum degression in FIT support levels quarterly-annual degression level) is taken into consideration.

Despite lower electricity prices for businesses compared to the residential market, as well as lower estimated increases in prices throughout time, the grid parity is expected fairly soon. This is due to the greater return generated through own consumption for businesses (electricity consumption levels are the highest when the PV systems generates the most electricity – in the daytime). This offsets the lower electricity network prices.

5.1.3 Utility PV electricity generation cost vs. coal-fired generator electricity generation cost: findings

According to my analysis, the PV generator at the utility scale is expected to reach grid parity at the beginning of 2017 which is an astonishing outcome. We have to note that this type of PV generator is not incentivized in any manner, i.e. excluding even the governmental 2ROCs scheme which generates revenue for every MWh of electricity produced. The revenues and returns are solely based on a PPA (power purchase agreement) made by involving parties, the investor and electricity buyer (and the property owner is a different entity than the investor). The PPA electricity rate is based on current electricity trends and is linked to the future inflation movements.

The LCOE movements of a coal-fired generator include the trends in coal price movements, as well as the cost movements of operation and maintenance. Future project costs also start to account the carbon capture technology costs as these are to be included more and more often due to the increased carbon prices.

My main findings are far more optimistic than the assumptions made by the industry and academia as well as my hypothesis. Analysis shows that the LCOE will be at the same level by the beginning of 2017, which is much sooner than the general industry and government expectation.

5.2 Applying the findings to the grid parity notion

After the practical analysis undertaken through a comparison of the financial plans of different types and sizes, analyzing their cost/performance ratio and competitiveness today as well as in the future, brought me to the conclusion that the results are by far more optimistic than the grid parity assumptions introduced by the industry and academia.

With regards to the grid competitiveness of residential, commercial and utility scale power plant to the electricity grid in the first two cases, and the electricity production cost in the second one, my assumptions come across as more optimistic than those from the industry. The main reason for this is taking into account the maximum market uptake possible as well as not including the project financing availability factor that significantly affects the project success. Therefore, I believe that the availability of financing and the conditions, such as interest rates of finance institution, seriously dictate the project feasibility and the general industry growth in the UK, as well as globally.

CONCLUSIONS AND FUTURE WORK

The main conclusion I can extract from the research undertaken is that solar energy has a bright future also in the UK. Due to its high initial cost in the past and slow technology advancement due to its non-competitiveness, the government had to intervene in order to accelerate the uptake and its market penetration and also attract the industry from other global markets in order to increase competition i.e. lower the prices.

Within the last years we have seen immense market growth all around the globe; UK markets have grown and developed from almost zero to the eighth biggest solar PV market with almost 1.4 GW installed capacity by December 2012 (DECC, 2013).

My estimations about the PV market in the UK and its point of achieving the grid parity was based upon the industries' views and the electricity (and coal) price movement to-date and future subvention levels as well as equipment price movements.

Conclusion of my research shows that PV technology will need less than a half a decade to become an equally competitive generation source even in the UK, even with more than 50% lower irradiation levels than Spain, for instance. The residential sector will reach grid parity with the electricity grid prices as early as in 2014 (Hypothesis: 2018) considering the maximum market uptake, consequential maximum periodical feed-in tariff reduction and the equipment price drop, considering the following assumptions.

Residential and commercial segment:

- Assumption 1: PV system equipment price will decrease 6% annually.

- Assumption 2: Retail/ wholesale electricity price will increase 3% annually.
- Assumption 3: FIT rate will decrease 14% annually.

Commercial and industrial sector will, according to my analysis, reach grid parity point surprisingly early, in mid- 2013 (Hypothesis: 2020).

In the utility segment, the grid parity is expected to be reached later but still very early – in 2017 where the PV generator will be able to equally compete with the conventional coal-fired generator, as the O&M and carbon costs will increase (however the cost of coal is expected to settle as well as carbon cost due to the CCT technology which will become required by law for coal-fired power generators) whereas further cost reductions in the next decade are expected in the PV technology development.

Utility segment:

- Assumption 1: PV system price will decrease 6% annually.
- Assumption 2: Price of coal will increase 1.5% annually, O&M costs will increase by 2% annually.

I also need to stress the fact that the grid parity findings are based upon the historic industry evolvement and even more on the future framework being established for the growth of the PV in the UK. The PV development assumptions are subject to the realistic future market uptake which depends on the market conditions and could distort the current picture if evolving at a different pace.

I must emphasise that due to the sensibility of the research I have not undertaken the analysis of the financial plans of residential and commercial PV application excluding the FIT tariffs as this would not represent current realistic market conditions, and would thoroughly change the picture and trends of future PV developments, hence realistic support levels were included in the LCOE calculation.

Future suggestions for interesting research would definitely relate to:

1. **Financing**
    - Availability of finance and different finance concepts,
    - Risk evaluation,
    - Mitigating the risk,
    - Improving the risk/cost/performance estimation models.

2. **Technology improvement**
    - Improving efficiencies vs. cost competitiveness.

3. **Regulatory consistency and security**

- Sustainability and predictability of support models and its effect on the market deployment.

These are the areas that will bring importance input to the industry's continuous innovation and progression towards becoming a leading power generation source allowing us a sustainable green future.

The Report of International Energy Agency clearly sums up my thoughts on the role of PV within the renewable energy sector, IEA in its Energy Outlook 2011 (2011, p. 2) states "The age of fossil fuels is far from over, but their dominance declines. Demand for all fuels rises, but the share of fossil fuels in global primary energy consumption falls slightly from 81% in 2010 to 75% in 2035; natural gas is the only fossil fuel to increase its share in the global mix over the period to 2035. In the power sector, renewable energy technologies, led by hydropower and wind, account for half of the new capacity installed to meet growing demand." At the pace of growth of the PV sector, it will very soon become a paramount segment in the electricity generation mix.

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POVZETEK/ ABSTRACT

V nenehno rastočem globalnem okolju potreba po električni energiji konstantno narašča. Tako industrija kot gospodinjstva porabijo več električne energije kot kadarkoli prej. Globalna poraba se približuje točki kjer konvencionalni viri energije (nafta, premog in zemeljski plin) postajajo redki, stroški njihovega pridobivanja in distribucije k končnim uporabnikom pa skokovito naraščajo. Najpomembneje pa je dejstvo, da rast globalnega povpraševanja po električni energiji predstavlja veliko grožnjo okolju.

Države in energetska podjetja se zavedajo potrebe po razširitvi svojih portfeljev generatorjev električne energije z namenom zmanjšati odvisnosti od čedalje bolj negotove in nestabilne razpoložljivosti energentov, kar bo resno vplivalo na gibanje tržnih cen električne energije. Velika Britanija pričakuje pomanjkanje dobave električne energije do leta 2020, čemur bo botrovalo pomanjkanje kapacitet proizvodnje električne energije in nezadostna dobava zemeljskega plina, slednja naj bi vrhunec dosegla leta 2015 (Constable & Sharman, 2008, str. 30). Na angleškem trgu je prisoten naraščajoč trend gibanja cen električne energije, ki so v zadnjih dvajsetih letih narasle za ca. 75 odstotkov (National Grid, 2011, str. 16).

Zgoraj omenjeni razlogi so, skupaj z obvezujočimi zakonodajnimi predpisi, ki narekujejo zmanjšanje izpustov toplogrednih plinov, poglavitni razlog za postopen prehod k nizkoogljičnim tehnologijam. A za to so potrebne določene spremembe trga električne energije, ki se nanašajo predvsem na višjo stopnjo liberalizacije in decentralizacije proizvodnje ter distribucije električne energije. Vlade intenzivno spodbujajo razvoj tehnologij obnovljivih virov kar kaže na to, da ta segment države jemljejo čedalje bolj resno. To spodbujajoče dejstvo nakazuje na to, da lahko v naslednjih dveh desetletjih pričakujemo temeljite spremembe v sektorju proizvodnje ter distribucije električne energije, kjer bodo generatorji iz obnovljivih virov prispevali pomemben delež v globalnem portfelju proizvodnje električne energije.

Lastniki ter upravljalci energetskih družb se že danes soočajo s pomembnimi strateški odločitvami glede vključitve obnovljivih generatorje v portfelje svojih podjetij, kar kaže na velik potencial alternativnih virov energije, še posebej fotovoltaike (Berry, 2008, str. 5). Do nedavnega so bili konvencionalni generatorji električne energije prva izbira energetskih podjetij, danes pa se kot alternative ponujajo prihajajoče tehnologije, ki so precej manj intenzivne v smislu porabe surovin vendar enako ali celo bolj stroškovno učinkovite ter bolj trajnostne kot kadarkoli prej.

Angleška vlada je, kot večina drugih članic Evropske unije, vzpostavila podporne sheme za spodbujanje proizvodnje električne energije iz obnovljivih virov kot so vetrna, sončna ter vodna energija. Te tehnologije so bile manj kot pred desetletjem v povojih, in daleč od

tega, da bi bile komercialno dovolj privlačne ter zato nujno potrebne podpore vlade, ki so edine ki bi lahko pospešile razvoj in tako omogočale prodor fotovoltaike na trg.

Tako v Veliki Britaniji kot v drugih državah Evropske unije se fotovoltaična tehnologija hitro približuje točki, kjer bo postala prevladujoča koncept proizvodnje električne energije iz obnovljivih virov. Glavne lastnosti, ki omogočajo fotovoltaiki tako hiter in velik prodor na trg je predvsem njena vsestranskost, učinkovitost ter nizka stopnja tveganja investicije. Tehnologije obnovljivih virov zaradi ugodnih državnih spodbud beležijo skokovito rast na svetovnih trgih. Ta trend rasti je pričakovati tudi v prihodnje, v različnih geografskih regijah. V letu 2011 je bilo v Veliki Britaniji kar 9,5 odstotka električne energije proizvedene iz obnovljivih virov energije, kar je kar 2,7 odstotka več kot leta 2010. V zadnjih letih je segment fotovoltaike najhitreje rastoči segment med vsemi obnovljivimi tehnologijami (DECC, 2012, str. 45).

Hitra rast v zadnjih nekaj letih je pripeljala k ostrem povečanju konkurence na trgu fotovoltaične industrije kar je povzročilo še hitrejšo rast in razvoj tehnologije ter bistveno znižanje cen fotonapetostnih modulov. Posledično se je razmah med fotonapetostno in konvencionalno proizvodnjo električne energije začel zmanjševati, kar pomeni da se stroški proizvodnje električne energije fotonapetostnih generatorjev približujejo stroškom proizvodnje električne energije konvencionalnih generatorjev. Fotovoltaična industrija postaja čedalje bolj neodvisna od finančnih podpor držav in bo postopoma postala neposredna konkurenca konvencionalnim generatorjem električne energije po vsem svetu.

Strošek proizvodnje električne energije fotonapetostnih generatorjev (tako imenovani LCOE – angl. *Levelized cost of Electricity*) je glavno orodje, ki nam služi kot glavni kazalec izvedljivosti projekta generatorja električne energije ter omogoča neposredno primerjavo stroškov proizvodnje električne energije različnih vrst generatorjev in tehnologij.

Raziskovalna hipoteza

»Sončna energija naj bi v Veliki Britaniji dosegla stroškovno konkurenčnost konvencionalnim energetskim virom leta 2020. Vendar upoštevajoč dejstvo, da je električna energija distribuirana rezidenčnem sektorju najdražja (predvsem zaradi stroškov distribucije in vzdrževanja omrežja), se zatorej moja hipoteza konkurenčnosti do leta 2020 nanaša zgolj na industrijski sektor. Na rezidenčnem trgu predvidevam, da bo stroškovna konkurenčnost dosežena že prej, in sicer leta 2018.«

Upoštevajoč dejstvo, da cene fotonapetostnih modulov upadajo precej hitreje kot narašča cena električne energije iz omrežja, lahko z gotovostjo sklepamo, da je predvsem rezidenčni trg fotovoltaične energije v Veliki Britaniji precej blizu prvi fazi konkurenčnosti električni energiji iz omrežja, če ni te faze ponekod celo že dosegla. To pomeni da je strošek proizvodnje električne energije ali »LCOE« enak ali nižji strošku odkupa električne energije iz omrežja. Tu je pomembno izpostaviti še en pomemben faktor, in sicer nerazvitost in nerazpoložljivost tehnologij shranjevanja električne energije rezidenčnih fotonapetostnih sistemov. Namreč skoraj polovico električne energije, ki jo fotonapetostni sistem proizvede, tipično gospodinjstvo v Veliki Britaniji izvozi, saj je večina električne energije je proizvedene v času, ko je sonca največ in je poraba najmanjša, največja poraba pa takrat, ko sonca ni ter je proizvodnja električne energije iz fotonapetostnega sistema minimalna oziroma je ni. To pomeni, da namesto porabe lastne proizvedene elektrike, gospodinjstvo le-to proda v omrežje ter jo odkupi nazaj, ko jo potrebuje – po tržni ceni, kar predstavlja znižanje donosnosti investicije fotonapetostne elektrarne.

Glavni trije predpogoji, ko se navezujejo na zgornjo postavljeno hipotezo:

- Obstoj predvidljive in trajnostne energetske zakonodaje (kot obstoječa ali še bolj pregledna in trajnostna), ki spodbuja konkurenco na trgu ter razvoj novih tehnologij.
- Vsaj ohranitev oziroma nadaljnje zmanjšanje zakonodajnih in administrativnih ovir za nemoten nadaljnji razvoj trga obnovljivih virov.
- Stroški konvencionalne električne energije se bo neizogibno povečevali po stopnji, ki jo ocenjujeta industrija in stroka. Razlogi za porast cen so predvsem posledica zmanjševanja razpoložljivosti surovin, povečanje stroškov vzdrževanja omrežij, itd.

O FOTOVOLTAIKI

Fotovoltaična oziroma fotovoltaična tehnologija nam omogoča proizvodnjo električne energije na čist, nemoteč in trajnosten način. Za to uporablja najrazpoložljivejši vir energije na Zemlji – Sonce. Fotovoltaična tehnologija ne povzroča nikakršnih izpustov škodljivih emisij ogljikovega dioksida – poglavitnega onesnaževalca ozračja in povzročitelja podnebnih sprememb.

Kaj je fotovoltaika in kako deluje

Fotonapetostni proces omogoča pretvorbo neposredne sončne svetlobe, ki je eden najbolj bogatih virov energije na Zemlji, v enosmerni tok električne energije (angl. *DC current*). Ta je proizveden z uporabo fotonapetostnih celic, sestavljenih iz polprevodnega materiala, najpogosteje silicija. Sončna svetloba pade na površino fotonapetostne celice, kjer se čez plasti celic ustvari električno polje, kar povzroči dva nasprotna si naboja – en pozitiven in en negativen. To povzroči neravnovesje elektronov med sprednjim in zadnjim delom celice ter nastanek električnega toka. Večja je intenzivnost sončnega obsevanja, višja je proizvodnja električne energije iz sončne celice/modula.

Energija, pridobljena iz sončne celice se meri v vršni moči – kilovatih (kWp). To je hitrost, s katero fotonapetostna celica/modul proizvaja električno energijo ob maksimalni učinkovitosti/vršni moči, v polnem sončnem obsevanju. Fotonapetostni moduli, ki združujejo večje število celic, so na voljo v različnih oblikah in velikostih ter so primerni za strešno montažo ali montažo na tleh. Ta tehnologija omogoča možnosti različnih aplikacij: od vesoljskih satelitov, uporabe v prometu pa vse do sončnih kalkulatorjev, ur, uličnih svetilk, itd.

Prve praktične aplikacije fotovoltaike je začela izvajati NASA, in sicer na satelitih, ki krožijo okoli orbite. Kasneje, leta 1970, se je tehnologija začela uporabljati tudi v komercialne namene ter se sčasoma na zahtevo vlade Združenih držav Amerike in počasi začeli tudi intenzivneje tržiti. Leta 1983 je svetovna proizvodnja fotonapetostnih modulov presegla 9.3 MW.

Fotovoltaika danes

V začetku leta 2012 je fotovoltaična industrija v nekaterih regijah postala že konkurenčna konvencionalnim virom proizvodnje električne energije in tako skorajda neodvisna od državnih spodbud. Tu govorimo predvsem o dveh najbolj zrelih trgih, in sicer Nemčija in Italija, kjer je kapaciteta inštalacij že presegla več gigavatov (v nadaljevanju GW), in kjer fotovoltaika predstavlja pomemben delež proizvedene električne energije v celotnem portfelju generatorjev električne energije (EPIA, 2011, str. 5). Italijanski trg predstavlja skoraj 28 odstotkov vseh inštalacij na svetu (9.3 GW). Sledi ji Nemčija s 25 odstotki in (ca. 7.5 GW) inštaliranih kapacitet (EPIA, 2012, str. 5). Tu lahko vidimo, da evropski trgi odraščajo ter postajajo zrelejši, kar pomeni da se bo rast zaradi nasičenosti trga upočasnila, prav tako je pričakovano postopno znižanje državnih spodbud, v povprečju predvidoma pet odstotkov na letni ravni (IHS iSuppli, 2012).

Intenzivna rast fotovoltaične industrije se je počasi začela usmerjati na trge v razvoju. IMS research (2012) v svojem poročilu izpostavlja ameriške in azijske trge, ki naj bi postali dve najbolj perspektivni regiji in naj bi prispevali k več kot 85 odstotkov vseh inštalacij v letu 2013, medtem ko bo delež evropskega trga fotonapetostnih inštalacij padel za več kot 50 odstotkov.

Prvih šest držav z najvišjimi inštaliranimi kapacitetami v letu 2011 so bile Italija, Nemčija, Združene države Amerike, Kitajska, Japonska in Francija, v tem zaporedju. Novi perspektivni trgi, ki bodo uravnotežili upočasnjeno rast Evropskih trgov so Daljni vzhod ter Severna in Južna Amerika (IHS iSuppli, 2012). Ena od največjih in najhitreje razvijajočih se trgov, ki že kaže prve znake skokovite rasti je Kitajska, ki je prav tako začela z izvajanjem svoji podpornih shem za obnovljive vire energije, kar je že močno spodbudilo rast na domačem trgu (Pinelli et al., 2012, str. 3).

Fotovoltaične tehnologije in njihov prodor na trg

Danes je na trgu veliko tehnologij, vendar le nekaj jih je dovolj tehnološko dovršenih in stroškovno učinkovitih, da bi bile poslovno privlačne in da bi omogočale dovoljšnjo donosnost investicije.

Tehnologija kristalnega silicija

Tehnologija kristalnega silicija (v nadaljevanju c-Si) je trenutno prevladujoča tehnologija na vseh svetovnih trgih ter predstavlja okoli 90 odstotkov celotnega fotovoltaičnega trga (IEA & OECD, 2010b, str. 7). Kristalne silicijeve fotonapetostne celice so izdelane iz tankih slojev, ekstrudiranih iz enega kristala (monokristalni silicij) oziroma iz bloka silicijevih kristalov (polikristalni silicij). Trenutno se učinkovitost tehnologije giblje med 11 in 19 odstotki.

Tankoplastna tehnologija

Druga tehnologija, ki je že prisotna na globalnih trgih, je tako imenovana tankoplastna tehnologija. Tovrstni moduli/celice so izdelani po postopku deponiranja zelo tankih plasti fotoobčutljivih materialov na podporno steklo, nerjaveče jeklo ali plastiko (IEA & OECD, 2010b, str. 24). Proizvodni stroški tankoplastne tehnologije so precej nižji v primerjavi s c-Si tehnologijo, ki je vsebuje več silicija. Nižja cena pomeni tudi sorazmerno nižje izplene – običajno 4–11 odstotna učinkovitost.

Koncentrirana tehnologija

Še ena perspektivna fotovoltaična tehnologija je tako imenovana koncentrirana fotovoltaična tehnologija (CPV), ki za razliko od zgornjih dveh uporablja neposredno sočno svetlobo in jo koncentrira preko optičnih sredstev (običajno leče ali mala ogledala) na manjše površine visoko učinkovitih PV celic. Ta tip tehnologije predstavlja nižje stroške investicije ter povečuje učinkovitost sončne elektrarne. Koncentrirana tehnologija je še v fazi razvoja a predstavlja velik potencial, saj potrebuje za delovanje precej manjše površine kot ostale vrste fotovoltaičnih tehnologij.

Ostale tehnologije

Fotovoltaika je izjemno hitro razvijajoče se industrija, kjer se iz dneva v dan pojavljajo nove tehnologije. Nekateri od njih imajo velik potencial, da postanejo vodilna fotovoltaična tehnologija, a v tem trenutku še niso komercialno tako privlačne kot c-Si tehnologija.

Nekatere najbolj perspektivnih tehnologij:

- Tehnologija koncentrirane sončnih celic (omenjena zgoraj).

- Tehnologija upogljivih celic (angl. *Flexible cells*).
- Tehnologija barvno občutljivih celic (angl. *Dye-sensitized cells*).

Fotonapetosna industrija je trenutno ena najhitreje razvijajočih se panog, saj se namreč zaradi svoje aplikativnosti in modularnosti lahko postavlja ob bok trgom pridobivanja surove nafte, vetrni industriji ter industriji razvoja mobilnih telefonov (Breyer & Gerlach, 2010, p. 4). Ena največjih prednosti fotovoltaike je zagotovo njena modularnost in fleksibilnost, kar pomeni, da obstaja veliko možnosti uporabe tehnologije na različnih ravneh (Breyer & Gerlach, 2010, p. 4). Trenutne potrebe po trajnostni in obnovljivi energiji vodijo fotovoltaiko v množično komercializirano tehnologijo z ogromnim potencialom rasti in zmanjševanja stroškov (IEA & OECD, 2010b, str. 31).

TRG ELEKTRIČNE ENERGIJE V VELIKI BRITANIJI

Velika Britanija se oskrbuje z električno energijo iz portfelja precej dotrajanih konvencionalnih generatorjev elekrične energije, kot tudi z vedno večjim številom nizkoogljičnih in obnovljivih generatorjev (DECC, 2012, str. 4):

- jedrskih elektrarn,
- plinsko-parnih elektrarn (angl. *Combined Cycle Gas Turbine – CCGT*),
- termoelektrarn na nafto in premog,
- črpalnih elektrarn (angl. *Pumped storage*),
- obnovljivih generatorjev (vetrni generatorji, vodni in sončni generatorji).

V letu 2011 je skupna kapaciteta proizvedene električne energije dosegla 365 teravatnih ur (v nadaljevanju TWh), kar je v primerjavi z letom 2010, ko je ta znašala 381 TWh, kar za 4,2 odstotka manj. Uvoz električne energije v letu 2011 pa se je povečal na 6.222 gigavatnih ur (v nadaljevanju GWh), ki je približno trikrat več kot v letu 2010 (2,663 GWh). Kljub dejstvu, da se je tako poraba kot proizvodnja električne energije v 2011 zmanjšala (vendar to ni reprezentativen trend), številke jasno kažejo na povečanje uvoza električne energije, kar pa je vsekakor povezano z dodatnimi stroški (DECC, 2012, str. 41). V Veliki Britaniji je več kot očiten trend hitrega naraščanja stroška proizvodnje električne energije. Vsi indikatorji kažejo, da se trg približuje točki, ko bo energetski položaj Velike Britanije postajal negotov zaradi rasti cen in nestabilnosti oziroma nezanesljivosti oskrbe z energenti (Constable & Sharman, 2008, str. 4–5).

Pričakovana je rast cen električne energije od 2 do 6,7 odstotkov na letni ravni (EPIA, 2011, str. 23–24). Glavni razlogi za to so precej očitni, in sicer: rast cen surovin, stroškov nadgradnje distribucijskih omrežij, stroškov fiksacije cen in drugih stroškov. To povečanje se eventuelno prenese na končnega potrošnika.

Kjub nestanovitnih makroekonomskih razmer je možno pa precej realno oceniti gibanja cen električne energije v prihodnje, in sicer na podlagi zgodovinskih gibanj cen električne energije na trgih.

Za to je potrebno najprej razlikovati med različnimi tržnimi segmenti energetskega sektorja:

- proizvodnja in prodaja električne energije na drobno (končnim kupcem),
- proizvodnja in prodaja električne energije na debelo (večji odjemalci),
- trgovanje z električno energijo (angl. *Power exchange*),
- proizvodnja električne energije (proizvajalci električne energije).

Spodnja ugotovljena trenda bosta služila kot podlaga za nadaljnje analize:

- 75 odstotno povišanje cen od leta 2000 do 2010 na trgu električne energije na drobno,
- 30 odstotno povišanje cen od leta 2000 do 2010 na trgu električne energije na debelo.

Ko govorimo o proizvodnji električne energije je pomembno izpostaviti dva pojma: Pasovna in vršna obremenitev proizvodnje električne energije. Pasovna obremenitev je minimalna količina energije, ki jo mora proizvajalec oziroma elektrodistribucijsko podjetje zagotoviti in imeti na voljo kupcem glede na pričakovano povpraševanje na trgu. Največja obremenitev pa na drugi strani predstavlja večjo kot običajno raven povpraševanja po električni energiji in predstavlja največjo možno porabo odjemalcev električne energije. Večina konvencionalnih generatorjev zaradi svoje velikosti ter vnaprej določene oziroma dodeljene pasovne obremenitve postane zelo toga in draga, ko gre za pokrivanje vršnih obremenitev. Zato v teh primerih manjši in srednje veliki generatorji, ki so bolj prilagodljivi in odzivni, prevzemajo in zadostijo povpraševanje/potrebe po vršnih obremenitvah proizvodne električne energije.

Fotonapetostna elektrarna je v teh primerih lahko zelo učinkovita, saj proizvede največ električne energije v opoldanskih urah – v času, ko je povpraševanje po električni energiji najvišje in ko je električna energija iz konvencionalnih najdražja, saj je tudi najbolj potrebovana. Zato so fotonapetostni proizvajalci električne energije v dobrem položaju, da postanejo alternativa obstoječim malim in srednje velikim konvencionalnim generatorjem električne energije in si sčasoma utrejo pot v industrijskem segmentu proizvodnje električne energije. Slabost fotonapetostnega generatorja pa je nezmožnost dobave konstantne količine električne energije, ki zaradi nenadzorovanih dejavnikov lahko precej niha (različne količine sončnega obsevanja v določenem času dneva ter posledično nestabilna proizvodnja in dobava električne energije), kar prinaša nižjo stopnjo predvidljivosti proizvedene električne energije v konicah. Prav nasprotno pa termoelektrarna na premog lahko zagotovi konstantno količino energije ob določenem času dneva, medtem ko sončne elektrarne tega ne zmore.

KONKURENČNOST FOTONAPETOSTNEGA GENERATORJA

Konkurenčnost fotonapetostnega generatorja je v ospredju razprave o stroškovni konkurenčnosti sončne energije. Da bi ugotovili na kateri stopnji konkurenčnosti je trenutno fotonapetostni generator v primerjavi s konvencionalnim proizvajalcem električne energije, moramo analizirati stroške proizvodnje električne energije iz fotonapetostnega generatorja v razmerju z njegovimi prihodki, ali z drugimi besedami – dinamična omrežna pariteta (angl. *»Dynamic Grid Parity«*), oziroma v razmerju s stroški proizvodnje drugih (konvencionalnih) proizvajalcev električne energije, ali z drugimi besedami – konkurenčnost na proizvodni ravni (angl. *»Generation Value Competitiveness«*).

Dinamična omrežna pariteta je opredeljena kot točka, kjer je v določen tržnem segmentu v določeni državi neto sedanja vrednost dolgoročnega neto zaslužka (upoštevajoč prihodke, prihranke, stroške in amortizacijo) iz proizvodnje električne energije iz fotonapetostne elektrarne enaka dolgoročnim stroškom za pridobivanja konvencionalne električne energije iz omrežja (EPIA, 2011, str. 5).

Konkurenčnost električne energije za končne potrošnike elektrike proizvedene iz fotonapetostnega generatorja je opredeljena kot dinamična omrežna pariteta. Zaradi različnih pogojev na trgih (različne ravni sončnega obsevanja ter drugih razmer na trgu) se dinamična omrežna pariteta ne bo zgodila hkrati po vsej Evropi. Ob trenutnem padcu proizvodnega stroška električne energije lahko dinamično omrežno pariteto v industrijskem segmentu v Italiji mogoče doseči že leta 2013. Ta se bo in nato razširila po vsej celini v različnih tržnih segmentov (EPIA, 2011, str. 5).

Konkurenčnost sončne energije na proizvodni ravni je opredeljena kot točka, kjer je v določeni državi dodajanje fotonapetostnega generatorja v portfelj generatorjev električne energije postane enako zanimiva s stališča vlagatelja o mnenju kot investiranje v tradicionalnem generator na osnovi tehnologije fosilnih goriv (EPIA, 2011, str. 5).

EPIA (2012, str. 15) predvideva od 36 do 51 odstotni padec cen komponent fotonapetostnega sistema v naslednjem desetletju, v vseh segmentih fotovoltaike. Njihove ocene temeljijo na preteklih stopnjah rasti cene električne energije kot tudi preteklega gibanja cen komponent fotonapetostnega sistema. Upoštevajoč povečanje učinkovitosti tehnologij ter pojava ekonomij obsega v bolj razvitih trgih, bo sončna energija postala cenovno konkurenčna konvencionalnim virom električne energije pred letom 2020. Stopnja rasti konkurenčnosti fotovoltaike pa bo odvisna od ravni sončnega obsevanja na posameznih geografskih lokacijah, cene električne energije na teh posebnih območjih, kot tudi politično zavezanost in podporo vlad k razvoju in vzdrževanju trajnostnih zakonodajnih okvirov ter prizadevanju k zmanjšanju kakršnih koli motenj, ki bi lahko zavirale rast fotovoltaične industrije na teh trgih.

Obstaja kar nekaj inovativnih načinov s katerimi angleška vlada spodbuja rast in razvoj trga tehnologij proizvodnje električne energije z nizkimi emisijami ogljika. Poglavitna shema je tako imenovana »Shema zagotovljenega odkupa električne energije« (angl. »*Feed-in tariff scheme*«), kjer država zavezuje energetska podjetja k odkupu električne energije proizvedene s strani končnih uporabnikov, slednji pa so upravičeni do subvencije v obliki denarnega izplačila za vsako proizvedeno uro električne energije ter dodatnega nadomestila za izvožen presežek električne energije. Končni uporabnik lahko z lastno proizvodnjo električne energije prav tako zmanjša svoj račun za elektriko saj le-to istočasno tudi porabi. »*ROCs*« je shema namenjena večjim projektom, kjer je investitor upravičen do fiksnega nadomestila za vsako megavatno uro (v nadaljevanju MWh) proizvedene električne energije, ki jo nato še vedno lahko proda na prostem trgu. *»The Green Deal«* je še ena shema namenjena predvsem rezidenčnim fotonapetostnim sistemom. Njen glavni namen je ponuditi končnim uporabnikom možnost nakupa sončne elektrarne brez vnaprejšnjega plačila in omogočiti odplačilo fotonapetostnega sistema skozi plačilo računa za elektriko. Plačilo ni vezano na končnega uporabnika temveč na objekt, kjer je nameščen fotonapetostni sistem. Še ena izmed shem je tudi »Zelena investicijska banka« (angl. »*The Green Investment bank*«), tj. finančna shema ustanovljena s strani vlade, katere glavna naloga je privabljanje zasebnih sredstev za financiranje »zelenih« investicij. Poleg tega obstaja tudi več vrst olajšav, ki so namenjene drugim »manj priljubljenim« tehnologijam obnovljivih virov.

PROIZVODNI STROŠEK ELEKTRIČNE ENERGIJE – LCOE (angl. Levelized cost of electricity)

Proizvodni strošek električne energije (v nadaljevanju LCOE) je glavni in kazalnik, ki prikazuje upravičenost izvajanja in razvoja projektov proizvodnje električne energije. LCOE je kratica za »Levelized cost of electricity« in je opredeljen kot neposredna primerjava stroškov proizvodnje energije iz različnih virov. LCOE je običajno izražen v valuti/kilovatno uro. V tej raziskavi nam bo LCOE omogočal ugotovitev, izračun in primerjavo stroškov električne energije, proizvedene s konvencionalnim generatorjem električne energije ter električne energije proizvedene z generatorjem iz obnovljivih virov.

Prihodnja gibanja LCOE fotonapetostne elektrarne so rezultat konkurenčnosti cen komponent na trgu (moduli, razsmerniki, konstrukcijski elementi) kot tudi konkurenčnosti cen razvojnih projektov (profitne marže inštalaterjev in razvijalcev projektov). EPIA (2012, str. 16) meni, da je tako v Veliki Britaniji kot v ostalih članicah Evropske Unije do konca tega desetletja pričakovati kar 50 odstotno znižanje LCOE. Vendar pa območja z višjimi ravnmi sončnega obsevanja najbolj vplivajo na to predpostavko. Kljub temu je vseeno pričakovano znatno zmanjšanje LCOE tudi v območjih z nižjimi stopnjami obsevanja, kot v je to Velika Britanija.

ANALIZA KONKURENČNOSTI FOTONAPETOSTNEGA GENERATORJA

V analitičnem delu raziskave je bila izvedena finančna analiza treh fotonapetostnih generatorjev (rezidenčni, industrijski ter t.i. »solarni park«) ter enega konvencionalnega generatorja na premog. Glavni namen je ugotoviti, ali lahko fotonapetostni generator konkurira v prvih dveh primerih tržni ceni električne energije (tržni ceni elektrike prodane na »drobno« ter »debelo«) – t.i. dinamična stroškovna konkurenčnost proizvodnje električne energije. V drugem primeru pa je namen ugotoviti ali je fotonapetostni generator lahko konkurenčen konvencionalnemu generatorju električne energije (ceni elektrike na proizvodnji ravni) – t.i. stroškovna konkurečnost proizvodnje električne energije. Raziskava je vključevala analizo strukture stroškov ter analizo virov prihodkov, ki so potrebni za izračun LCOE – proizvodnih stroškov električne energije. Za celovito primerjavo obeh vrst generatorjev je potrebno preučiti gibanje tržnih cen električne energije, cene goriva, cene opreme, kot tudi pričakovana gibanja vladnih regulativnih okvirov. Vsi ti dejavniki močno vplivajo na natančnost izračuna LCOE, ki indicira izvedljivost projekta in s tem njegovo konkurenčnost.

UGOTOVITVE

Namen analitičnega dela raziskave je bil potrditi oziroma ovržti glavno postavljeno hipotezo, ki je temeljila na mojem poznavanju energetskega trga v Veliki Britaniji, ter predvidevanjih in napovedih industrije in akademske sfere.

Rezidenčna fotonapetostna elektrarna vs. cena električne energije iz omrežja

Analiza stroškov, prihodkov projekta, tržnih cen ter trendov razvoja cen električne energije kažejo na to, da bo ob obstoječem trendu naraščanja cen električne energije ter upadanja cen komponent fotonapetostne elektrarne, bo strošek proizvodnje električne energije rezidenčnega sistema v Veliki Britaniji na enaki ravni kot cena električne energije iz omrežja začetkom leta 2014, kar je precej hitreje kot pričakovano. Spremenljivi faktorji v enačbi izračuna LCOE so temeljili na spodnjih predpostavkah:

- Cena komponent fotonapetostnega sistema bo padala za 6 odstotkov na letni rani.
- Cena elektrike na trgu na »drobno« bo naraščala za 3 odstotke na letni ravni.
- Državne spodbude bodo padale za 14 odstotkov na letni ravni.

Padec spodbud za obnovljive generatorje se opira na »idealni scenarij« kar pomeni, da so inštalirane dovoljšnje kapacitete, ki vzdržujejo redno nižanje proizvodne tarife za katero je načrtovan 3,5 odstotni padec vsako četrtletje. Na ta način ima namen Velika Britanija namen doseči konkurenčne ravni LCOE do leta 2020 brez spodbud.

Kot že omenjeno v prejšnjih poglavjih, pomemben dejavnik in pospeševalec rasti konkurenčnosti rezidenčnega fotovoltaike v Veliki Britaniji bi bil koncept »Net Metering-a« oziroma tako imenovanega neto merjenja, ki bi potrošnikom ponudil kredit za izvoz presežkov električne energije. Ti bi jo, kadar potrebno, uvozili v gospodinjstvo brez stroškov nakupa elektrike iz omrežja.

Industrijska fotonapetostna elektrarna vs. cena električne energije iz omrežja

Analiza stroškovne konkurenčnosti je v tem primeru primerjala stroškovno strukturo projekta ter prihodke industrijskega generatorja v velikosti 1 megavat (v nadaljevanju MW). Pridobljeni kazalci so omogočili izračun LCOE, ki je bil primerjan s ceno električne energije na trgu na »debelo«. Tu so cene električne energije precej nižje zaradi nižjih stroškov distribucije. V tem primeru so bili prav tako v LCOE izračunu prav tako upoštevane spodnje predpostavke:

- Cena komponent fotonapetostnega sistema bo padala za 6 odstotkov na letni rani.
- Cena elektrike na trgu na »debelo« bo naraščala za 3 odstotke na letni ravni.
- Državne spodbude bodo padale za 14 odstotkov na letni ravni.

Rezultat primerjave LCOE je presenetljivo pokazal, da bo stroškovna konkurenčnost električne energije proizvedene z fotonapetostno elektrarno industrijske velikosti dosegla nivo cen električne energije na trgu na debelo že v sredini leta 2013.

Razlog za tako hitro rast konkurenčnosti tovrstnih fotonapetostnih elektrarn je po mojih ocenah kombinacija agresivnosti rasti trga, ki je posledica trenutnih trendov gibanja cen komponent, ki so še nižje kot v rezidenčnem segmentu zaradi večjih količin ter posledično večjih kupnih moči investitorjev. Pomemben dejavnik je tudi dejstvo, da industrijski objekti porabijo v povprečju več kot 80 odstotkov elektrike v času ko fotonapetostna elektrarna proizvaja največ električne energije, zatorej so doseženi donosi še višji.

Ponovno je potrebno opomniti na dejstvo, da se padec spodbud za obnovljive generatorje opira na »idealni scenarij«, tj. v primeru, da so inštalirane dovoljšnje kapacitete, ki vzdržujejo redno zmanjšanje zagotovljene odkupne cene električne energije za katero je načrtovan 3,5 odstotni padec vsako četrtletje.

»Solarni park« vs. termoelektrarna na premog

V tem primeru je bil v analiziran strošek proizvodnje električne energije oziroma LCOE fotonapetostnega generatorja velikosti 359 MW katerega namen je izključno proizvodnja ter prodaja elektrike. Tega sem primerjal neposredno s stroškom proizvodnje električne energije termoelektrarne primerljive velikosti. Zaradi specifičnosti kalkulacije stroška proizvodnje električne energije oziroma LCOE je potrebno upoštevati precej več kompleksnih dejavnikov, ki v veliki meri vplivajo na izplen in učinkovitost elektrarne. »Superkritični« tip termoelektrarne na premog ne vključuje tehnologije zajemanja izpustov ogljikovega dioksida v okolje, kar v veliki meri poveča operativne stroške investicije. Prav ti so poglavitni dejavnik, ki jih je potrebno posebno podrobno preučiti, namreč stroški goriva (premoga) predstavljajo velik del investicije. Prav tako je potrebno upoštevati gibanje cen premoga kot glavnega energenta z namenom kar najpreciznejše izračunati proizvodni strošek električne energije analiziranim generatorjem.

Rezultati analize kažejo, da je fotonapetostni generator tudi v segmentu proizvodnje električne energije lahko še kako konkurenčen konvencionalnim generatorjem. Tovrstni fotonapetostni generator ima potencial doseči stroškovno konkurenčnost elektrarni na premog že precej zgodaj, in sicer v začetku leta 2017, kar je osupljiv rezultat. Tu je potrebno pripomniti, da je ta tip fotonapetostnega generatorja država ne spodbuja na nikakršen način (ne temelji na shemi »*2ROCs*«, ki je v Veliki Britaniji trenutno aktualna za večje sisteme). Prihodki in donosi temeljijo izključno na pogodbeno določeni odkupni električne energije (kupoprodajna pogodba), ki jo sklene investitor s kupcem električne energije.

V tem primeru fotonapetostnega generatorja je bila v LCOE izračunu upoštevana spodnja predpostavka:

- Cena komponent fotonapetostnega sistema bo padala za 6 odstotkov na letni ravni.

Za izračun gibanja stroška proizvodnje električne energije generatorja na premog je potrebno vključiti tako trende gibanja cen premoga kot tudi stroške obratovanje in vzdrževanja ter stroške sistema za zajemanje in shranjevanje ogljika, pa tudi okoljske takse. Izračun je temeljil na spodnjih predpostavkah:

- Cena premoga se bo povečevala za 1,5 odstotka na letni ravni.
- Ostali operativni stroški in stroški vzdrževanja se bodo povečevali za 2 odstotka na letni ravni.

Ugotovitve so veliko bolj optimistične od predpostavk industrije in akademske sfere, prav tako tudi moje hipoteze.

UPORABA DOGNANJ O STROŠKOVNI KONKURENČNOSTI

Rezultati analize presenetljivo kažejo optimistično sliko konkurenčnosti fotonapetostnih generatorjev tržnim cenam električne energije in tudi konvencionalnim generatorjem električne energije, v tem primeru termoelektrarne na premog.

Glavni razlog za presenetljive rezultate je predvsem upoštevanje idealnih scenarijev rasti trga. Realna situacija se lahko precej razlikuje v primeru, da ne bo dosežena dovoljšnja rast trga, kar pa je tudi močno povezano z razpoložljivostjo finančnih struktur in nasploh ugodnim investicijskim okoljem. Razpoložljivost financiranja je eden najpomembnejših dejavnikov, ki resno kroji usodo in narekuje hitrost razvoja fotovoltaične industrije, tako v Veliki Britaniji kot drugje po svetu.

SKLEPI IN PRIHODNJE DELO

Sončna energija ima svetlo prihodnost tudi v Veliki Britaniji. Zaradi nedostopnosti v preteklosti in počasnega napredovanja tehnologije je bila fotovoltaična tehnologija precej nekonkurenčna še posebej v državah z nizkimi ravnmi sončnega obsevanja. Vlade so morale posredovati, da bi pospešile zagon in tržni prodor industrije, kar je sčasoma povzročilo porast donosnosti projektov in posledično »prebudilo« industrijo ter tako spodbudilo konkurenco, zniževalo cene ter povečalo konkurenčnost panoge.

V zadnjih letih smo bili priča izjemni rasti trgov po vsem svetu. Angleški fotovoltaični trg je zrasel iz skoraj nič v 2009 do 8. največjega trga z skoraj 1.4GW nameščenih zmogljivosti do decembra 2012 (DECC, 2013).

Zaključki raziskave kažejo, da bo fotovoltaična tehnologija v manj kot pol desetletja postala povsem konkurenčen vir energije tudi v Veliki Britaniji, kjer je raven sončnega obsevanja skoraj za 50 odstotkov nižja kot je raven sončnega obsevanja v Španiji.

Poročilo Mednarodne agencije za energijo dobro povzema zgornje ugotovitve o vlogi fotovoltaike ter na splošno o sektorju obnovljivih virov energije v prihodnje. IEA v svojem »Energy Outlook 2011« (2011, str. 2) navaja: »Doba fosilnih goriv še zdaleč ni končana, vendar njihova dominantnost hitro upada.«

Če sklepamo po dinamiki rasti sektorja fotovoltaike, ki smo ji priča danes, bo ta tehnologija zelo kmalu postala najpomembnejši segment v portfelju proizvodnje električne energije, globalno.

ABSTRACT

The following work is an insight into the future of solar energy. For the first time after centuries of fossil fuels leading the forefront in electricity generation, the renewable resources have started to show a potential to become serious contributors to the global energy generation mix. It has grown from a small niche segment represented by “the green enthusiasts” a couple of decades ago, to one of the fastest growing industries in the world today. The most astonishing aspect is the pace of its growth, which is a true phenomenon. The main purpose of the paper is to analyse and showcase the evolvement of photovoltaics to the point where it is today, as well as indicate the potential and prospects that photovoltaics has within the UK and global energy sector.

My intention is to give out a clear message that photovoltaic technology is increasing in its importance and is being considered as a future paramount energy production source. Solar energy has started to shift the public’s mind-set as an upcoming shortage of non-abundant raw materials will force us to start thinking in a more sustainable way. This abstract introduction into the potential of solar energy is not just a fictitious image of an ideal world, but the manifestation of an immense progress in the last decade, that gives us realistic insights into the future of the industry’s development.

In order to verify the statements regarding the fast evolvement of the PV segment, I have decided to undertake an empirical analysis of renewable and coal-powered conventional electricity generators, to find out the current level of competitiveness of photovoltaic generators compared to the electrical from conventional resources. To get a proper benchmark I have first gathered the latest views and opinions on the grid parity notion – a point where the cost of electricity production from alternative energy sources is equal or lower to the cost of producing the electricity from conventional energy sources. Industry predicts that the UK solar generators to be competitive by 2018 on the residential front, and 2020 on the commercial and utility level. Analysis has brought me to some very surprising findings.

The pace of growth and the uptake of the PV on world’s markets, initially triggered by governmental support schemes, have been immense. This has eventually reflected in a significant decrease in the PV system prices and increased competition in the market. This continuous trend leads the PV industry fast towards the stage of grid competitiveness, whereby it shall become competitive to the UK conventional energy generators within the forthcoming years.

An astonishing evolvement of a technology that is present in the market for just over two decades has been reflected in a double digit market share in several European countries. All this is a result of smartly-led energy politics by the governments. If this can be maintained for the next decade just imagine how bright the future can be!