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On integrating large shares of variable renewables into the electricity system

Reinhard Haas[a]

[a]*Energy Economics Group, Vienna University of Technology*
Vienna, Austria
E-mail: haas@eeg.tuwien.ac.at

Abstract

In recent years increasing shares of intermittent renewable energy sources (RES) have changed the usual pattern of electricity markets especially in Western Europe remarkably. A major finding is that the way to a sustainable electricity system based mainly on RES could be paved in the next years without further significant subsidies. In this context we emphasize especially the considerable price decreases of PV which has brought this technology close to cost-effectiveness on household level, soon without any further need for subsidies.

Keywords: electricity markets; Renewables; flexibility; economics; supply security;

1. Introduction

In recent years, in a number of countries, mainly Germany, electricity generation from various variable renewable energy sources (RES) has been growing at remarkable rates. Overall in the EU-28 between 1990 and 2013 "new" renewables (excluding hydro) has been growing from less than 1% to about 13%, mainly from wind (Fig. 1). These increasing shares of variable RES have (especially in Germany) changed the usual pattern of electricity markets in Western Europe significantly[1-5] .

These developments have led to the situation that the development of electricity markets is currently at a crucial crossing. On the one hand, the way to a sustainable electricity system based mainly on RES could be paved in the next years without further significant subsidies. In this context we emphasize especially the considerable price decreases of PV which has brought this technology close to cost-effectiveness on household level, soon without any further need for subsidies.

On the other hand, there are forces which try to retain the old centralized fossil and nuclear-based generation planned economies. Centralized capacity payments (e.g. in France) and subsidies to eternity (e.g. for nuclear in England) should help to freeze this anachronistic pattern.

The core objective of this paper is to provide insights on the conditions that will bring about competitive sustainable electricity systems with remarkably higher shares of variable RES.

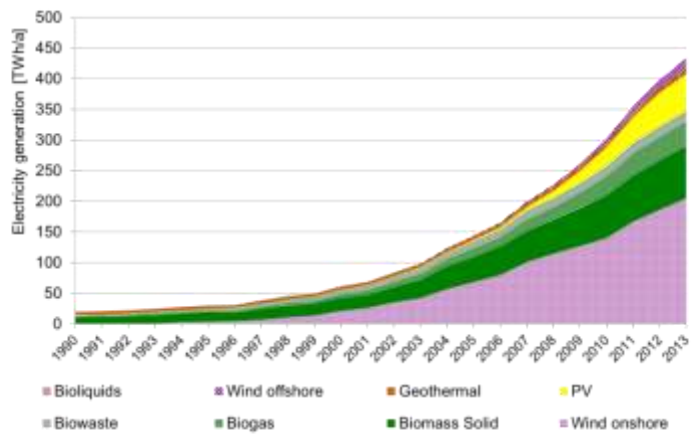

Figure 1. Development of electricity from "New" renewable energy sources (excluding hydro) in EU-28 between 1990 and 2013, in TWh (Source: EUROSTAT, numbers for 2013 preliminary)

2. Method of approach: how prices come about

This section discusses how the liberalization of the electricity markets in Europe changed the formation of prices in wholesale markets, and – as further described in Section 3 – the impact of rising shares of renewables on spot market electricity prices.

The liberalization process in Europe started in the late 1980s in the UK and gradually migrated to continental Europe with the 1999 the EU-directive [6]. One of the major features of the liberalized electricity markets was that the pricing regimes changed. In former regulated markets, prices were established by setting a regulated tariff, which was calculated by dividing the total costs of supplying service by the number of kWhs sold – with some differences between different groups of customers, see Fig. 3. The major change that took place after the liberalization was that prices were now expected to reflect the marginal costs of electricity generation ([7]). At the time when liberalization started considerable excess capacities existed in Europe. This led to the expectation that prices will (always) reflect the short-term marginal costs (STMC) as illustrated in Fig. 2. The major reason for this expectation was that there were huge depreciated excess capacities at the beginning of liberalisation!

The graph shows a typical merit order supply curve with conventional capacities including large hydro. The typical historical pattern of electricity generation in the European electricity markets consisted of conventional fossil, nuclear and hydro capacities. Since the late 1990s, most of the time nuclear contributed the largest share, followed by fossil and hydro. Non-hydro renewables were not a significant factor until recent times.

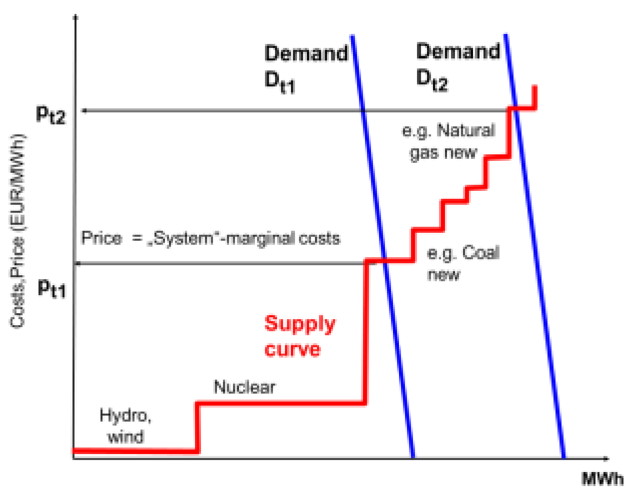

Figure 2. How prices come about in markets with conventional capacities including large run-of-river hydro

As shown in Fig 2, the intersection of the supply curve with demand determines the market clearing price at the system marginal costs. The curve Dt1 shows the demand curve at times of low demand e.g., at night and pt1 is the resulting (low) electricity price. Dt2 shows high demand times, e.g., at noon, and pt2 is the resulting (high) electricity price. The difference between pt2 and pt1 is the so-called price spread further described below. It provides useful information, for example, on the economic attractiveness of storage, which will be of high relevance in markets with large share of renewables. Until recently, the price spread has been of interest mainly with respect to pumped storage. That is to say, during periods when prices are low, water can be pumped into reservoirs; while generating electricity when the opposite is true.

The STMC price regime, illustrated in Fig 2, of course, will not be permanent nor always apply. Once excess generation capacity is exhausted, there will be a shift towards long-term marginal costs (LTMC). Similarly, generators are likely to behave strategically during high demand periods in markets with limited peaking capacity.

3. How variable renewable energy sources impact prices in electricity markets

The rise of renewables will impact spot prices, trading patterns and dispatching of conventional generation The explanation is simple. On a sunny day with ample solar generation, the supply curve is shifted to the right as schematically shown in Fig 3, which essentially pushes nuclear and fossil fueled generation "out of the market.

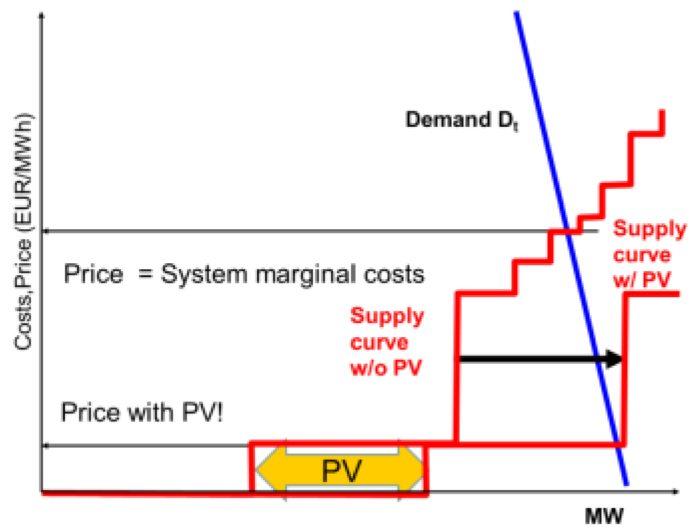

Figure 3. Merit order supply curve with and without additional PV capacities at on-peak time of a bright summer day with short term marginal costs for conventional capacities

Aside from the above-described effects, intermittent renewables will also influence the costs at which fossil generation – especially natural gas – are offered. The reason is that they would lead to much lower full load hours, e.g. only 1000 instead of 6000 h/yr before. Yet, the revenues earned from these hours must cover both the fixed and variable costs, see also Haas [3]. It also provides a detailed discussion of this problem of "missing money".

This leads to the following categories of presumed "problems": (i) Prices decrease to Zero or are even negative at a number of days; (ii) Lacking contribution margin to fixed costs for conventional flexible power plants.

However, what is still open in this discussion is that it is not yet clear, on how many days very high and on how many days very low (or negative) prices will prevail and how high or how low these prices will be?

Of further relevance in this context is how the price spread in European markets will evolve in the future as larger amounts of PV, solar thermal and wind generation are added to the network. The consequence for electricity prices are shown in Fig. 5 where a hypothetical scenario with high levels of generation from wind, PV and run-of-river hydro plants over a week in summer are depicted using synthetic hourly data for an average year in Germany, Fig. 4.. The graph shows significant volatilities in electricity market prices with total costs charged for conventional capacities – black solid line – ranging from zero to 14 cents/kWh within very short-term time intervals.

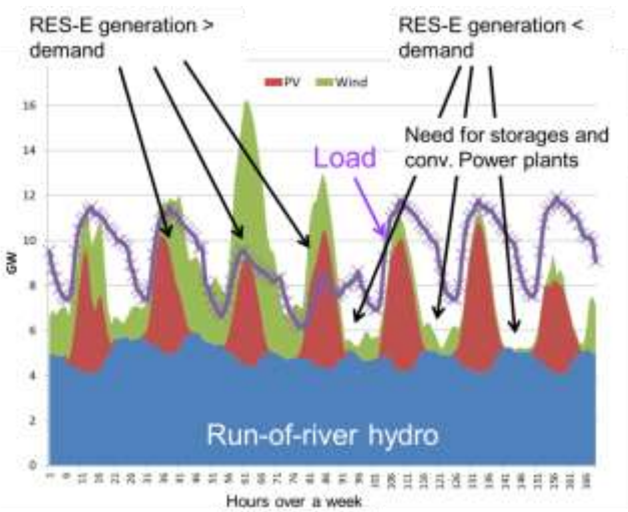

Figure 4. Development of intermittent renewables from wind, PV and run-of-river hydro plants over a week in summer on an hourly base in comparison to demand (Source: Haas [4])

The longer-term impact of variable and intermittent renewables on price spread on the grid is subject to speculation. The intuitive explanation is that when renewables are plentiful, say during windy or sunny periods, the prices will be extremely low, approaching zero or possibly going negative, while at other times – when demand is high and renewables are scarce – prices can be much higher due to strategic bidding by fossil generators exercising market power. This is graphically shown in Fig 5. Another major finding from Fig. 5 is that In the long run large amounts of intermittent RES will lead to increasing new price spreads. It is important to note that future high prices will not necessarily appear at peak-demand times but at times of low renewables availability. This will also change the operation of pumped hydro facilities and lead to new investment in energy storage technologies to take advantage of significant price differentials. Over time, the familiar patterns of the night-to-day-shift of generation will change in response to the unpredictable and variable rhythm of renewable generation.

Figure 5. Development of electricity market prices with total costs charged for conventional capacities over a week in summer on an hourly base (Source: Haas [4])

The most likely consequence of increased price volatility will be to make storage and flexible peaking units much more valuable than they currently are.

Given the price pattern in Fig. 5 we are convinced that it would be attractive for (some but sufficient) power plant operators to stay in the market or even to construct a very efficient new plant! This would lead to the market model of a revised energy-only markets.

4. Supply security

One major reason for the call for Centralized Capacity Payments is to retain supply security in the electricity system. The historical (anachronistic) definition of supply security is: At every point-of-time every demand has to be met regardless of the costs. In this context it is important to note that supply security is an energy economic term. It is different from technical system reliability.

The core problem is that so far the demand-side has been fully neglected with respect to contributing to an equilibrium of demand and supply in an electricity market. No culture of integration of demand has so far been developed. The major reason for this is that in times of regulated monopolies every demand could be met due to significant excess capacities. And still in the liberalized markets a huge excess capacities remained. This aspect – to develop the impact of demand-side and customers WTP – is essentially for a real electricity market and it is actually regardless of the aspect of an integration of larger shares of RES. In the context of the discussion of market design this historical view of supply security plus Centralized Capacity Payments (CCP) would lead to a new market DESIGN in the sense of a centrally planned economy.

5. Different types of market design

On contrary to the central planning approach a market-based one would take into account customers WTP. The equilibrium between demand and supply would come about at lower capacities. It is also important to note that where WTP is lowest the MC of providing capacity are highest, see Fig. 6.

A market-based approach will consider all options on the supply-side and the demand-side. There are much more dimensions than just generation for bringing about an equilibrium in electricity supply. The most important ones are:

- Demand–side management (technical): Measures conducted by utilities like cycling, of demand, e.g. of cooling systems)

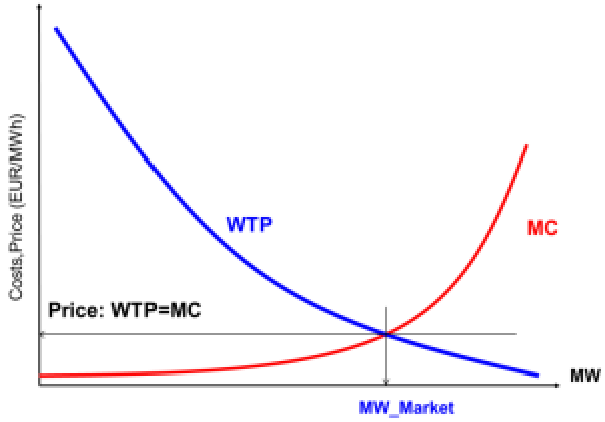

Figure 6. A market-based approach to supply security (Source: Haas [4])

- Transmission grid extension:
  if the grid is extended there is in principle always more capacity available in the system and the volatility of RES a well as demand evens out;
- Demand response due to price signals: Response of mainly large customers to price changes
- Smart grids: They allow variations in frequency (upwards and downwards regulation) and switch of voltage levels and contribute in this context to a load balancing;
- Storages: short-term and long-term storages – batteries, hydro storages, or chemical storages like hydrogen or methane – can help to balance significant volatilities of RES generation.

If we talk about capacity "MARKETs" models it is important to bear in mind that in most models it is virtually impossible to have finally a competitive "MARKET". How should competition take place in a specific region with only one supplier? For example in Southern Germany or in France? In this context the following statement of the EWI Cologne, in favour of capacity "MARKETs", is highly of interest: "in the comprehensive as well as in the focused CM there are no market mechanisms" ([8]).

The major discussed market models are summarized in Table 1. The classic Energy-only market (EOM) focusses on P= STMC. The revised EOM-model described in chapter III allows temporarily price increases above the STMC level. Including demand-side contracts leads to the EOM+DSC model. In this category fits also the idea of Erdmann ([9]) who suggests that the balancing groups should be responsible for providing capacities.

Finally two CM models are discussed. Because of the arguments above that these are no markets we use from now on the term Centralized capacity payments (CCP): One Comprehensive CCP model which treats existing and new capacities jointly. And a Focused CCP approach which differs between existing and new capacities. In both of these market models – as in the classic EOM the price should equal the STMC (see Energy&Management, [8]).

Table 1. Survey on currently discussed electricity market models

	P= STMC	P= LTMC	Demand-side contracts	Existing power capacity	New power capacity
EOM classic	X				
EOM revised		X			
EOM + DCM		X	X		
Comprehensive CCP	X			X	
Focused CCP	X			X	X
Strategic reserve	X				

EOM…Energy-only market
CCP…Centralized capacity payments
DCM…Demand-side capacity market

The major open questions regarding CCP are:

- Which quantity of capacity should get payments and where?
- How to split in existing and new capacity?
- How to tune with grid extension? Every grid extension has undoubtedly an impact of necessary capacities in a specific area
- Who plans? On national or international level?

6. The international dimension

Based on these open questions one of the most important aspects is the international dimension. The price patterns in different European electricity markets are shown in Fig 7 for the period from 2000-2013 where to some extent price volatility and considerable differences between various sub-markets are observed. Italy tends to experience higher prices and more volatility due to its over-reliance on imported electricity, congested transmission lines, and heavy reliance on expensive natural gas. In the case of the NORDPOOL, which includes Sweden, Norway, Finland, and portions of Denmark, the pattern is different due to heavy reliance on hydro and lack of strong interconnection with Continental Europe. Despite these differences, a remarkable convergence of prices has taken place even in Western continental Europe. Currently, there is a wide-integrated Western-Central European electricity market which consists (at least) of Germany, France, The Netherlands, Austria, Switzerland, Poland, Czech Republic. That is to say that any measure in one of these countries will affect the market structure in others.

Figure 7. Development of day-ahead spot market prices in different European electricity markets 2000-2014

The discussion in Europe starts with the request for CCM on national level. Yet, because the Western European electricity markets is strongly integrated – see Fig. 7 – the national planning activities has at least to some extent to consider the international dimension. Transboundary grid extentions and storage availability are some important aspects. This leads after some time undoubtedly to international planning of CCM. The next logical step is to think about an international joint concept for financing. And this would lead very soon to central European planning. Conclusion: Increasing planning leads to higher and higher inefficiency in the system and increasing costs

The alternative would be strictly national CCP. Would they be more efficient? In this context the following statement of the EWI Cologne, in favour of CCP, is highly of interest:

“If we introduce capacity markets they must really ensure full supply security. That is to say the capacities we need must at least to some extent be higher than expected demand, including a security margin” and further “in the comprehensive as well as in the focused CM there are no market mechanisms” (Energy&Management, [8]). Now imagine the excess capacity that comes about if all European countries do this on a national level.

The major reason, why at least currently there is no need for a CCM in Europa that there are still many other options in the market, which we think are by far not yet exhausted. However, to exhaust these options some dogmas has to be changed. Especially the historically prevailing and still existing definition of supply security – that every demand has to be met at every point-of-time regardless of what are the costs – has to be revised in a way that compares the costs of (all) supply-side and demand –side options as well as customers WTP for capacity depending on time.

In this context of core relevance is finally that a demand –side capacity market is developed. So far consumers has never been asked what the value of capacity is for them and what they are willing to pay for specific quantities of capacity.

Summing up the major key findings of this analysis are:

- The still applied concept of supply security is anachronistic and contradictory to market principles. It has to be revised in a way that considers customers’ WTP;
- National CCP will never work because there will not be any competition
- CCP will never work out as „markets“ because of area monopolies;
- CCP will be the death of all ideas of competition and head to a strictly planned economy
- CCP completely neglect the demand-side which has never been really developed!
- most important now: exhaust the full potential of the creativity of all market participants especially of the demand-side!
- The most important – so far neglected – issue for a real electricity market actually regardless of the aspect of an integration of larger shares of RES is the development of the demand-side.
- Our contribution to the discussion: an incentive payment for new very efficient plants

7. Dimensions of electricity markets

The major results are:

1) To integrate larger shares of RES-E and to enhance competition of core relevance is a pricing system in an EOM where the prices signal scarcity or excess capacities at every point-of-time (quarters of an hour);
2) More flexibility in the organization of the market is required: To better integrate RES-E in the market the time intervals in markets should be reduced (more emphasis on intraday markets, shorter trading intervals (from hours to ¼ hours); shorter ahead leading times for market clearing and forecasting of RES-E production);
3) Most important to balance variations in residual load is an optimal portfolio of flexibility options which already exists today but is not fully harvested due to low economic incentives. Some of this flexibility options are, see Fig. 8:

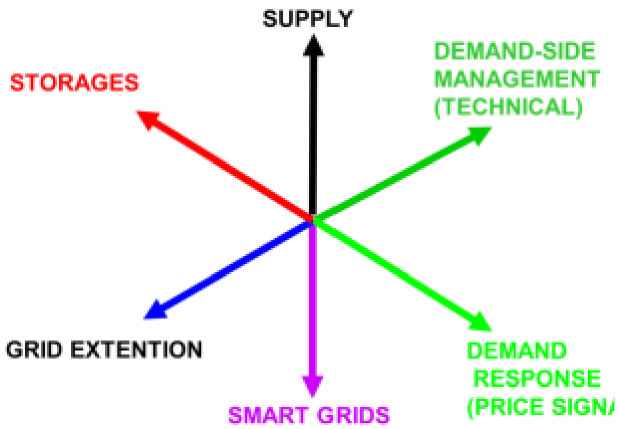

Figure 8. Dimensions of electricity markets

- Short-term and long-term storages – batteries, hydro storages;
- Technical demand-side management measures conducted by utilities like cycling, load management)
- Demand response due to price signals mainly from large customers to price changes, time-of-use pricing
- Transmission grid extention leads in principle to flatter load and flatter generation profiles;
- Smart grids: They allow variations in frequency (upwards and downwards regulation) and switch of voltage levels and contribute in this context to a load balancing

4) A key role in this new concept will play balancing groups. These are the entities which finally have to balance generation, flexibilities and demand options.

8. Conclusions

The major conclusion of our analysis is that capacity markets are a step back to a planned economy with – all in all – much higher costs for society. The only "negative" aspect of a market without capacity component will be that – at least in the short run –temporarily higher costs than the short-term marginal costs will occur. However, after some time the market will learn to benefit from these higher costs and also from the very low costs at times when RES are abundant. A reasonable price spread will come about that provides incentives for different market participants to benefit from these spreads. In total we think that in addition to pure power generation capacities other elements like Smart grids, technical and economic demand-side management, short-term storage options will even out a large part of the residual load profile (the difference between demand and supply from variable RES).

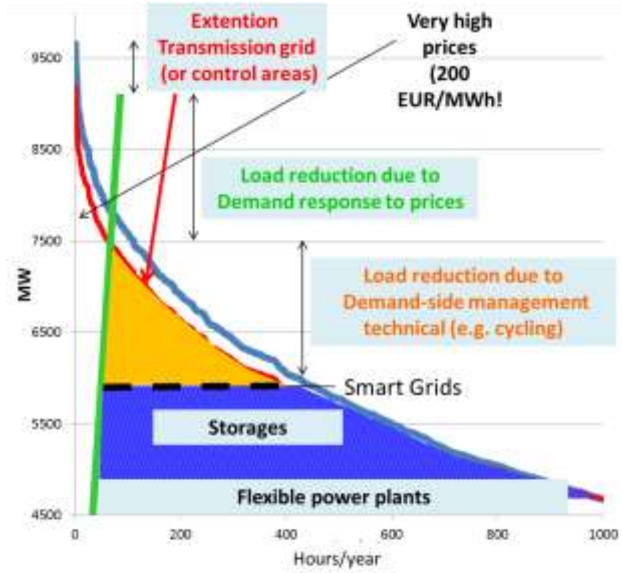

Figure 9. Options for coping with peak residual load in electricity markets

The most important conclusion is that the evolution of such a creative system of integration of RES in Western Europe may also serve as a role model for largely RES-based electricity supply systems in other countries world-wide. So there is especially NOW no need for CCP. If all our arguments would turn out to be wrong it would still be sufficient to introduce such a model later and to abolish the electricity markets.

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The 1st International Conference on Energy, Environment and Economics (ICEEE 2016) was held at Heriot-Watt University, Edinburgh, EH14 4AS, UK, 16-18 August 2016. ICEEE2016 focused on energy, environment and economics of energy systems and their applications. More than fifty eight delegates from 31 countries with diverse expertise ranging from energy economics, solar thermal, water engineering, automotive, energy, economics and policy, sustainable development, bio fuels, Nano technologies, climate change, life cycle analysis etc. made conference true to its name and completely international. During conference total 51 oral presentations and six posters were shared between delegates. The presentations showed the depth and breadth of research across different research areas ranging from diverse background. ICEEE2016 aimed:

- To identify and share experiences, challenges and technical expertise on how to tackle growing energy use and greenhouse gas emissions and how to promote sustainability and economical, cost effective energy efficiency measures.

In total 11 technical sessions and two invited talks both from academia and industry provided insight into the recent development on the proposed theme of the conference. Preparation, organisation and delivery of the conference started from July 2015 and further co-ordinated by vibrant team of Conference Centre, Heriot Watt University. Conference organisers would like to acknowledge support from the sponsors particularly World Scientific Publication ltd and its team members for the delivery of the conference. Organisers are also thankful to all reviewers who contributed during peer review process and their contributions are well appreciated. At the end and during vote of thanks following awards have been announced and we would like to congratulate all well deserving delegates.

- Best Paper –Academia: Amela Ajanovic, EEG, TU Vienna, Austria
- Best Paper – Student : Christian Jenne,University of Duisburg-Essen, Germany
- Best Poster – Student: Yoann Guinard, University of New South Wales, Sydney, Australia
- Best Poster – Academia: E. Salleh, Universiti Kebangsaan Malaysia, Malaysia
- Active Participation Award - Yoann Guinard, University of New South Wales, Sydney, Australia

At the end we would like to extend our gratitude to all of you for your participation and hopefully welcome you again during ICEEE2017.

Editors:

Dr. Singh is Senior Scientist at Indian Agricultural Research Institute, New Delhi, India. Her area of expertise are bio energy and bio fuels, environmental engineering, carbon accounting and renewable energy integration for rural development.

Dr. Kumar is visiting faculty at Prince of Songkla University, Thailand. He have 16 years of research and teaching experience in the field of solar energy, drying and energy efficiency.

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