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On the economics and environmental benignity of electric vehicles

Amela Ajanovic

Vienna University of Technology, AT

Author's mail: ajanovic@eeg.tuwien.ac.at

Abstract

Electric vehicles (EVs) are considered as an important means to cope with current environmental problems in the transport sector. However, their current use is very limited mostly due to considerably higher capital costs, especially because of the battery, and limited driving ranges in comparison to conventional cars.

The objective of this paper is to investigate the prospects of various types of EVs from an economic and environmental point of view. The major focus is on investigation of the sensitivity of the environmental benefits of EVs depending on the development of the carbon intensity of the electricity mix in the EU.

Our method of approach is based on calculation of total cost of ownership of EVs in comparison to conventional cars, and a life-cycle approach to assess their environmental benignity. The analysis of future prospects it is based on technological learning especially regarding investment costs of batteries.

There are different types of EVs with the different level of electrification and different possible contribution to the reduction of emissions. Largest reduction of GHG emissions could be reached with zero-emission vehicles, BEVs and FCVs, if they are using electricity from RES. However, despite the high increase of electricity generation from RES in recent years the CO_2 emissions of the electricity generation mix in the EU are still on a rather high level and are expected to decrease only slightly up to 2020. This fact questions the effectiveness of all strategies to reduce carbon emissions in the EU by promotion of EVs. Thereby, to truly bring about a significant reduction in carbon emissions due to the forced market penetration of EVs it is important to identify strategies which can link development of market penetration of EVs and electricity from RES.

Keywords: Electric vehicles; economics; environmental benignity, carbon intensity.

1. Introduction

Due to the environmental problems, such as greenhouse gas (GHG) emissions and air pollution, which are caused by the use of fossil fuels for mobility, interest in electrification of passenger car transport has been rapidly increasing over the last decade.

Since electric vehicles (EVs) has been regarded as an environmentally friendly alternative to conventional internal combustion engine (ICE) cars, their use has been supported and promoted in almost all European countries mostly on local and national level. The portfolio of used policies and measures is very broad and different in EU countries. Basically, all measures implemented can be divided in monetary (such as subsidies and tax exemptions) and non-monetary (e.g. free parking spaces, use of bus lanes, etc.) measures. All this measures can increase attractiveness of EVs but they cannot assure their environmental benefits.

However, reduction of GHG emissions is a cornerstone of the European climate and energy policy. In the scope of the climate change and energy strategies for 2020 and 2030 the European Union has set clear targets regarding

- the reduction of GHG emissions,
- increase of the share of renewables in final energy consumption as well as
- increase in energy efficiency [1,2].

In addition, in the scope of the White paper on transport 2011 the European Commission adopted a roadmap of 40 concrete initiatives for the next decade. This should dramatically reduce Europe's dependence on imported oil and cut carbon emissions in transport by 60% by 2050 [3]. Furthermore, by 2050 all conventionally-fuelled cars should be removed from cities.

All these European goals and strategies support use of EVs, directly or indirectly. Increasing electricity production from reviewable energy sources could make EVs more environmentally friendly.

However, in spite of the supporting policies the number of EVs in total car stock is currently very low all over the world [4]. When purchasing a new vehicle, different parameters are taken into account, as shown by Lebeau et al., (2012) [5]. This study showed that costs are most important parameter in the decision making process. Other important parameters are charging time, maximum speed and driving range. Unfortunately, environmental performances have relatively low impact in decision making process, only 7%.

It is clear that the major reason for low use of EVs is their high total mobility cost in comparison to conventional cars powered by fossil fuels. In addition, some technological characteristics of EVs, especially operating range and charging time, are important barriers for faster market penetration of EVs.

The core objective of this paper is to investigate the prospects of various types of EVs from an economic and environmental point of view. This paper is based on our previous works [4,6] where five types of EVs - Battery Electric Vehicles (BEV), Hybrid Electric Vehicles (HEV), Plug-In Hybrid Electric Vehicles (PHEV), Range Extenders (REX) and Fuel Cell Vehicles (FCV) – have been described and analysed in detail. However, in this paper we focus on investigating the sensitivity of the environmental benefits of EVs depending on the development of the carbon intensity of the electricity mix in the EU.

2. Methodology

Our method of approach is based on calculation of total cost of ownership of EVs in comparison to conventional cars and a life-cycle approach to assess the environmental benignity of different types of EVs.

For the economic assessment the most crucial parameters are investment costs, km driven per year, depreciation time of the car and interest rate. The analysis of future prospects is based on technological learning regarding investment costs of batteries.

The total driving costs in Euro per 100 km driven (C_{km}) are calculated as [4]:

$$C_{km_{i_t}} = \frac{(IC_{i_t} + \tau_{REG\,i_t}) \cdot \alpha_i}{skm_{i_t}} + \left(\sum_{k=1}^{m} P_{f_{k_t}} \cdot FI_{ki_t} \cdot sh_k\right) + \frac{C_{O\&M\,i_t}}{skm_{it}} \quad (1)$$

where:

IC……investment costs [€/car]

τ_{REG}…registration tax

α……..capital recovery factor

skm…..specific km driven per car per year [km/(car.yr)]

P_f…….energy price incl. taxes [€/kWh]

sh……share of energy carrier on km driven

$C_{O\&M}$…operating and maintenance costs

FI……..energy consumption [kWh/100 km]

The current fuel price depends on the cost of fuel (C_f), and possible taxes (such as value-added tax (VAT), excise tax, CO_2 based tax):

$$P_{f\,k_t} = C_{f_{k_t}} + \tau_{CO_{2k_t}} + \tau_{VAT_{k_t}} + \tau_{exc_{k_t}} \quad (2)$$

To capture the dynamic effects of changes in the future developments of the investment costs of alternative powertrains we apply the approach of technological learning. Technological learning is illustrated for many technologies by so-called experience or learning curves. In our model we split up specific investment costs $IC_t(x)$ into a part that reflect the costs of conventional mature technology components $IC_{Con\_t}(x)$ and a part for the new technology components $IC_{New\_t}(x)$.

$$IC_t(x) = IC_{Con\_t}(x) + IC_{New\_t}(x) \quad (3)$$

where:

$IC_{Con\_t}(x)$…specific investment cost of conventional mature technology components (€/kW)

$IC_{New\_t}(x)$…specific investment cost of new technology components (€/kW)

x ………..cumulative capacity up to year t (kW)

For $IC_{Con\_t}(x)$ no more learning is expected. For $IC_{New\_t}(x)$ we use Eq. (4) to express an experience curve by using an exponential regression depending on investment cost of new technology components depending on the learning index (b) and the investment cost of the first unit (a), see e.g. [7]):

$$IC_{New\_t}(x) = a \cdot x_t^{-b} \quad [€/car] \quad (4)$$

The environmental assessment of EVs is based on the well-to-wheels (WTW) life cycle assessment (LCA) [8]. The vehicle operation is considered in the step where the energy carrier is used to propel the vehicle, called ‘tank-to-wheels’ (TTW). Emissions associated with the car production and scrappage are included in this part. The stage before this, entitled ‘well-to-tank’ (WTT), focuses on the delivery of energy to the vehicle. It involves all processes from harnessing a primary energy flow or stock to different forms of energy conversion, distribution and storage. The environmental benefit of the WTT phase depends on how the energy carrier is produced, e.g. which primary sources are used for electricity generation. There is a large difference between electricity produced from hydropower and coal fired plants. A WTW analysis connect the WTT and TTW phases, as illustrated in Fig. 1.

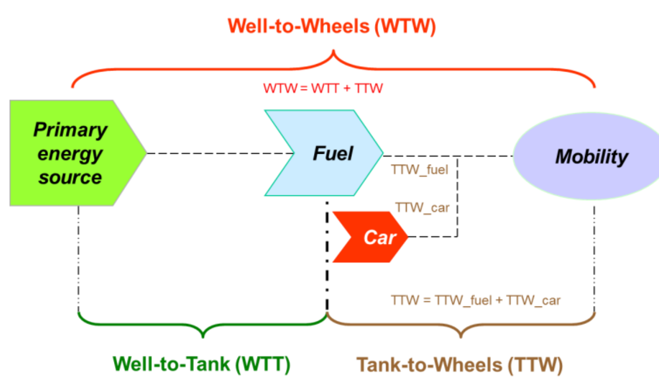

Fig. 1 WTW method of approach

In the following we analyse the whole well-to-wheel emissions related to the provision of the energy service mobility including also the embedded life-cycle emissions of the car.

$$WTW = WTT + TTW_{\_fuel} + TTW_{\_car} \qquad (5)$$

where

WTT………… emissions depending on the energy and material flows in the WTT part of the energy supply chain

TTW_fuel…….. emissions associated with the energy use in cars

TTW_car……… emissions associated with the car production and scrappage.

3. Results of the economic assessment

The total cost of ownership (TCO) is an important attribute in decision making process by purchasing new car. A TCO analysis is necessary to understand the cost structure of different automotive powertrains. Since the costs associated with a vehicle occur at different moments in time, it is necessary to calculate the present value of all costs.

Figure 2 shows the cost structure of total driving costs in Euro per 100 kilometres driven for different types of EVs in comparison to gasoline and diesel cars. The total costs are divided in three categories: capital costs, operation and maintenance costs, and fuel (energy) costs. Currently, the largest part of the total costs is capital cost for all types of vehicles, especially in the case of FCV and BEV. It can be noticed that the advantages of alternative powertrains regarding lower fuel costs are relatively neglectable in comparison to high capital costs. For specific details regarding underlying assumptions for these calculations (e.g. maintenance costs, depreciation time of vehicle, annual km driven) see [4].

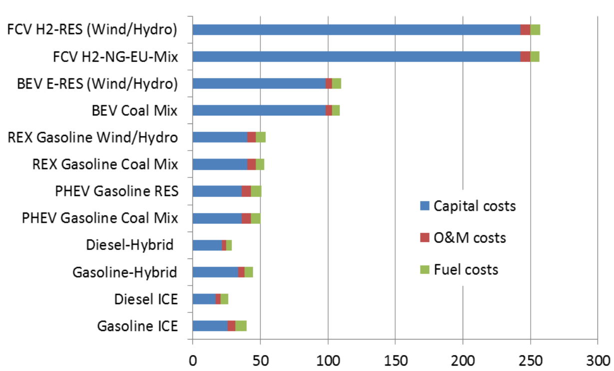

Fig. 2 Structure of current costs of mobility with electric vehicles in comparison to conventional ICE vehicles

In the long term the fuel (energy) costs will depend on the performance of conversion technologies and availability of resources. It can be counted with the increasing price of fossil fuels. The development of technologies such as solar and wind will be a key determinant of future electricity costs [8].

Due to the technological learning effect, capital costs of all alternative automotive technologies could be significantly reduced in the future, especially new and not completely mature technologies e.g. BEV and FCV. Consequently, mobility costs of all investigated vehicles could be in a much narrower cost-range by 2050 than today, see Fig. 3.

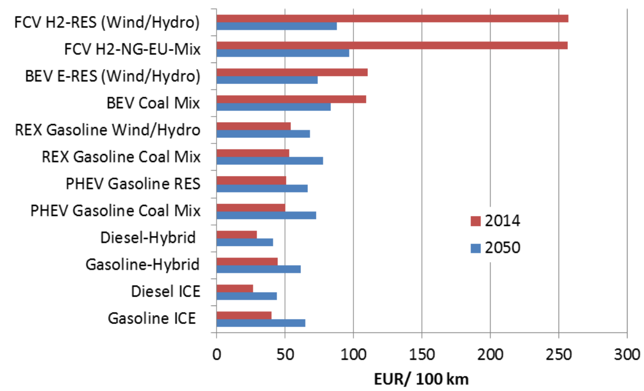

Fig. 3 Total current and future costs of mobility with electric vehicles in comparison to conventional ICE vehicles

4. Results of the environmental assessment

Electric vehicles are more or less environmental friendly technology depending on the type of EVs and primary energy used for electricity generation. Total emissions of passenger car mobility (E_i) can be very different depending on the energy and material flows in the WTT part of the energy supply chain, the efficiency of the energy use in cars (in TTW part) as well as emissions associated with the car production and scrappage. They are calculated in g CO_2 per km driven as:

$$E_i = \sum_{k=1}^{m} E_{WTT_k} + \sum_{k=1}^{m} E_{TTW_k} + E_{car_i} \text{ (g CO}_2\text{/km)} \qquad (6)$$

where

i…type of car (e.g. PHEV)

k…type of energy carrier (e.g. electricity, gasoline)

Figure 4 shows current CO_2 emissions per 100 km driven for the whole energy supply chain and for various types of EVs in comparison to conventional gasoline and diesel cars. Power of all cars analysed is 80 kW.

It is obvious that for all kinds of EVs CO_2 emissions in the $TTW_{\_fuel}$ part are lower. The lowest CO_2 emissions are in the case of BEV powered by electricity from renewable energy sources (RES), wind or hydropower, and FCV powered with hydrogen produced from RES. For these EVs TTW$_{_fuel}$ emissions are zero.

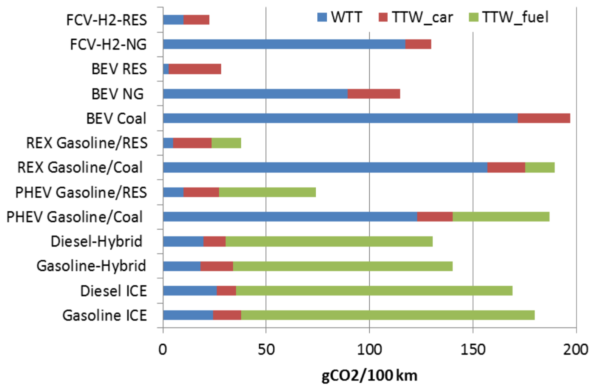

Fig. 4 CO_2 emissions per km driven for various types of EVs in comparison to conventional cars (power of car: 80kW)

5. Impact of carbon intensity of the electricity generation mix on environmental benefits of EVs

As shown above there is a tremendous difference in the environmental performance of EVs depending on the primary energy sources used for electricity generation (e.g electricity generated in coal power plants vs. electricity from RES), see Fig. 4. As next, we have analysed current and possible future environmental performances of BEV and PHEV depending on electricity mix used in the EU.

The power generation mix in 2010 is shown in Fig. 5. We can see a quite diversified picture without really dominating energy source.

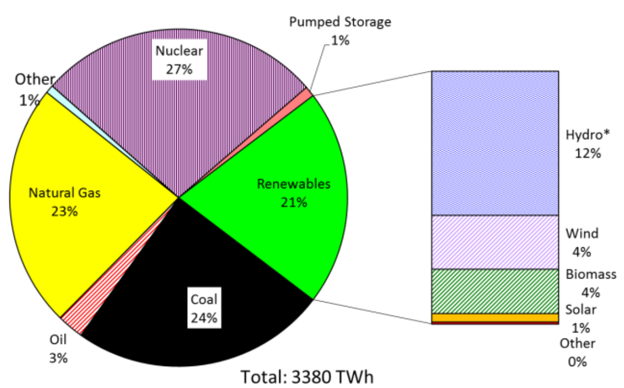

Fig. 6 Share of energy sources for electricity generation in 2010 [9]

If we look at the development of electricity generation from RES in the last years we could expect significant reduction of average carbon intensity per kWh electricity generated in the EU-28. The reason is that between 1997 and 2014 the share of electricity generation from RES has increased from 12% to approximately 24%, see Fig. 6. Due to this development one would expect a significant decrease of carbon intensity of the electricity generation mix.

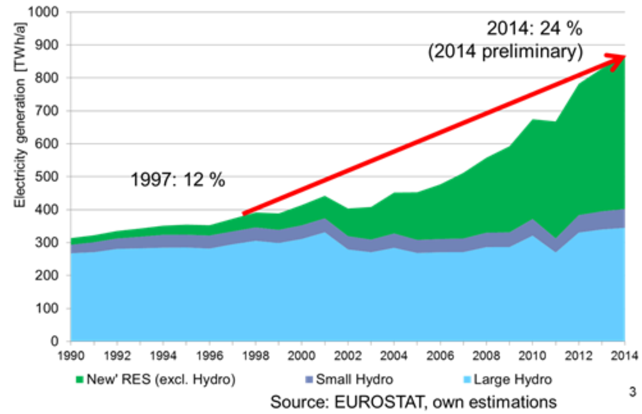

Fig. 6 Development of electricity from renewables (including hydro power) in EU-28 between 1990 and 2014, in TWh (Source: [10], own estimations, numbers for 2014 are preliminary)

Based on current situation and future expectations, Fig. 7 shows mix of energy sources used for electricity generation in 2020 in comparison to 2010 and 2015. In this figure it can be noticed increase of the RES in electricity generation as well as the continuous decrease of nuclear energy used.

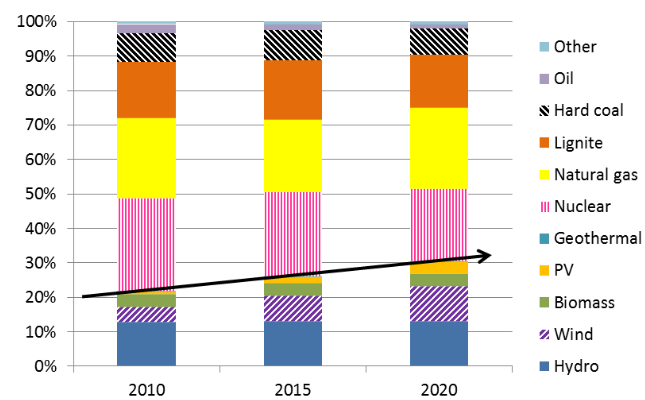

Fig. 7 Share of energy sources for electricity generation 2010-2020

Next, we identify the carbon emission factors. They are based on [4], [10-12]. Figure 8 documents the development of the carbon intensity of electricity from various energy sources from 2010 to 2020. The corresponding primary energy carbon emission factors are documented in Annex, Table A-1. For the assumptions regarding power plant efficiency improvements, see Annex, Table A-2. The most important finding is that there is only a slight decrease in the CO_2 emissions of the average electricity mix in the EU from 2010 to 2020.

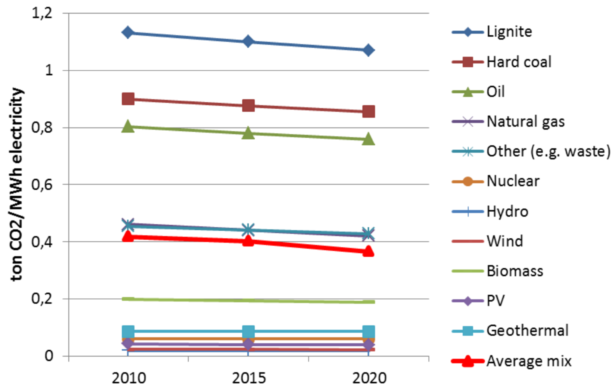

Fig. 8 CO_2 emission factors for all considered energy sources per MWh electricity generated, 2010-2020

Finally, the results of these analyses are used for calculation of the WTW emissions of BEV and PHEV for the average EU-mix of electricity generation in comparison to electricity generation from a RES-mix for 2010, 2015 (preliminary numbers), and 2020 (scenario). In addition, the impact of energy mix (mix of fossil fuel and electricity) used in PHEV is analysed, see Fig. 9. For PHEV we have considered two cases regarding the ratio of electricity to gasoline used: (i) 50% to 50%, and (ii) 75% to 25%.

A major finding from this analysis is that the share of electricity used in PHEV is much more important than the impact of the carbon intensity change in the EU electricity mix. The change of the EU-mix between 2010 and 2020 has a very small impact on the magnitude of the overall carbon intensity.

The WTW emission of the mobility with EU-mix remains up to 2020 still much higher than that of the RES-mix.

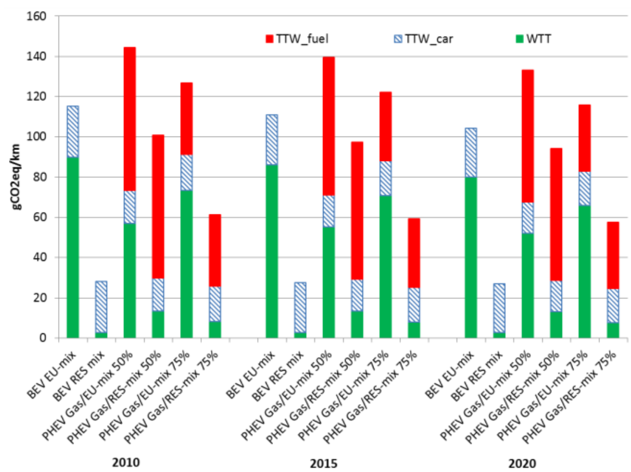

Fig. 9 WTW emissions of BEV and PHEV (with different shares of electricity, and for the EU-mix of electricity generation in comparison with electricity generation from a RES-mix for 2010, 2015, and 2020)

6. Conclusions

The major conclusions of this analysis are: Despite the high increase of electricity generation from RES in recent years the CO_2 emissions of the electricity generation mix in the EU are still on a rather high level and are expected to decrease only slightly by 2020. This fact questions the effectiveness of all strategies to reduce carbon emissions in the EU by means of promoting EVs. Thereby, to truly bring about a significant reduction in carbon emissions due to the forced market penetration of EVs it is important to identify strategies for a linked development of market penetration of EVs and electricity from RES.

Abbreviations

GHG – Greenhouse gas emissions
ICE – internal combustion engine
EVs – Electric vehicles
BEV – Battery electric vehicles
HEV – Hybrid electric vehicles
PHEV – Plug-in hybrid electric vehicles
REX – Range extenders
FCV – Fuel cell Vehicles

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Annex

Table A-1 Specific CO_2 emission factors for primary energy 2010-2020

ton CO_2/MWh primary energy	**2010**	**2015**	**2020**
Lignite	0.396	0.396	0.396
Hard coal	0.342	0.342	0.342
Oil	0.281	0.281	0.281
Natural gas	0.198	0.198	0.198
Other (e.g. waste)	0.150	0.150	0.150
Nuclear	0.020	0.020	0.020
Hydro	0.020	0.020	0.020
Wind	0.024	0.023	0.022
Biomass	0.070	0.070	0.070
PV	0.043	0.041	0.039
Geothermal	0.030	0.030	0.030

Table A-2 Efficiencies of power plants 2010-2020

	2010	**2015**	**2020**
Lignite	0.35	0.360	0.370
Hard coal	0.38	0.390	0.400
Oil	0.35	0.360	0.370
Natural gas	0.43	0.450	0.470
Other (e.g. waste)	0.33	0.340	0.350
Nuclear	0.330	0.330	0.330
Hydro	1.000	1.000	1.000
Wind	1.000	0.999	0.998
Biomass	0.35	0.360	0.370
PV	1.000	0.998	0.996
Geothermal	0.350	0.350	0.350

Commonwealth Energy and Sustainable Development Network (CESD-Net)

CESD-Net is a major global initiative in energy and sustainable development. The objective of network is to promote energy and sustainable development in commonwealth countries.

Focussing on Multidisciplinary Research, Promoting Future Low Carbon Innovations, Transferring Knowledge and Stimulating Networking among Stakeholders to Ensure the UK Achieves World Leading Status in Energy and Sustainable Development. https://www.weentech.co.uk/cesd-net/

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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