Correlation Analysis for Determining the Potential of Home Energy Management Systems in Germany

Aline Kirsten Vidal de Oliveira[1], Christian Kandler[2]

[1] CAPES Foundation, Ministry of Education of Brazil, Brasilia – DF, 70.040-020
alinekvo@gmail.com
[2] Lehrstuhl für Energiewirtschaft und Anwendungstechnik, Technische Universität München, Arcisstr. 21, D-80333 Munich
christian.kandler@tum.de

Abstract. This paper describes the implementation of a model in MATLAB that estimates the potential of home energy management systems based on different component criteria. This is done by the estimation, in a given territory, of the correlation of favorable elements for the installation of integrated systems for energy generation and electromobility. The model is applied to the territories of Germany, evaluating its potential for home energy management systems in current and future situations.

Keywords: Electromobility, Renewable Energy, Energy Management Systems

1 Introduction

Due to the current global concerns about CO2 emissions and dependency on fossil fuels, electric cars are seen as an alternative to traditional vehicles. However, they increase the load on the power grid, creating a need for changes in the power system, which is a major source of greenhouse gas. Thus, electric cars are only able to reduce emissions when renewable energy sources are used to charge them [1].

For this reason, the research project “Energy-autarkic electric mobility in the Smart-Micro-Grid” (Energieautarke Elektromobilität im Smart-Micro-Grid – e-MOBILie), aims to link electric mobility with local renewable power generation in an integrated approach. It will demonstrate, through simulations and a prototype, how to integrate electric vehicles into the energy management structure of intelligent buildings [2].

Research companies like Navigant Research, ABI Research and Grand View Research have made estimations of the potential of HEM systems (Home Energy Management Systems), by evaluating its revenue forecast. This market is likely to expand in the coming years as new products are introduced, especially in Europe where the growth will be more prominent, particularly due to British government incentives [3]. However, this kind of data does not estimate the installation potential of complete HEM systems and a method to do this is shown in this paper, based on the model developed in [4].

The installation of a HEM system is facilitated in one-family households that already have one or more favorable elements, like a photovoltaic system (PV system), a garage with an electric car or a heat pump. Therefore, finding the number of houses that have these favorable elements means finding the potential for the installation of these systems. In order to do this, data on general characteristics of Germany related to the main project is used as input of the model, including predictions for the next thirty-five years. The work uses data about the amount and distribution of private photovoltaic systems, electric cars, houses with garages and private heat pumps.

The MATLAB model uses the number of one-family households from a territory as its domain where the elements are randomly distributed, what allows the visualization of possible correlations between them. By repeating this process several times, one can generate an estimation, for example, of the number of houses that have both existing photovoltaic systems and garages. Such houses have the potential to install a system for integration between in-house-generation and an electric car. The model described in this paper identifies these correlations and determines the stochastic distribution of the results. These results enable an analysis of the potential application of HEM systems in a particular region, thus indicating the applicability of the main project within a territory.

2 Data Search

For relevant results, the search for data input is one of the most important parts of the model development. The number of one-family households, private PV systems, private heat pumps, private electric cars and houses with garage are used as input for the model and they provide more accuracy when they are distributed in states. The input data used for the model covers the current situation of Germany and its forecasts for 2020, 2030 and 2050.

Some government organizations, like “Agentur für Erneuerbare Energie” and “Bayerische Staatsregierung” have interactive maps that present information about the distribution of renewable energies in Germany. However, some kinds of necessary data, like the number of existing houses with garages, cannot be found by the distribution in the area. For this reason, they are estimated using simple statistics or absolute values obtained in the literature.

The data are more accurate for the periods of 2015, 2020 and 2030, since there are many reports and statistics available that provide this kind of information. On the other hand, there are not so many reports about forecasts for 2050, and some extrapolations had to be done. Consequently, the data for 2050 is not so precise, especially because it ignores the lifetime of the equipment.

3 Model Description

The model developed in MATLAB correlates data to find the number of houses that have two or more elements favorable to the installation of HEM systems in a locality.

The model utilizes, as basis, the number of one-family-households in a given region divided by areas that can be states, cities or countries and uses it as the territory where the elements are randomly distributed and the overlays are collected. In this paper, three elements are explored, but the model is easily expandable for the use of more or less elements. In addition, it can be applied to any territory where the number of houses is available, from a neighborhood to the entire world. Figures 1, 2, 3 and 4 describe the steps of how the correlation process works.

After the steps are executed, the overlays are collected, which means that the model will register the number of times that a site has a combination of the distributed factors. Since the data is randomized, the process is executed several times, generating different correlations in each model run.

Fig. 1. Step 1: The model uses as domain the number of one-family households of each state. The figure shows an example with Germany as territory, where the draw of houses represents the number of one-family-households of each state.

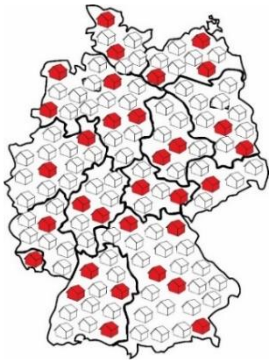


Fig. 2. Step 2: The data from one element, like PV systems for example, is distributed in the territory. As it is not possible to know exactly each house has a PV system installed, this distribution is randomly made. The houses with PV Systems are presented in red.

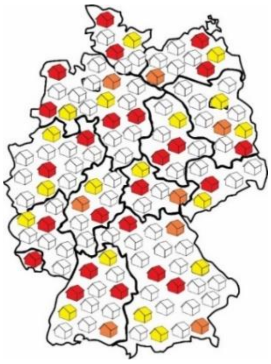


Fig. 3. Step 3: Other element is distributed, for example electric cars, here in yellow. When the data of the element is distributed by areas (here states), the number of units is randomized in each area. Otherwise, the total number is randomized in the total territory. It may happen that some houses have a PV system and an electric car. These houses are the ones with potential for HEM systems and they are represented in orange.

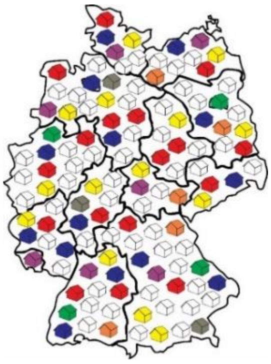


Fig. 4. Step 4: When other element is distributed, for example heat pumps (blue), it is possible to collect the number of all the houses that have potential for HEM systems. They are houses with an electric car and a heat pump (green), an electric car and a PV system (orange), a heat pump and a PV system (purple) and an electric car, a PV system and a heat pump (grey).

The sum of each run of the model is presented through histograms and a statistical analysis of the correlated data is performed, in order to determine its stochastic distribution. That means, finding a mathematical function that describes the statistical variable in an accurate way. This is largely used for describing phenomena in areas such as psychology, image processing and computer network traffic [5, 6, 7].

The software MATLAB has tools that fit the data to various stochastic distributions and give the statistics measures like Bayesian Information Criterion (BIC). This criterion estimates the accuracy of a fitting distribution, where the one with the lower BIC is the best fit. This model compares the result with the following distributions: beta, Birnbaum-Saunders, exponential, extreme value, gamma, generalized extreme value, inverse Gaussian, logistic, log-logistic, lognormal, Nakagami, normal, Rayleigh, Rician and t-location-scale. When the difference between the BIC of the best fit and the normal distribution is lower than six, the normal distribution is assumed as the best fit, since it is better-interpreted and only differences above six show strong evidence of a fit. [8]

After a proper stochastic distribution is found, the distribution parameters are estimated based on the sample data. In this way, the curve can be easily reproduced. Figure 5 demonstrates the result of the model for a German best-case scenario in 2020. The figure contains information about the data used and exhibits the histogram resulted from the model. In the histogram, it is possible to see that from the 100 iterations, in more than 20, the number of correlations between PV systems, heat pumps and electric cars were circa 3450, what means that a result of around 3450 is the most probable. In red, it is visible the approximation of the histogram to a normal distribution, which has its parameters listed. The figure displays also the criterions of approximation to the fit.

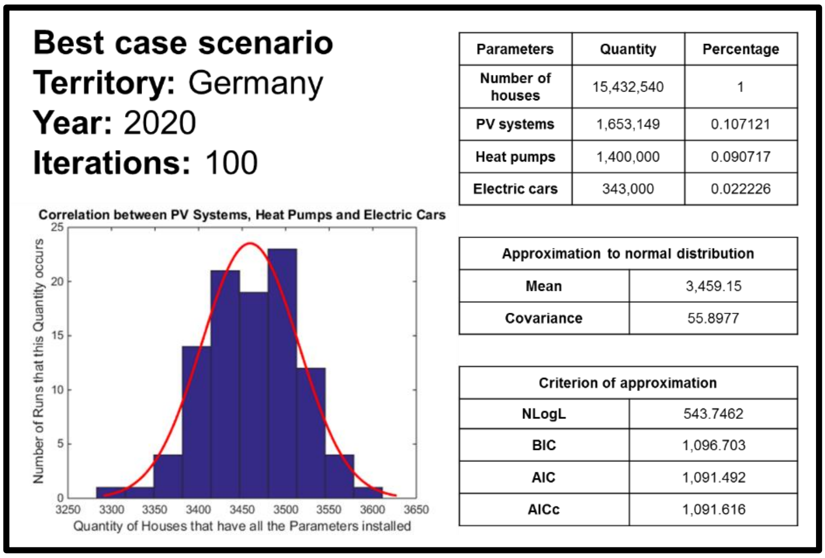


Fig. 5. Result of the model in a German best-case scenario in 2020

3.1 Dependencies

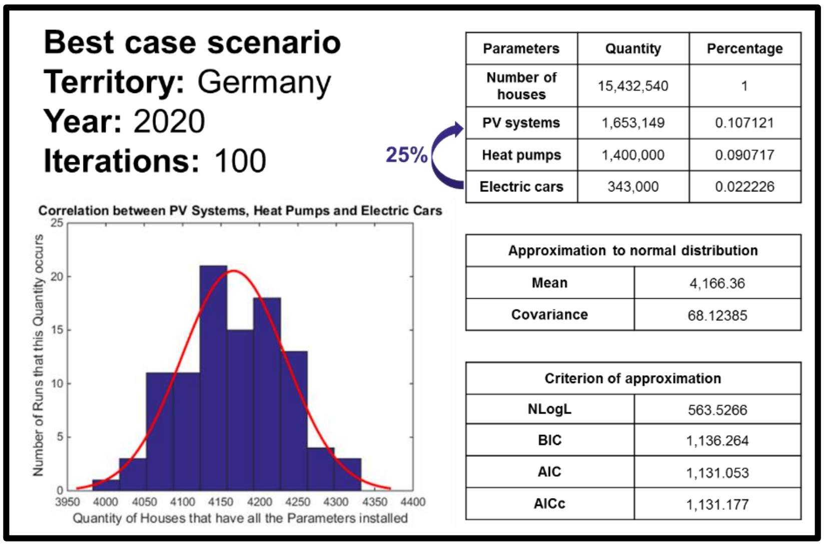
The model deals with total random data, but in reality, there are some correlations that should be considered. A person that already has a PV system installed at home, for example, is probably concerned about the environment and therefore is more susceptible to buy an electric car than others are. Because of that, some "dependencies" were added to the model, so according to the choice of the user, it is possible to increase the probability that a determined parameter can appear in a house that already has another one.

Figure 6 shows the results of a simulation with the same data input of the simulation of Figure 5, but adding a dependency of 25% from electric cars to PV systems. That means that the owners of private PV systems are 25% more likely to buy electric cars. Therefore, the probability of them to buy an electric car is:

$$Probability\ of\ a\ PV\ system\ owner\ to\ buy\ an\ electric\ car = (1 + 0{,}25) * Probability\ of\ anyone\ buy\ an\ electric\ car \qquad (1)$$

The dependency causes differences in the results that can be seen in the histogram and in the mean of the normal distribution, which have raised. It is also perceptible that the mean of the normal distribution of the figure 5 is 3,459.15, result that is very close to the multiplication of the number of one-family households by the percentages of the elements, that is 3,333.18. With that alone, the model would be irrelevant, since similar results can be easily calculated. However, with the possibility of adding the dependencies between elements, the model proves its importance.

Since it is hard to find this kind of difference of probability, a sensibility analysis is done in order to obtain a range of the possible results. The following example, in figure 7, shows the results of the correlations between PV systems, heat pumps and electric cars for a German best-case scenario in 2020. In this scenario, it is assumed that one is more likely to have an electric car if they already have a heat pump installed. This increase in probability varies from 0 to 90%, as showed in the figure bellow. This range of dependencies is simulated for each case testing different dependencies and a range of possible results is obtained.



Parameters	Quantity	Percentage
Number of houses	15,432,540	1
PV systems	1,653,149	0.107121
Heat pumps	1,400,000	0.090717
Electric cars	343,000	0.022226

Approximation to normal distribution	
Mean	4,166.36
Covariance	68.12385

Criterion of approximation	
NLogL	563.5266
BIC	1,136.264
AIC	1,131.053
AICc	1,131.177

Fig. 6. Results for a German best-case scenario in 2020 with a dependency of 25% from electric cars to PV systems

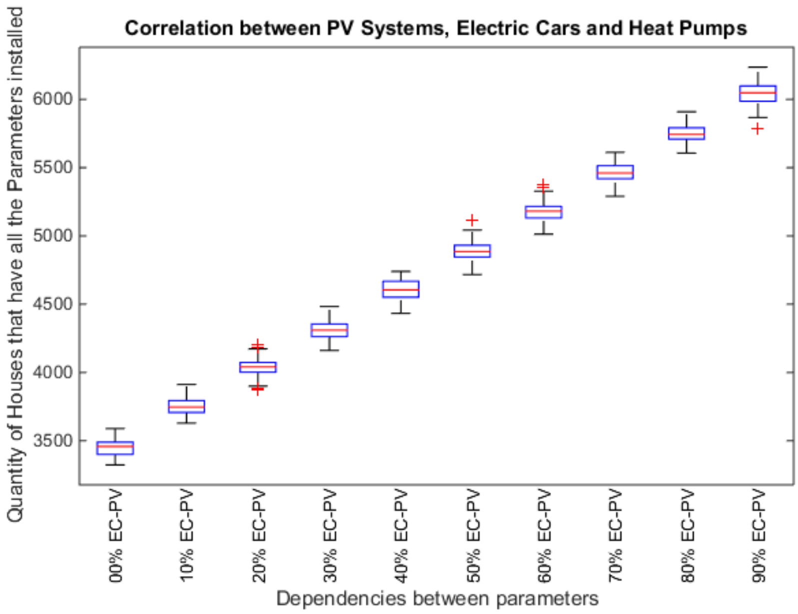


Fig. 7. Results for a German best-case scenario in 2020 with different dependencies

4 Results and Analysis

Figure 8 shows the results of the correlation between PV systems, electric cars and heat pumps in Germany. It is clear the big potential for installation of HEM systems, since the number of houses that have all favorable elements can be higher than 100,000 from 2030. However, the minimum value is low for all the years simulated. The worst-case scenario of the data of electric cars, which suggests a scenario where the number of electric cars will not raise from 2015, causes this result. The problem is more perceptible in the years of 2030 and 2050, when the difference between the worst-case and the other scenarios is bigger. It is possible to conclude that the correlation results are only probable with an increase in the number of electric cars.

From the model is also possible to obtain correlations combining only two elements, as seen in figures 9 and 10. They show combinations that are of interest of the project e-MOBILie, which links electromobily with local renewable generation, for the years of 2015 and 2020. The results present a big quantity of houses with a PV system and an electric car, which are great opportunities for the installation of HEM systems. Even today, there are at least 249 of these houses in Germany, where the first systems could be installed. In five years these number can reach 25,000 houses.

Table 1 presents all the ranges of the results obtained with the simulations. Here, it is clear the pessimistic worst-case scenarios obtained, as the differences between the biggest and the smallest results are very large.

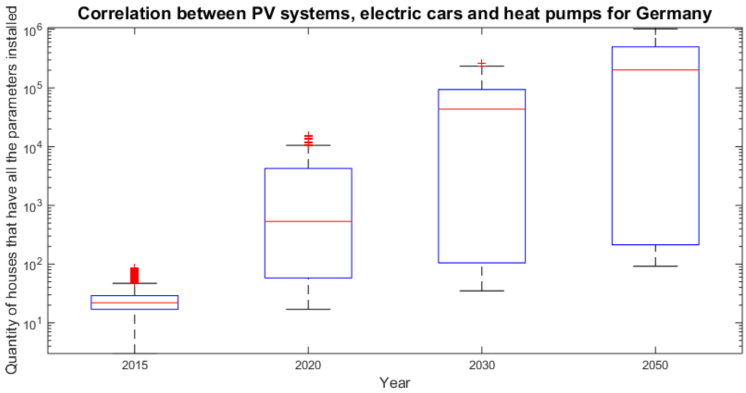


Fig. 8. Results of the correlation between PV systems, electric cars and heat pumps in Germany

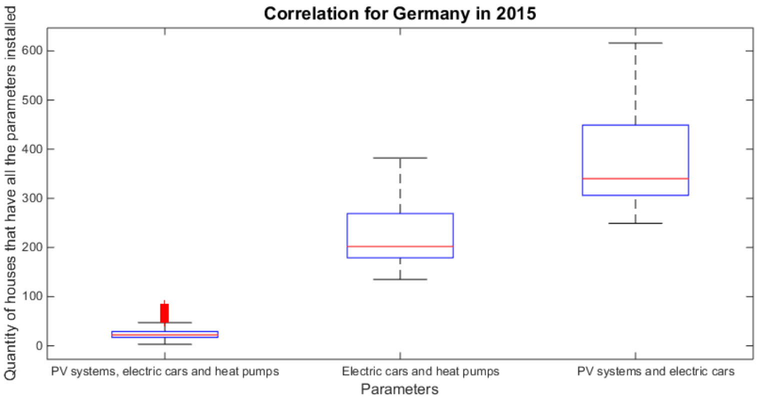


Fig. 9. Results of correlations for Germany in 2015

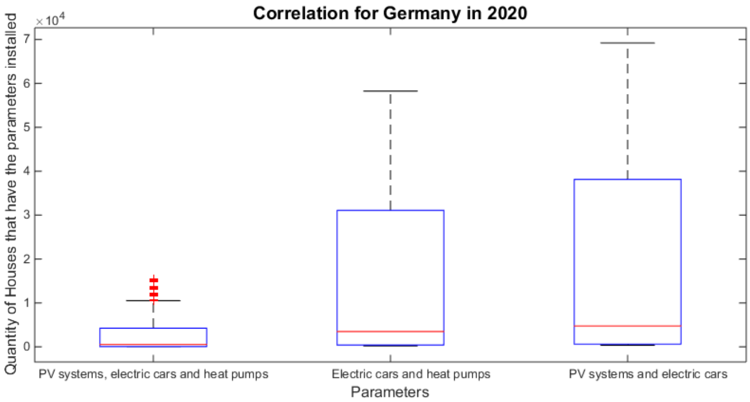


Fig. 10. Results of correlations for Germany in 2020

The total number contains the range results of one-family households that have two or three favorable elements for the installation of HEM systems. It is evident that the potential is huge, and it can reach almost 4 million houses in 2050 in Germany.

Table 1. Summary of results

Elements	2015	2020	2030	2050
PV, HP and EC	3 – 85	17 – 15,371	35 – 261,893	92 – 1,013,344
PV and EC	249 – 616	350 – 69,207	407 – 656,429	479 – 1,516,312
HP and EC	135 – 382	208 – 58,248	363 – 883,016	735 – 3,369,894
Total	381 – 913	541 – 112,084	735 – 1,277,552	1,122 – 3,872,862

These results can be compared to other authors who evaluate forecasts of the area. The report from the National Electromobility Platform (NPE), for example, shows a forecast of 1,022,000 private car charging stations in Germany by 2020. [9, p. 46] This is an old-dated prediction, based on the previous objective of 1 million electric cars in 2020. Based on [10, p. 2], this number will not be reached and a new forecast of private car charging stations based on the new number should be made. Assuming that there will be 700,000 electric cars in Germany in 2020 [10, p. 2] and 57.6% of the private charging stations are installed in garages of private houses [11, p. 22], the forecast is updated. In figure 11, this forecast is compared with the maximum number of houses with the potential for HEM systems from table 1. Based on that, it is possible to suppose that approximately 6.3% of the houses with a charging system can have potential for installing a HEM system in 2015 and 25% in 2020.

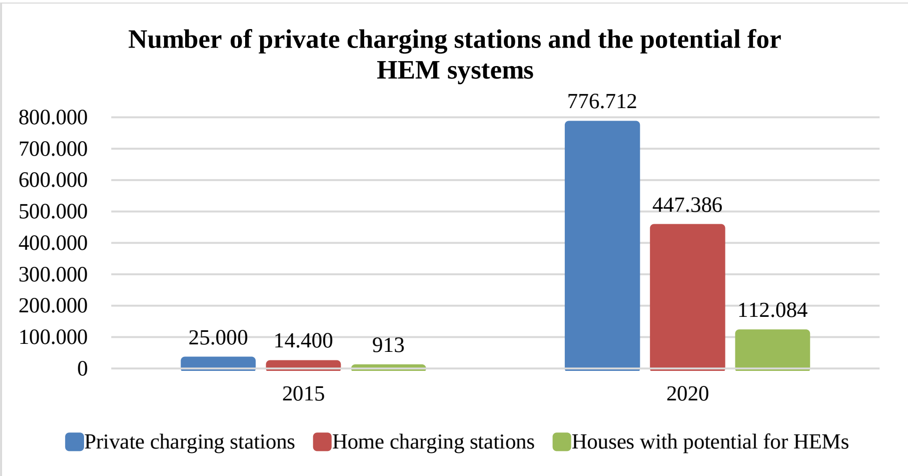


Fig. 11. Number of private charging stations and the potential for HEM systems

5 Conclusions

The model developed met the established objectives, being a reliable tool to estimate the potential of HEM systems, mainly when accurate data is available. A big amount of relevant data on factors related to the local generation of renewable energy and electromobility were gathered, what already illustrates the current and future scenario of this market. These data were correlated and analyzed, giving a good visualization of the possible application of the project e-MOBILie, also allowing the analysis of the future scenario. The model gives also the possibility of entering dependencies between elements and using ranges as inputs. Those things are the most interesting characteristics of the model as they differ it from estimations made with simple calculations.

It is possible to conclude that the market grown of HEM systems depends mostly from the success of the electric cars penetration. Since it succeeds, there is a big potential for the installation of these systems, with the possibility that the number of one-family households with at least two favorable elements to HEM systems installation reaches almost 4 million in 2050.

As proposed, the model is easily expandable and can be applied to other areas of study, as for example, the estimation of houses that have more than one technological devices (cellphones, laptops...). The expansion is also possible by raising the number of elements used in this research, adding factors such as wind turbines or battery banks installed. The model is also made to run to any territory, so this estimation can be expanded for other domains and even an evaluation of the world HEMS potential is possible. In order to do this, improvements in the velocity of the simulation shall be made.

Other further development could be to conduct surveys to have more accurate data for the inputs. To find out how much one is likely to buy an electric vehicle when they already have a PV system installed at home, for example, would turn possible to have one exact value for dependencies and to restrict the range of results. One other possibility is to use data that takes the life-time of the equipment into account or use statistics to estimate it. That would bring results that are more complete, especially for long-term forecasts like 2050. In addition, new trends, statistics and reports are realized periodically and the results obtained in this work can be frequently updated so estimations that are more precise are achieved.

References

1. A. Y. Saber and G. K. Venayagamoorthy, "Plug-in Vehicles and Renewable Energy Sources for Cost and Emission Reductions," *IEEE Transactions on Industrial Electronis*, pp. 1229-1238, 2011.
2. Lehrstuhl für Energiewirtschaft und Anwendungstechnik, "e-MOBILie - Schaufenster Elektromobilität," Lehrstuhl für Energiewirtschaft und Anwendungstechnik, [Online]. Available: http://www.ewk.ei.tum.de/forschung/projekte/e-mobilie/. [Accessed 2015 June 21].

3. J. S. Hill, "Home Energy Management Revenue Set To Hit $22 Billion," CleanTechnica, 3 March 2015. [Online]. Available: http://cleantechnica.com/2015/03/03/home-energy-management-revenue-set-hit-22-billion/. [Accessed 13 Mai 2015].
4. A. Kirsten Vidal de Oliveira and C. Kandler, *Correlation Analysis for Determining the Potential of Home Energy Management Systems in Bavaria, Germany and Europe,* Munich, 2015.
5. T. Tayamachi and J. Wang, "Transmission Characteristic Analysis for UWB Body Area Communications," in *International Symposium on Electromagnetic Compatibility*, 2007.
6. B. Li and Z. Zhao, "Cloth 3D Attributes Animation Based on a Wind Noise," in *Symposium on Photonics and Optoelectronics*, 2012.
7. P. Cisar and S. M. Cisar, "Fitting univariate distributions to computer network traffic data using GUI," in *IEEE 13th International Symposium on Computational Intelligence and Informatics (CINTI)*, 2012.
8. R. E. Kass and A. E. Raftery, "Bayes Factors," *Journal of the American Statistical Association,* vol. 90, pp. 773-795, June 1995.
9. Nationale Plattform Elektromobilität (NPE), "Fortschrittsbericht 2014 – Bilanz der Marktvorbereitung," Gemeinsame Geschäftsstelle Elektromobilität der Bundesregierung (GGEMO), Berlin, 2014.
10. F. Hacker, R. von Waldenfels and M. Mottschall, "Wirtschaft lichkeit von Elektromobilität," Februar 2015. [Online]. Available: http://ikt-em.de/_media/Gesamtbericht_Wirtschaftlichkeit_von_Elektromobilitaet.pdf. [Accessed 27 March 2015].
11. National Organisation Hydrogen and Fuel Cell Technology, "Ergebnisbericht - Der Modellregionen Elektromobilität 2009 – 2011," Bundesministerium für Verkehr, Bau und Stadtentwicklung, Berlin, 2012.