

# Short-term Wind Forecasting to Support Virtual Power Player Operation

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## Abstract

This paper proposes a wind speed forecasting model that contributes to the development and implementation of adequate methodologies for Energy Resource Management in a distribution power network, with intensive use of wind based power generation. The proposed forecasting methodology aims to support the operation in the scope of the intraday resources scheduling model, namely with a time horizon of 10 minutes.

A case study using a real database from the meteorological station installed in the GECAD renewable energy lab was used. A new wind speed forecasting model has been implemented and its estimated accuracy was evaluated and compared with a previous developed forecasting model. Using as input attributes the information of the wind speed concerning the previous 3 hours enables to obtain results with high accuracy for the wind short-term forecasting.

## 1. Introduction

European countries have been facing a high penetration of electricity generation from renewable sources, representing the wind power a significant share. Wind power is a clean energy and an environmentally friendly source generation. However, power generation is uncertain due to the variability of wind speed. The integration of this resource on electricity market requires obtaining knowledge of wind power/speed forecasting to allow decision-making. Virtual power players face an enormous challenge and accurate wind power forecasting is crucial to deal with the uncertainty in wind power and also to support the wind power scheduling dispatch [1, 4].

From all renewable resources, the wind power is one of the most promising technologies. However, it raises great challenges into the existing power network. With the increasing wind power capacities, power system operators are facing many new challenges because of its variability and difficult predictability [5].

Under the deregulation of the electricity sector, the importance of wind power forecasting to the involved players and system operators is increasing all over the world [6, 7].

It has been demonstrated in previous research works that there is a necessity for accurate wind forecasting in order to enable that wind power can be integrated into the scheduling and dispatch decisions of the power system operators [8]. Wind power forecasting is required for the day-ahead and intraday decision making. In the context of planning and operation of power systems, decision making is carried out iteratively at different timeframes from day-ahead to minutes-ahead [9].

In the smart grid context, the wind speed forecasting enables to support the power operation in the scope of the intraday resources scheduling model, namely with a time forecasting horizon of 5 or 10 minutes. Therefore, the intraday is crucial to support distribution network operators in the short-term scheduling problem.

The use and trade of renewable energy in the market is not a trivial task because of the uncertainty associated with power generation from this type of resources, particularly for wind farms [10]. Good wind predictions are essential for schedulers to deal with all the involved market and technical requirements.

This paper proposes a data-mining-based methodology to forecast wind speed based on a real database collected from the GECAD (Knowledge Engineering and Decision-Support Research Group of the Polytechnic of Porto) renewable energy lab. A comparison of the developed forecasting model with a previous implemented wind speed forecasting model has been made. The wind speed forecasting model will be integrated in the Energy Resource Management (ERM), namely in the intraday model that supports distribution network operators in the short-term scheduling problem.

The rest of the paper is organized as follows: section 2 briefly reports the wind speed/power forecasting in Virtual Power Players context; section 3 summarizes the energy resource management methodology, namely in what concerns the wind speed forecasting to support the short-term scheduling of energy resources; in section 4 a case study is presented to illustrate the application of the proposed methodology using the wind prediction models. The conclusions and future work are reported in the last section.

## 2. Wind Speed/Power Forecasting in Virtual Power Players Operation

The increasing fossil fuels shortage and consequent increase of their price, and the involved environmental concerns that this type of fuel brings, led to an increase in the use of renewable energy sources.

From the environment point of view the advantages of using renewable energy sources are clear. However, despite the favourable scenario to distributed generation (DG) growth, there are important aspects to consider, both of economic and technical nature. Issues such as the dispatch ability (namely in wind and photovoltaic technologies), the participation of small producers in the market and the maintenance high costs, are problems that must be overcome to take advantage of an intensive use of DG [11].

Aggregating strategies can enable owners of renewable generation to gain technical and commercial advantages, achieving higher profits from the specific advantages of a mix of several generation technologies and overcoming serious disadvantages of some technologies [12].

The aggregation of DG plants gives place to the concept of Virtual Power Player (VPP) [13]. VPPs are multi-technology and multi-site heterogeneous entities, being relationships among aggregated producers and among VPPs and the remaining electricity market agents a key factor for their success [12, 13, 14, 15]. Player coalitions are especially important to address VPPs as these can be seen as a coalition of agents that represent the aggregated players [12, 15].

Figure 1 illustrates the concept of the virtual power player.

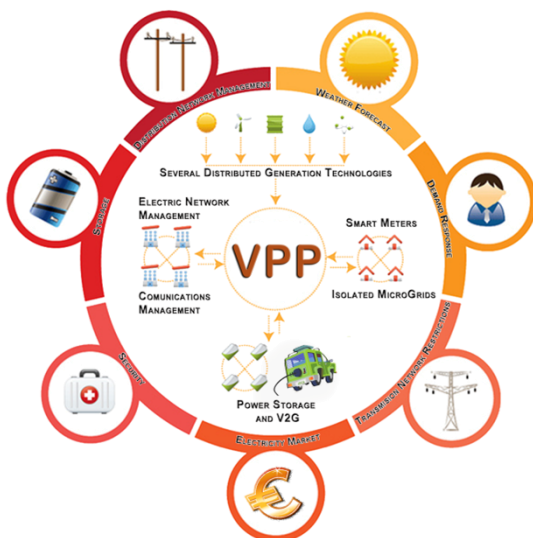


Figure 1 – Virtual Power Player (VPP) framework structure

Coalition formation is the coming together of a number of distinct, autonomous players that agree to coordinate and cooperate, acting as a coherent group, in the performance of a specific task. Such coalitions can im-

prove the performance of the individual players and/or the system as a whole. The coalition formation process comprises several phases: coalition structure generation, optimization of the value of the coalition and payoff distribution [15, 16].

Regarding the coalition formation process, for VPP modelling, the three main activities of coalition structure generation, optimization of the value of the coalition and payoff distribution should be considered under a scenario where players operate in a dynamic and time dependent environment.

To sell energy in the market VPP must forecast the generation of aggregated producers and “save” some power capacity to assure a reserve to compensate the generation oscillation of producers with technologies dependent from natural resources.

The VPP can use different market strategies, considering specific aspects such as producers established contracts and range of generation forecast. The prediction errors increase with the distance between the forecasting and the forecast times. The standard errors are given as a percent of the installed capacity, since this is what the utilities are most interested in (installed capacity is easy to measure); sometimes they are given as the mean production or in absolute numbers.

Considering the example of the Spanish market (OMEL), the spot market session closes at 11:00 AM; therefore the time slice between the predictions and real day is 13 to 37 hours. In this context, the VPP can change its market strategy during the day to manage the risk. These strategies also depend on reserves; in other words, VPP can change the reserve to maintain the risk; however, if a VPP has a bigger reserve the costs are higher.

Another important factor for the VPP market strategy is the price of bought energy from the aggregated producers. The price considered for each producer must be agreed with the VPP so that competitive prices can be obtained, to allow the producers to have revenues from their investments in reasonable periods of time.

If subsidies exist, these will have to be included in the calculation of the prices considered for the producers. The price of the reserve will also have to be previously agreed between the VPP and the producers.

Aggregated producers’ operation has to be supervised by the VPP and adequate internal control and management measures implemented. This includes internal reserve management to overcome shortage or surplus generation, which considers the generation resources of all aggregated producers and internal and external available/contracted reserve means.

Firstly, all the capacity available from the different aggregated distributed energy resources must be gathered to establish the electricity amount to trade on the market. The different generation costs must be analyzed to define the interval for envisaged proposals. This means VPP agents will have an utility function that aggregates all the involved units’ characteristics. The analysis of the aggregated producers’ proposals will be done according to each unit capabilities and costs.

After the market session, the VPP agent undertakes an internal dispatch, analyzing and adjusting its generation and reserve to maximize profits and informs the aggregated producers about their dispatch.

Finally, in function of the generation, the used and unused reserve of each producer and the established contracts of the VPP fulfilment, the VPP determines the producers' remuneration.

From internal dispatch to electricity market negotiating amounts, an adequate forecast of wind speed is essential for the management of a VPP. Errors in prediction may lead to serious problems of both technical and economical nature. Besides the forecast accuracy requirements, this, in most cases, must be performed in very short time windows.

### 3. ERM – Energy Resource Management Methodology

The high quantities of wind turbines in distribution networks may be worrying, since wind power is stochastic, especially in the short and very short term (e.g. over any given hour, 30 minute, or 10 minute period). This has created a completely new challenge to the system operators to maintain the continuous balance of electricity supply and demand [21].

The short-term scheduling of energy resources leads to two main relevant aspects to be considered – the necessity of having a solution in a short-time and the uncertainties related to the increasing integration of distrib-

uted energy resources based on intermittent natural energy sources [19].

The ERM methodology for energy resources scheduling allows the dispatch according to the forecast of generation and of consumption in different time horizons (day-ahead, hour-ahead and real-time) [9,10,11]. This paper focuses on the proposed scheduling model for 10 minutes time anticipation resource scheduling (Fig. 2). The 10 minutes ahead scheduling is applied to each 10 minutes period adjusting the short-term generation and load demand forecasts. The implementation of the developed simulator is based on a genetic algorithm (GA) approach that is applied to the optimization problem [17, 21].

The algorithm manages the connected generators with available power capacity (spinning reserve), storage units, EVs, loads with intensive DR reduction/curtailment contracts, and considers market penalties [18]. The main goal is to minimize the operation cost and to minimize the impact in the day-ahead and hour-ahead energy resources scheduling. In this way the operation costs and the market penalties are minimized.

Considering 10-minutes-ahead resource schedule, a real-time horizon schedule phase is designed. The real-time schedule corresponds to the 10-minutes-ahead schedule, which is performed for each period of 10 minutes, ten minutes ahead of the envisaged period.

The proposed wind forecast methodology has been designed to be included in an application that supports distribution network operators in the short-term scheduling problem, in the smart grid context, as illustrated in Fig. 2.

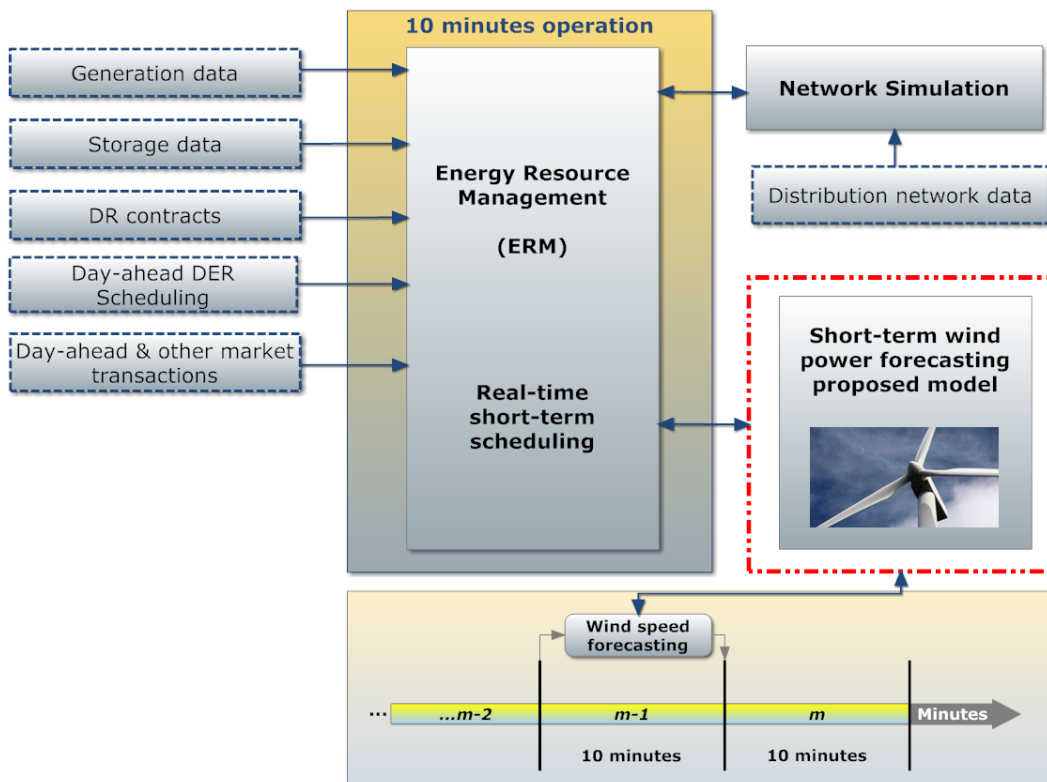


Figure 2 - Wind forecasting methodology to support intraday operation

The 10 minutes-ahead schedule is applied to each period of 10 minutes [9], adjusting the short-term generation and load demand forecasts. To execute these scheduling, it is necessary to measure the status of the network operation, namely the load demand, the storage system status and the EVs location and the status of their batteries. With these parameters, it is necessary to run a new forecast process to improve the quality of the scheduling solutions.

All the resources (generators, storage units, demand response programs, and the intraday market) are considered for the 10-minutes ahead scheduling. The proposed wind forecasting methodology aims to support the operation in the scope of the intraday model (spotted red square in Fig. 2), namely the 10-minute-energy resources scheduling.

## 4. Experimental results

The proposed forecasting methodology aims to support the operation in the scope of the intraday resources scheduling model, namely with a time horizon of 10 minutes. This intraday model supports distribution network operators in the short-term scheduling problem, in the smart grid context.

The present case study uses a real database concerning wind speed from the meteorological station installed in the GECAD (Knowledge Engineering and Decision-Support Research Group of the Polytechnic of Porto) renewable energy lab. The database includes the values of the wind speed, recorded with time intervals of 10 minutes during the entire year of 2011.

Fig. 3 presents the framework methodology used to predict the wind speed.

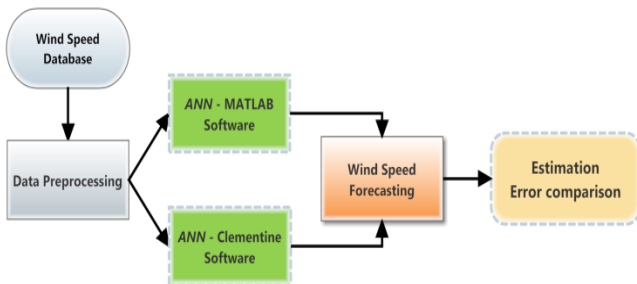


Fig. 3 – Framework of the proposed Short-term wind forecasting methodology

This case study uses an Artificial Neural Network (ANN) based approach to forecast the wind speed taking into consideration historical data.

The prediction accuracy of the developed short-term wind forecasting model, implemented in MATLAB, is evaluated and compared with a previously developed wind speed forecasting model, implemented in IBM SPSS Modeler and presented in [19].

Starting from the collected data, a data pre-processing module was implemented in order to prepare the database properly to the estimation model. Only wind speed attribute was selected to be used in the

ANN training model because it leads to better results than using more input attributes [20].

The wind speed has been forecasted taking into account the historical data. Thus, and based on previous works of the authors [20], the ANN obtained better results when the last 3 hours were used as input attributes.

Therefore, in the present case study it was used the last 3 hours to predict the wind speed for a 10-minute interval and the estimated error is presented and compared between the two short-term wind forecasting models.

In order to evaluate the accuracy of the wind speed prediction, the mean absolute percentage error (MAPE) can be used. MAPE is defined as follows:

$$MAPE = \frac{100\%}{N} \sum_{h=1}^N \left| \frac{P_h^a - P_h^f}{P_h^a} \right| \quad (1)$$

where  $P_h^a$  and  $P_h^f$  are the actual and forecasted wind power, respectively, at period  $h$ , and  $N$  corresponds to the number of forecasted periods.

The neural net is trained with 11 months of wind speed recorded data, and the test data for this case study is 1 month. The forecast is made using the previous 3 hours of wind data (in 10-minute intervals). It is intended to predict the next 10 minute-interval to support the short-term scheduling problem, which requires updated wind speed forecasting for the distributed generation based on wind resources. The models used as input attribute the month, hour, minute and the recorded wind speed value concerning the last 3 hours. The output corresponds to the wind speed for the next 10 minutes, as illustrated in Fig. 4.

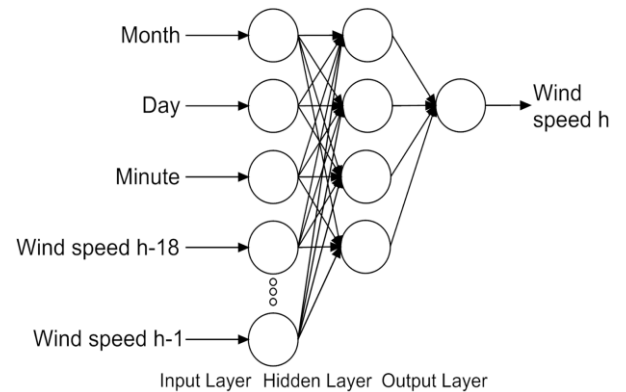


Fig. 4 – ANN structure

After wind speed prediction, the Energy Resource Management (ERM) module can be used with the accurate forecast results provided by the methodology proposed in this paper. Fig. 5 presents the stream of the previous implemented ANN (IBM SPSS Modeler). It is clear the separation between the training and test model as well the input data. The arrows indicate the direction of data over the previous implemented model [20].

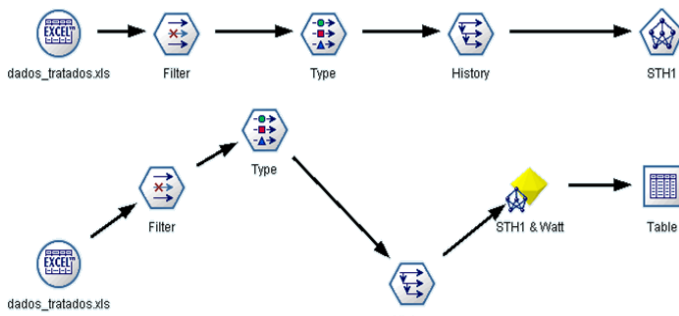


Figure 5 – Stream of the previous ANN implemented – IBM SPSS Modeler software [20]

Fig. 6 illustrates the wind speed forecasting for the last 6 hours of the day December 15<sup>th</sup> 2011. Analysing Fig. 6 it is possible to see the good obtained prediction accuracy.

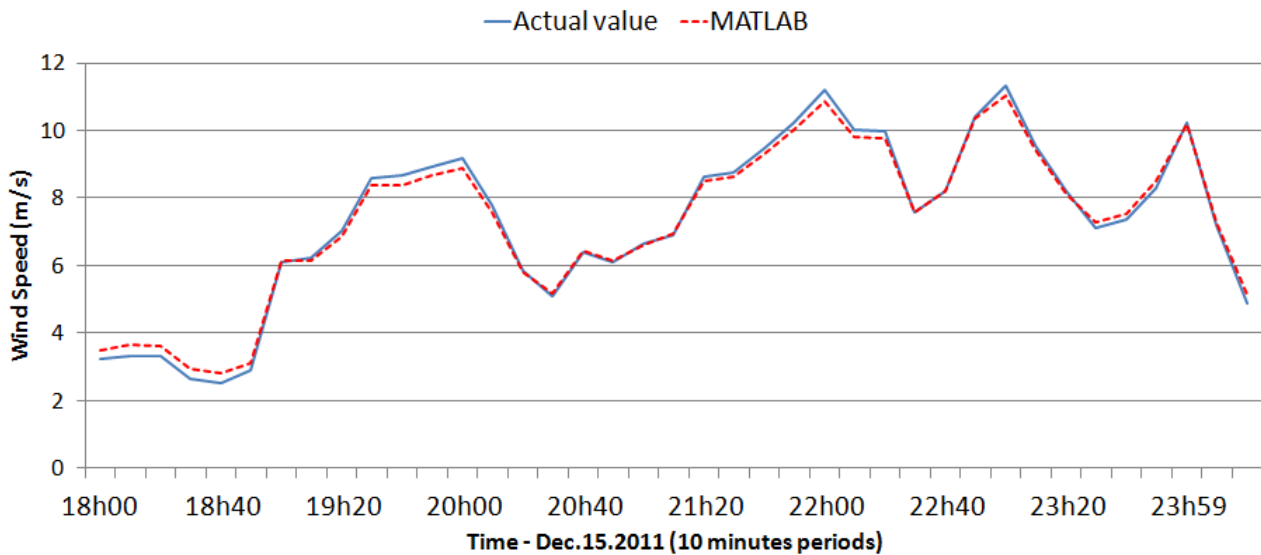


Figure 6 – Wind speed forecasting using the implemented ANN – MATLAB

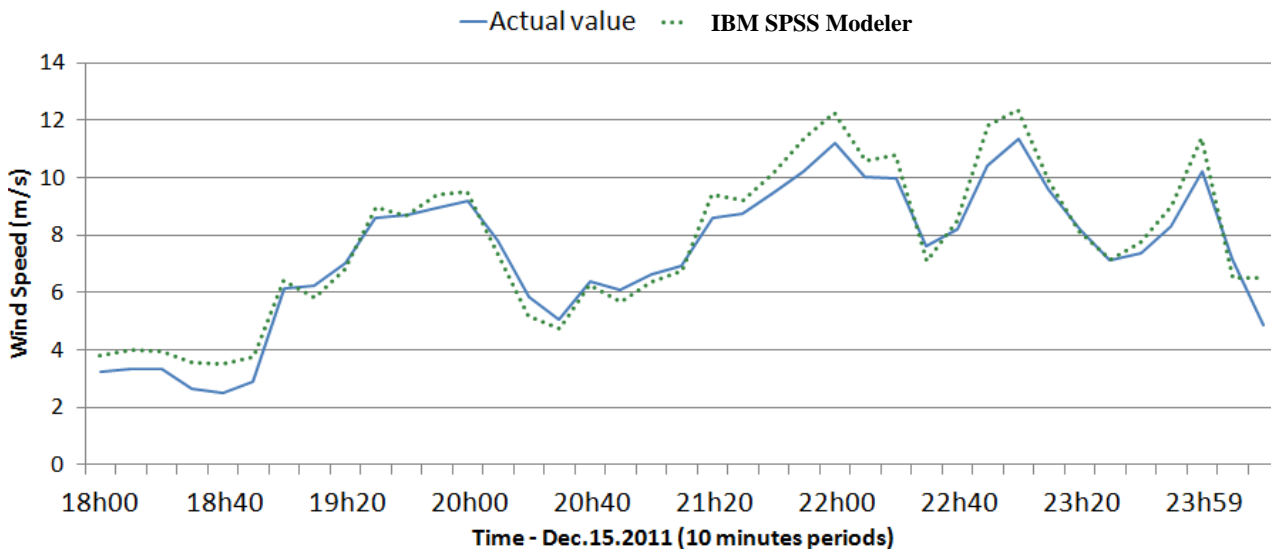


Figure 7 – Wind power forecasting using the previous implemented ANN – IBM SPSS Modeler [20]

Fig. 7 shows the wind speed forecasting obtained using the previous implemented ANN – IBM SPSS Modeler. In this case it is possible to observe that the estimated error is higher, mainly is some peaks and valleys.

Table I presents the MAPE value that have been calculated for this case study using the two forecasting methods.

TABLE I – COMPARATIVE MAPE RESULTS

		MAPE (%)
New forecasting model	MATLAB Model-ANN	2.90
Previous forecasting model	IBM SPSS Modeler Model-ANN	9.99

These results clearly show that the ANN model presents better estimation accuracy when the two methods are used under the same conditions.

## 5. Conclusions

A new wind speed forecasting model has been implemented and its estimated accuracy was evaluated and compared with a previously developed forecasting model. Using as input attributes the information of the wind speed concerning the previous 3 hours enables to obtain results with high accuracy for the wind short-term forecasting.

It was used a real database concerning wind speed provided from the meteorological station installed in the GECAD renewable energy lab.

This work contributes to the development and implementation of adequate methodologies for Energy Resource Management in a distribution power network, with intensive use of wind based power generation.

This is an extremely important asset to support the operation of a Virtual Power Player (VPP). By detaining appropriate forecast capabilities, VPPs are able to adequately manage the internal resources of their control areas, resulting in great advantages for the VPP and for the considered resources, namely in what concerns the need for energy negotiation outside the VPP control area, and the unnecessary waste of power from wind sources.

The proposed methodology is especially relevant because of the high accuracy of the forecasted wind speed values that are fed to the 10-minute-ahead energy resource management module. This allows undertaking a re-schedule of energy resources which uses forecasted values very close to the actual ones leading to lower operation costs. The results demonstrated good estimated accuracy when the estimation used the historical database concerning wind speed. Indeed, an important conclusion already obtained was that using only as input attributes the information of the wind speed concerning the previous 3 hours enables to obtain results with high accuracy for the wind short-term forecasting.

The obtained results clearly show that the new method, which has been implemented in MATLAB environment, allows obtaining better results than the previously proposed one.

## Acknowledgements

“This work is supported by FEDER Funds through COMPETE program and by National Funds through FCT under the projects FCOMP-01-0124-FEDER: PESt-OE/EEI/UI0760/2011, PTDC/EEA-EEL/099832/2008, PTDC/SEN-ENR/099844/2008, and PTDC/SEN-ENR/122174/2010”.

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## Biographies



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