Impact of Cloud Computing on Enhancing the Use of Renewable Energy

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***Abstract* — Renewable energy has been identified as one of the disruptive technologies that have the potential for massive impact on the society for the coming years. A major concern for using renewable energy such as solar photovoltaics and wind is its variable nature. The importance of this concern is increasing in recent years as the penetration levels of renewable energy have been increasing rapidly in the electric power grids worldwide. Forecasting is a major tool that can be used to address the variable nature of renewable energy. Cloud Computing provides the enabling technology to handle the complexity of renewable energy forecasting and can enhance more widespread and more effective utilization of renewable energy. This paper presents the new applications of using Cloud Computing to enhance the use of renewable energy through the achievement of two goals. The first goal is to present a Cloud Computing-enabled renewable energy forecasting system--the FaaS (Forecast-as-a-Service) framework--to demonstrate the technical feasibility. Based on the service-oriented architecture (SOA), the FaaS has been successful in generating user-specified solar or wind forecast on demand and at reasonable costs. Using the FaaS as the starting point, the second goal of this paper is to present from a broader perspective the potential impact of Cloud Computing on the use of renewable energy. Cloud Computing, coupled with other technology trends, supports the development of new applications and business models that could flourish the renewable energy industry.**

Keywords – Cloud Computing; services; service-oriented architecture; forecasting; renewable energy; cyberinfrastructure.

I. INTRODUCTION

Providing almost unlimited computing resources on a pay-per-use basis, Cloud Computing provides new options for data-intensive and computation-intensive applications. Cloud computing not only makes possible the completion of complex computational tasks within shorter time frames but also enables such capabilities to be available at affordable costs. This paper describes the impact of Cloud Computing on the use of renewable energy.

Renewable energy has been identified as one of the disruptive technologies that have the potential for massive impact on the society for the coming years [1]. A major concern for using renewable energy such as solar photovoltaics and wind is its variable nature. The importance of this concern is increasing in recent years as the penetration levels of renewable energy have been increasing rapidly in the electric power grids worldwide. Forecasting is a major tool that can be used to address the variable nature of renewable energy. Based on the forecast information, variability can be accommodated on the power supply side by implementing measures such as generation scheduling and storage backup, and on the power consumption side by implementing demand-side management and demand response programs. Accurate forecasting of renewable energy will provide important contribution to the realization of smart grid and enable more widespread and efficient utilization of renewable energy. Cloud Computing provides the enabling technology to handle the complexity of renewable energy forecasting.

This paper presents the new applications of using Cloud Computing to enhance the use of renewable energy through the achievement of two goals. The first goal is to present a Cloud Computing-enabled renewable energy forecasting system--the FaaS (Forecast-as-a-Service) framework--to demonstrate the technical feasibility. Based on the service-oriented architecture (SOA), the FaaS has been successful in generating user-specified solar or wind forecast on demand and at reasonable costs. The FaaS framework can be used as a software-as-a-service (SaaS) to provide prospecting or operational forecast for solar or wind power systems. It can also be used as a platform-as-a-service (PaaS) to develop more capabilities or more customized functionalities.

Using the FaaS as the starting point, the second goal of this paper is to present from a broader perspective the potential impact of Cloud Computing on the use of renewable energy. Cloud Computing, coupled with other technology trends, supports the development of new applications and business models that could flourish the renewable energy industry.

This paper offers contributions that are different from those reported in existing literature. Although both the FaaS and the CloudCast [2] are concerned with forecasting, FaaS is different from CloudCast not only in terms of the services provided but also in terms of the underlying design. Efforts to bring together service-oriented architecture and Cloud Computing have been reported in the literature [3][4]. FaaS is different from these efforts in that FaaS also addresses service pricing issues. There are patterns for object-oriented software design [5] and patterns for SOA service design [6]. The FaaS Framework may be viewed as the preliminary version of a Cloud Computing pattern for on-demand quantitative forecasting processes. By improving the flexibility and economics of renewable energy forecasting services, FaaS also achieves the goal of Services Computing [7].

Section II presents the concepts and implementation of the FaaS framework and the forecasting results generated. Broader impact of Cloud Computing on the use of renewable energy is discussed in Section III. Conclusions are contained in Section IV.

II. CLOUD-ENABLED FORECASTING SYSTEM

As shown on the top of Figure 1, a quantitative forecasting process may be grouped into four major steps: problem definition; data collection; analysis and model formulation; and forecast generation. . Using the principles of service-oriented architecture (SOA), each of these major steps can be performed by a composite service. Figure 1 shows the layered organization of a SOA framework used in the FaaS framework for the forecasting of renewable energy. Services in the Service Layer consist of the fundamental and agnostic services that are not coupled to any specific application. They perform tasks such as data transfer over the Internet (Transfer Tools services), statistical analysis (Statistical Tools services), forecasting (Forecast Tools services), etc. Many of these basic services are used in both the wind and the solar power forecasting processes.

On top of the Service Layer are the Composite Service and Workflow Layer. The External Data Collection Framework (EDCF) is responsible for gathering relevant data from different sources over the Internet. These data are available from a variety of sources: federal agencies, national databases and archives, private organizations, universities, data vendors and equipment vendors. From these sources, different types of data are rendered in different formats: satellite images, sensor measurement data, computer model data, vendor product data, etc.

The Internal Data Retrieval Framework (IDRF) processes and analyses the externally collected data and stores the results as internal data for future uses. The Forecast Generation Framework (FGF) generates the pertinent forecast of either wind or solar power at the location specified by the user. The FaaS controller serves to organize the entire forecast process and orchestrates different services to implement the workflow.

Each of the major steps shown on top of Figure 1 is performed by a composite service: the EDCF for data collection; the IDRF for the support of analysis and model formulation; the FGF for forecasting and the FaaS controller for problem definition and overall coordination.

The EDCF, IDRF, FGF and the FaaS controller are all composite services designed by applying SOA principles [6][8]. They are implemented by using the Windows Communication Foundation (WCF) [9], Microsoft Azure and .NET technologies [10].

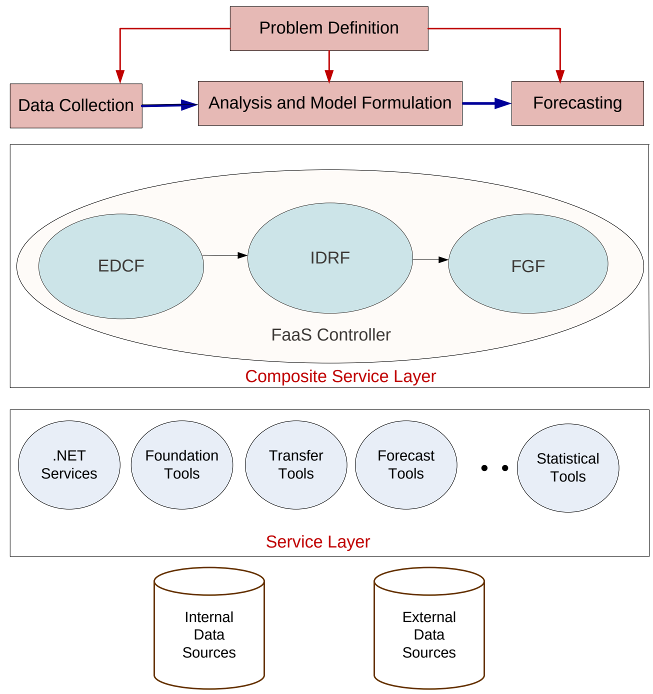

Figure 1. A SOA-based framework for the forecasting process

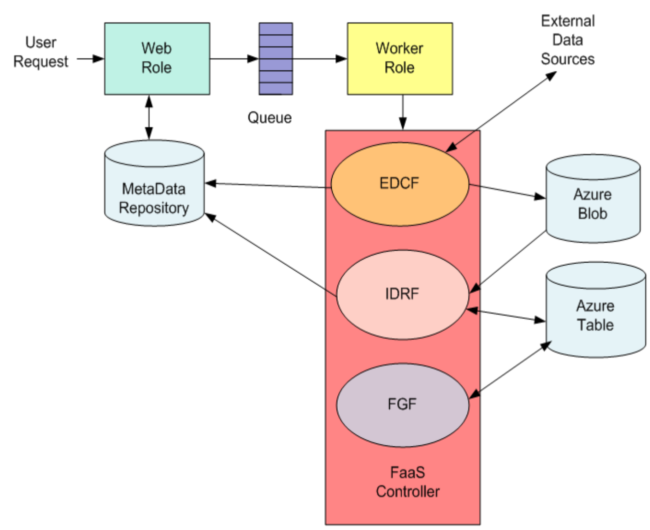

Figure 2. Implementation of the FaaS framework using Windows Azure

Figure 2 shows the implementation of the FaaS system using the Windows Azure Cloud Computing platform. To initiate a forecast process, a user through a web page specifies the renewable energy source (solar or wind), the location (latitude and longitude), the kind of forecasting

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services (prospecting or operational), uncertainty quantification (with or without), and whether characteristics of energy conversion equipment (such as a particular model of a solar panel or a wind turbine from a list of manufacturers) should be included in the computation to make the forecast more realistic. Based on the customer-specified forecast request, the FaaS controller formulates a workflow consisting of all the tasks that need to be performed.

If relevant data are not available in the internal database (bottom layer in Figure 1), the FaaS controller informs the EDCF to obtain the needed data from external sources over the Internet and store the collected data in the Azure Blob storage. The FaaS system keeps a database of external data sources in a Meta Data Repository (MDR). MDR stores information about what kind of data a data source provides, the web address, the protocol for data access and the data format. Based on the metadata from the MDR, the EDCF initiates a data collection process to gather data for the location (or the nearest location) requested by the user from the pertinent data source. The EDCF utilizes the Transfer Tools services (shown in Figure 1) and other basic services to accomplish the external data collection process.

The IDRF takes the raw data from the Azure Blob storage, performs data analysis and stores the results in the Azure Table storage in the standardized formats for which the forecasting models are designed. As a composite service, the IDRF utilizes the appropriate services based on the metadata for the raw data. For example, the Statistical Tools service is used to generate statistics for long term historical data analysis. The Discrete Fourier Transform service is used to generate frequency domain components.

Using data prepared by the IDRF and stored in the Azure Table storage, the FGF generates the forecast based on the user's request. Different forecasting methods are implemented as services and used by the FGF. The forecast results are emailed to the user.

Because of the variety of information involved in the FaaS framework, it is important to have a well-organized Meta Data Repository (MDR) and an effective Meta Data Repository Management System (MDRMS) [11]. EDCF, IDRF, FGF and the FaaS controller all interact with the MDR through the MDRMS.

Figure 3 shows an example of the results provided by the FaaS system in response to a request for solar power forecast for operational planning purpose. The forecast is performed at the user-specified location in terms of latitude and longitude. If data is not available internally or externally for the requested location, data for the nearest location with data will be used to generate the forecast and the user will be notified of this distance. For example, Figure 3 shows that the distance between the requested and actual location for the forecast is 2.52 km. A number of basic services have been developed for tasks such as the computation of distances based on longitude and latitude coordinates, calculation of sky clearness index (K_D in Figure3), statistical analysis of data, etc. Figure 3 shows that the day ahead solar energy forecast is 6.036 kWh/m^2.

You requested operational forecast data.

Time of Report Delivery		3/24/2013 7:04:47 PM GMT	
Time of Request		3/24/2013 7:04:44 PM GMT	
Cost		16.68 dollars	
Location: Name		Blacksburg, Virginia	
	Latitude 37.217	Latitude you entered 37.2	
	Longitude 80.417 W	Longitude you entered 80.4 W	
State Code		VA	
Source of Renewable Energy		Solar	
Solar Panel:	Vendor	Sun Power	
	Model	SPR-200-WHT-U	
	Efficiency	16.08 %	

Distance between requested and actual location: 2.52 km

Day-ahead Forecasted Energy Production: 6.036 kWh/m^2

K_D : 0.705

Figure 3. An example of forecast results in response to a request

Due to the complexity of SOA, the costs of SOA-based projects are difficult to estimate although there have been attempts to do so [12][13]. This project attempts to develop a method to price services so that a customer has the option to decide whether to proceed with the forecast request after viewing the estimated cost. The approach taken by the FaaS adopts the divide-and-conquer concept and product pricing concepts [14].

The price of each service is computed by using a 3-step process.

Step 1: Calculate the total cost by combining the cost of manpower for software development, the cost of resources utilized, etc., and imposing an overhead rate and indirect costs.

Step 2: Estimate the expected number of usage of this service over a time horizon before the next major update.

Step 3: Divide the total cost computed in step 1 by the expected number of usages in step 2 to obtain the service price per usage.

When services are combined to form composite services, the prices of constituent services are included in the cost of resources utilized. All the costs and prices are updated periodically after more usage information becomes available.

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To implement this pricing method, each service is equipped with two endpoints – one endpoint is used for technical functionalities and the second endpoint is used for pricing purposes. When a service is consumed because of its technical functionalities, the pricing endpoint of the same service will also be incorporated into the overall pricing workflow. When a certain mission is accomplished by a sequence (or workflow) of services, not only the technical requirement is met but the associated price of accomplishing the mission is also calculated.

Using the economic endpoints of all services involved, the FaaS controller estimates the cost for the request and send the cost estimate to the requester. If the requester accepts the estimated cost, the requester will provide the email address to which the forecast results will be sent. The FaaS system will then perform the required tasks in the cloud and deliver the forecast results over the Internet after the work is complete.

Figure 3 shows that the estimated cost for that particular forecast request is US$ 16.68. Table I shows an example of the overall solar forecasting cost and the costs of the composite services for project prospecting and operational planning, respectively. The prices for prospecting forecasts are usually higher than those of the operational forecasts because they involve data over longer time horizons and utilize more computational resources. Results of this project indicate that the costs of prospecting forecasts are in the range of US$ 60-80 per request while the costs for operational forecasts are in the range of US$ 10-20 per request. Additional services, such as uncertainty quantification, can be requested for additional prices in the order of a few dollars. These costs are much lower than the monthly or annual subscription fees charged by current renewable energy forecast service vendors.

Figure 4 shows the application of the FaaS system to solar power forecasting. A similar diagram can be drawn to show the application of the FaaS system to wind power forecasting. As shown in the upper half of Figure 4, a large volume of data is needed for solar power forecasting. These data are available from a variety of sources that provide data of different types and in different formats. The EDCF is designed to obtain data of different types from various sources over the Internet and store them in the Azure Blob storage. The IDRF processes the raw data into a unified format useful for the different forecasting methods implemented as services. This two-step process is the approach adopted by the FaaS system to handle big data. FaaS demonstrates that automated collection and processing of large amount of data in various formats and from different sources is a unique capability provided by Cloud Computing.

As shown in the lower half of Figure 4, this framework delivers different types of forecasts to different types of users. There are potential users who want forecasts of future solar power production to support the making of investment decisions. Current users of solar power need to know the short-term forecasts to make arrangement for operation. Electric utilities need to know the solar power forecast with quantified uncertainty to properly plan for their operation. The FaaS system delivers a variety of user-specified forecast results over the Internet to meet forecast needs at reasonable costs. On-demand delivery of user-specified services at different levels of details for various kinds of applications is another unique capability provided by Cloud Computing.

TABLE I. AN EXAMPLE OF THE COSTS OF FORECASTING SERVICES

Forecast Type	Service	Cost (US $)	Overall Cost (US $)
Project Prospecting	EDCF	10.55	62.89
	IDRF	32.02	
	FGF	20.32	
	FGF (with UQ)	22.87	65.44
Operational Planning	EDCF	3.84	13.92
	IDRF	3.06	
	FGF	7.02	

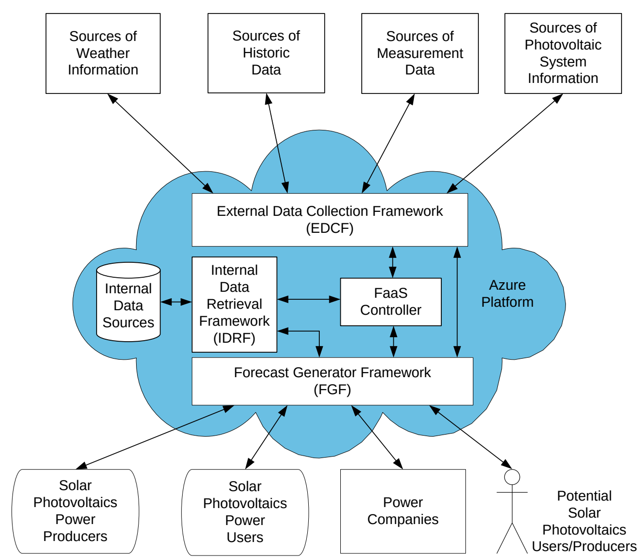

Figure 4. Application of FaaS to solar energy forecasting

III. IMPACT OF CLOUD COMPUTING

Renewable energy forecasting is data-intensive and computation-intensive. Providing almost unlimited computing resources on demand, Cloud Computing provides new options for the computation and delivery of different kinds of services, and opens up new opportunities for entrepreneurs to establish new business models. Creativity and innovativeness of entrepreneurship will add new impetus to enable more widespread utilization of renewable energy and will hasten the fulfillment of its potential to meet the energy needs of human society.

Depending on what responsibilities are shifted to the cloud, current and potential users of renewable energy can choose a service model and a deployment model most appropriate for their respective situations. SaaS provides flexibility and cost effectiveness. An organization only needs to connect to the forecast application software through a Web browser and use it, without the hassle and expense of developing, implementing, or supporting it. FaaS is an example of such an application.

The FaaS framework enables different users to specify and pay for only the forecast services they need on demand. Cloud-based systems, such as the FaaS, are especially meaningful to individuals and small companies that would like to consider using renewable energy but lacks the resources to obtain forecast information that fits their particular needs. Cloud-based systems, such as the FaaS framework, can provide a broad impact by removing some barriers for more widespread use of renewable energy. Although some government agencies and large research labs that have substantial computing resources have the capability to perform similar computational tasks as those described in this paper, these organizations do not provide on-demand forecasting services at affordable prices to the general public, especially for customized services at customer-specified locations. A few commercial vendors provide forecasting services but they usually demand higher prices and long-term commitment. Since a Cloud-based system, such as the FaaS system, can provide customized forecast services on an on-demand pay-only-what-you-need basis, it plays an important role in making renewable energy forecasting widely accessible and affordable for current and potential renewable energy users.

The use of PaaS is appropriate when new capabilities need to be developed for a particular application. Generic services delivered with the PaaS can increase the speed of development and reduce costs. FaaS can function as a PaaS and provide these benefits by making its underlying services (developed as SOA services) available to developers to build new composite services and application-specific services as well as workflows. Users that want to use FaaS as PaaS have access to the service libraries to develop new capabilities by using/modifying/adding SOA services.

Forecasting renewable energy availability is even more important for isolated power systems because the forecasts enable the system operators to better prepare and manage the balance between the load demand and the power generation. Convenient and cost-effective access to accurate renewable energy forecasting can encourage the use of renewable energy especially in rural areas where it is expensive to build electric power transmission and distribution infrastructures. Efforts by the U.S. Department of Agriculture to develop wireless broadband access in small and medium-sized communities would enable the availability of Cloud-based forecast systems, such as the FaaS system, to many new renewable energy users.

Internet access is essential for the benefits of Cloud Computing to materialize. Mobile Internet technology, consisting largely of smartphones and tablets, has been undergoing fast growth in recent years not only in developed countries but even more remarkably in developing countries. Because of the prohibitive cost of building conventional wired infrastructure in developing countries, wireless Internet is expected to grow very rapidly in the coming years [15]. In parallel to this development, Cloud-based forecasting services delivered over mobile Internet are especially useful for the development of distributed renewable energy systems in developing countries where electric power grids have not been extensively developed, especially in rural areas.

Due to the advance in technologies such as miniature sensors and wireless networks, Internet of Things (IoT) will be widely adopted especially in health care, infrastructure and public-sector services in the coming years [16]. By using sensors to gather information which is then transmitted using wireless networks, IoT is bringing significant improvement to remote monitoring. With more information gathered by using IoT on a continual basis, the number of information sources shown in the upper portion of Figure 4 will increase significantly. Because of the amount of data generated, Cloud Computing technologies have been suggested to merge with IoT to form the Cloud of Things (CoT) [17]. CoT combines two of the twelve disruptive technologies that will transform life, business, and the global economy in the coming years [1]. Renewable energy forecasting and effective utilization of renewable energy can benefit greatly from the information collected by using IoT and processed/analyzed by using CoT. The FaaS system presented in this paper may be viewed as an early version of a more comprehensive CoT system along this trend.

Urbanization is an important factor to be included in the planning for sustainability. Currently more than half of the world population lives in the cities. Urban areas of the world are expected to absorb almost all the future population growth while at the same time drawing in some of the rural population. To handle the issues caused by growing urbanization, cities need to be transformed into "smart cities" that manage their resources (including renewable energy sources) efficiently. Internet of Things and Cloud Computing are enabling technologies that can increase the "smartness" by increasing the cities' awareness of its environment and situations. Along this direction, the ClouT project has been initiated as a collaborative project jointly funded by the 7th Framework Programme of the European Commission and by the National Institute of Information and Communications Technology of Japan. Cloud-based data collection and analytic systems, such as the FaaS system, will play an important role in smart cities in the future.

In the future, the FaaS framework may be expanded into an even more powerful Cyber-Infrastructure For Renewable Energy (CIFRE) as shown in Figure 5. CIFRE will serve as a focal point for obtaining and sharing data and information, upgrading models by using new and shared data, sharing different kinds of SOA services to build new applications, combining forecasts obtained from using different approaches and from different forecasters, collaboration and cooperation between different combinations of stakeholders, education and training, etc. Cloud Computing will be instrumental in the development and deployment of CIFRE.

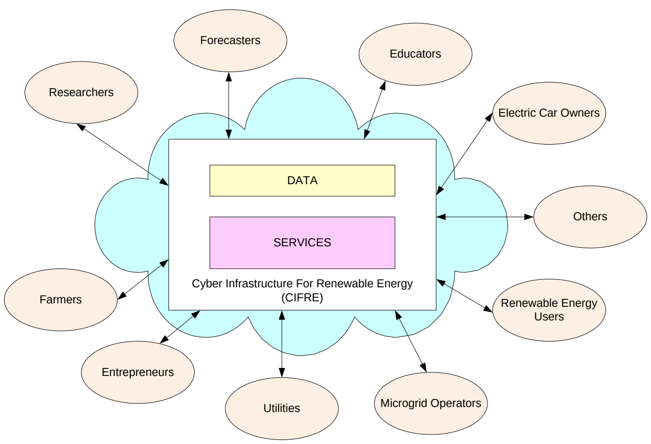

Figure 5. CIFRE (Cyber infrastructure for renewable energy) in the cloud

IV. CONCLUSIONS

This paper presents a Cloud Computing-enabled renewable energy forecasting system--the FaaS (Forecast-as-a-Service) framework. Based on the service-oriented architecture, the FaaS has been successful in generating user-defined solar or wind forecast on demand at reasonable costs. FaaS demonstrates that Cloud Computing offers two unique capabilities in the forecasting of renewable energy. The first one is automated collection and processing of large amount of data in various formats and from different sources. The second one is on-demand delivery of user-specified services at different levels of details for various kinds of applications.

A service pricing method that equips each service with a technical endpoint and an economic endpoint has been developed for the FaaS framework. When a mission is accomplished by a workflow, not only the technical requirement is met but the associated price is also calculated by using this method.

The broader impact of Cloud Computing on the use of renewable energy is presented. Coupled with mobile internet and Internet of things, Cloud Computing supports the development of new applications such as Cloud of things, smart cities, CIFRE and more widespread utilization of renewable energy in the rural areas.

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