

WIND FARM SITE SUITABILITY ANALYSIS IN LAKE ERIE USING WEB-BASED  
PARTICIPATORY GIS (PGIS)

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## ABSTRACT

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This study presents the design and implementation of a web-based Participatory Geographic Information System (PGIS) framework intended for offshore wind suitability analysis. The PGIS prototype presented here integrates GIS and decision-making tools that are intended to involve different stakeholders and the public for solving complex planning problems and building consensus. Public involvement from the early planning stage of projects with a spatial nature is very important for future legitimacy and acceptance of these projects. Therefore, developing and executing a system that facilitates effective public involvement for resolving contentious issues can help fostering long-lasting agreements. The prototype here is a distributed and asynchronous PGIS that combines a discussion forum, mapping tool and decision tool. The PGIS is implemented following a thin-client server environment with three-tier architecture and the potential strengths and benefits of this PGIS are demonstrated in a hypothetical case study in Lake Erie, northern Ohio. In the hypothetical case study, participants evaluate the importance of three decision alternatives using different evaluation criteria for expressing their individual preferences. The individual preferences are aggregated by the Borda Count (BC) method for generating the group solution, which is used for synthesizing the different evaluation aspects such as the importance of criteria, ranking of the decision alternatives and planning issues related to environmental and socio-economic concerns from the participants.

This is dedicated to my family and friends. Thank you for your unreserved love, support,  
and encouragement

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## INTRODUCTION

Global warming resulting from human-induced emissions poses important policy challenges that can have significant implications for macroeconomic stability and economic well-being. Today's economy, which is mainly based on depleted fossil fuels, minerals and oil, could not be sustained if technologies remain constant while energy demands increase substantially (Grassi *et al.*, 2012; IPCC, 2011; Sadur *et al.*, 2011). The need to control human-induced atmospheric emissions of greenhouse gases requires development of other clean and renewable sources of energy. Renewable energy sources (RES) include replenishable natural resources such as geothermal, solar, bioenergy, ocean, and wind (Leung and Yang, 2012; IPCC, 2011; Mirhosseini *et al.*, 2011; Molina-Ruiz *et al.*, 2011). Among these RES, currently wind energy is given the most attention due to its widespread distribution, economic viability, significant market value, potential in power generation, and presence of advanced technology (Adelaja, 2012; Coskun and Türker, 2012; Limpo, 2011; Snyder and Kaiser, 2009).

Offshore wind energy in the U.S. represents one of the largest RES. Thus, developing offshore wind generating capacity is one of the most important steps for reducing global warming. For instance, some of the future plans of the U.S. Department of Energy (USDOE) examine the technical feasibility of generating 20% of the country's electricity demand from wind energy by 2030 (NREL, 2010; AWEA, 2008). Short term implementation of those plans suggest that net generation from wind power increased by 28.1 % from 2009 to 2010, bringing its share of total generation to 2.3 percent (USEIA, 2011). Offshore wind energy development in the U.S. is in its early stage; however, there are some projects which are in the planning phase. These include the Cape Wind project (Massachusetts), the Bluewater Wind project (Delaware),



the LIPA offshore wind park (New York), and the Galveston offshore wind project (Texas) (USDOE, 2013; Leung and Yang, 2012; Snyder and Kaiser, 2009).

Over the last decade, the world's wind power generation capacity has been growing rapidly. This increase is due to implementation of federal policy initiatives promoting the development of offshore wind farms and other advancements achieved by wind turbine technologies such as efficiency and scalability (Grassi *et al.*, 2012; Leung and Yang, 2012; Omitaomu *et al.*, 2012). At present, there is an increasing interest in development of offshore wind farms due to several advantages: stronger and constant offshore winds that exist in the offshore environment; closeness to coastal urban load centers, where most electrical energy demand exists and opportunities for wind development on land are limited; and efficiency of the offshore wind turbines, which can produce more electricity and can maintain higher levels of electricity generation for longer periods of time (Adelaja *et al.*, 2012; Landry *et al.*, 2012, Leung and Yang, 2012; O'Keeffe and Haggett, 2012; Vagiona and Karanikolas, 2012; Esteban *et al.*, 2011; Dvorak *et al.*, 2010).

One of the major problems in offshore development is identifying the appropriate site for wind energy farms. Determining wind farm site suitability is a difficult, complex, and protracted process that requires evaluation of many different criteria (Grassi *et al.*, 2012; Tegou *et al.*, 2010) since it combines environmental, economic, and social considerations. Environmental considerations are important and are routinely carried out for wind farm establishment (Leung and Yang, 2012, Snyder and Kaiser, 2009). For example, some environmental impacts of wind farms include turbine noise, visual effect and aesthetic and other impacts on humans, and effects on ecosystems, including the killing of wildlife, especially birds and bats (Leung and Yang, 2012; O'Keeffe and Haggett, 2012; Saidur *et al.*, 2011). Economic considerations in the siting of wind farms include the costs associated with the acquisition, development, and operation of the

site (Grassi *et al.*, 2012; Dvorak *et al.*, 2010). Social and political considerations are related to acceptance of a proposed offshore wind project by both residents along the shore, other stakeholders from tourism and fishing industries, and policy makers. Their concerns include fear about harm to the local environment leading to negative impacts on the fish stocks, and loss of property value and income from tourism (Haggett, 2011; Blyth-Skyrme, 2010; Firestone *et al.*, 2009). The differences in viewpoints among stakeholders and the spatial nature of the information regarding offshore wind siting problems require a tool that can handle these issues effectively.

In recent years, Geographic Information System (GIS) has become a major tool used to select the most suitable sites for offshore wind installation. For instance, Beacham *et al.* (2009) used Boolean overlay analysis in ArcGIS to identify suitable offshore wind sites in South Carolina. In this study, the raster format criteria were reclassified as suitable (1) and non-suitable (0); then they used Boolean multiplication of the reclassified layers to identify suitable sites. Another study accomplished by Schillings *et al.* (2011) illustrated the use of a web-based spatial decision support system (SDSS) to locate and assess offshore wind potential at the North Sea. This SDSS tool uses overlay analysis of raster layers weighted by user's inputs to generate the final offshore wind farm suitability map. Similarly, Vagiona and Karanikolas (2012) used GIS and multi-criteria decision making (MCDM) to identify offshore wind sites in Greece. In this research, Vagiona and Karanikolas applied constraints to all coastal areas to identify places that do not fulfill a certain set of criteria and excluded them from further analysis. Then, they used Analytical Hierarchy Process (AHP) and pairwise comparison of the evaluation criteria to determine weights that show the importance of each criterion. They also performed pairwise comparisons of the candidate sites with respect to each criterion generating weights and then aggregated the weights for each candidate site from each criterion to locate the most appropriate

sites for offshore wind farm. This integration of GIS capabilities and MCDM techniques is also known as the SDSS framework (Malczewski, 1999; 2006). Such frameworks are often extended to accommodate collective group decision making, where individuals involved in the decision making process can articulate their individual preferences for the decision problem in the process. The potential of this integration accommodates for Collaborative Spatial Decision Support System (CSDSS) where individuals are united by a common issue-driven interest that acknowledges the complexity of geographic realities in the solution process.

Traditional GIS technologies have been used for local and regional planning in the past; however, their complex nature coupled with requirement to involve key players (interest groups) in the planning process limits their uses (Barton *et al.*, 2005). According to Jelokhani-Niaraki and Malczewski (2012), these key players are the stakeholders who are affected by the consequences of the planning decision. Thus, for the planning process to be effective, it is very important to involve different groups of stakeholders (Tang, 2006). In recent years, an important GIS trend suggests the development of a simplified Graphical User Interface (GUI) that is capable of engaging the different groups of stakeholders as “community” in the planning process (Barton *et al.*, 2005). This approach, also known as Participatory GIS (PGIS), involves public participation so that the decision-making process becomes more democratic and unbiased. PGIS is, therefore, an attempt to simplify and bring GIS from a ‘closed’ expert-oriented to an ‘open’ user-oriented environment and utilize its technologies in the context of the needs and capabilities of communities that will be involved with and affected by development projects and programs (Trang, 2004; Cinderby, 1999).

According to Balram and Dragičević (2006), the PGIS application in community planning has bridged the gap between planning and geographic information science. The decision-making process in PGIS also involves information exchange, discussion and negotiation

among stakeholders in order to clarify, refine, and resolve the spatial problem in hand. PGIS integrates people, geographic information data, exploratory tools and structured discussion in order to utilize the knowledge, expertise, and experience of multiple stakeholders (Jankowski *et al.*, 2008; Tang, 2006; Wang and Cheng, 2006; Jankowski and Nyerges, 2003).

Meng and Malczewski (2010) and Trang (2004) explained how PGIS practitioners use a public participation ladder as the conceptual framework to guide public participation. In this ladder, non-participation is put at the base of the ladder while higher levels of public participation are at the top. The public participation increases as the ladder level increases, leading to empowerment of the public with more control of the decision-making process. The advancement of internet technologies in recent years is leading PGIS implementation in a web-based environment (Web-PGIS), which provides an easy way for sharing public opinion with decision makers without any place and/or time limitation by enhancing the level of public involvement (Borouhaki and Malczewski, 2010; Rambaldi *et al.*, 2006).

The Web-PGIS framework has addressed one of the problems observed in traditional GIS by allowing participants to express their views anonymously, without any fear of confrontation from anyone (Meng and Malczewski, 2010). Research show that implementation of web-based PGIS can be achieved in various application domains such as onshore wind farm planning (Berry *et al.*, 2011; Simão *et al.*, 2009), regional social networking (Kubota *et al.*, 2012) and flood risk analysis (Musungu and Motala, 2012). Berry *et al.* (2011) developed an application which integrates wind farm sites visualization mapping tool and a web-based survey tool which facilitates public participation in wind farm planning. On the other hand, Simão *et al.* (2009) developed a conceptual system framework for web-based PGIS that combines an information area, a multi-criteria spatial decision support system (MC-SDSS), and an argumentation map. Other research by Jelokhani-Niaraki and Malczewski (2012) and Borouhaki and Malczewski

(2010) presented web-based prototypes that allow users to set weights of evaluation criteria for decision alternatives under consideration and generate both individual and aggregated group solutions. Decision alternatives represent the basic structure of a decision problem that is used in the selection of a decision maker's course of action (Malczewski, 1999). To date, little research has been done in the implementation of web-based PGIS for wind farm site selection applications. Therefore, this limitation has stimulated this research. The current work differs from other studies by Berry *et al.* (2011) and Simão *et al.* (2009) in such a way that it supports the evaluation of integrated web-based decision alternatives using public participation through web-based PGIS intended for offshore wind farm site selection.

In this research project, a custom-built, web-based PGIS tool was developed and its capabilities are demonstrated using a hypothetical dataset that could be generated in real settings by potential stakeholders. The potential of the tool is illustrated by evaluating three predefined decision alternatives using various evaluation criteria in the southwestern part of Lake Erie, Ohio. The three main components that are emphasized in the illustrated tool include: a discussion forum, mapping tool, and decision tool. The discussion forum is used to facilitate communication and debate among users regarding different criteria before they use the decision tool. The map tool is used in conjunction with the discussion forum for exploration and visualization of the decision alternatives associated with different criteria while the decision tool allows participants to make their decisions by ranking the decision alternatives using different sets of criteria and casting their votes. The methodology, the proposed conceptual framework, and the system architecture are discussed in the sections below.

## CHAPTER I. METHODOLOGY

Implementation of the prototype PGIS tool involves configuration of the client-server environment, development of the database which serves as storage for both spatial and non-spatial data, development of the different components including forums, spatial maps and a decision module, and their integration in the web-based framework. In the next section, the conceptual framework of the proposed web-based PGIS and the system architecture are discussed.

### 1.1. The Conceptual Framework

The advantage of implementing PGIS in a web-based environment is that it allows a group of people to interact about common interests, tasks and ideas through easy access and integration of different tools (Jankowski *et al.*, 2008, Alesheikh *et al.*, 2002). Some of the features that are present in an effective PGIS are designed to support communication and collaboration for a community of non-technical users using spatial data visualization and decision analysis modules (Jankowski and Stasik, 1997).

In this research, the proposed conceptual framework is a web-based PGIS for ranking decision alternatives associated with offshore wind farm site selection which contains suggested modules by Jankowski and Stasik (1997) including visualization through mapping, collaboration through a discussion forum and a voting module for decision making purposes through an asynchronous and distributed environment. An asynchronous and distributed environment refers to a system that is designed specifically to facilitate user participation during different-time and different-place environments, which improves turnout and involvement in web-based collaborative decision making (Jankowski *et al.*, 2008). The integration of the mapping and the decision tools in the proposed framework follows a loose coupling (ad hoc linkage) approach in

terms of data exchange between different modules. This approach also has the capability to combine functionalities of different tools by sharing data in a web-based environment (Jelokhani-Niaraki and Malczewski, 2012; Malczewski, 2006). In the system, the decision tool and mapping tool share the same data, which are stored in a database, while the communication tool runs independently. The literature suggests different communication tools such as the Argumentation Map (“Argumap”) that integrates geographically referenced discussions and a web-based GIS capable of structuring debates with spatial elements in asynchronous online discussions (Sidlar and Rinner, 2007; Rinner *et al.*, 2008). However, the prototype in this study uses a communication tool customized by a .NET forum for the purpose of easy customization and integration with the proposed ASP.NET (Active Server Page) development environment used here.

The most common way of achieving a distributed and asynchronous environment for web-based PGIS is through implementation of client-server architecture. In this architecture, the client requests different services such as mapping, communication, decision analysis, data processing, and data storage while the server provides the services (Jelokhani-Niaraki and Malczewski, 2012, Karnatak *et al.*, 2007, Barton *et al.*, 2005). There are many implementations of client-server architecture in different studies including urban planning (Mansourian, 2011; Meng and Malczewski, 2010), tourism development (Brown and Weber, 2013), transportation improvement program (Zhong, 2008), and watershed management (Sun, 2013; Zhang, 2011) where the chief objective of the PGIS is to involve different grassroots and community-based groups for broadening public involvement in policymaking. The following section illustrates the system architecture of the proposed prototype, which uses ideas from existing PGIS frameworks.

## 1.2. System Architecture

Figure 1 illustrates the conceptual PGIS framework of the thin client-server architecture. This approach uses fully “server-side” processing that facilitates robust management and deployment of the system with easy data update, integration, and implementation (Alesheikh *et al.*, 2002). The client-server adopted here is a three-tier system configuration, which is the fundamental framework for the model design that segments the application into three tiers of services. The advantages of the three-tier system architecture over other systems includes high security, performance, scalability, and reusability of modules and system services (Mari *et al.*, 2011; Zhang *et al.*, 2011; Jankowski *et al.*, 2008). In the current implementation the three-tier architecture is composed of the Presentation, Business Logic or Middle, and Data tiers. The Presentation tier is the top-most level of the system and used by participants to interact with the system using a simple web browsing interface. The main function of the interface is to translate and interpret tasks and results that are comprehensive for the users. The web server, Internet Information Services (IIS), and ASP or Servlet connectors, which facilitate the communication between the Presentation client tier and the Data tier, are under the Business Logic tier. In the prototype, the Business Logic tier integrates different modules such as the decision tool, .NET classes, the ArcGIS server and the communication tool. This tier coordinates the application processes such as decision making, evaluations and calculations that are used for data processing between the two adjacent tiers. The third tier is the Data or Database tier, which is used to store and retrieve both spatial and non-spatial information that is passed back to the Business Logic tier and then back to the user. In this implementation, the Data tier includes two main components: PostgreSQL and MS SQL server. The PostgreSQL uses a geodatabase and tables to organize the spatial data related to users’ information and their preferences. A one-to-many relationship is maintained between a user and related tables. The PostGIS plug-in stores and



manages the spatial data in the PostgreSQL database which is subsequently accessed by ArcGIS Server, which is the mapping server. Lastly, the MS SQL relational database stores the non-spatial information from all debates posted by the participants associated with the communication tool. Here the data flow between the tool's interface and the database is handled by the .NET Framework Data Provider for SQL Server connection string.

The ArcGIS Server mapping server is used for creating and managing GIS Web services, applications, and for accessing spatial data stored in the PostgreSQL database, where ArcGIS Viewer for Silverlight is used to deploy robust web applications. The two main components of ArcGIS Server that are involved in the process are server object manager (SOM) and server object container (SOC). The SOC machine hosts the server objects (services) while the SOM manages the set of server objects that are distributed across one or more SOC machines. When the SOC receives a request from the SOM for the mapping service; it processes the request and returns back the result to the SOM. Then, the SOM presents the map to clients through the Representational State Transfer (REST) in the ArcGIS Viewer for Silverlight. REST is a set of system architecture principles that facilitates data transfer between client and server over a network using standard protocols such as Hypertext Transfer Protocol (HTTP).

In the prototype, the decision tool is developed using ASP utilizing different .NET classes. It also uses .NET Data Provider for PostgreSQL (Npgsql) connection string to communicate with the database. The decision tool implements Multi Criteria Decision Analysis (MCDA) also referred to as Multi Attribute Decision Analysis (MADA) which deals with decision problems from a number of alternatives. The tool accepts users' preferences such as criteria and rank of decision alternatives based on the selected criteria and stores the data in the PostgreSQL database. Moreover, it is also responsible for retrieval of data from the database and presentation of the analysis results to the users.

MCDA is a decision-support process that provides procedures and techniques to structure and evaluate complex problems by assessing a set of alternatives using different criteria. In MCDA, the criteria are evaluated based on their relative importance to assess the problem in hand (Borouhaki and Malczewski, 2010; Taranu, 2009; Malczewski, 1999). According to Jelokhani-Niaraki and Malczewski (2012), Borouhaki and Malczewski (2010), and Malczewski (2006), the capabilities of MCDA and GIS can be integrated to facilitate participatory spatial decision making. As the result of this integration participants can explore and visualize the locations of alternatives and rank or weight these alternatives based on the preferred criteria.

Figure 2 shows the relation between three spatial alternatives associated with different site locations and some number of different criteria. In this figure, the matrix of criteria and alternatives illustrates the fundamental flow of the spatial MCDA process, which requires the assignment of a rank/weight to each of the alternatives based on the selected criterion. The ranking/weighting values in this figure are represented as  $r_{ij}$ , where  $i$  is the  $i^{\text{th}}$  alternative and  $j$  is the  $j^{\text{th}}$  criterion. Table 1 shows the calculated scores for the alternatives where the end result of this process represents an ordered ranking of alternatives. In this study, the data values associated with each of the alternatives are used to calculate the scores by implementing the Borda aggregation method (Gorsevski *et al.*, 2013; Emerson, 2011; Zarghami, 2011; Munda, 2008; Ratliff, 2002).

Borda's method or the Borda Count (BC) was first introduced by a French scientist named Jean Charles de Borda at the end of the 18<sup>th</sup> century (Gorsevski *et al.*, 2013; Emerson, 2011; Zarghami, 2011; Munda, 2008; Ratliff, 2002). BC represents a social choice method that is generated by a large group of people for decision making purposes and features the properties called anonymity, neutrality, and consistency in the social choice literature (Munda, 2008). This "positional" method assigns a score corresponding to the positions in which an alternative

appears within the ranked list of preferences. For instance, if there are N number of alternatives under consideration, then the alternative that is ranked first gets N-1 points and the alternative ranked next to the first ranked alternative gets N-2 points. This process of assigning scores continues up to the last ranked alternative that gets zero points. Subsequently, the points assigned to each alternative are summed up in order to calculate the total score and identify the ranking order. Thus, the alternative with the highest total score is considered to be the most preferred.

In this study, the decision alternatives are ranked from first to third position in terms of preferred importance. To get a clear understanding, the method is further explained using a numerical example. Using the three alternatives (a-c) and 21 participants as shown in Table 2, alternative 'a' is ranked in first position by eight (8), second position by zero (0), and third position by thirteen (13) participants, respectively. The points assigned for each rank range for 0 to 2 where score of 2 is assigned for all first ranked outcomes, a score of 1 for all second ranked outcomes, and 0 for all third ranked outcomes. Hence, the total score for each alternative is summarized below by applying the Borda rule. As shown below, the Borda score for alternative 'c' is higher than all the other alternatives. A careful observation of Table 2 shows that alternative 'a', which has the most first ranked outcomes, is also the one with the strongest opposition since 13 outcomes reside into the last position. Therefore, alternative 'c' is the most highly favored by the participants.

$$\text{Alternative 'a'} = (2 \times 8) + (1 \times 0) + (0 \times 13) = 16$$

$$\text{Alternative 'b'} = (2 \times 7) + (1 \times 9) + (0 \times 5) = 23$$

$$\text{Alternative 'c'} = (2 \times 6) + (1 \times 12) + (0 \times 3) = 24$$

However, the merit of Borda's method is in the aggregation of participant's scores where individuals collectively make a choice from a set of presented alternatives. Such an approach

achieves a consensus solution by preventing contentious participants who rank some alternatives very high and some very low from having dominance and thereby promotes a consensual solution.

## CHAPTER II. STUDY AREA AND DATA

### 2.1. Study Area

The hypothetical study area is located in northern Ohio along the western Lake Erie shore (Figure 3). Five counties in Ohio are included in the study area, including Lucas, Ottawa, Sandusky, Erie, and Lorain. According to the US Census Bureau's report (2010), the total population in these five counties is more than 0.9 million, which is equal to 8% of the State's total population. Major cities and towns located in the study area are Sandusky, Toledo, Port Clinton, and Huron.

Lake Erie is fresh water and it is the shallowest of the Great Lakes (averaging only 19 meters) and overall the smallest by volume. Lake Erie can be naturally divided into three basins: western, central, and eastern. The study area covers the western and central parts of the lake. The average depth of the western part of the lake is 10 m and the central part is 18.5 m (Holcombe *et al.*, 2003; Herdendorf, 1992). The study area is characterized by strong wind with an annual average speed of 7 to 7.5 m/sec, highest in November and lowest in July, which is favorable for offshore wind energy generation. The area is characterized by high ice concentration in mid-December to mid-February, with the ice concentration decreasing from mid-February to mid-April (GLWEC, 2009; Kunkel *et al.*, 2002). The wetlands of Lake Erie support a variety of plant and bird species. For instance, according to Herdendorf (1992), there are over 300 plant species in the aquatic and wetland habitats of western Lake Erie. The Ohio National Wildlife Refuge (ONWR), which is known for its rich biodiversity, is part of the study area. Moreover, birds such as waterfowl, wading birds, shore birds, gulls and terns, raptors and perching birds use Lake Erie wetlands for migration, nesting and feeding.

The U.S. Department of Energy (USDOE, 2011) reported that the average annual electric consumption of Ohio is around 154,145 million kWh and it shows a 1.4 % increase annually

(NREL, 2010). In the Great Lakes Region, there is a potential of 700GW of offshore wind energy production. Of this amount from Lake Erie, it is possible to generate up to 45GW in Ohio (NREL, 2010). This energy is equivalent to 98,550 million kWh with a 25% production capacity. It is therefore possible to cover around 63.9% of the state's energy consumption with offshore wind energy. According to the Lake Erie Energy Development Corporation (LEEDCo, 2011), Lake Erie is a favorable and cost effective location for offshore wind farm installation.

In the study area there are three decision alternatives to be assessed by the participants. As shown in Figure 3, "Site 1" is located near Maumee Bay, "Site 2" is located east of Kelleys Island, and "Site 3" is located off the far northwestern corner of Lorain County. These decision alternatives were identified since they fulfill the wind resource required for offshore wind farm development, which is at least 7 m/s at a turbine height of 90 meters (or 262 ft) above the local surface (NREL, 2010). To demonstrate the functionalities of this prototype tool and to illustrate the potential application for evaluation of alternatives for wind farm selection, the simple hypothetical scenario uses a total of three sites for ranking of alternatives.

## **2.2. Decision Making Alternatives**

SDSS for suitable offshore wind site selection involves ranking of the decision alternatives based on different evaluation criteria. In this study a total of eight evaluation criteria were used, including: Population Density (PD), Bird Habitat (BH), Commercial Fishery Effort (CF), Distance from Shore (DS), Fish Habitat (FH), Distance from Navigable Waterways (NW), Sport Fishery Effort (SF), and Distance from Utilities (UT) (Figure 4). The criteria used in this demonstration were identified based on detailed literature review, US offshore wind energy siting legislations, and data availability (Adelaja *et al.*, 2012; AWS Truewind, 2010; NREL, 2010; AWEA, 2008; HEI, 2008). In addition, in this study the evaluation criteria are intended to

address different wind farm development planning issues related to environmental and socio-economic concerns which can impede the decision making process. The consideration of environmental issues is to minimize any potential ecological impacts, while socio-economic considerations are to minimize construction, operation and maintenance costs and impacts on the local economy and quality of life affected directly or indirectly due to wind farm installation.

BH and FH fall under the environmental consideration while the socio-economic considerations include SP, CF, UT, PD, NW, and DS. In this project, rather than fully accounting for all possible evaluation criteria and concerns, the main objective was to demonstrate the flexibility of this PGIS prototype, which could be altered by using different evaluation criteria and concerns for different site specific problems and requirements. The classification of evaluation criteria has been done based on recommendations of the Ohio Department of Natural Resources (ODNR, 2012) Office of Coastal Management.

### **2.2.1. Bird Habitat**

Planning of new offshore wind energy site selection should consider the impact on the natural habitat of birds. The study area is known to possess two national wildlife refuges (NWRs) including Cedar Point and Ottawa NWRs, and three Important Birds Areas (IBA) sites which are included in the American Birds Conservancy list of the 500 most important IBAs in the United States (Guarnaccia and Kerlinger, 2007). According to Audubon Ohio (2012), IBA is a conservable site identified on the basis of its international significance for the conservation of birds at the global, regional or sub-regional level for: threatened, congregatory, assemblages of restricted-range and biome-restricted bird species. As stated by NREL (2010) and Baisner *et al.* (2010), the major risks from offshore wind turbines to sea and resting birds are collisions and mortality, physical habitat loss from displacement, and visual stimulus/avoidance response and

barrier effects, including fragmentation of the ecological habitat network (e.g., migration pathways, breeding or feeding areas). Therefore, offshore wind farms should be located out of bird habitat (GLWEC, 2009). In this study, the electronic spatial data of IBAs in vector format were collected from ODNR (2012) and used to show the location and proximity of bird habitats relative to the proposed wind farm sites. Therefore, sites that are far from bird habitat are most suitable for offshore wind farms.

### ***2.2.2. Fish Habitat***

The effect of offshore wind installation on fish habitat is one of the main environmental concerns that should be addressed during wind farm site planning. Fish habitat is disturbed and altered during and after installation of wind farms (Blyth-Skyrme, 2010; NREL, 2010; GLWEC, 2009). Therefore, it is important to know the fish habitat in the water body ahead of making any further decision on the suitable site. As stated by the US Fish and Wildlife Service legislation, offshore wind sites should be away from fish nursery and spawning areas. These areas are habitat for larval and young-of-year fishes (NREL, 2010). In this study, the fish habitat map in a vector data format was acquired from ODNR (2012). Then, the data were incorporated into GIS and classified into four classes: as walleye nursery, adult walleye, walleye/perch, and dead zone. The walleye nursery class is considered the least suitable area. Adult walleye and walleye/perch are moderately suitable fish habitats, while the class representing the dead zone is the most suitable area for wind farms.

### ***2.2.3. Sport Fishery Effort***

Sport fishery is a common activity in Lake Erie. According to GLWEC (2009), in 2006 alone a total of 1.25 million fishing licenses were sold in Ohio, generating around \$1 billion. Of these licenses, one third were sold in the counties along the Lake Erie shore. From the different



fish species that exist in the lake, walleye and yellow perch are most popular for sport fishery. Sport fishery effort is compiled by the average hours targeting walleye and yellow perch using an area of 10-minute quadrangle from 2000 to 2006. The spatial data layer for this criterion was acquired from ODNR (2012). The sport fishery map was grouped into four classes as 0-4,000, 4,000-25,000, 25,000-106,000, and 106,000-700,000 hours. The classes are based on the total hours spent by people in the areas. Classes with higher average hours are least suitable and classes with lower average hours are most suitable for wind farm installation.

#### ***2.2.4. Commercial Fishery Effort***

This criterion is related to the amount of fish that are produced for commercial purposes from the study area. Since Lake Erie is known for its large fresh water commercial fisheries, this criterion needs careful attention (GLWEC, 2009). Wind turbine installation is opposed by fishermen fearing loss of their traditional fishing grounds, which are their income source. Therefore, offshore wind turbine siting should involve this criterion in the planning phase. The fish productivity of an area is measured based on the amount of fish harvest, which is measured in trap net lift (GLWEC, 2009). ODNR (2012) provided the vector map showing the total number of commercial fishery effort trap-net lifts by 10-minute quadrangle, from 2000 to 2006. The map was classified into four classes as 0-32, 32-250, 250-600, and 600-2900 trap net lifts. Therefore, suitability decreases from the first class, 0-32 traps, to the fourth class, 600-2900 traps.

#### ***2.2.5. Utilities (Transmission)***

The third socio-economic factor considered was proximity to utilities or transmission lines. According to GLWEC (2009), cable installation has a significant impact on the cost of an offshore wind project. Cable cost is dependent on the project proximity to existing transmission

stations. The closer the project site to existing transmission stations, the less the cable installation cost. Therefore, offshore wind energy developers prefer to develop the closest site so that it can access existing transmission stations easily and deliver energy to customers with less cost. In this study, data on existing transmission stations along the shore was collected from ODNr (2012). Thereafter, in GIS using the buffer tool, distance was calculated from these places in different intervals. The distance was grouped into seven classes as 0-5, 5-10, 10-15, 15-20, 20-25, 25-30, and 30-35 miles. Classes with shorter distances such as 0-5 and 5-10 are most suitable, classes with medium distances such as 10-15 and 15-20 are moderately suitable, while the other three classes are least suitable for wind farm installation.

#### ***2.2.6. Population Density***

Population density is assessed based on the number of residents per square kilometer. As stated in HEI (2008), when considering population density from an economic point of view, areas suitable for offshore wind energy installation are those which are close to higher population densities. As reported by AWS Truewind (2010), these areas are the main consumers of the produced energy. In this study, census tract vector data of the counties, located along the shore, were collected from the US census office to calculate the population density (US Census Bureau, 2010). Then, the population density was calculated by dividing the total population by the total area of each census tract in GIS. The population density layer was classified into five classes as 0-200, 201-500, 501-900, 901-1400, and 1400-2277. Therefore, sites that are close to high population density are given higher priority than those which are far away.

#### ***2.2.7. Navigable Waterways***

Offshore wind sites that are located far away from navigable waterways are more suitable sites. These sites will not affect any transportation route in the water body (AWS Truewind,

2010; HEI, 2008). The spatial data for navigable waterways was collected from ODNR (2012). Then, the data was added in GIS to generate buffer zones at 0-1, 1-2, and 2-3 miles interval. Limitation of the distance into these three zones is to reduce the cost of offshore wind turbine installation and to accommodate concerns related to turbine components' transportation to far distances. Therefore, sites that are in the third zone that is 2-3 miles are most suitable, followed by the second zone that is 1-2 miles, and sites in the 0-1 mile zone are least suitable.

#### ***2.2.8. Distance from Shore***

Noise pollution, shadow flickering, and aesthetic effects on people living along a shore are important concerns for the acceptance of offshore wind farm projects by community along a coast. Some people living along the shore claim that wind turbines close to the shore diminish their quality of life, decrease their property value, and affect the local economy supported by income generated from coastal recreation and tourism (Saidur *et al.*, 2011; NREL, 2010; HEI, 2008). As a result, the distance from the shore at which wind turbines are going to be installed should be given more attention. In this study, the shoreline data from ODNR (2012) were used to generate buffer distances with three classes: 0-3 miles, 3-6 miles, and 6-9 miles.

## CHAPTER III. PROTOTYPE IMPLEMENTATION

The PGIS prototype used in this study was developed within ESRI's ArcGIS Server environment using ASP.NET, Visual Basic(VB), Silverlight Viewer, and Cascading Style Sheet (CSS) applications. The intention of the prototype was to provide a simple interface for non-experienced GIS users. The main components that comprise the prototype were organized under different themes, including the discussion forum, mapping tool and decision tool. The easy-to-use interface was based on the principles of web usability, such as guided user interface elements that are easy to follow, and elements of the navigation tool arranged logically and similar to a traditional web site navigation bar. The description of the user interface and the ranking of the alternatives is discussed below.

### **3.1. User Interface and System Description**

Figure 5 illustrates the PGIS web interface that is associated with the main page of the project, and which can be accessed by web browsers such as Internet Explorer, Chrome or Mozilla Firefox. The default web page is used for navigation between different levels that are used for the development of a thorough understanding of the criteria associated with different decision alternatives. The main goal of the default web page is to acquaint the participants with the project and the process of selection alternatives for suitable offshore wind farms. As shown in Figure 5, the default web page contains a location map of the case study area and a brief description of the main components used in this PGIS.

The “Background” theme presents all the details associated with the project, including the basics of wind energy, the benefits and the concerns associated with wind farms, development of wind projects, the PGIS concept, information regarding the criteria used in the project, and

instructions for using the tool. In addition, participants can access a manual which contains a brief explanation of how to utilize the different components in this prototype.

Figure 6 shows the mapping interface where participants can explore individual criteria associated with decision alternatives. The main purpose of this component is for data visualization that communicate the spatial extent of the criteria and the location of the decision alternatives that will drive the decision making process. Here the visualization helps with the overall understanding of the spatial criteria, providing valuable insights and reasoning behind the ranking of the decision alternative. The background map information is powered by the Google Maps interactive map interface (API) that helps participants to create a better understanding of location while the familiarity and simplicity of Google Maps helps the general public to participate in this complex decision making planning process. In addition, the system allows for displaying different background Google Maps including roadmaps (normal, default 2D map), satellite (photographic map), terrain (map with mountains, rivers, etc.) and hybrid (photographic map with roads and city names).

As shown in Figure 6, the easy-to-use mapping interface contains basic mapping functionalities such as zoom and pan, shown in the top right corner. Participants can use these tools to manipulate and explore the spatial data associated with different criteria in the case study area. The map content includes a legend display that provides useful narrative and graphic descriptions for understanding what is being viewed in the map. For instance, the figure shows that the “Decision Alternatives” and the “Fish Habitat” layers have been selected in the Map Contents Panel. The “Decision Alternatives” layer shows the location for the proposed wind farm locations that correspond to the displayed attribute table. The data from this attribute table are primarily stored in the PostgreSQL database and the table contains information about different geographic features that are used to find, query, and symbolize information. The “Fish

Habitat” layer shows the legend and the distribution of the four main species, including walleye nursery, adult walleye, walleye/perch, and dead zone, separated by different colors. In addition, participants can also display or hide map layers for better visualization of the spatial data.

Figure 7 shows the forum component that is used to facilitate discussion among participants for exchanging views and ideas on spatially-related issues. The forum is customized by Jibit, which is developed by ASP.NET technologies and MS SQL Server as a backend (database). Specifically, the main objective of this module is to accommodate participants or community members to discuss issues such as impacts on the local community influenced by selection of different criteria and alternatives or to generate new ideas based on different feedback. The module allows for an ongoing, asynchronous discussion and can help each participant to better formulate his or her opinion, which may evolve throughout the discussion process. Such a module is capable of catering to a large group of participants and supports various tools such as text, maps, sketches, images and annotations to express and convey their opinions. In addition, for better integration of the public to participate in the ongoing discussion, a facilitator can guide the discussion process. Some of the tasks for the facilitator may include coordination of the planning process, advising on the proper use of the tools, providing working materials and information, and ensuring a participant’s full involvement in the discussion.

The discussion and interaction among participants precede the voting module that is used for the ranking of the alternatives by individual participants. Participants are required to register before using the forum and voting module. The registration details from the participants are only used to help with the identification of participants and to collect the voting preferences for inclusion of criteria and ranking of alternatives.

Figure 8 shows the decision tool or the voting module for ranking the decision alternatives associated with the selection of wind farm location. The decision tool is the core part of the

system that is used to collect voting preferences from the participants. Here, the participants can vote on the importance of each criterion and the rank of the alternatives. In this study, the ranking method was used due to its simplicity and unambiguousness in collaborative and participatory decision-making (Jelokhani-Niaraki and Malczewski, 2012; Malczewski, 2006). For instance, Figure 8 shows that the two selected important criteria include bird habitat (BH) and commercial fishery (CF). The selection of the criteria activates the ranking information where participants can select the rank for each decision alternatives that relates to a specific criterion. Rank 1 indicates the most suitable site, rank 2 the second most suitable, and rank 3 the least suitable location for wind farm installation. For instance, Site 3 is the most suitable location for a new wind farm in relation to the bird habitat criterion whereas Site 1 is the least suitable location. Participants can also easily display the mapping module from the decision tool by using the link ‘Display Map’. This helps participants to see the spatial relationship between criteria and the decision alternatives while using the decision tool.

The flow chart in Figure 9 highlights the data flow process behind the voting tool. After the participant is logged in, the decision module requires the participant to select the important criteria, which are used for the ranking of the decision alternatives. Before the information is submitted to the database, the system checks for errors such as selection of at least one criterion and whether the participant has cast his or her vote earlier. After the participant submits his or her vote, the score and voting position of the decision alternatives is calculated by adding the ranks for each alternative from every voter using the Borda Count approach. The calculated group scores can be accessed from the voting module using the “View Score” link. The voting results in Figure 10 are calculated by a ranked voting technique that assigns ranks to decision alternatives based on the most and the least suitable location for a wind farm.

In Figure 11, the flow chart presents the data flow implemented in calculation of the group score and rank of decision alternatives. When participants request the group score, the data are fetched from the database. Then, the score is calculated using the Borda Count method. Subsequently, the rank for the decision alternatives based on the group score will be calculated. Moreover, based on the new result, the system updates the old group score and rank in both the database and the map.

Participants can also visualize the voting results using a chart display before and after casting their vote. Figure 12 shows the scores for the decision alternatives and the importance of the criteria. For instance, Figure 12 shows that Site 1 is the most suitable decision alternative while Site 3 is the least suitable decision alternative for a wind farm location. Also, the most preferred criterion for the participants is the fish habitat, while distance from shore and utilities are the most controversial criteria used for the selection of the wind farm location.



## CHAPTER IV. DISCUSSION

In development of PGIS, the set of evaluation criteria depend on the problem under consideration and the suggestions of stakeholders who participate in the planning phase. These stakeholders have to be representatives of diverse areas of competence, political agendas, and social values. This can be achieved by following inclusive participation (Zhong *et al.*, 2008; Jankowski and Nyerges, 2003). The inclusive participation approach follows the principle of involving public representatives as participants. Otherwise, if participants are only activists, interested groups, planners and professionals, then the public voice will be biased or dominated by certain opinions that may not be representative of the community. Therefore, the public's involvement should be from the early stage of the planning process to build mutual understanding and consensus among participants (Tang, 2006). This also will later lead to legitimization and public acceptance of the decision process.

Participants can be informed and empowered about the initial idea through different mechanisms such as stakeholder workshops, consensus conferences, deliberative opinion polls, negotiated rulemaking, task forces, and town meetings (Insua *et al.*, 2008). However, recently public participation practices are using information technology (IT) for public involvement rather than these traditional methods of participation. The mentioned mechanisms allow participants to express their concerns and suggest criteria to be considered in the decision process. Based on Malczewski (1999), the procedure for identifying the criteria should be a multistep iterative process. That is, the process should be done repeatedly to accommodate all concerns of the stakeholders. In this research, the implemented web-based PGIS is flexible and can incorporate different criteria other than the eight criteria which we had already included in the current version of the tool. This could be accomplished by public involvement in discussion forums for selection of goals and criteria that should be considered in the offshore wind farms

planning process (Meng and Malczewski, 2010; Taranu, 2009; Karnataka *et al.*, 2007). For instance, this module can be used for idea generation, collection and sorting of ideas, and improvement of the planning process based on feedback.

The identification of stakeholders is an important step while developing a PGIS. This will help to address issues and concerns of stakeholders. Furthermore, it will give confidence to the stakeholders in how to use the developed system. In this study, the main objective was to demonstrate the potential of web-based PGIS as a SDSS tool using a hypothetical scenario without the involvement of stakeholders' opinion in the planning phase. However, as a starting point this research consulted various studies to identify some of the criteria that are important in offshore wind farm planning (Leung and Yang, 2012; Hagget, 2011; Limpo, 2011; Firestone *et al.*, 2009; GLWEC, 2009; HEI, 2008). A real scenario of PGIS development for wind farm site selection should involve description of concerns to participants, discussion among participants, setting criteria, and voting on the decision alternatives. During the description of concerns, participants will be informed about the problem and background information. Then they will express their concerns regarding the wind farm project during the discussion phase. This stage helps to address the NIMBY (Not In My Back Yard) syndrome often associated with suitable wind farm site selection. The criteria set by participants will serve as a means to evaluate the decision alternatives. Once a common understanding and consensus is achieved between participants regarding the criteria, the next step will be voting for achieving group decision making (Zhong *et al.*, 2008).

Different approaches can be followed to use the web-based PGIS in order to achieve group decision making. For instance, facilitators can moderate the forum discussions and guide the process where voting goals may include gathering of additional data to measure stakeholder attitudes. Other models, such as an "open assess poll" that uses continuous voting (i.e.,

submitting a voting option on a website) or “online poll” that may use a survey in which participants communicate responses via the internet, are also possible.

## CHAPTER V. CONCLUSION

This study demonstrated the design and implementation of a conceptual framework for distributed and asynchronous web-based PGIS. The PGIS framework integrated three components, including a discussion forum, mapping tool and decision tool. The potential implementation was illustrated by using a hypothetical case study to show the strengths and the benefits from PGIS in facilitating suitable offshore wind farm site selection in Lake Erie. The hypothetical case study implemented a standard decision-making scenario by ranking three predefined sites or decision alternatives using eight different spatial criteria in a collaborative and transparent way.

The implementation of the proposed framework used a thin client-server environment with three-tier architecture. The integration of software tools included technologies such as ESRI ArcGIS server in conjunction with API Silverlight Viewer, ASP.NET, PostgreSQL database, and Jibit free discussion forum with MS SQL Server database. The final PGIS product of this integration used a standard GIS-based multi-criteria evaluation approach that accommodates multi-user environments and supports group decision making. The mapping tool is used for visualization, exploration and comparison of decision alternatives and their corresponding properties such as total score and rank. The decision tool is designed to perform ranking of the decision alternatives based on the evaluation criteria, using the Borda Count (BC) method as a means to calculate the group scores of each decision alternative. Lastly, the discussion forum is used to facilitate communication and debate among participants.

In summary, the intention of this study was to show the potential of a web-based PGIS for offshore wind suitability analysis that integrates alternatives, evaluation criteria, and participants using new technological ideas. The strength of this methodology is the flexibility for modification and customization when implemented in different study areas or other applications

and problems that require spatial decision support. Although the system was not fully tested with real stakeholders, its potential implementation to resolve complex issues of important public planning problems was demonstrated through a hypothetical scenario. As Jankowski (2000) highlighted, the development of PGIS can be tested and its public acceptance can be increased by following an approach which involves identification of criteria by stakeholders, selection of decision alternatives by a group of experts, and evaluation of decision alternatives by randomly selected group of the general public.

Future recommendations for improvement include the consideration of open source software and technology. Such technologies will help to avoid dependency on expensive and proprietary software such as ArcGIS server, ASP.NET, and MS SQL server. In terms of functionality, the prototype could include additional modules for dynamic inclusion and exclusion of decision alternatives, different voting approaches, aggregation of individual scores to obtain a group solution, and simplification of the importance of the criteria using sets of linguistic terms such as “low”, “medium”, and “high”. The use of linguistic terms or quantifiers can help with the conversion of human language to inputs that can be formulated mathematically, which can further simplify the system and encourage wider participation in the spatial decision-making process.

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## APPENDIX A: FIGURES

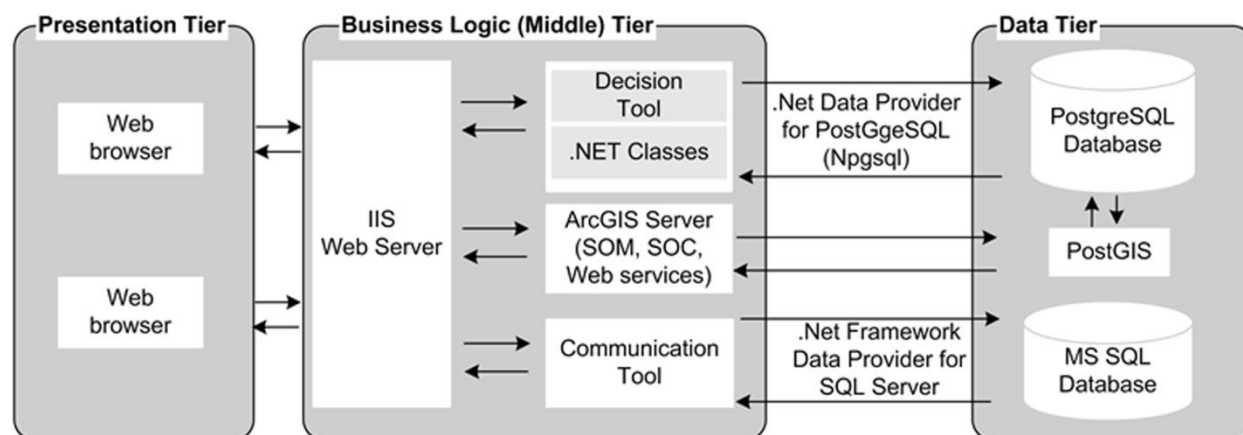


Figure 1. System Architecture

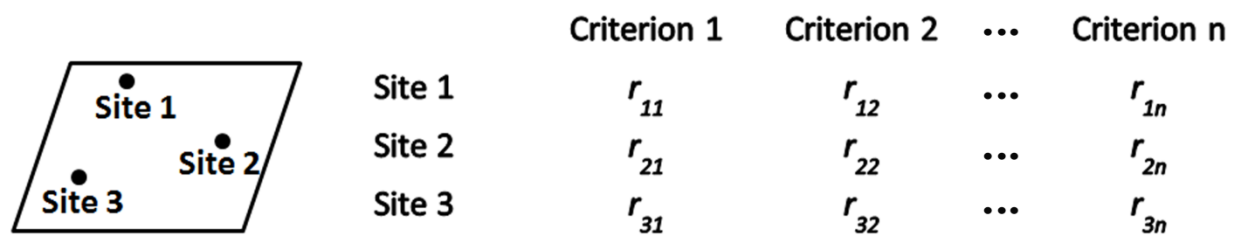


Figure 2. Relation between Alternatives and Criteria

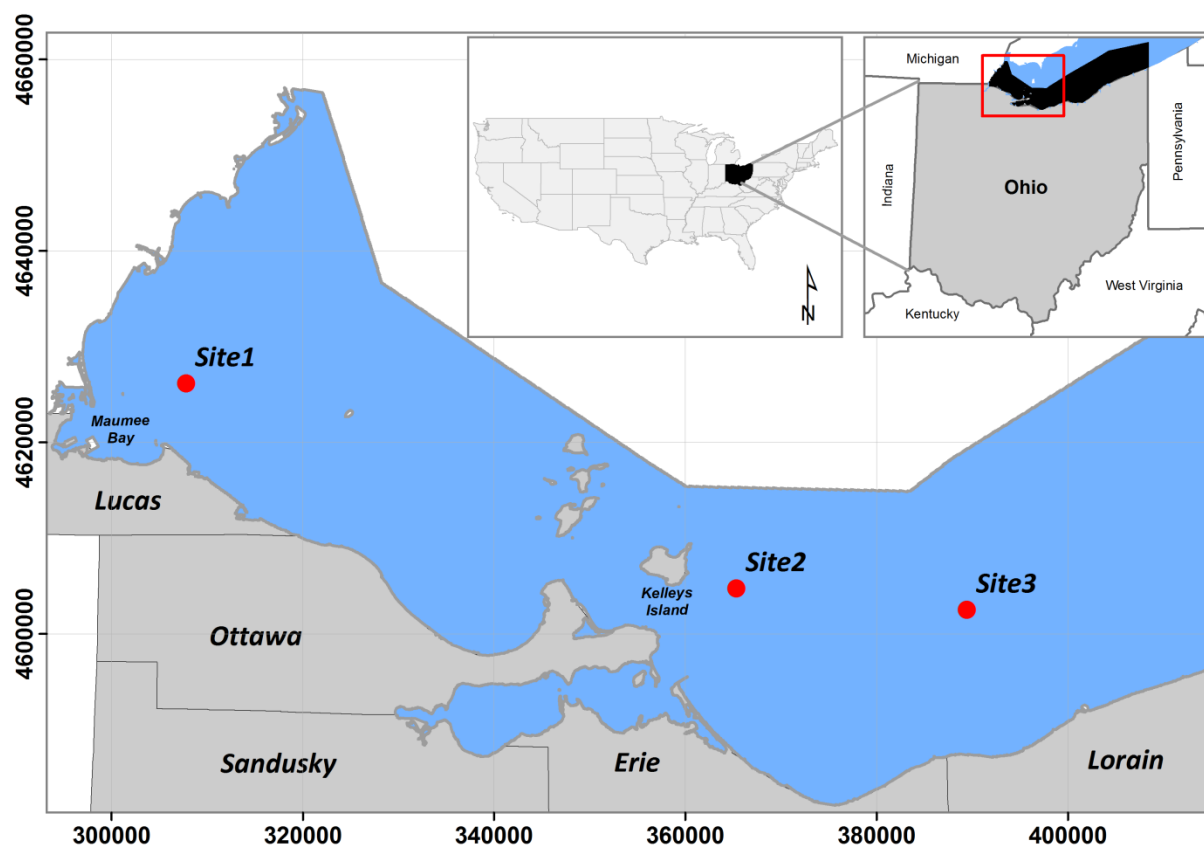


Figure 3. Location Map of the Study Area

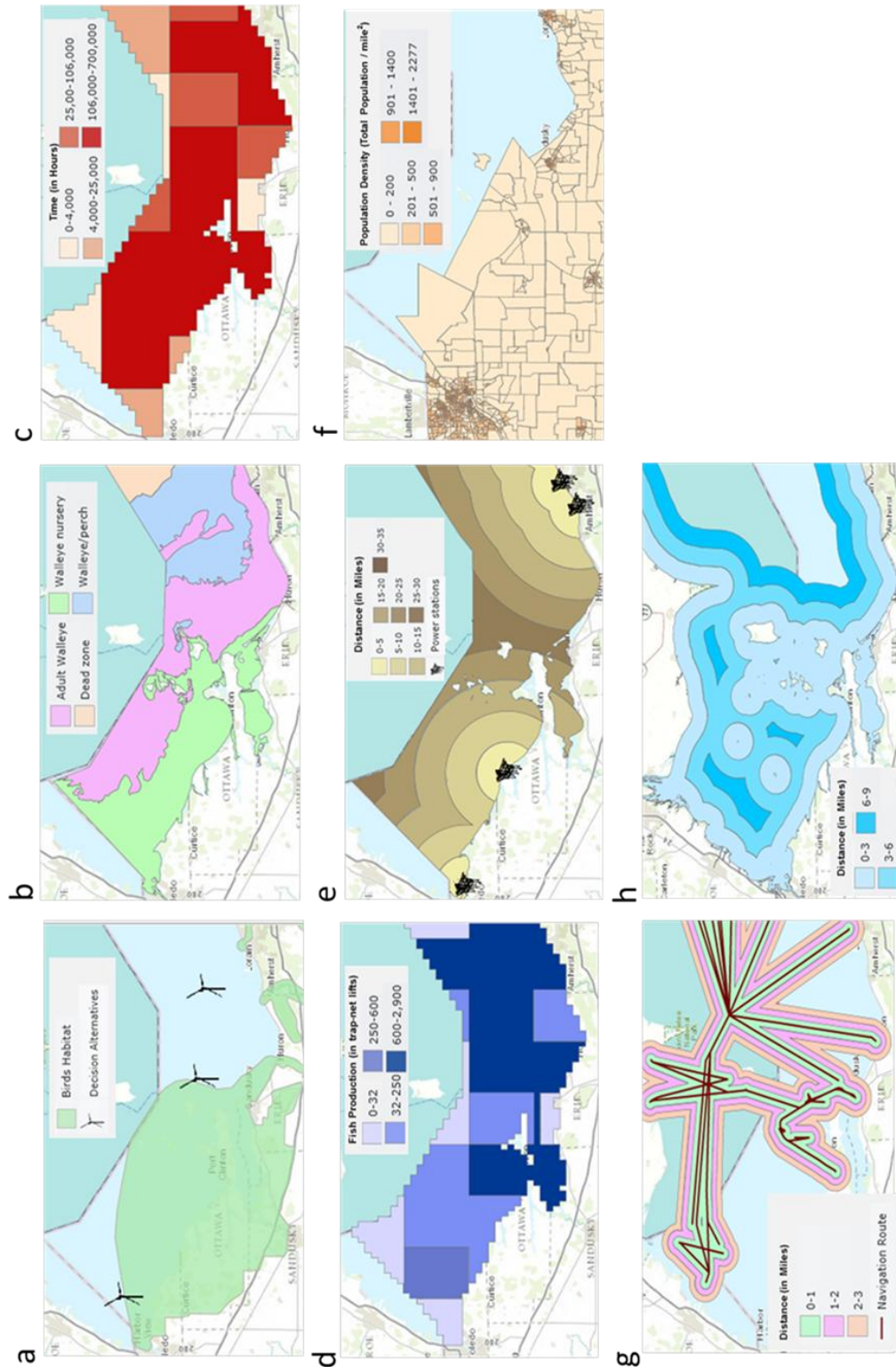


Figure 4. Evaluation Criteria (a) Bird Habitat, (b) Fish Habitat, (c) Sport Fishery Effort, (d) Commercial Fishery Effort, (e) Distance from Utilities, (f) Population Density, (g) Distance from Navigable Waterways, and (h) Distance from Shore



Figure 5. Home Page of the Prototype PGIS



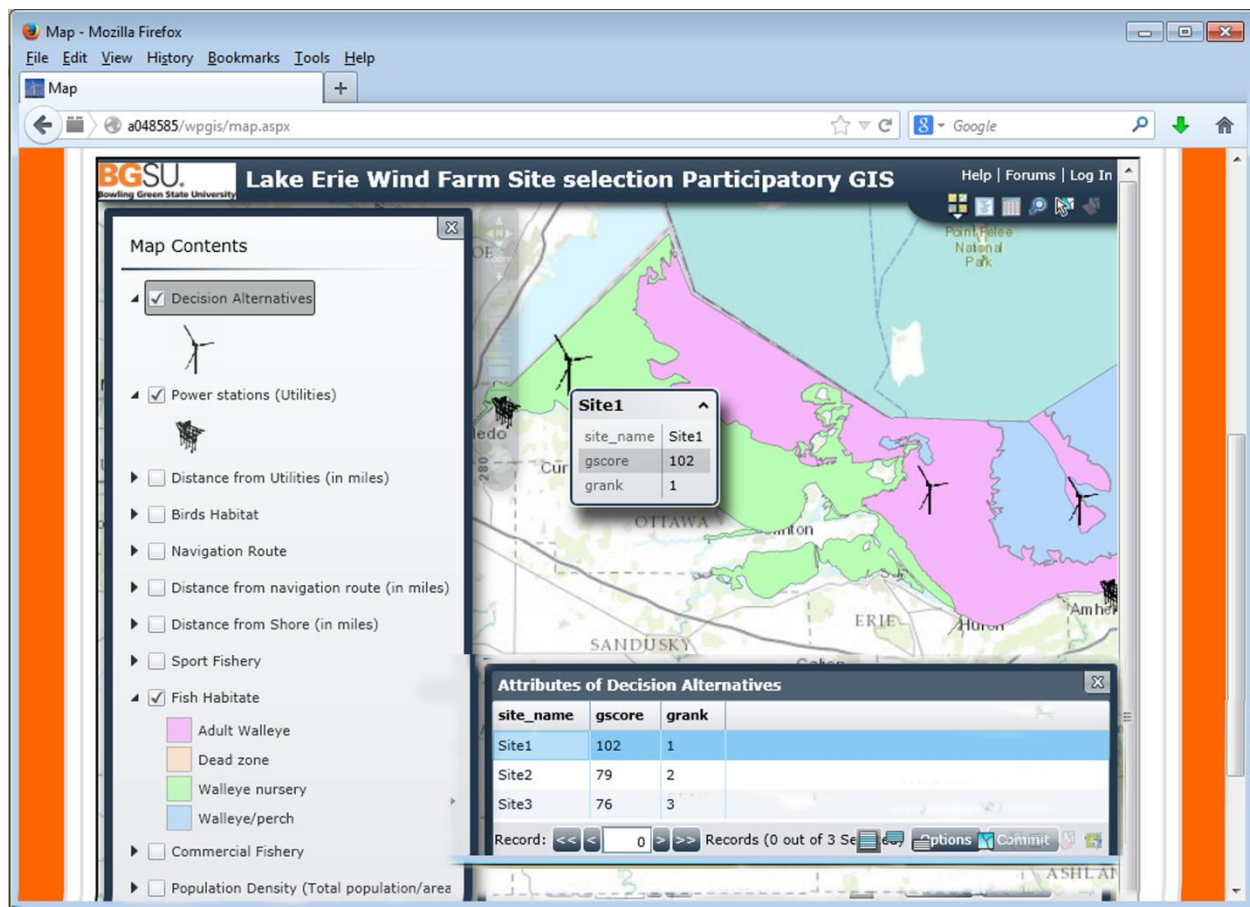


Figure 6. Mapping Tool Interface with Map Contents Dialogue Box and Attribute Table of the Decision Alternatives

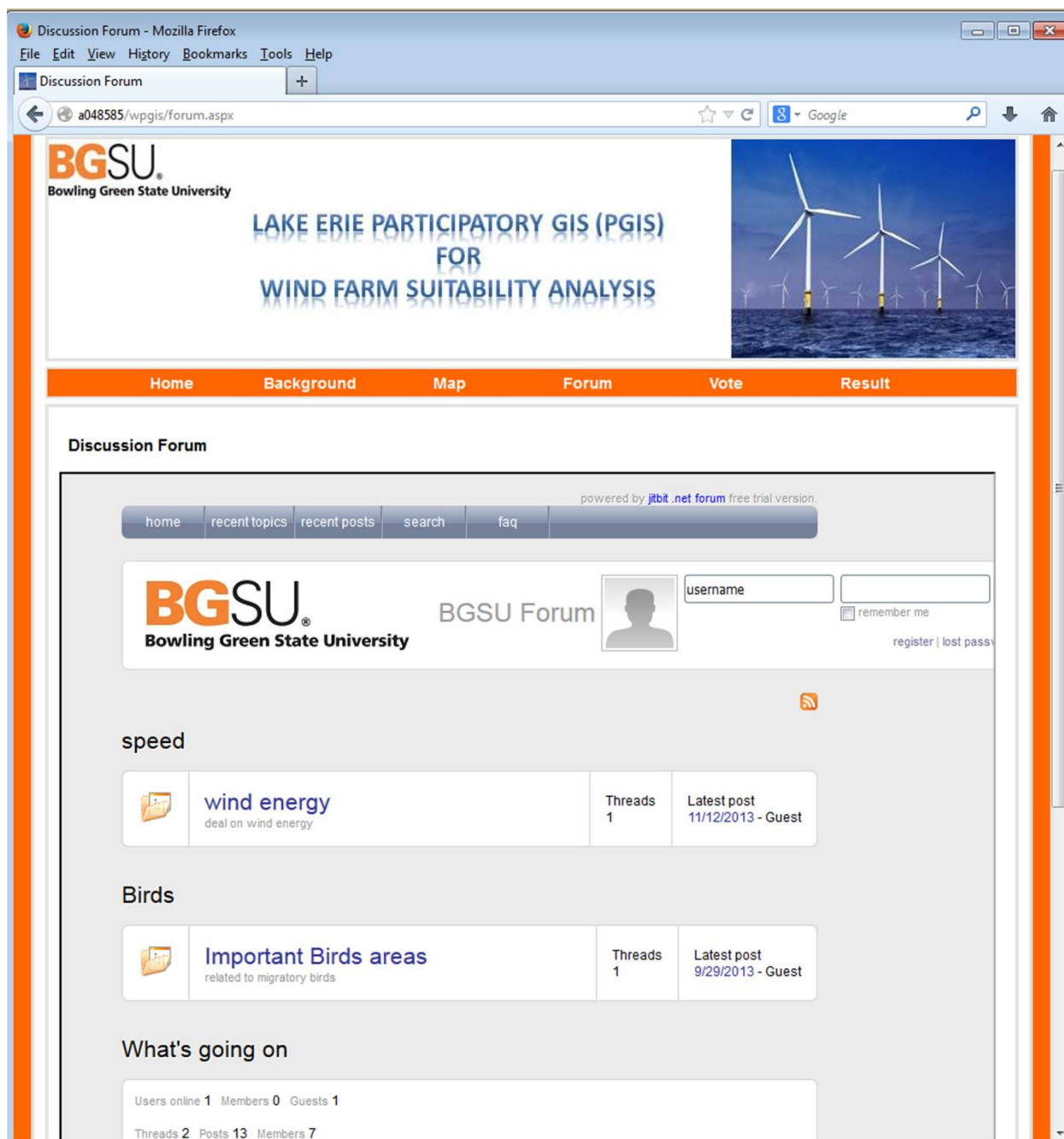


Figure 7. Interface for the forum

Vote - Mozilla Firefox


File Edit View History Bookmarks Tools Help

Vote

a048585/wpgis/vote.aspx

BGSU  
Bowling Green State University

# LAKE ERIE PARTICIPATORY GIS (PGIS) FOR WIND FARM SUITABILITY ANALYSIS



Welcome, Addisu!  
LOGOUT

## Voting

Please select at least one criteria in order to participate in the vote

Rank values indicate that 1-most suitable for wind farm, 2-second most suitable, and 3-the least suitable

[Display Map](#)

\* Required Field

### Voting Information

| Criteria   | Site1       | Site2       | Site3       |
|--|-------------|-------------|-------------|
| <input type="checkbox"/> Population Density (PD )            | select rank | select rank | select rank |
| <input checked="" type="checkbox"/> Bird Habitat (BH )       | 3           | 2           | 1           |
| <input type="checkbox"/> Navigable Waterways (NW )           | select rank | select rank | select rank |
| <input type="checkbox"/> Distance from Shore (DS )           | select rank | select rank | select rank |
| <input checked="" type="checkbox"/> Commercial Fishery (CF ) | 2           | 1           | 3           |
| <input type="checkbox"/> Fish Habitat (FH )                  | select rank | select rank | select rank |
| <input type="checkbox"/> Sport Fishery (SF )                 | select rank | select rank | select rank |
| <input type="checkbox"/> Utilities (UT )                     | select rank | select rank | select rank |

[Submit](#) [View Score](#)

Figure 8. Decision Tool Interface

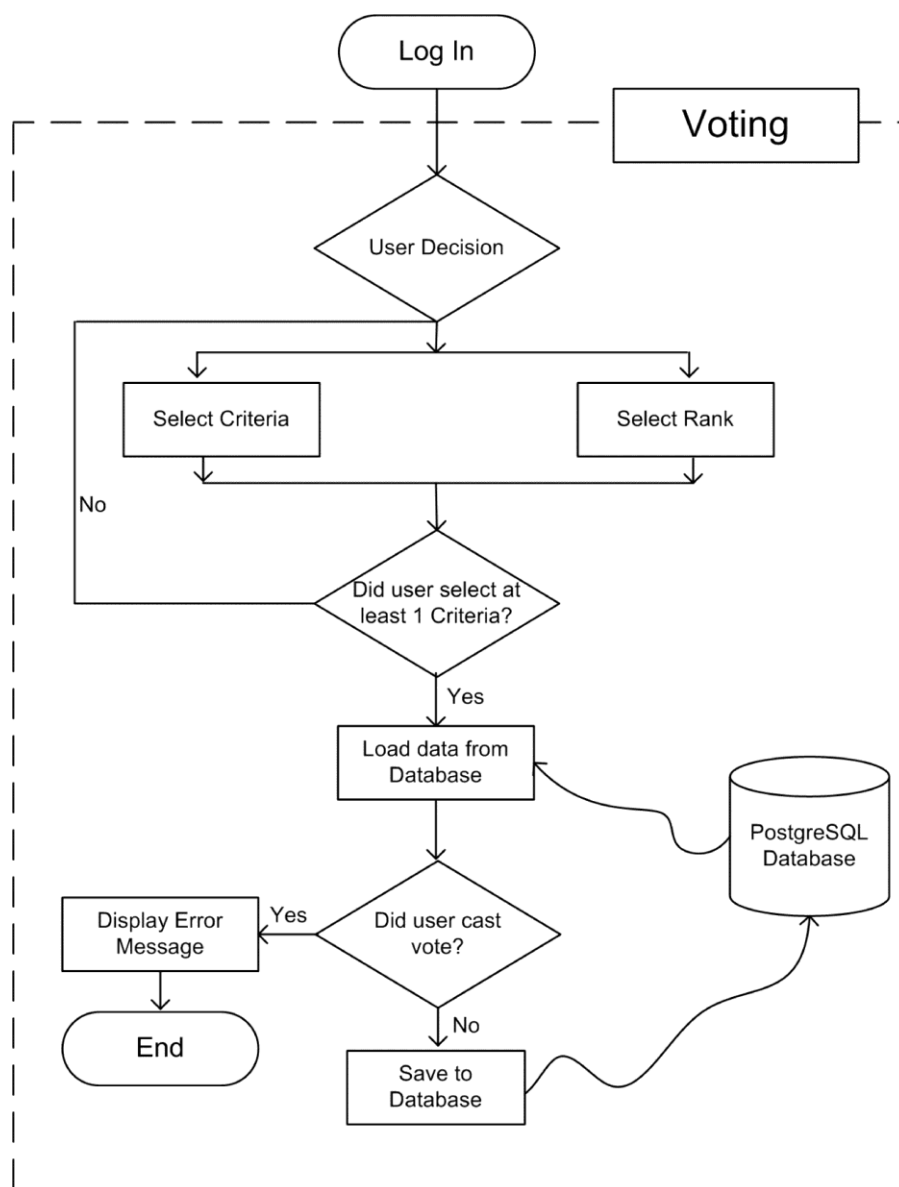


Figure 9. Data Flow in the Decision Tool

Score - Mozilla Firefox


File Edit View History Bookmarks Tools Help

Score

a048585/wpgis/code/result.aspx

BGSU  
Bowling Green State University

# LAKE ERIE PARTICIPATORY GIS (PGIS) FOR WIND FARM SUITABILITY ANALYSIS



Welcome, Addisu!  
LOGOUT

## Group Score

Here you can check the group score and updated map of decision alternatives.

Group Score

| Decision Alternatives | Total Score | Total Number of Voters |
|-----------------------|-------------|------------------------|
| Site 1                | 102         | 17                     |
| Site 2                | 79          |                        |
| Site 3                | 76          |                        |

[Show score](#) [Update](#) [Display Updated Map](#)

Click update button to update score and rank of decision alternatives

Figure 10. Interface of Score Page

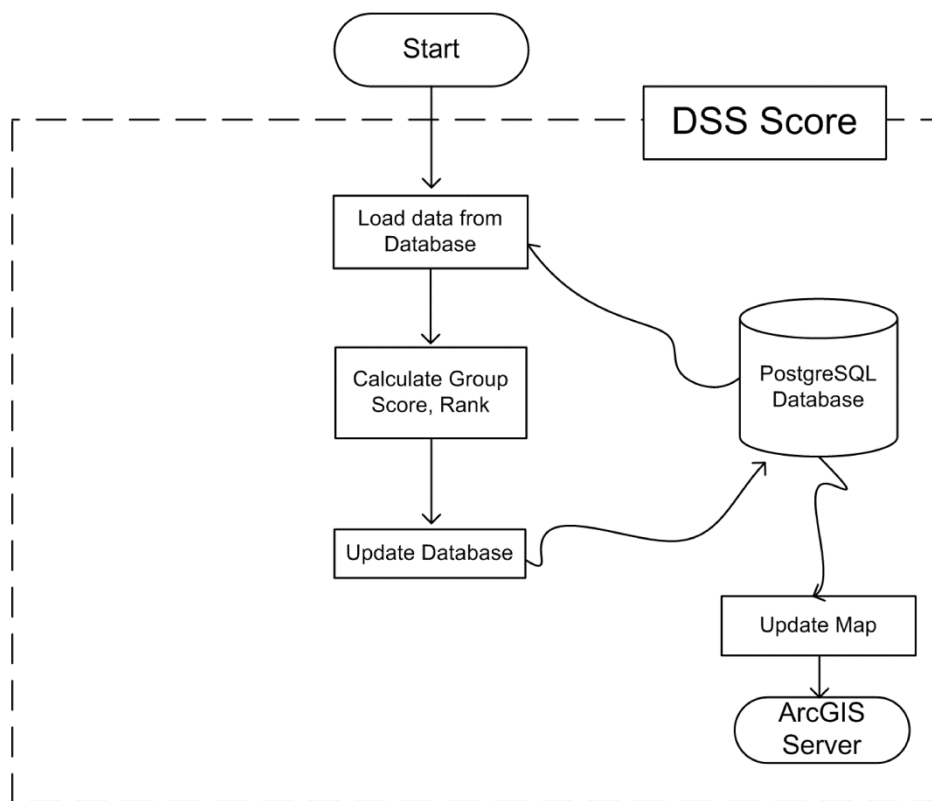


Figure 11. Data Flow for Group Score

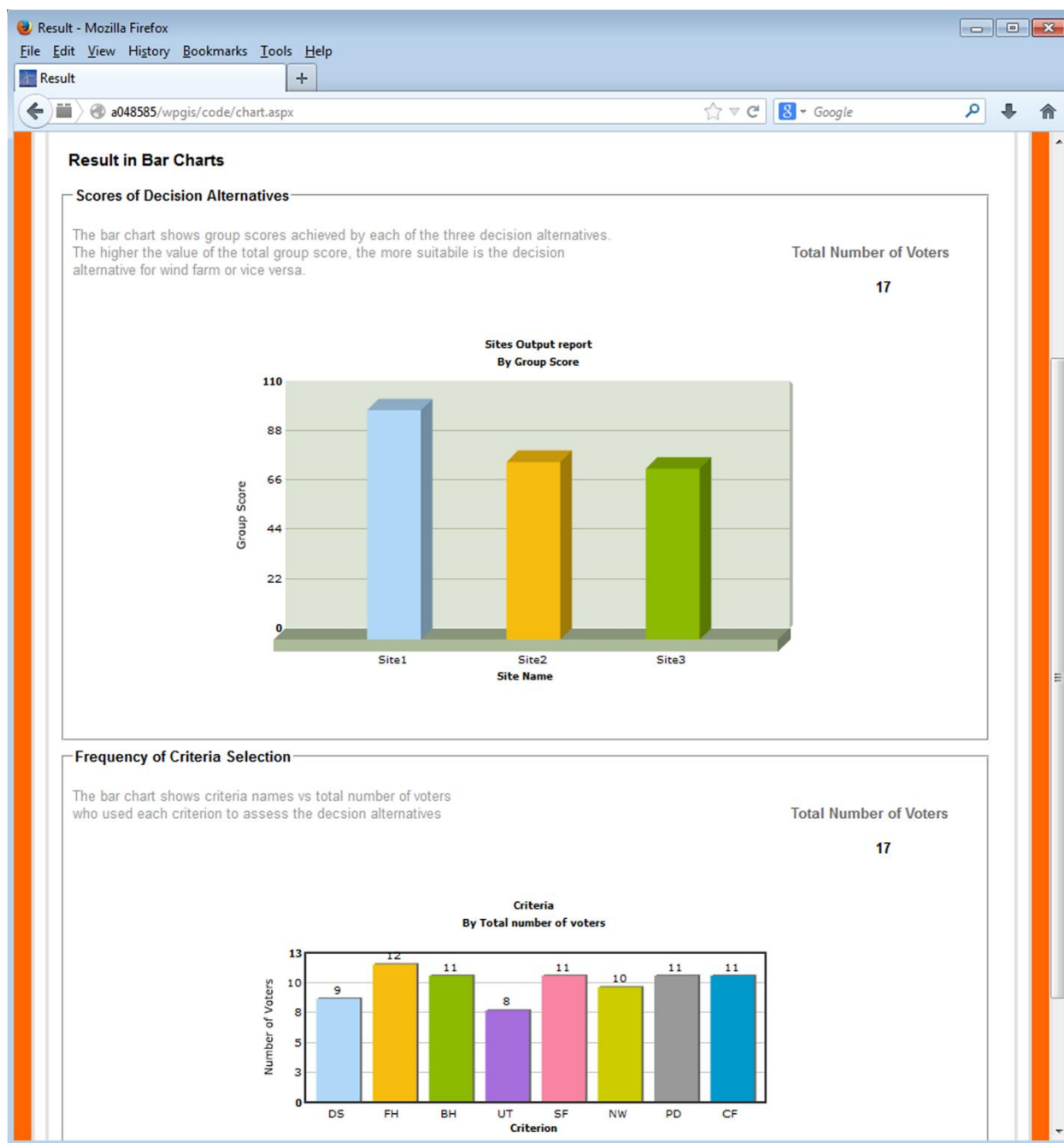


Figure 12. Charts for Total Score and Frequency of Criteria

## APPENDIX B: TABLES

Table 1. Calculated Scores and Ranks after MCDA is performed

|               | <b>Criterion 1</b> | <b>Criterion 2</b> | <b>...</b> | <b>Criterion n</b> | <b>Score</b>       | <b>Rank</b>       |
|---------------|--------------------|--------------------|------------|--------------------|--------------------|-------------------|
| <b>Site 1</b> | $r_{11}$           | $r_{12}$           | $\dots$    | $r_{1n}$           | Score <sub>1</sub> | rank <sub>1</sub> |
| <b>Site 2</b> | $r_{21}$           | $r_{22}$           | $\dots$    | $r_{2n}$           | Score <sub>2</sub> | rank <sub>2</sub> |
| <b>Site 3</b> | $r_{31}$           | $r_{32}$           | $\dots$    | $r_{3n}$           | Score <sub>3</sub> | rank <sub>3</sub> |



Table 2. Numerical Example of 3 Alternatives and 21 Participants

| <b>Ranking</b>                    | <b>Alternatives</b> |          |          | <b>Points</b> |
|-----------------------------------|---------------------|----------|----------|---------------|
|                                   | <b>a</b>            | <b>b</b> | <b>c</b> |               |
| 1 <sup>st</sup>                   | 8                   | 7        | 6        | 2             |
| 2 <sup>nd</sup>                   | 0                   | 9        | 12       | 1             |
| 3 <sup>rd</sup>                   | 13                  | 5        | 3        | 0             |
| <b>Number of<br/>Participants</b> | 21                  | 21       | 21       |               |

## APPENDIX C: CODE

## 1. Code Behind the Voting Interface

```

Imports Npgsql
Imports System
Imports System.Data
Imports System.Web
Public Class vote
    Inherits System.Web.UI.Page
    Protected Sub Button1_Click(ByVal sender As Object, ByVal e As EventArgs) Handles Button1.Click
        Dim conn As NpgsqlConnection
        Dim myAdapter As NpgsqlDataAdapter
        Dim mySqlString As String
        Dim checkuser As New NpgsqlCommand
        Dim temp As Integer
        Dim count As Integer
        conn = New
NpgsqlConnection("Server=localhost;Port=5432;Userid=postgres;Database=wpgis;password=gisstudent"
)
        conn.Open()
        mySqlString = "SELECT count(*) FROM vote1 where username='" + Session("login") + "'"
        checkuser = New NpgsqlCommand(mySqlString, conn)
        temp = checkuser.ExecuteScalar()
        conn.Close()
        count = 0
        For Each ctrl As Control In Panel1.Controls
            If TypeOf ctrl Is CheckBox Then
                If CType(ctrl, CheckBox).Checked Then
                    count = count + 1
                End If
            End If
        Next
        If count >= 1 Then
            If temp < 1 Then
                If ChkB1.Checked Then
                    conn.Open()
                    mySqlString = "INSERT INTO vote1 VALUES ('" + Session("login") + "','" + Label14.Text
+ "','" + DDL1.SelectedItem.ToString + "','" + DDL2.SelectedItem.ToString + "','" +
DDL3.SelectedItem.ToString + "')"
                    myAdapter = New NpgsqlDataAdapter(mySqlString, conn)
                    myAdapter.SelectCommand.ExecuteNonQuery()
                    conn.Close()
                End If
                If ChkB2.Checked Then
                    conn.Open()
                    mySqlString = "INSERT INTO vote1 VALUES ('" + Session("login") + "','" + Label16.Text
+ "','" + DDL4.SelectedItem.ToString + "','" + DDL5.SelectedItem.ToString + "','" +
DDL6.SelectedItem.ToString + "')"
                    myAdapter = New NpgsqlDataAdapter(mySqlString, conn)
                    myAdapter.SelectCommand.ExecuteNonQuery()
                    conn.Close()
                End If
            End If
        End If
    End Sub
End Class

```

```

End If
If ChkB3.Checked Then
    conn.Open()
    mySqlString = "INSERT INTO vote1 VALUES ('" + Session("login") + "','" + Label18.Text
+ "','" + DDLList7.SelectedItem.ToString + "','" + DDLList8.SelectedItem.ToString + "','" +
DDLList9.SelectedItem.ToString + "')"
    myAdapter = New NpgsqlDataAdapter(mySqlString, conn)
    myAdapter.SelectCommand.ExecuteNonQuery()
    conn.Close()
End If
If ChkB4.Checked Then
    conn.Open()
    mySqlString = "INSERT INTO vote1 VALUES ('" + Session("login") + "','" + Label20.Text
+ "','" + DDLList10.SelectedItem.ToString + "','" + DDLList11.SelectedItem.ToString + "','" +
DDLList12.SelectedItem.ToString + "')"
    myAdapter = New NpgsqlDataAdapter(mySqlString, conn)
    myAdapter.SelectCommand.ExecuteNonQuery()
    conn.Close()
End If
If ChkB5.Checked Then
    conn.Open()
    mySqlString = "INSERT INTO vote1 VALUES ('" + Session("login") + "','" + Label22.Text
+ "','" + DDLList13.SelectedItem.ToString + "','" + DDLList14.SelectedItem.ToString + "','" +
DDLList15.SelectedItem.ToString + "')"
    myAdapter = New NpgsqlDataAdapter(mySqlString, conn)
    myAdapter.SelectCommand.ExecuteNonQuery()
    conn.Close()
End If
If ChkB6.Checked Then
    conn.Open()
    mySqlString = "INSERT INTO vote1 VALUES ('" + Session("login") + "','" + Label24.Text
+ "','" + DDLList16.SelectedItem.ToString + "','" + DDLList17.SelectedItem.ToString + "','" +
DDLList18.SelectedItem.ToString + "')"
    myAdapter = New NpgsqlDataAdapter(mySqlString, conn)
    myAdapter.SelectCommand.ExecuteNonQuery()
    conn.Close()
End If
If ChkB7.Checked Then
    conn.Open()
    mySqlString = "INSERT INTO vote1 VALUES ('" + Session("login") + "','" + Label26.Text
+ "','" + DDLList19.SelectedItem.ToString + "','" + DDLList20.SelectedItem.ToString + "','" +
DDLList21.SelectedItem.ToString + "')"
    myAdapter = New NpgsqlDataAdapter(mySqlString, conn)
    myAdapter.SelectCommand.ExecuteNonQuery()
    conn.Close()
End If
If ChkB8.Checked Then
    conn.Open()
    mySqlString = "INSERT INTO vote1 VALUES ('" + Session("login") + "','" + Label28.Text
+ "','" + DDLList22.SelectedItem.ToString + "','" + DDLList23.SelectedItem.ToString + "','" +
DDLList24.SelectedItem.ToString + "')"

```

```

        myAdapter = New NpgsqlDataAdapter(mySqlString, conn)
        myAdapter.SelectCommand.ExecuteNonQuery()
        conn.Close()
        conn = Nothing
    End If
    Label30.Visible = True
    Label30.Text = "You have successfully casted your vote!!!"
Else
    MsgBox1("This user named " + Session("login") + " had already casted his/her vote. So you
cannot vote again!")
End If
Else
    MsgBox1("Please select at least 1 criteria!!!")
End If
For Each ctrl As Control In Panel1.Controls
    If TypeOf ctrl Is CheckBox Then
        CType(ctrl, CheckBox).Checked = False
    End If
    If TypeOf ctrl Is DropDownList Then
        CType(ctrl, DropDownList).SelectedIndex = 0
    End If
    If TypeOf ctrl Is DropDownList Then
        CType(ctrl, DropDownList).Enabled = False
    End If
    If TypeOf ctrl Is RequiredFieldValidator Then
        CType(ctrl, RequiredFieldValidator).Enabled = False
    End If
Next
End Sub
Private Sub LinkButton2_Click(ByVal sender As Object, ByVal e As System.EventArgs) Handles
LinkButton2.Click
    Label30.Visible = False
End Sub
Private Sub MsgBox1(ByVal msg As String)
    Dim lbl As New Label
    lbl.Text = "<script language='javascript'" & Environment.NewLine & _
        "window.alert('" + msg + "')</script>"
    Page.Controls.Add(lbl)
End Sub
End Class

```

## 2. Code Behind the Result Interface

```

Imports System
Imports System.Data
Imports System.Web
Imports Npgsql
Imports InfoSoftGlobal
Imports Utilities
Public Class result
    Inherits System.Web.UI.Page

```

```

Protected Sub Page_Load(ByVal sender As Object, ByVal e As System.EventArgs) Handles
Me.Load
    Dim conn As New NpgsqlConnection
    Dim mysqlstring As String
    Dim totalvoters As New NpgsqlCommand
    conn = New
NpgsqlConnection("Server=localhost;Port=5432;Userid=postgres;Database=wpgis;password=gisstud
ent")
    conn.Open()
    mysqlstring = "SELECT Count(DISTINCT username) FROM vote1"
    totalvoters = New NpgsqlCommand(mysqlstring, conn)
    Label2.Text = totalvoters.ExecuteScalar
    conn.Close()

```

End Sub

```

Protected Sub Button2_Click(ByVal sender As Object, ByVal e As EventArgs) Handles
Button2.Click
    Dim conn As New NpgsqlConnection
    Dim mysqlstring As String
    Dim myAdapter As New NpgsqlCommand
    conn = New
NpgsqlConnection("Server=localhost;Port=5432;Userid=postgres;Database=wpgis;password=gisstud
ent")
    mysqlstring = "SELECT t7.score1,t6.score2,t6.score3 FROM (SELECT t5.id,t5.score2,t4.score3
FROM (SELECT sum(t3.score) as score3, sum(t3.score)* 0 as id FROM (SELECT t2.total*2 as
score,t2.id FROM (SELECT site3 as id, count(site3) as total FROM vote1 GROUP BY site3) t2
WHERE(t2.id = 1) UNION SELECT t2.total*1 as score,t2.id FROM (SELECT site3 as id,
count(site3) as total FROM vote1 GROUP BY site3) t2 WHERE t2.id=2 UNION SELECT t2.total*0
as score,t2.id FROM (SELECT site3 as id, count(site3) as total FROM vote1 GROUP BY site3) t2
WHERE t2.id=3) t3)t4 INNER JOIN (SELECT sum(t3.score) as score2, sum(t3.score)* 0 as id
FROM ( SELECT t2.total*2 as score,t2.id FROM (SELECT site2 as id, count(site2) as total FROM
vote1 GROUP BY site2) t2 WHERE(t2.id = 1) UNION SELECT t2.total*1 as score,t2.id FROM
(SELECT site2 as id, count(site2) as total FROM vote1 GROUP BY site2) t2 WHERE t2.id=2
UNION SELECT t2.total*0 as score,t2.id FROM (SELECT site2 as id, count(site2) as total FROM
vote1 GROUP BY site2) t2 WHERE t2.id=3) t3)t5 ON t4.id=t5.id)t6 INNER JOIN (SELECT
sum(t3.score) as score1, sum(t3.score)* 0 as id FROM (SELECT t2.total*2 as score,t2.id FROM
(SELECT site1 as id, count(site1) as total FROM vote1 GROUP BY site1) t2 WHERE(t2.id = 1)
UNION SELECT t2.total*1 as score,t2.id FROM (SELECT site1 as id, count(site1) as total FROM
vote1 GROUP BY site1) t2 WHERE(t2.id = 2) UNION SELECT t2.total*0 as score,t2.id FROM
(SELECT site1 as id, count(site1) as total FROM vote1 GROUP BY site1) t2 WHERE t2.id=3) t3)t7
ON t7.id=t6.id"
    myAdapter = New NpgsqlCommand(mysqlstring, conn)
    Dim dr As NpgsqlDataReader
    conn.Open()
    dr = myAdapter.ExecuteReader
    Dim dt As New DataTable
    dr.Read()
    txtsite11.Text = dr(0).ToString
    txtsite22.Text = dr(1).ToString
    txtsite33.Text = dr(2).ToString

```

```

Button3.Enabled = True
Label3.Visible = True
HyperLinkMap.Enabled = True
conn.Close()
End Sub

```

```

Protected Sub Button3_Click(ByVal sender As Object, ByVal e As EventArgs) Handles
Button3.Click
    Dim conn As New NpgsqlConnection
    Dim mysqlstring As String
    Dim myAdapter As New NpgsqlCommand
    conn = New
NpgsqlConnection("Server=localhost;Port=5432;Userid=postgres;Database=wpgis;password=gisstud
ent")
    conn.Open()
    mysqlstring = "UPDATE decision_alternatives SET gscore = CASE site_name WHEN 'Site1'
THEN " & txtsite11.Text & " when 'Site2' then " & txtsite22.Text & " when 'Site3' then " &
txtsite33.Text & " END WHERE site_name in ('Site1','Site2','Site3');"
    mysqlstring += "UPDATE decision_alternatives SET grank=t1.rank1 FROM (SELECT gscore,
RANK() OVER (ORDER BY gscore DESC) AS rank1 FROM decision_alternatives) t1 WHERE
t1.gscore = decision_alternatives.gscore;"
    myAdapter = New NpgsqlCommand(mysqlstring, conn)
    myAdapter.ExecuteNonQuery()

    MsgBox1("You have successfully updated both the group score and rank of the decision
alternatives on the map!!!")
End Sub
Private Sub MsgBox1(ByVal msg As String)
    Dim lbl As New Label
    lbl.Text = "<script language=javascript>" & Environment.NewLine & _
        "window.alert('" + msg + "');" & Environment.NewLine & _
        "</script>"
    Page.Controls.Add(lbl)
End Sub
End Class

```

### 3. Code Behind the Chart Interface

```

Imports Npgsql
Imports InfoSoftGlobal
Imports Utilities
Public Class chart
    Inherits System.Web.UI.Page

    Protected Sub Page_Load(ByVal sender As Object, ByVal e As System.EventArgs) Handles Me.Load
        Dim mysqlstring As String
        Dim totalvoters As New NpgsqlCommand
        'Database Objects - Initialization
        Dim conn As New NpgsqlConnection
        conn = New
NpgsqlConnection("Server=localhost;Port=5432;Userid=postgres;Database=wpgis;password=gisstudent"
)
        conn.Open()

```

```

mysqlstring = "SELECT Count(DISTINCT username) FROM vote1"
totalvoters = New NpgsqlCommand(mysqlstring, conn)
Label5.Text = totalvoters.ExecuteScalar
Label7.Text = totalvoters.ExecuteScalar
conn.Close()
FCLiteral.Text = CreateChart()
FCLiteral1.Text = CreateChart1()
End Sub

Public Function CreateChart() As String

'Database Objects - Initialization
Dim conn As NpgsqlConnection
conn = New
NpgsqlConnection("Server=localhost;Port=5432;Userid=postgres;Database=wpgis;password=gisstudent"
)

'Dim oRs As DbConn, strQuery As String
'strXML will be used to store the entire XML document generated
Dim strXML As String
Dim util As New Util()
'Dim strQuery As String
Dim cmd As New NpgsqlCommand()
'Generate the graph element
strXML = "<graph caption='Sites Output report' subCaption='By Group Score' xAxisName='Site
Name' yAxisName='Group Score' decimalPrecision='0' showNames='1' showvalues='0' numberSuffix='
formatNumberScale='0'>"

' SQL Query
cmd.CommandText = "select * from decision_alternatives"
cmd.Connection = conn
conn.Open()
' Open Data Reader
Dim oRs As NpgsqlDataReader = cmd.ExecuteReader
'Iterate through each factory
While oRs.Read()

'Generate <set name='..' value='..' />
strXML = strXML & "<set name='" & oRs.Item("site_name").ToString() & "' value='" &
oRs.Item("gscore").ToString() & "' color='" & util.getFCColor() & "' />"

End While

' Close Data Reader
oRs.Close()
'Finally, close <graph> element
strXML = strXML & "</graph>"

'Create the chart - Column 3D Chart with data from strXML
Return FusionCharts.RenderChartHTML("../FusionCharts/FCF_Column3D.swf", "", strXML,
"TotalScore", "550", "350", False)

```

```

End Function
Public Function CreateChart1() As String

    'Database Objects - Initialization
    Dim conn As NpgsqlConnection
    conn = New
NpgsqlConnection("Server=localhost;Port=5432;Userid=postgres;Database=wpgis;password=gisstudent"
)
    'Dim oRs As DbConn, strQuery As String
    'strXML will be used to store the entire XML document generated
    Dim strXML As String
    Dim util As New Util()
    'Dim strQuery As String
    Dim cmd As New NpgsqlCommand()
    'Generate the graph element
    strXML = "<graph caption='Criteria' subCaption='By Total number of voters'
xAxisName='Criterion' yAxisName='Number of Voters' decimalPrecision='0' showNames='1'
numberSuffix=' formatNumberScale='0'>"

    ' SQL Query
    cmd.CommandText = "select criteria, count(criteria) as Total from vote1 group by criteria"
    cmd.Connection = conn
    conn.Open()
    ' Open Data Reader
    Dim oRs As NpgsqlDataReader = cmd.ExecuteReader
    'Iterate through each factory
    While oRs.Read()

        'Generate <set name=..' value=..' />
        strXML = strXML & "<set name='" & oRs.Item("criteria").ToString() & "' value='" &
oRs.Item("Total").ToString() & "' color='" & util.getFCColor() & "' />"

    End While

    ' Close Data Reader
    oRs.Close()
    'Finally, close <graph> element
    strXML = strXML & "</graph>"

    'Create the chart - Column 3D Chart with data from strXML
    Return FusionCharts.RenderChartHTML("../FusionCharts/FCF_Column2D.swf", "", strXML,
"TotalScore", "500", "250", False)

End Function
End Class

```