Web-based atlas to facilitate marine renewable energy site selection in western Canada

Julien Cousineau and Sean Ferguson

Abstract—**A web-based Marine Energy Resource Atlas was developed to assist marine renewable energy stakeholders with preliminary site selection and feasibility investigations in the rivers and coastal waters in western Canada. The Atlas offers a clean and simple interface through which users are able to interact with the underlying geospatial data and customize investigations to fit their specific design and development criteria. The Atlas represents a uniquely flexible and accessible decision support system that can be operated online via a web browser and does not require any specialized geographic information system software. As such, the Atlas is an effective tool to quickly investigate multiple scenarios with different resource, socio-economic, and environmental criteria. Resulting hotspot delineations are visualized in the web browser and are updated in real-time in response to user-interaction and criteria adjustments. It is anticipated that the flexibility and ease-of-use of the Atlas will facilitate site selection and ultimately contribute to well-informed marine renewable energy resource management. Additionally, the Atlas represents the first tool to offer decision support capabilities for tidal, wave, and river hydrokinetic resources under a common system and interface.**

Keywords— **marine renewable energy, atlas, decision support system, multi-criteria decision analysis, resource assessment, GIS.**

I. Introduction

GROWING concern regarding climate change and increased emphasis on sustainable decision making has sparked an interest in renewable energy, with great attention and focus being directed toward energy harnessed from tidal, wave, and river hydrokinetic resources. Despite a growing body of research and technological advances, deployment of marine renewable energy (MRE) devices within Canada remains relatively low, with the exception of a few exploratory technology demonstrations (e.g. [1], [2]). Previous research has shown that Canada's coastal regions and rivers are abundant in MRE resources [3], [4]. Although large-scale assessments are available in literature, this information is not yet available to stakeholders in a manner that permits meaningful interpretation and assessment of the practical energy resource with consideration of socio-economic and environmental criteria. Furthermore, resource assessment findings have primarily been disseminated through literature (i.e. static documents with limited interactivity) which limits the extent to which the resource datasets may be queried and interrogated. These gaps hinder well-informed MRE site selection and ultimately represent barriers to further development and deployment of large-scale MRE technologies in Canadian waters.

To address the aforementioned gaps, the authors present the Marine Energy Resource Atlas (hereafter referred to as the "Atlas"). The Atlas is a web-based geospatial decision support system (DSS) that is designed to facilitate preliminary MRE site selection and support feasibility investigations in rivers and coastal waters in western Canada (Figure 1). The Atlas is highly interactive and employs multi-criteria decision analysis (MCDA) to compute site suitability throughout the study domain based on user-specified criteria. The distribution of site suitability is visualized in real-time over a base map. In addition to resource assessment datasets for tidal, wave, and river hydrokinetic resources, the Atlas also contains a number of socio-economic and environmental datasets pertinent to assessing the feasibility of MRE development. These datasets include, for example, proximity to the transmission grid, proximity to ports and terminals, and proximity to protected areas. The Atlas can therefore be used to easily and comprehensively assess MRE resources within a framework that permits prioritization and weighting of various socio-economic, environmental, and stakeholder objectives. Furthermore, the Atlas is the first MRE DSS to offer support for tidal, wave, and river hydrokinetic energy resources under a common system and interface. These features make the Atlas ideally suited to support well-informed preliminary site selection and ultimately facilitate the implementation of sustainable energy solutions.

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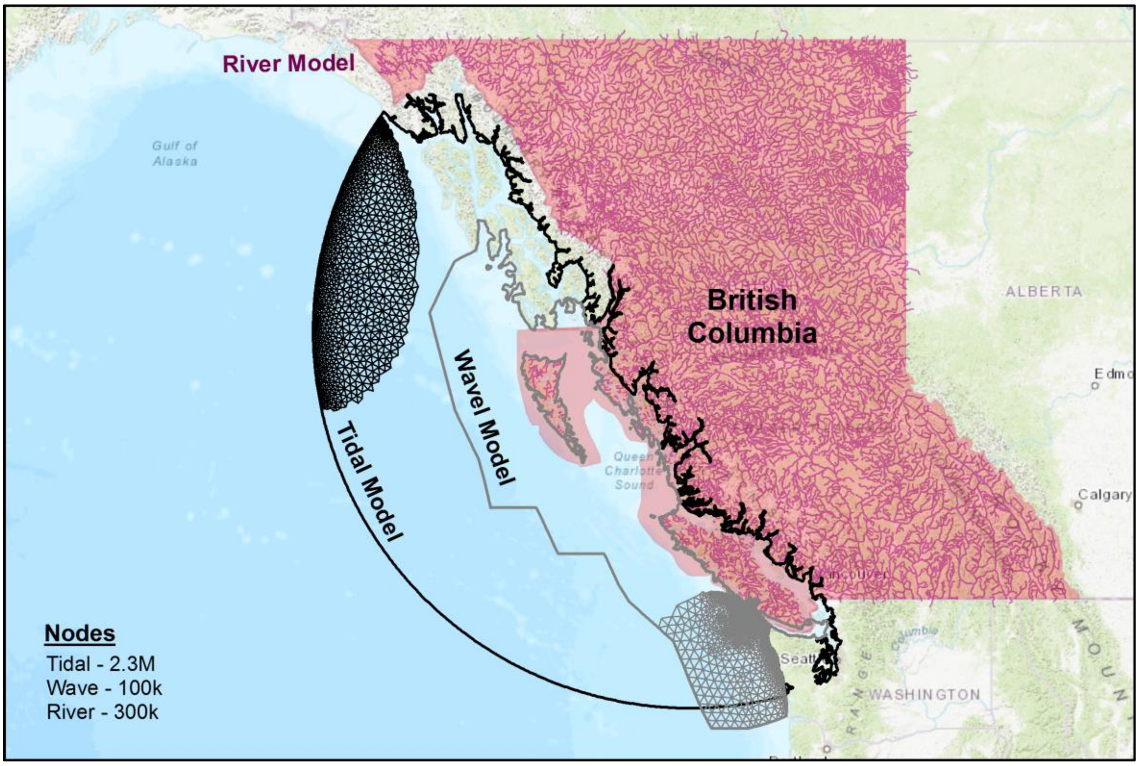

Fig. 1. Extent of the marine energy models in western Canada. Unstructured triangular mesh and river reach were used to support tidal, wave and river modelling for the resource assessments.

II. Background

A. Resource Assessments

A number of resource assessments have been conducted in the past to characterize MRE resource availability in western Canada [3]–[6].

The tidal resource assessment [5] was conducted by the National Research Council (NRC) of Canada using hydrodynamic modelling techniques. A numerical hydrodynamic model was used to simulate water depths, velocities, power, and annual energy production (AEP) in coastal and offshore waters in western Canada. The model used bathymetry data sourced from the Canadian Hydrographic Service (CHS) [7] and the National Oceanic and Atmospheric Administration (NOAA) [8]. The model output was provided on an unstructured triangular mesh consisting of over 2.3 million nodes, with increased resolution in nearshore areas. The mesh was generated such that all channels and inlets greater than or equal to 200 m in width are captured by the mesh. At the highest nearshore resolution, spacing between mesh nodes is approximately 50 m. Accordingly, intricate geographical features such as small channels and inlets are well-represented in the mesh. This is an important feature for tidal resource assessment since the greatest velocities generally occur where tidal currents are constricted.

The wave resource assessment was conducted by the University of Victoria [6], [9]. The model domain was discretized using an unstructured triangular mesh and simulated values were output at mesh nodes. The simulated data include water depth, spectral wave heights and periods, and wave power for over 250,000 nodes.

The river hydrokinetic resource assessment was conducted by the NRC [4], [10]. Regionalization techniques were used to estimate flows at ungauged stations across Canada and hydraulic geometry relationships were used to estimate channel dimensions. The resulting datasets included average depth, average width, average velocity, average power, and flow duration curves for every reach in Canada. Data for over 21.5 thousand reaches were included in the Atlas for the province of British Columbia.

Figure 1 shows the extent of the tidal, wave and river models in western Canada.

B. Previous Multi-Criteria Decision Analyses

Previous studies have employed MCDA techniques with geographic information systems (GIS) to evaluate MRE development site suitability within a spatial domain [11]–[15]. In the initial stages, this methodology involves gathering relevant datasets and compiling the data into geospatial layers. Typically, criteria layers are categorized as either constraint layers or factor layers. Constraint layers represent design restrictions and dictate whether a given location is acceptable or unacceptable [16]. For example, one might specify that all locations within 1000 m of protected areas are unacceptable for development. Conversely, factor layers indicate suitability at a given location based on a pre-defined scale. For example, one might specify that locations in the immediate vicinity of the transmission grid are most desirable whereas locations further away from the transmission grid are less desirable, but not unacceptable. Prior to data integration, each factor layer must be normalized to a common scale and weighted to reflect importance relative to other factor layers. Ultimately, constraint and factor layers are integrated using geospatial algebraic methods to produce a summary layer indicating site suitability throughout the study domain [17], [18].

Data-integration processes are typically performed using a raster-based approach where the study domain is discretized as a uniform grid ([15], [19], [20]). Raster-based discretization is an effective means to facilitate MCDA, but specifying a uniform grid resolution throughout the study domain introduces a trade-off between nearshore accuracy and computation time [19]. A fine grid will produce high-resolution results but will be computationally demanding, and a coarse grid will foster fast computation times but may not provide sufficient detail near the shoreline or in other key areas of interest.

The data-integration principles of MCDA have been applied in Canada's coastal regions and rivers in the context of marine conservation and renewable energy development. For example, online mapping products delineating renewable energy resource availability in New Brunswick and the Bay of Fundy were made available through the Renewables for Nature project conducted by the World Wildlife Federation (WWF) [20]. The map tool is designed such that users are able to overlay the resource availability maps with pre-computed geospatial layers representing conservation value [20], [21]. These conservation layers were computed by weighting and integrating numerous socio-economic and environmental databases. The end-product may be thought of as a two-factor DSS (i.e. resource availability and conservation value). The Renewables for Nature project was focussed on presenting conflicts between resource availability and locations of high conservation value. However, operational and deployment feasibility considerations (connection the transmission grid, for example), were not considered.

Similarly, the British Columbia Marine Conservation Analysis (BCMCA) team produced geospatial layers indicating conservation value in the vicinity of B.C.'s coast [19], [21], albeit as a demonstration of Marxan decision support methods [22]. The summary layers present conservation value as a scaled factor throughout the study domain. Similar to the Renewables for Nature project, the layers were computed from numerous socio-economic and environmental databases. However, data integration was conducted using the Marxan decision support tool [19].

Geospatial data layers and MCDA results are commonly communicated though figures in print [11], [14], [19] or static-layers in online map services [19], [20]. This approach is based on the principles of visual presentation and is an effective strategy to communicate preconceived key points to the user [23], [24]. However, this approach does not permit the user to formulate custom data interrogations. Users are constrained to making decisions based on pre-processed visuals and do not have the freedom to explore different scenarios. In the context of MRE development feasibility, interested stakeholders may wish to emphasize or diminish the influence of certain constraints or factors. In order to support this degree of flexibility, the DSS must support user-interaction and exploration of the underlying datasets [23], [24].

III. Objective

The main objective of the Atlas is to support preliminary site selection and feasibility investigations in western Canada for tidal, wave, and river hydrokinetic energy developments. Building upon a concept-level DSS developed in 2017-18 [12], the Atlas was developed with the intention of producing a flexible and interactive DSS that is capable of supporting user-driven MCDA with detailed and expansive datasets pertinent to MRE development suitability. An additional goal of the Atlas is to collate and house relevant data in one location and to ensure that the data and DSS capabilities are easily accessible to stakeholders.

IV. Methodology and Development

Web-based GIS platforms and development frameworks such as ArcGIS Online, OpenGeo, Leaflet, Mapbox, and others have introduced great advances in browser-supported geospatial data visualization, allowing users to access data and maps without installing specialized software. These platforms also enable developers to incorporate specific functionalities into the web-based maps to assist users and enhance the users'-experience. These features can be designed such that meaningful data exploration and navigation can be conducted by the user with minimal prior knowledge of GIS systems and geospatial data analysis techniques. Ease-of-development and customization capabilities vary amongst different online GIS services. Typically, the developer must have specialized knowledge of web-development and JavaScript programming in order to produce interactivity features.

Although these online GIS services can be employed to effectively communicate key visual information to the audience, they do not support MCDA data-integration applications, nor do they allow querying of large datasets (>50,000 data points) in an interactive way. Most platforms use a data management system such as MySQL, PostgreSQL, MongoDB, or others to query spatial datasets. Depending on the type of query, results can take a few seconds to hours to process. This hinders the flexibility to customize MCDA criteria and explore different scenarios in an interactive DSS [23], [24] and,

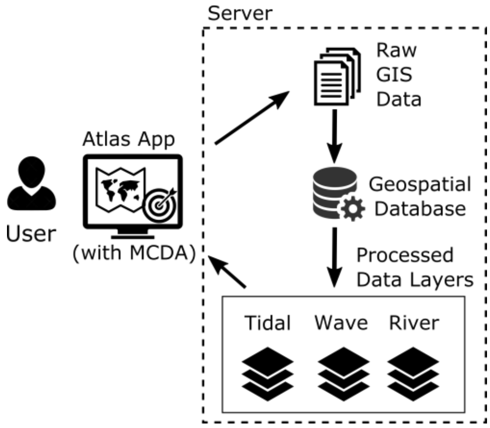

Fig. 2a. Configuration of the Atlas with WebGL. Model data layers are downloaded from the Sever and the MCDA is computed in the web-browser using WebGL.

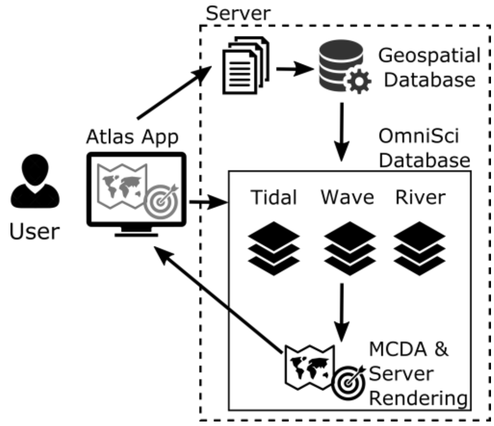

Fig. 2b. Configuration of the Atlas with OmniSci. The MCDA is computed on the server and results are transferred to the web-browser.

ultimately, limits the transferability of the research findings and hinders practical use of the data.

Recently, general-purpose graphics processing units (GPGPU) techniques and platforms have fundamentally changed the scale of datasets that can be processed and visualized in near-real-time. For example, OmniSci [25] is a data analytics platform designed to process billions of records in milliseconds using GPUs. It features a relational database backend with advanced visualization and analytic features to enable hyper-interactive exploration of large datasets.

Another approach that uses GPGPU computing is the Web Graphics Library (WebGL). WebGL is a JavaScript API for rendering interactive 3D and 2D graphics within any compatible web browser. It can process millions of records in milliseconds using the GPU of the user's machine.

Both, OmniSci and WebGL, are feasible solutions to produce a flexible and interactive DSS that is capable of supporting user-driven MCDA with detailed and expansive datasets pertinent to MRE development suitability. Both solutions are discussed in this paper.

C. *Configurations*

The web-based Atlas is comprised of two components; the server (back-end) and the application (front-end). The server mainly consists of managing the geospatial datasets and preparing the data for MCDA. One database is reserved for storing the raw GIS data layers, whereas another database is reserved for storing and serving pre-processed datasets for the MCDA. The application (front-end) is a graphical user interface (GUI) that handles the data visualization, user management, and the interactive features permitting the user to customize the MCDA to fit their needs. The MCDA is either handled by WebGL in the application (Fig. 2a) or by OmniSci on the server (Fig. 2b).

D. *Geospatial Database*

The Atlas contains resource availability data layers for tidal, wave, and river hydrokinetic energy. The layers were developed using data from past theoretical resource assessments conducted in the vicinity of the study area [4], [5], [8].

For most applications relevant to MRE resource and impact assessment, distance-based criteria can be used to assess the importance of socio-economic and environmental factors. For example, at a given location, the distance to the transmission grid or the distance to the closest port location might be of interest to tidal energy stakeholders. Accordingly, a multitude of socio-economic and environmental data layers were pre-computed using Python programming techniques, based on distances to key features throughout the study domain. Some socio-economic and environmental data layers represent desirable traits, such as proximity to the transmission grid, and some represent undesirable traits, such as proximity to protected areas or submarine cables [26]. Socio-economic and environmental data layers relevant to marine energy were discretized based on the same computational mesh nodes or river reach nodes used to support the tidal, wave, and river modelling.

Socio-economic and environmental constraint layers are often produced by applying fixed buffers around key features to identify unacceptable locations [13], [14], [27]. However, this limits the flexibility and transferability of the DSS because users are unable to explore different scenarios (for example, different buffer sizes). Furthermore, although some criteria may technically represent design constraints only, it may be desirable to evaluate suitability in un-restricted regions. For example, MRE development may not be permitted within a specified buffer region around protected areas, but users may wish to indicate that desirability increases with distance away from protected areas in the remaining unrestricted regions. For this reason, socio-economic and environmental data layers included in the Atlas were processed such that they contain raw distance values; buffering and normalization of the layers is governed by the user's decisions. Essentially, users are free to decide whether each data layer is treated as a factor, a constraint, or a factor with a constraint. To assist users, suggested buffer specifications are presented in the Atlas based on literature. Furthermore, users are free to include or disregard individual socio-economic and environmental layers to reflect their investigative preferences. Additionally, by avoiding fixed constraint and buffer requirements, this approach enhances the adaptability of the Atlas to future changes in regulatory requirements and best-practices.

The following socio-economic and environmental data layers are included in the Atlas, each representing proximity to the listed features:

- Boat launches
- Diving sites
- Environmental monitoring locations
- Ferry routes
- Ferry terminals
- First nation communities
- Freshwater finfish tenures
- Major natural resources projects
- Marinas
- Moorages
- Navigation hazards
- Oil and gas pipeline rights-of-way
- Ports and terminals
- Protected areas
- Saltwater finfish tenures
- Shellfish tenures
- Shipwreck locations
- Shoreline
- Submarine transmission cables
- Submarine telecommunication cables
- Transmission grid

Shoreline feature data were obtained from NOAA [28], submarine telecommunication cable feature data were obtained from cablemap.info [29], submarine transmission cable feature data were obtained from BC Hydro, and protected areas feature data were obtained from the Canadian Council on Ecological Areas [30]. All other socio-economic feature data were obtained through the British Columbia Data Catalogue repository [31]. All distances in the data layers were computed assuming travel along a hypothetically flat terrestrial or water surface, except for the transmission grid data layer for tidal and wave energy resources, where values represent the distance of travel along the ocean floor. This methodology was selected under the assumption that stakeholders will be most interested in the length of submarine cable required to connect wave and tidal energy conversion devices to the existing transmission grid.

E. *Domain Discretization*

In raster data models, geospatial data are represented as an array of equally sized cells arranged in rows and columns [32]. Conversely, in vector data models, geospatial data are represented as points, lines, and/or polygon features which need not conform to a structured arrangement pattern. Unlike most studies, which employ a raster-based discretization to perform MCDA with a fixed cell resolution, the study domain was discretized using a novel vector-based approach. Geospatial data layers pertaining to tidal and wave energy were discretized based on a collection of nodes coinciding with the node locations of the unstructured triangular meshes used to support the respective resource assessments. Geospatial layers pertaining to river hydrokinetic energy were discretized based on a series of nodes evenly spaced streamwise along river segments throughout the study domain. For tidal and wave applications, this vector-based approach permits MCDA to be performed with dynamic resolution throughout the study domain, thus alleviating the trade-off between producing detailed results and maintaining acceptable computation time.

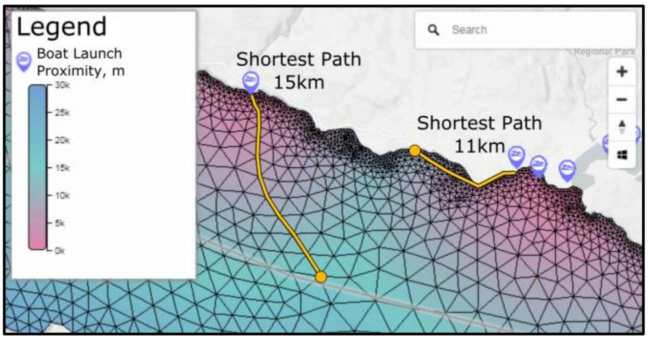

Fig. 3a. Example of shortest-path computation for boat launch. For tidal and wave applications, the shortest-path algorithms was used to compute proximity between node locations and key features (i.e. boat launches) This technique restricted travel around obstructions such as islands and peninsulas.

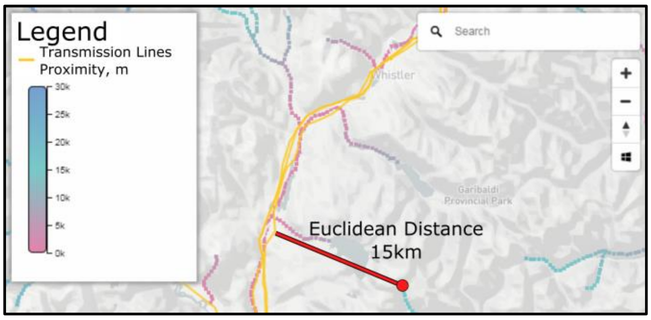

Fig. 3b. Example of shortest-distance computation for transmission lines. For river hydrokinetic, proximity computations were conducted using the straight Euclidean distance between nodes and key features.

F. *Layer Preparation*

Geospatial layer preparation was conducted using Python programming. A number of scripts were developed to assign relevant values to node locations.

For the tidal, wave, and river hydrokinetic resource data layers, values derived from the respective resource assessments could be assigned directly to node locations. Other model data that were used in the modelling were assigned directly to node locations (i.e. depth).

Most socio-economic geospatial layers represent proximity to key features (e.g. proximity to port locations). For these layers, additional computation was required in order to compute proximity between node locations and key features supplied as point, line, or polygon shapefiles. For tidal and wave applications, these computations were supported by shortest-path algorithms included in the open-source Python library, NetworkX [33], restricting travel to the edges outlined by the computational meshes. This technique adequately handled shortest-path computations around obstructions such as islands and peninsulas (Fig. 3a). For river hydrokinetic applications (and some tidal and wave applications), proximity computations were conducted using the straight Euclidean distance between nodes and key features (Fig. 3b).

G. MCDA

The Atlas uses MCDA methods to compute suitability at each location in the study area based on selected data layers and specified criteria. Each data layer (resource or socio-economic/environmental) is accompanied by an interactive value function. The value function defines the normalization scheme applied to the corresponding data layer such that raw values, a_{ik}, are transformed to normalized values, $v(a_{ik})$, fitted to a scale from 0 to 1 using the following equation,

$$v(a_{ik}) = \left(\frac{\max_i\{a_{ik}\} - a_{ik}}{\max_i\{a_{ik}\} - \min_i\{a_{ik}\}}\right)^{\rho}$$

for the k-th criterion of the i-th alternative to be minimized, or

$$v(a_{ik}) = \left(\frac{a_{ik} - \min_i\{a_{ik}\}}{\max_i\{a_{ik}\} - \min_i\{a_{ik}\}}\right)^{\rho}$$

for the k-th criterion of the i-th alternative to be maximized, where ρ represents a parameter which can be adjusted to reflect risk, and $\min_i\{a_{ik}\}$ and $\max_i\{a_{ik}\}$ represent the minimum and maximum criterion values of the k-th criterion, respectively [16].

Users can manipulate the shapes of the value functions to reflect the design criteria to be employed in the MCDA. For example, in Figure 4, the user has specified that proximity to the transmission grid is desirable, desirability diminishes with increasing distance away from the transmission grid, and locations further than 30 km away from the transmission grid are unsuitable for development. The user is also able to influence the shape of the value function by interacting with the ρ-value. A ρ-value between 0 and 1 produces a concave-down value function representing a risk-aversion strategy, a ρ-value of 1 produces a linear value function, and a ρ-value greater than 1 produces a concave-up value function representing a risk-affinity strategy [16]. In Figure 4a, the user has specified a concave-up curve representing a risk-aversion strategy. Each data layer is also accompanied by a slider which the user can manipulate to indicate the weight (or importance) of each data layer with respect to other data layers.

The normalized and weighted data layers are integrated using a weighted linear combination to determine overall suitability at each location in the study domain. However, if the minimum or maximum acceptable criteria for any data layer is not met at a given location, then the suitability of that location is assigned a 0 value. Referring to Figure 4b, for example, any locations that are located further than 30 km away from the transmission grid would be assigned an overall suitability value of 0 regardless of the desirability of other parameters (depth, velocity, etc.) at those locations. In essence, this functionality allows users to decide whether each criteria data layer is treated as a factor, a constraint, or a factor with a constraint.

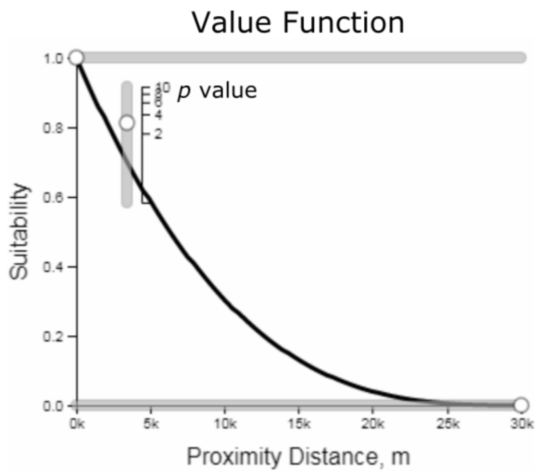

Fig. 4a. Interactive value function. Proximity distance are transformed to a scale from 0 to 1, with 0 representing the worst condition and 1 representing the best condition.

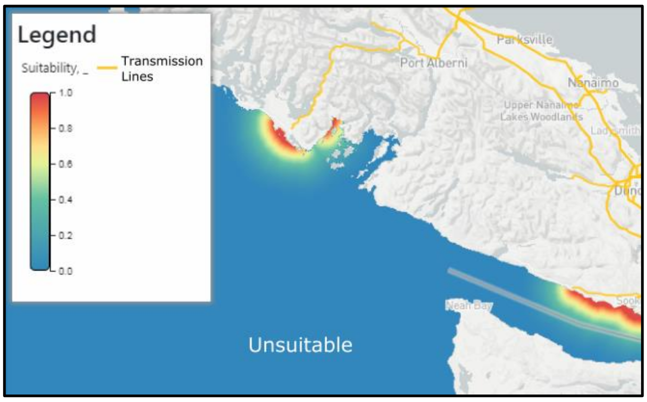

Fig. 4b. Site suitability using the transmission grid dataset.

Although the MCDA methods are not complex, implementing it in an application to produce a flexible and interactive DSS can be challenging. Using central processing unit (CPU) computing (the conventional approach), the Atlas was able to process and visualize the results for 50 thousand nodes without any delays. However, processing the MCDA was time consuming and unmanageable using the wave, river and tidal models which contain 100k, 300k and 2.3 million nodes respectively. The use of GPGPU computing has created new possibilities and has given the Atlas the capability to process millions of nodes in milliseconds. Both the WebGL and OmniSci, implementation of the MCDA are explained below:

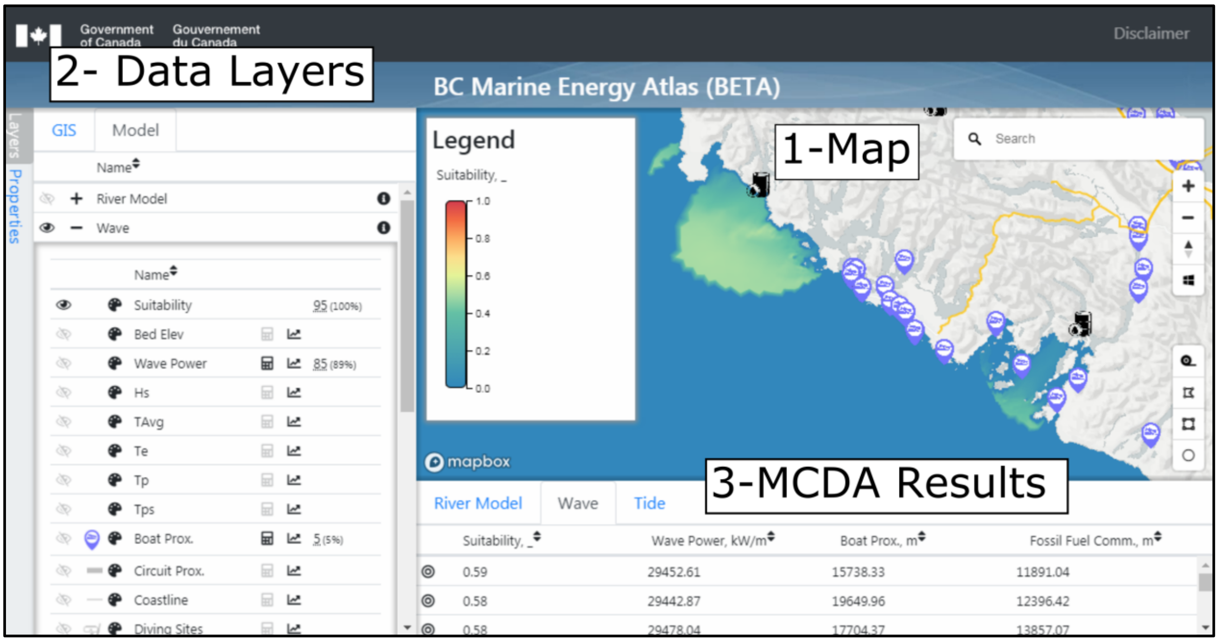

Fig. 5. The Marine Energy Resource Atlas user interface

1) WebGL

To perform MCDA in WebGL, all selected data layers (resource and socio-economic/environmental) need to be available in the web-browser application. The data can either be downloaded from the server or retrieved from the web-browser cache. Once retrieved, the MCDA is computed in WebGL using the data layers, value functions, and weights. Results from the MCDA are rendered automatically in the web-browser.

The main disadvantage of the WebGL approach is the need to download all data layers in the web-browser. For example, if a user was performing a MCDA on the tidal model using 10 layers, the Atlas would need to download 90 Mb of data. This can introduce some delays in the computation, initially. Once the data is downloaded, it is cached in the application and retrieved instantly for subsequent MCDA computations. There are also potential drawbacks of the WebGL approach related to performance. Since the MCDA and data visualization are processed in the web-browser, the performance is dependent on the GPU card of the client's computer; the application will tend to perform better when run on a desktop computer as opposed to a mobile device.

2) OmniSci

Instead of performing the MCDA on the web-browser, the MCDA can be computed on the server using OmniSci. The MCDA is computed by querying the processed database stored in OmniSci and by retrieving the value functions and weights specified in the web-browser. This avoids the computational effort of downloading data layers and avoids processing in the web-browser. However, there are disadvantages related to the interactive display of MCDA results in the web browser. This can be achieved only through server-rendered visualizations (i.e. Vega) which allow the rendering engine to directly render the results of the query without requiring the data to leave the GPU.

H. Graphical User Interface

The Atlas web-interface (Fig. 5) was developed using JavaScript (JS) programming and associated open-source libraries. It has three main components; Map, Data Layers and MCDA results. The Atlas was developed with the intention of producing a clean and focussed visual environment to foster intuitive interaction with the underlying datasets. Buttons, scroll-bars, and mouse-action features are integrated into the web-interface in such a way that the functionality is obvious to the user. These interactive features were incorporated into the web application using a suite of JS libraries including React and Ant Design [34], [35].

The map component is supported by Mapbox GL [36], a JS library that uses WebGL to render interactive geospatial data. This approach eliminated reliance on traditional GIS software and eliminated the associated limitations. As a result, this approach enabled a high degree of flexibility and customization. As such, the library was adopted and slightly modified to process and render model data layers and to process the MCDA within WebGL. This allows the rendering engine to

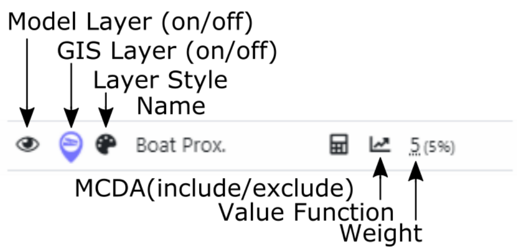

Fig. 6. Model sublayer options. Users can set the visibility of the model, set the visibility of the associated GIS layer, edit the style, include/exclude the layer in the MCDA, edit the value function, and edit the weight.

render the MCDA results directly on the map. Other standard geospatial tools such as measuring distance and area were added to the application to support preliminary site selection and feasibility investigations for marine energy developments. All geospatial data were converted into vector tiles, packets of geographic data organized into pre-defined tiles for transfer over the web, to enable quick rendering in the application.

Two lists are shown in the Data Layer menu: GIS (raw geospatial data) and model layers (processed layers). Similar to a typical GIS platform, users are able to change layer visibility, order, and style, and view associated metadata. Each model (tidal, wave, and river) contains a list of model layers representing the resource and socio-economic datasets. Users are able to select which model layers to include in MCDA computations. Model layers are accompanied by a value function and weight slider so that users can specify criteria for MCDA. Suitability results from the MCDA are also included as a layer that users are able to view and navigate.

For the value function, users are presented with an interactive graph which allows them to specify the suitable and unsuitable range, and adjust the data normalization method [38] (Fig. 6). Furthermore, users are able to adjust the weights assigned to each factor layer. These functionalities enable users to customize preliminary assessments to fit specific project criteria. For example, if a developer is particularly concerned about proximity to the nearest port location, or if their particular MRE devices can only be deployed within a certain depth range, then they are able to adjust the MCDA to reflect these criteria.

The Atlas also provides a table of suitable locations based on MCDA computations. Each table row corresponds to a specific location and shows the suitability index of that location as well as values corresponding to each selected data layer (e.g. average current speed, proximity to boat launches). Each table row is also accompanied by a button to pin-point the location on the map. These functionalities enable users to find and locate suitable sites with ease.

In addition, the Atlas provides functionality to export additional model information, such as temporal (e.g. speed time-series) and spectral data (e.g. spectral distribution) to further investigate the suitability of the site.

V. EXAMPLE

Figure 7 illustrates a hypothetical scenario where the Atlas has been employed to assess site suitability as a function of average tidal current speed, proximity to the shoreline, and proximity to remote communities that use diesel fuel as a primary source of energy.

The hypothetical assessment presented in Figure 7, illustrates the following logic:

- Figure 7a: The user has accessed the Atlas via a web browser and activated the tidal model layer. The user has

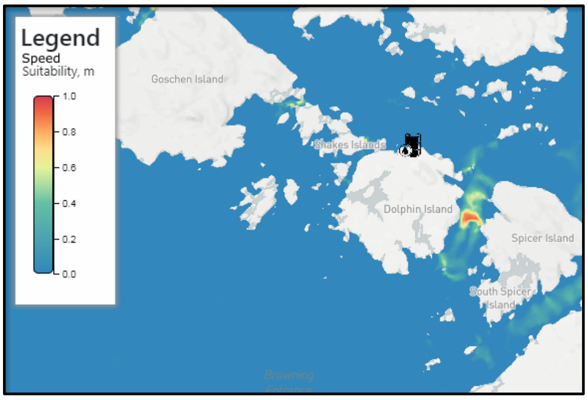

Fig. 7a. Average current tidal speed suitability.

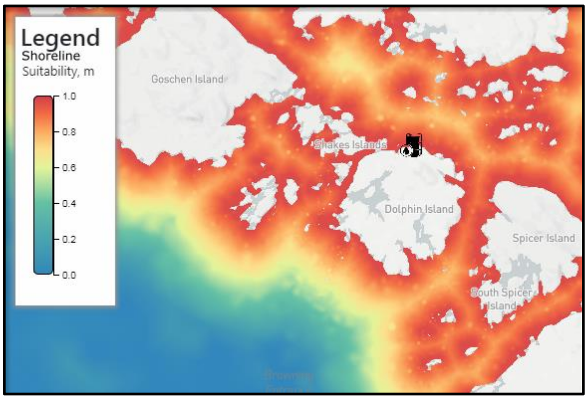

Fig. 7b. Shoreline suitability.

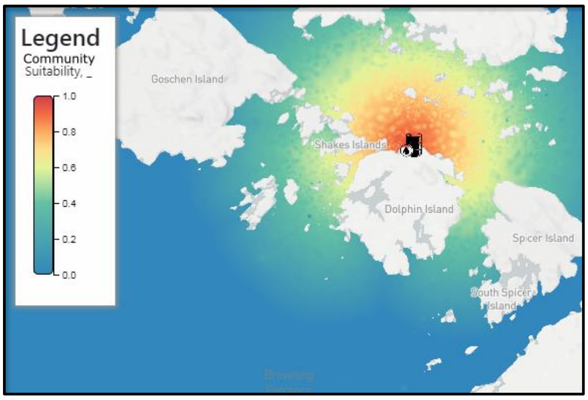

Fig. 7c. Remote Communities suitability.

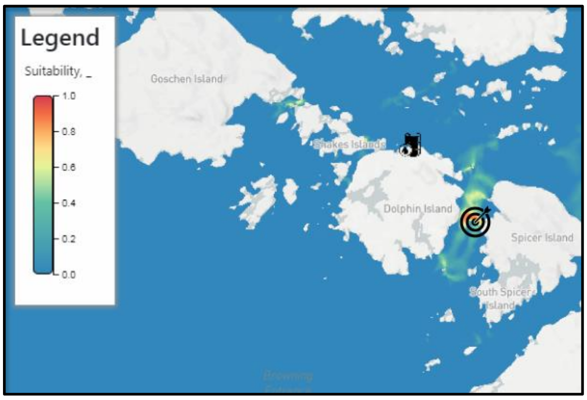

Fig. 7d. A hypothetical scenario is displayed showing site suitability as a function of (a) average tidal current speed, (b) proximity to the shoreline, and (c) proximity to remote communities that use diesel fuel as primary source of energy.

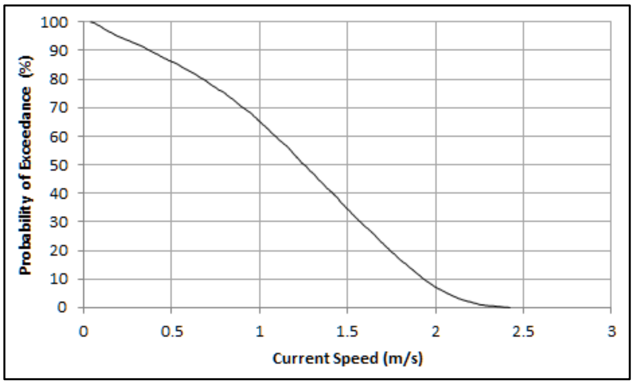

Fig. 7e. Example of probability of exceedance for tidal current speed at a suitable site.

introduced the average tidal current speed data layer into the MCDA computations. The user has specified that high average tidal current speeds are desirable and that any locations with average tidal current speed lower than 0.5 m/s are unacceptable. The user has also specified that locations with average tidal current speed greater than 2.0 m/s are most desirable. A linear normalization scheme has been selected. Since it is currently the only layer in the analysis, the average tidal current speed data layer has a weight of 100%.

• Figure 7b: The user has introduced the shoreline data layer into the MCDA computations. The user has specified that suitability decreases with increasing distance away from the shoreline and that any locations beyond 5 km of the shoreline are unacceptable. A weight of 5% has been assigned to the shoreline data layer; correspondingly, the weight of the average tidal current speed data layer has dropped from 100% to 95%.

• Figure 7c: The user has introduced the remote community layer into the MCDA computations. The user has specified that sites that are close to remote communities are most desirable, and suitability decreases with increasing distance away from remote communities. Any locations beyond 30 km of a remote community are unacceptable. A weight of 5% has been assigned to the remote community data layer; correspondingly, the weight of the average tidal current speed data layer has dropped from 95% to 90%.

• Figure 7d and Figure 7e: With the help of the MCDA summary table and the map, the user was able to find suitable sites, view the current speed time-series retrieved from the model and view the probability of exceedance for current speed.

The example presented in Figure 7 demonstrates how a user could identify potentially suitable sites for MRE development based on criteria related to the average tidal current speed, the shoreline, and remote communities that use diesel fuel as primary energy source. This functionality could help stakeholders target areas for further detailed investigation by providing a coarse description of site suitability based on customized criteria specifications.

VI. CONCLUSION

The Atlas hosts an extensive collection of data layers pertinent to MRE development feasibility. Interaction with the underlying data is supported such that users are able to formulate customized data interrogations and quickly visualize site suitability based on a broad range of user-defined criteria. Users are able to manipulate MCDA criteria to reflect specific resource, socio-economic, and environmental requirements or preferences. Accordingly, the Atlas can be used as an effective tool to support preliminary site selection tasks and identify locations that warrant further detailed investigation. Since the Atlas was developed as a web-based tool, it is easily accessible to stakeholders via a web browser; installation of specialized software is not required. Furthermore, the Atlas is the first MRE DSS to offer support for tidal, wave, and river hydrokinetic energy resources under a common system and interface.

The Atlas is still in development and a beta version is currently being tested on https://www.bc-atlas.ca. Both, OmniSci and WebGL are feasible solutions to produce a flexible and interactive DSS. The two approaches have advantages and disadvantages in terms of maintenance, ease of use, development, connectivity, security and server cost. Although the OmniSci option appears to be the superior approach, web servers with GPUs are expensive and can cost thousands of dollars per month depending on the number of clients and usage. On this basis, the WebGL approach was maintained in the beta version and in the first release in 2019. This first release will also contain documentation and video tutorials.

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