Viability of Open-Source Wind Resource Assessment Software

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Abstract: ***As the world shifts towards renewable energy sources, newer and larger projects come to fruition every year. Renewable energy projects require a complex analysis before proceeding with development. Part of this analysis procedure is resource assessment. This research aims to determine the viability of using open-source software for industry applications. This is performed through a comparison of the current industry standard software, WAsP, and Continuum. A site with a wide range of land cover conditions is chosen to see how the different software performs under varying conditions. Multiple different measured wind data inputs are used in the comparison, allowing for a comprehensive study. A focus is made on the software's accuracy, while also comparing the analytics and outputs. The interface, workflow, input data, outputs, computational cost and additional requirements of each software package are discussed. It is found that Continuum is accurate within 8 % when compared to WAsP's annual energy production and capacity factor outputs. Due to the open-source nature of Continuum, it also lends itself to further customised developments that could be advantageous when performing resource assessments. WAsP is found to have preferential reporting outputs, however. This research highlights the open-source resource assessment process, from input to output.***

Additional keywords: Wind resource assessment; open-source software; WAsP; Coninuum; AEP; wind energy software

1 Introduction

The global trend for energy is increasing significantly. In 2010, the global energy amounted to 12 457 Mtoe (million tonnes of oil equivalent). In 2022, this rose 17.08 % to 14 585 Mtoe [1]. This is expected to increase another 20.10 % to 17 517 Mtoe by 2035 [2]. Figure 1 illustrates this trend.

The world is in a transitionary period, where many countries are incorporating a higher renewable energy penetration in their energy mix. Wind energy technology has seen rapid growth over the last decade, with wind turbine hub heights and rated capacities increasing significantly. Figure 2 indicates that wind energy would form over 30 % of the global installed energy capacity by 2050.

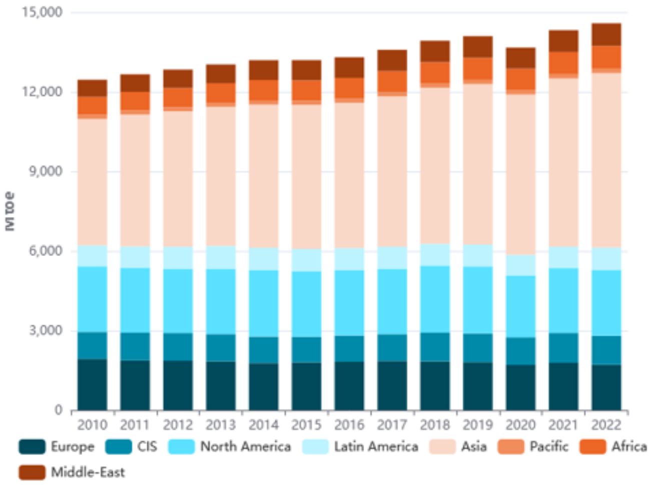

Figure 1 Trend of global energy use [1]

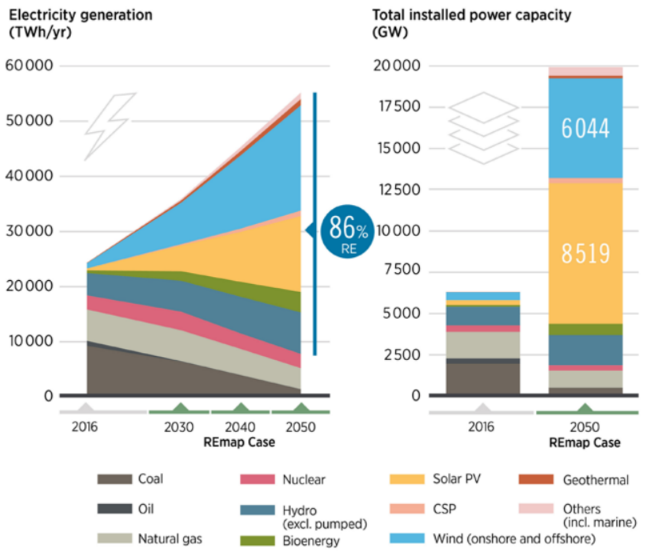

Figure 2 Electricity generation trends [3]

Due to the substantial increase in wind farm installations, there have also been improvements to wind farm planning. The project's viability needs to be analysed as part of the wind farm planning process. This is heavily dependent on the site location since wind resources differ depending on location. The wind resource assessment has been introduced to assess the site-specific wind resources. This is a process whereby the topographical data of a site is analysed, together with the wind speed, to create an estimation of the wind farm.

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Wind resource assessment is important for multiple reasons. Some of the most important include:

1. There may be multiple parcels of land available for development. Wind resource assessment will assist in choosing the most suitable location.
2. The chosen location may not be feasible. It is common to conduct pre-feasibility studies using desktop resource assessment software to determine whether a wind farm will be a good investment.
3. Wind resource assessment can model losses that one may expect, resulting in a more accurate estimation of annual energy production (AEP).
4. Wind resource assessment can provide wake maps that can be used to optimise wind farm layouts.
5. Wind resource assessment is critical for the bankability of a project. The bank would like assurance that the wind farm will produce enough energy to offset its costs.
6. Wind resource assessment offers site suitability analysis, which can be useful for determining whether problems like shadow flicker or noise will be an issue.

Once pre-feasibility studies have been completed, a meteorological (met) mast will typically be installed at the preferred site. Here, data will be measured for (typically) a minimum of one year.

The objectives of the study include:

1. Determine the different types of inputs required for WAsP and Continuum.
2. Understand the difference in the resource assessment process in WAsP and Continuum.
3. Determine if Continuum's results are comparable to WAsP's.
4. Understand which software package makes sense to use.

2 Literature Review

The current industry standard for desktop wind resource assessments is the Wind Atlas Analysis and Application Program (WAsP), developed by the Danish Technical University (DTU) [4]. This is proprietary, closed-source software requiring a license to use. The license for a single user in 2023 is €1990 for one year. There is also a fee of €1800 to upgrade from WAsP 11 to WAsP 12 since WAsP 11 is no longer supported. There are discounts for subsequent years' licenses [5].

On the contrary, there is an alternative freely available, open-source wind resource assessment software package by the name of Continuum. This software package has a similar goal to WAsP, and allows one to also estimate the AEP and optimise the siting of a wind farm. Continuum can be downloaded as an installation file or the direct source code from GitHub [6].

Continuum has published a study where it compared itself with OpenWind and WAsP. The results of each software package were compared to 11 meteorological (met) sites, using a round-robin analysis, as shown in Table 1. Continuum obtained the lowest RMS error of 1.55 % [7].

Table 1 Comparison of wind resource assessment software [7]

Excluded Met Site	OpenWind	Continuum	WAsP
Mast 1	−6.6 %	0.8 %	−5.1 %
Mast 2	−4.0 %	−1.7 %	−5.5 %
Mast 3	0.5 %	0.6 %	1.1 %
Mast 4	1.9 %	−0.8 %	3.9 %
Mast 5	−0.3 %	−1.1 %	−3.0 %
Mast 6	3.8 %	3.2 %	4.9 %
Mast 7	2.6 %	−0.7 %	−0.2 %
Mast 8	−1.6 %	−1.5 %	−1.2 %
Mast 9	−1.9 %	0.2 %	−2.4 %
Mast 10	1.7 %	2.8 %	3.0 %
Mast 11	0.5 %	−0.5 %	−1.1 %

Two wind flow models are currently used in the industry: linear models and computational fluid dynamics (CFD). Linear models are computationally cheap but sacrifice accuracy. CFD models are computationally expensive and require expert knowledge, but can generate more accurate results. Continuum claims to have created a new wind flow model that combines the benefits of both models. Continuum allows all imported met data to simultaneously generate site-calibrated models. This results in a claimed balance between accuracy and computational cost [8].

3 Data Inputs

Acquiring suitable input data is required before proceeding with wind resource assessments. The resource assessment is dependent on the climate conditions of the location of interest. Three main input data components are required: surface roughness, elevation and wind climate.

Surface roughness is a parameter used to define the land cover in a region. Regions of low surface roughness are interesting to wind energy developers since this indicates less resistance to the wind in that region. Examples of types of regions with low surface roughnesses include sand dunes, oceans, lakes and grasslands. Examples of types of regions with high surface roughness are industrial, commercial, urban and forest areas.

The surface roughness data is provided by the Department of Forstery Fisheries and Environment (DFFE). This freely available dataset is in the form of a raster covering South Africa's extent. The raster is made up of 74 layers, which are associated with various land cover classes. Each class is associated with a surface roughness length and displacement height.

Since the raster covers the extent of South Africa, it needs to be processed in Geographic Information System (GIS) software first before use in Continuum. A key (in .csv format) is required for successful interpretation of the land cover in Continuum. This maps the land cover class type to the associated numerical values in the raster.

WAsP does not require the same land cover input data process. Instead, it has built-in access to Global Wind Atlas (GWA) surface roughness data sets.

Elevation data is extremely important as it can significantly impact the wind resources in an area since it directly affects the flow of the wind. Exposure to cliff and ridge lines usually indicates a more turbulent wind, while the presence of mountains may funnel wind at high speeds. Through satellite imagery, high-resolution terrain data has been acquired. The Wind Atlas for South Africa (WASA) elevation map is used as the elevation input for Continuum. This is freely available. Once again, pre-processing in GIS software is a requirement to extract site-specific elevation data. Similar to the surface roughness data, WAsP sources elevation data from the GWA.

Wind climates form the last of the required inputs. Generalised Wind Climates (GWC) are freely available through the WASA project. GWCs come in the form of five different heights, with five different roughness classes, with wind speeds at all of these heights and classes. They are available on a 3.3 km spatial resolution across South Africa, allowing GWCs to be found close to a site of interest. WAsP accepts these files, however, Continuum requires an Observed Wind Climate (OWC). For example, an OWC can be created in Python for a set height and roughness class. To compensate, multiple OWCs are extracted from a single GWC and used in the Continuum model.

It is important to note that the inputs used represent a typical use case in each software package. This provides a realistic analysis and comparison. In an ideal case, a resource assessment would include wind mast observation data (as opposed to modelled data from WASA, for example). However, this is an expensive process. A desktop wind resource assessment is a much more cost-effective process to gain an initial understanding of the site of interest.

4 Methodology

A suitable site needs to be chosen to evaluate WAsP and Continuum. The site of interest is in Stellenbosch, South Africa with co-ordinates of 33°50′24.43″S 18°46′37.75″E. Although this is a relatively small site for a wind farm, it will serve the purpose of comparison and has diverse land cover and significant elevation changes within a 12 km radius. This diversity tests how the models in each software package react to a more complex scenario, compared to simple grasslands. The site is shown in Figure 3.

Three turbines are used in the comparison. The turbines were 2.6 MW in size and modelled on the Vestas V100-2.6 MW VCS 50 Hz platform. The UTM coordinates of the turbines are provided in Table 2.

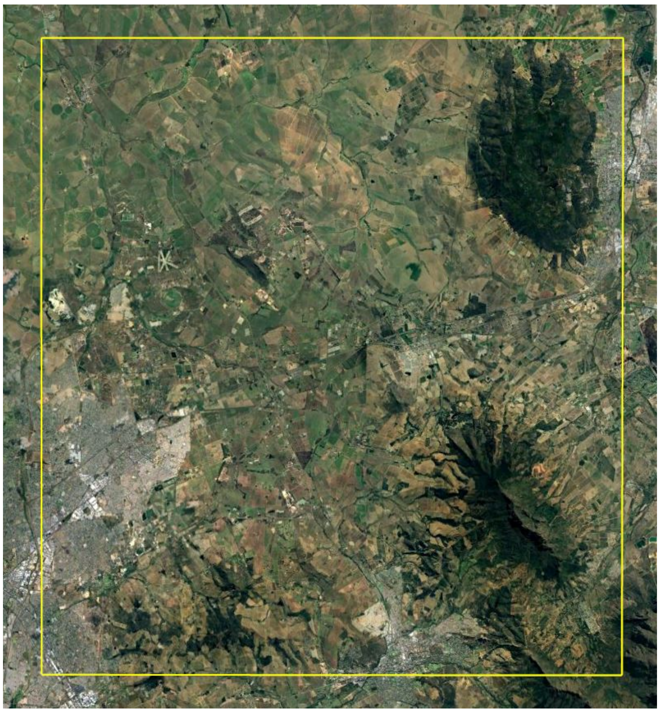

Figure 3 Site for evaluation, in Stellenbosch, South Africa

Table 2 UTM co-ordinates of each turbine

Turbine	UTMx	UTMy
One	294300	6252637
Two	294896	6254031
Three	294076	6253435

One of the major outputs of a resource assessment is an estimation of the AEP. This provides the user with an estimation of how much energy will be produced in a year. Both software packages provide an AEP output value allowing for direct comparison.

Another important metric, provided in both packages, is the capacity factor of a wind turbine. This provides information on how much power a turbine produces in a year as compared to its rated value.

WAsP's graphical user interface (GUI) is displayed in Figure 4. The project hierarchy is shown in the left window, which has to be populated by the user with the essential elements for a successful simulation. These include:

1. A terrain map with orography (contour lines) information.
2. A roughness map with land cover type information.
3. Appropriate wind climate information.
4. A resource grid.
5. Locations of wind turbines.
6. Performance data of the wind turbines to be used.

In Figure 4, the window on the right displays either the simulation results or more information about the individual elements in the hierarchy. Information about individual elements may include a turbine's power curve, a wind rose, etc. In this instance, the AEP is calculated for the resource grid.

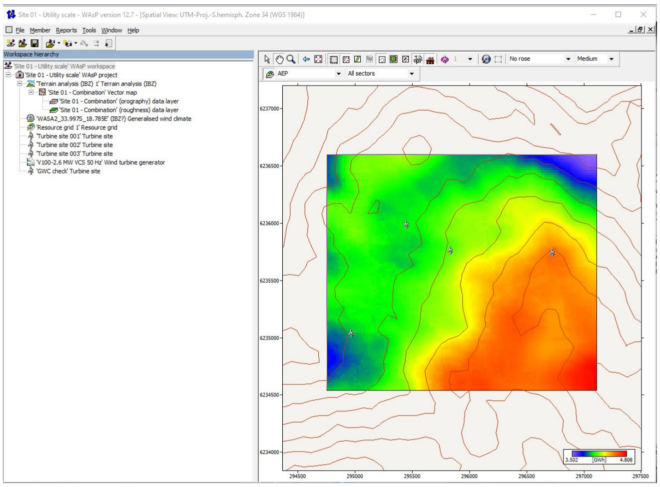

Figure 4 Opening screen for WAsP

WasP assumes that measurements at one location (where the observations are made) can be used for predicting at another location (for example where the turbine is located) provided that the effects of terrain, roughness and obstacles are removed from the data at the first location and then added as they apply to the second location. The removal of these factors from the observed data yields the so-called GWC, as shown in Figure 5.

The user would typically start by specifying the orography of a chosen terrain. A dedicated, separate program called the 'Map Editor' is provided with WAsP for this purpose. It allows the user to import maps, for example from the GWA, which can then be edited if required. The roughness information may be imported in a similar manner and combined with the orography information to provide a single input to WAsP. A background map may also be imported and overlaid to further assist with checking and editing the input file. Figure 6 shows the contour lines overlaid on the background map as obtained from Map Editor. Figure 7 shows the same but for the roughness values.

The user is then required to decide on the extent of a resource map, an area where the solution values are calculated.

The next element required is the GWC. The data for the GWC must be imported from an external source, either as an OWC or as a GWC. The OWC typically consists of measurements from a LiDAR or meteorological mast which records the wind speed and direction for one or more years. In the case of the GWC, the post-processing of the wind data has already been done and is used as is.

One or more turbine sites must be selected to obtain AEP values. Once the sites have been identified, a suitable wind turbine must be selected. This can be done in one of two ways. Firstly, WAsP has a database of wind turbines that the user can choose from. The database fully describes the re-

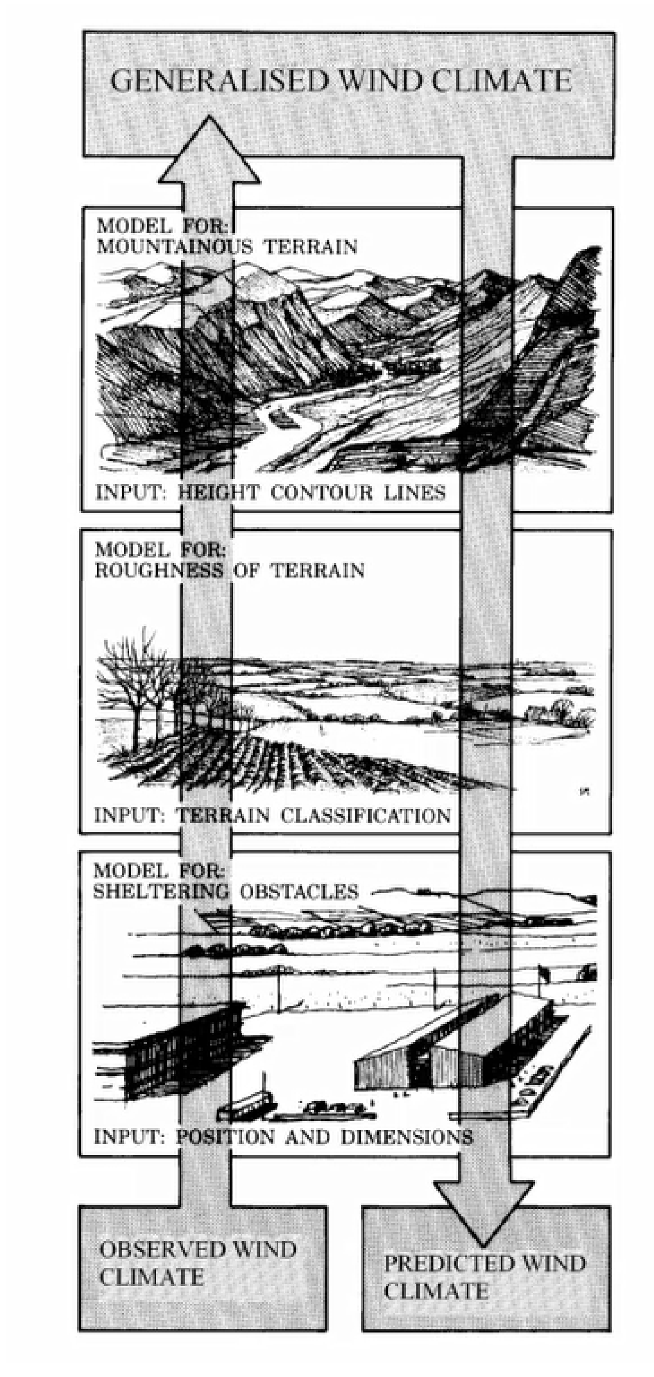

Figure 5 The modelling approach in WAsP [9]

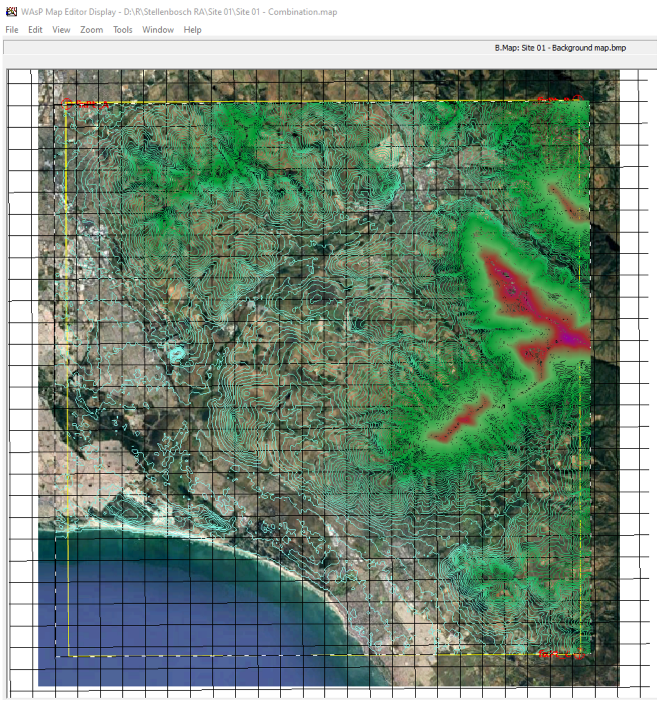

Figure 6 Background map with contours in WAsP

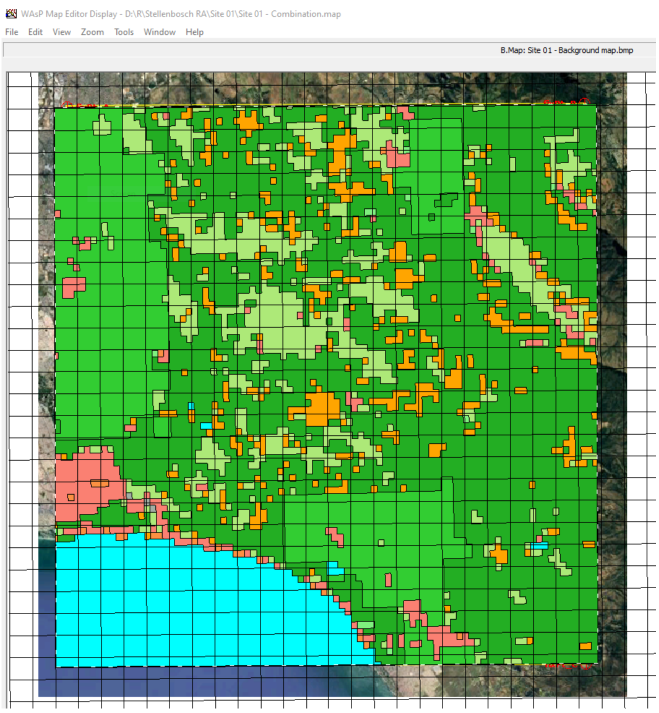

Figure 7 Background map with roughness data in WAsP

spective turbine for simple integration in WAsP. Secondly, the user may import the wind turbine specification data, provided that the input file is formatted correctly. This is useful if a custom turbine or a turbine not on the database is being used.

WAsP can also interact with Google Earth which the user must obtain and install separately. The use of Google Earth in conjunction with WAsP allows the user to produce figures such as the one shown in Figure 8 which adds to the visual quality of the outputs.

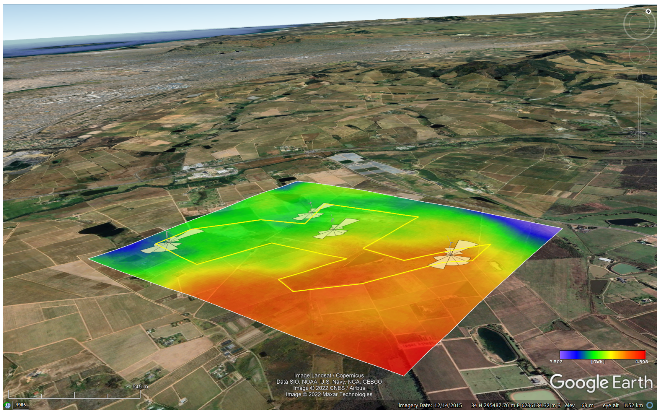

Figure 8 WAsP data overlaid on a Google Earth map

Continuum can be downloaded as a single compiled binary or through source code. A user must prepare topographical and wind speed data outside of the package prior to any analysis. The opening screen allows the user to input the critical data for a resource assessment. The opening screen of Continuum is shown in Figure 9. The red user interface buttons clearly highlight what information is needed before generating outputs.

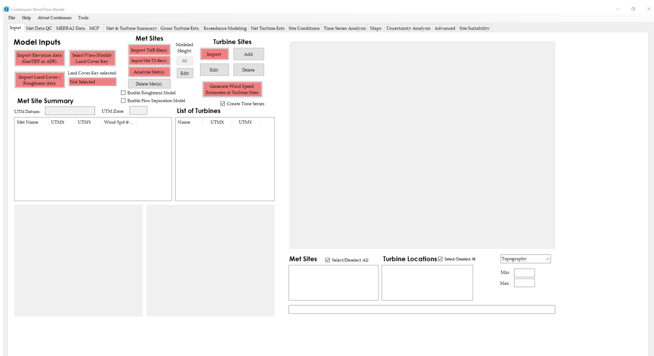

Figure 9 Opening screen for Continuum

Each tab contains a calculation step, encouraging the user to traverse from left to right during the model development. There are 14 tabs in total:

1. **Input**: Importing of basic data (measurements, topography and farm sighting).
2. **Met Data QC**: Analysis of the time series data with filtering and quality control options.
3. **Merra 2 Data**: For downloading long term data sets.
4. **MCP**: Measure correlate and predict time series data with long-term data sets.
5. **Met & Turbine Summary**: Details of locations for met

stations and turbines.

6. **Gross Turbine Estimates**: the capacity factor (CF) and wind speed at selected locations excluding loss factors.
7. **Exceedance Modelling**: Calculation of loss factors to be applied through Monte-Carlo simulations.
8. **Net Turbine Estimates**: Final CF for turbine locations.
9. **Site Conditions**: For extreme weather condition statistics .
10. **Time Series Analysis**: Yearly and monthly summaries.
11. **Maps**: the creation of wind speed maps, AEP maps or wake maps.
12. **Uncertainty**: Round Robin analysis for turbine wind speed and gross energy uncertainties.
13. **Advanced**: Continuum advanced analysis
14. **Site Suitability**: Shadow flicker, ice hits and sound levels determine the site's suitability.

Starting at the input tab, the raster files for the land cover and elevation of the area are imported. Pre-processing of these rasters is done in QGIS (Quantum Geographic Information System), a free, open-source GIS processing tool. The pre-processing is simply obtaining the land cover and elevation (discussed in Section III) for a (minimum of a) 12 km radius from all turbines and met sites. On the same tab, the OWC is also imported. Finally, the proposed turbine locations are imported using UTM co-ordinates manually or through a .csv file. Figure 10 indicates the locations of the four GWC files used and the turbine locations in the Continuum software.

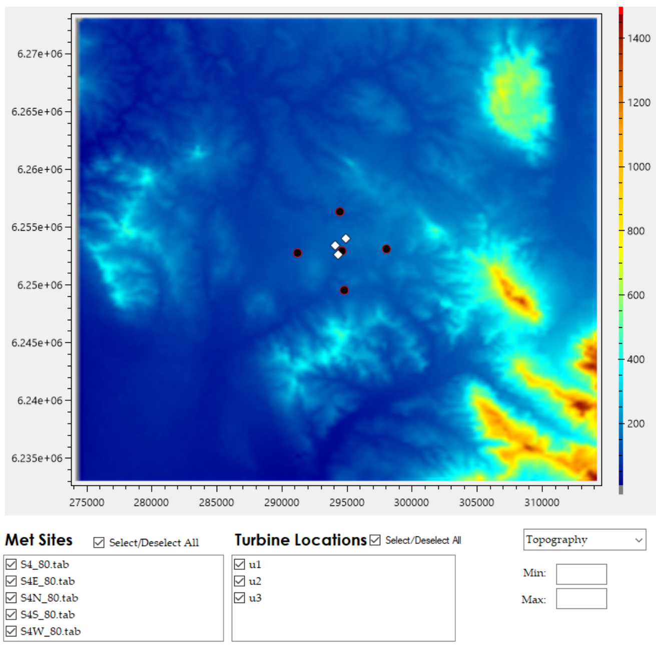

Figure 10 Turbine and GWC locations in Continuum. Their locations are clearly marked, relative to the topography which is also shown.

Continuum's Met & Turbine Summary tab shows information on the topographic influences on the farm. Information is given for a set radius around points of interest. A user can then compare the hub height wind speed to the upwind and downwind exposure, roughness, and elevation and displacement heights.

The Gross Turbine Estimates tab shows the estimated AEP and capacity factors for all turbine locations in the model. These values do not include any de-rating due to losses or wake effects. The information can be exported as a .csv file to use in a report. The user must import a turbine model that has thrust and power values over the machine's operating range. As shown in Figure 11, the user must also supply the turbine's operational height and revolutions per minute (rpm).

Figure 11 Gross Turbine Estimates tab in Continuum. The wind speed distribution is shown above the power and thrust curve plot in the top right.

Losses are applied to the model in a probabilistic manner. This includes typically applied losses such as availability, electrical, balance of plant, power curve degradation, extreme wind, etc. Continuum provides a summary of these losses in its Exceedance Modelling tab. After the Monte Carlo analysis is performed, multiple P (probability values, eg. P90) are presented. These values are commonly used when seeking financing from banks.

With losses incorporated into the model, a user can now determine the farm's net AEP and CF values.
To get this, a user must select an appropriate wake model and set custom conditions for the calculation. This includes choosing a wake loss model, which has been chosen as the Eddy Viscosity Wake Model in this case. The net AEP and CF are presented in the Turbine Estimates Tab, which also includes information on the waked wind speed distribution and wake losses.

Continuum has options for creating a wake, AEP and exposure maps. These can then be exported as resource grids or .csv files. A user can generate these maps per sector or by taking the combined result. Markers on the map can be activated or deactivated for both turbines and met mast locations. Furthermore, the map resolution can be customised to optimise accuracy and computational cost. A wake loss map is shown in Figure 12.

5 Results and Discussion

The gross AEP at each turbine site is calculated in WAsP and Continuum. Gross AEP is the theoretical energy output, before considering any losses. The results are shown in Table 3.

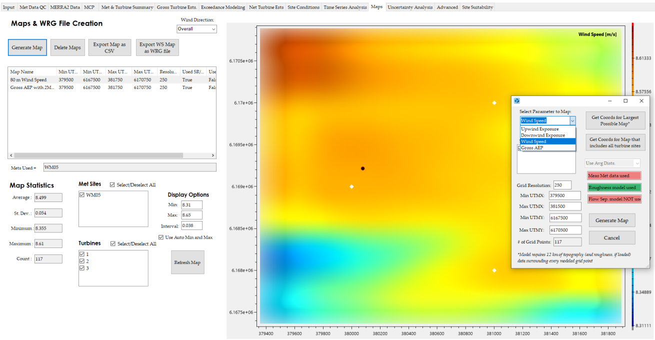

Figure 12 Maps tab in Continuum. This is an important feature that assists in optimising wind farm design. Exposure and AEP maps can also be generated.

WAsP is the baseline reading since it is the current industry standard. The gross AEP error ranges from 12.24 % to 18.24 %. This is quite a large error, especially if the wind resource assessment is to be done in a marginal business case scenario. Continuum appears optimistic with energy production, reporting higher values than WAsP.

Table 3 Gross AEP of each turbine in MW h

Turbine	WASP	Continuum	Difference	% diff.
One	4338	4869	531	12.24
Two	4620	5392	772	16.71
Three	4474	5290	816	18.24

However, net AEP is more commonly looked at when trying to estimate what the wind farm will realisitcally produce. The net AEP is the gross AEP after losses have been applied. The net AEP for each turbine is shown in Table 4. It is visible that the error has decreased significantly, ranging from 1.38% to 6.98%. This proves that Continuum's exceedance modelling creates a much more realistic picture.

Table 4 Net AEP of each turbine in MW h

Turbine	WASP	Continuum	Difference	% diff.
One	4288	4347	59	1.38
Two	4543	4860	317	6.98
Three	4413	4697	284	6.44

Similarly to the net AEP result, the capacity factor comparison also shows promise. The turbines' capacity factors are shown in Table 5. The error ranges from 1.54% to 7.24%. Once again, this is a much-reduced error compared to the gross estimates.

These are excellent results for Continuum. Achieving outputs within 10 % of WAsP is an amazing result for this software package. It must also be noted that WAsP is clearly used as a baseline in this instance. WAsP is not perfect and also introduces its own errors due to modelling and input data. This means that the true wind resource may be closer to what WAsP has estimated, or closer to what Continuum has estimated, or somewhere in between, or, albeit unlikely, not

Table 5 Capacity factor for each turbine

Turbine	WASP	Continuum	Difference	% diff
One	18.8	19.09	0.29	1.54
Two	19.9	21.34	1.44	7.24
Three	19.4	20.6	1.2	6.19

close to any of the estimations.

Continuum is most certainly within the realm of pre-feasibility desktop studies used in the preliminary wind farm development process. Wind resource assessment is not just about results but also about ease of use and output presentation since the software is used as a business case tool.

WAsP provides a detailed wind farm report with a neat presentation and all necessary output information. WAsP's notable output maps include wind maps, wind resource grids, wind roses and wake maps. Continuum does not provide such a report. Instead, outputs must be exported in a .csv format and post-processed in another software tool, such as Python. Alternatively, the user can screenshot the output maps. Albeit more tedious in Continuum, this can be seen as both an advantage and disadvantage. The process of acquiring ready output information is slower, but if the process can be automated, using Python code, for example, it can offer more control.

In terms of computational cost, WAsP is significantly more efficient than Continuum. Considering that most wind farms have tens of turbines, this research presented a smaller-scale simulation by comparison. Despite this smaller scale, Continuum still took over eight hours to complete. WAsP completed the simulation in under ten minutes.

A major advantage of Continuum is that it is open-source. In addition to meaning that it is free and publicly available, it lends itself to complete the open source up- and downstream processes involved in wind resource assessments. Anybody can access free land cover, elevation and wind speed data online. This data can be processed for free using the open-source QGIS. Simulations, analyses and optimisations can then be done in Continuum, completing the open-source chain. This presents a strong argument for Continuum in lowering the barrier to entry for wind farm development.

Continuum can also be customised by editing the source code. This gives it the advantage of streamlined or custom processes as a result of end-user development.

Although Continuum is free, the €1990 cost of WAsP may be justified in large, commercial projects. A commercial wind farm project typically has a large budget. The cost of WAsP may be insignificant to the overall budget, especially if the project requires the most accurate energy modelling for their financial outputs. With this reasoning, Continuum is useful in smaller projects, or in projects where a preliminary desktop study can be done, not requiring high accuracy for initial results. For example, Continuum may be useful to crop farmers interested in increasing their wind energy capacity, or for rural areas that may need renewable energy to power their infrastructure.

Although both software packages can have a steep learning curve, WAsP supports an easier workflow once competent with the software. No external software is needed. With Continuum, QGIS is required to manipulate land cover, whereas the GWA can be easily accessed within WAsP. Furthermore, some countries may not have an accessible land cover raster like the one supplied by DFFE in South Africa. This gives WAsP an advantage in scenarios where land cover may be difficult to obtain or if the user prefers a simplified workflow.

In this research, the usage of WAsP was found to be more stable compared to Continuum. This makes sense, as WAsP has a large team and financial support from DTU. There are more constant updates to WAsP, giving it the advantage of incrementally improved capabilities over time with ongoing development.

A summary of the pros and cons of each software package is described in Table 6 and 7 respectively.

Table 6 Summary of the pros and cons of WAsP

Pros	Cons
More accurate energy modelling results	Has a cost of €1990
Seen as industry standard with proven track record	Closed-source
Integration with data inputs such as the GWA	Difficult to customise to specific applications
Analysis workflow is comprised within one software package	Can have a steep learning curve if never used before
Large user base with ongoing development and support	
Able to generate high quality reports	
Low relative computational cost	
Stable	

6 Conclusion

Wind resource assessments form the foundation of any wind farm development. The industry standard software for completing this task, WAsP, is compared to its open-source counterpart, Continuum. A site in Stellenbosch, South Africa, is used with three Vestas 2.6 MW turbines for evaluation. Although a small area is chosen, it has diverse land cover and elevation, making it a good fit for the comparison.

It was found that Continuum provides results that are close to WAsP's, with net AEP and capacity factor error within 8%. These close results show the value of the Continuum software package since it creates a viable open-source wind resource assessment workflow, from input data to results.

WAsP was found to have better ease of use since it offers an output report, databases for input data (mitigating additional pre-processing) and a significantly more efficient model with low computational cost.

Table 7 Summary of the pros and cons of Continuum

Pros	Cons
Freely available	Higher relative computational cost
Open-source	Not as accurate as WAsP
Ability to customise to specific applications, eg. automation	Have to manipulate input files in external software
Tab-based interface makes it easy for beginners to understand where to find things	Can have a steep learning curve to generate outputs and ensure input compatibility if never used before
Able to generate high quality graphs	Less stable (more bugs)
Reasonable accuracy	Lower industry penetration
Useful in preliminary desktop or academic studies	Smaller development team and funding
	No automated output report
	More computationally expensive

Evidently, the industry standard, WAsP, justifies its price for wind farm developers. Wind farm developers have to carefully adjust their financial models to ensure competitiveness when bidding and developing. The cost of WAsP is an insignificant amount of the total project cost while offering peace of mind and improved model accuracy to the developer.

Continuum's error presents an interesting use case where it is not yet useful for wind farm development, but most certainly has its place in desktop studies, preliminary feasibility studies and academic research. The open-source nature of Continuum allows it to be used in customised studies and applications. It is also useful in smaller-scale projects, where the cost of WAsP cannot be justified.

Future work should investigate comparing the results from WAsP and Continuum to recorded, observed wind farm power generation and wind speed data that can be trusted to be true. This will assist in determining which software's result is closer to reality instead of being closer to WAsP's industry-standard baseline. Furthermore, scaling the analysed wind farm up will present results that more clearly define accuracy differences.

References

[1] Enerdata. Total energy consumption, 2023. URL `https://yearbook.enerdata.net/total-energy/world-consumption-statistics.html`.

[2] Y. Matsuo, A. Yanagisawa, and Y. Yamashita. A global energy outlook to 2035 with strategic considerations for asia and middle east energy supply and demand interdependencies. *Energy Strategy Reviews*, 2:79–91, 06 2013. doi: 10.1016/j.esr.2013.04.002.

[3] IRENA. Future of wind, 2019. URL `https:`

//www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Oct/IRENA_Future_of_wind_2019.pdf.

[4] S.K. Sveinbjornsson. *Analysis of WAsP (Wind Atlas Analysis and Application Program) in complex topographical conditions using measured production from a large scale wind farm.* PhD thesis, 2013.

[5] WAsP. New software prices, 2023-03-23. URL https://www.wasp.dk/news/2023/03/software-prices-as-of-july-1st-2023.

[6] Continuum Wind. Continuum wind energy software. URL https://www.continuumwind.com/.

[7] E. Walls. Results of a wind flow modeling side-by-side comparison: Wasp, openwind and continuum, 2015-08-30. URL https://www.continuumwind.com/_files/ugd/b20a30_46a2350fdeb64cb396331cdc0562508f.pdf.

[8] E. Walls. Continuum wind flow model: Introduction to model theory and case study review. *Wind Engineering*, 39(3):271–298, 2015. doi: 10.1260/0309-524X.39.3.271. URL https://doi.org/10.1260/0309-524X.39.3.271.

[9] U. Yılmaz, F. Balo, and S. Sua. Simulation framework for wind energy attributes with wasp. *Procedia Computer Science*, 158:458–465, 01 2019. doi: 10.1016/j.procs.2019.09.076.