SHITTU, Q. and EZENKWU, C.P. 2024. Cost optimisation in offshore wind through procurement data analytics. In Arai, K. (eds.) *Intelligent computing: proceedings of the 12th Computing conference 2024 (Computing 2024)*, 11-12 July 2024, London, UK. Lecture notes in networks and systems, 1019. Cham: Springer [online], volume 4, pages 80-98. Available from: https://doi.org/10.1007/978-3-031-62273-1_6

Cost optimisation in offshore wind through procurement data analytics.

SHITTU, Q. and EZENKWU, C.P.

2024

Cost Optimisation in Offshore Wind through Procurement Data Analytics

Quadri Shittu[1] and Chinedu Pascal Ezenkwu[2]

[1, 2] Robert Gordon University, Aberdeen AB10 7AQ, UK
[1] q.shittu@rgu.ac.uk, shittuqa@gmail.com
[2] p.ezenkwu@rgu.ac.uk

Abstract. Governments have implemented a variety of national and international efforts to reduce carbon emissions to prevent the damaging effects of climate change on the environment and the global economy through the execution of several policies, including the Paris Agreement. Achieving the objectives of the Paris Agreement, which seeks to keep the increase in average global temperature to well below 2 degrees Celsius and, preferably, below 1.5 degrees Celsius above pre-industrial levels, will need a shift towards renewable energy sources like solar and wind power. As a result of these efforts, renewable energy sources' capacity is projected to expand in the upcoming years. Offshore wind is the UK's leading renewable energy source for power generation. Recently, cost optimisation efforts in the offshore wind industry have been through engineering design, especially with increasing turbine capacities. This research demonstrates how data analytics can achieve cost optimisation in procurement activities of offshore wind projects, which presents opportunities to reduce the Levelized Cost of Energy (LCOE). Ten (10) offshore wind projects have been selected in the UK offshore wind industry by building a workflow and designing an analytic app using Alteryx Designer. The workflow is built on procurement quotations of wind turbines, marine vessels, and export cables to optimise procurement costs and delivery timelines while fulfilling the established constraints for the respective projects. The optimisation results identified three areas of cost-optimisation opportunities: Contracting, Collaboration, and Reusing Components.

Keywords: Data Analytics, Offshore Wind, Cost Optimisation, Climate Change, Renewable Energy

1 Introduction

1.1 Overview

Governments have put in place national and international efforts to reduce carbon emissions to combat the negative impacts of climate change on the environment and the world economy. These commitments of different governments have resulted in several policies, including the COP21 Paris Agreement 2015, aimed at achieving net-zero by 2050. The Paris Agreement, which aims to keep the global average temperature increase below 2 degrees Celsius and below 1.5 degrees Celsius over pre-industrial levels, largely depends on the transition to renewable energy sources like solar and wind. International Renewable Energy Agency (IRENA) reported that global renewable energy generation capacity increased by over 40% between 2000 and 2021, from 754 GW to 3,064 GW [13]. The report also demonstrates that renewable energy sources are rapidly used as the standard for new, least expensive power generation [13].

With a focus on UK energy transition efforts, offshore wind has led to overall power generation from renewable sources [5]. As reported by the department, offshore wind equally takes the lead in terms of overall capacity from renewable means. Based on a study by the Department for Business, Energy & Industrial Strategy (BEIS) in the UK, offshore wind has been projected to experience cost reductions over time due to technological advancements [2]. This indicates strict competition in the developers' administrative prices of energy generation. While there are constant supply chain challenges, the developers must be strategic to reduce costs and enhance profits.

Various efforts have been made to achieve cost optimisation in offshore wind projects, one of which, and the most prominent, is an increase in turbine capacities. Organisations have invested in advanced technologies to reduce major construction, operations and maintenance costs. These cost optimisation efforts are driven by engineering design. Although digitalisation and the use of engineering software in design simulations have provided these organisations with voluminous, quality, and insightful data, the current practice in this field is yet to exploit the application of data analytics in achieving cost optimisation in offshore wind projects. The preceding thesis forms the motivation for this research. This research focuses on how data analytics can optimise cost using procurement data. Since the offshore wind supply chain is highly competitive due to fewer suppliers based on offshore expertise, companies must utilise available data from the procurement processes to reduce costs through analytics. This research will demonstrate how various procurement factors can be used analytically in choosing vendors with the best prices and delivery timelines. This approach demonstrates how developers can benefit economically with reduced procurement costs and possible means to cut down on environmental waste by recognising the areas of cost-saving opportunities identified in this research.

This study highlights the potential benefits of utilising data analytics to optimise procurement costs in UK offshore wind projects. The research leverages a procurement data model focusing on wind turbine components, marine vessels, and export cables by analysing ten projects. These projects were selected based on successive years of project commissioning and the increasing wind turbine capacities from one project to another. A cost optimisation workflow is created using Alteryx Designer, a data analytics software, to determine the best vendor options based on procurement cost models. Despite existing efforts in engineering design-driven cost reduction, this research sheds light on the untapped potential of data analytics in reducing procurement costs. It emphasises the importance of timely and strategic procurement for various project components, providing a solution for achieving cost optimisation in the offshore wind industry through data analytics.

1.2 Background Information

Renewable Energy. Renewable energy sources in no order include – wind power, hydropower, solar, biomass, nuclear energy, tidal energy, and geothermal energy. Piotr [16] reported that renewable electricity needs to grow more quickly to meet the targets of net-zero emissions by 2050, where the renewable portion of generation will climb from about 29% in 2021 to more than 60% by 2030. Piotr also noted that wind and solar PV (Photovoltaic) technologies together accounted for about 90% of the increase in renewable electricity output in 2021, a record 522 TWh increase globally. After only a 0.4 percentage point growth in 2021, the proportion of renewable energy in the world's electricity generation increased to 28.7% [16]. With the focus on achieving net-zero within the next three decades, one can imagine how much effort will be made to fully transition into renewable energy sources. These efforts towards green energy involve major investments in projects associated with various financial risks.

In the UK, the Department for Energy Security & Net Zero has released the energy trends report between October 2022 and March 2023 [5]. According to the report, production from renewable energies roughly matched the previous record high of 2020, and the share of renewable energy in power generation rose to 41.4% from 39.6% last year (2022), partly because of record-breaking wind and solar generation. A record-high 24.6% of all electricity was generated by wind [5]. Figure 1 demonstrates the total change throughout this period as well as the generation changes year-over-year since the previous record year, 2020 (i.e., change from 2020 to 2021 and 2021 to 2022). The department also reported that the generation decreased by 9.3% in 2021 but grew by 10% in 2022, with minimal growth for the entire period (0.1%). The decline in 2021 was brought on by much lower wind and rainfall totals (2020 had been extremely beneficial for both) and low levels of new capacity [5]. It can be noted that Offshore Wind has taken the lead in renewable energy generation in the UK from 2020 to date.

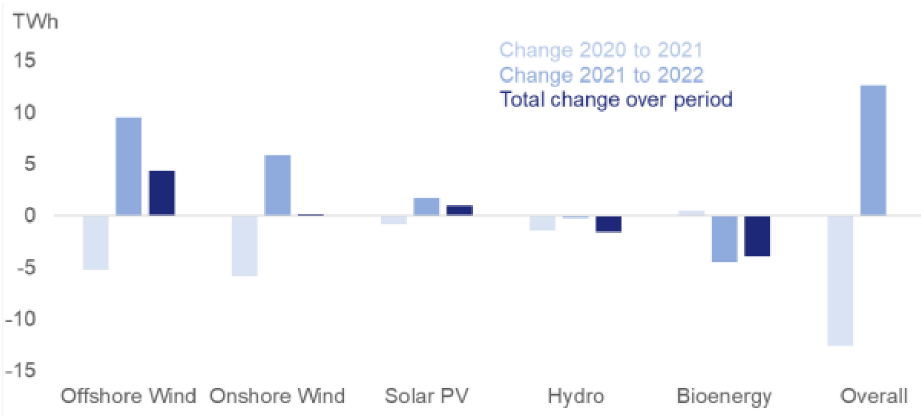


***Figure 1**: Renewable Energy Generation ([5], p.16)*

Figure 1 shows the renewable energy generation, while Figure 2 shows the renewable energy generation as compared to capacity between 2020 and 2022. Offshore Wind is greater in proportion when compared to Onshore Wind due to increased capacity at offshore locations.

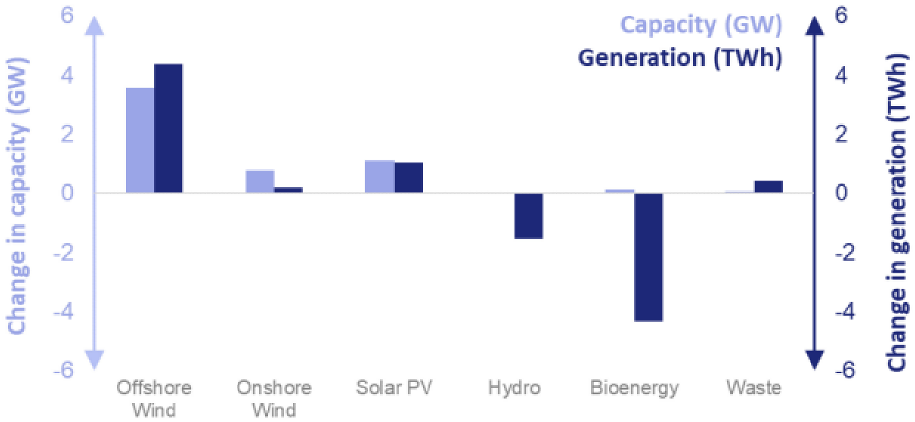


***Figure 2**: Renewable Energy Generation vs. Capacity ([5], p.17)*

Offshore Wind Cost. According to a report published in 2020 by the Department for Business, Energy & Industrial Strategy (BEIS) in the UK, it was projected that the offshore wind would experience considerable cost reductions in capital and operating costs over time with turbine size due to the rapid pace of technological developments and economies of scale [2]. Table 1 shows projections for cost reductions for offshore wind projects to be commissioned in 2025 up to 2040.

Table 1*: Offshore Wind Cost Projection. ([2], p.13)*

	2025	**2030**	**2035**	**2040**
Pre-development (£/kW)	130	130	130	130
Construction (£/kW)	1,500	1,300	1,100	1,100
Fixed O & M (£/MW/year)	36,300	28,000	24,500	22,500
Variable O & M (£/MWh)	4	4	4	4
Load factor (net of availability)	51%	57%	60%	63%
Operating period	30 years			

In another report published by IRENA [13], it was noted that cost-saving initiatives like the standardisation of turbine and foundation designs, the industrialisation of offshore wind component manufacturing in regional hubs, and the advancement of installation techniques' sophistication and speed reflect on the industry's growing maturity [13]. The report also states that with developer expertise, the use of specialised ships made for offshore wind operations, and advances in turbine size that amortise installation efforts for one turbine over ever-larger capacities, installation times and costs per capacity unit have been declining. The introduction of dedicated ships for maintenance and the size and efficiency advantages of servicing offshore wind farm zones rather than individual wind farms have all contributed to lower operations and maintenance (O&M) costs. Because manufacturers are continually gaining knowledge from recent experience and putting improvements into future products, there is now a greater availability of wind turbines [13].

Costs rise when installing and running wind turbines in the challenging marine environment offshore. Because of this, planning and project development expenses are higher and lead times are longer [13]. The properties of the seabed and the locations of the offshore wind resource sites must be documented, and acquiring permits and environmental approvals is frequently more difficult and time-consuming. The farther the project is from a suitable port, the more expensive the logistics are, and the more expensive the foundations are in deeper water. International Energy Agency (IEA) [12] reported that in 2018, a 1 GW offshore wind project typically costs over $4 billion to build, including transmission, but over the next ten years, costs are predicted to drop by more than 40%. The report also states that a 60% decrease in the price of turbines, foundations, and their installation is responsible for the overall decline. Currently, transmission costs make up approximately a quarter of all offshore wind expenses, but as new projects are built farther inland, this percentage is expected to rise to roughly one-half [12]. It will be necessary to innovate in transmission, for instance, by working to push the boundaries of direct current technology to support new projects without increasing their overall costs [12].

1.3 Cost Optimisation in Offshore Wind

It can be noted that offshore wind is making significant progress in accelerating the achievement of net-zero. It is, however, important to note that projected cost reductions in the total cost of offshore wind projects will consequently impose some financial constraints on developers. This is because developers will keep competing to win auctions at the best strike prices, they will be forced to optimise costs by whatever means possible to make profits. Technological advancement has been reported severally as a major way of reducing costs. A notable achievement in cost reduction is the use of high-voltage direct-current (HVDC) transmission technology in place of high-voltage alternating-current (HVAC) because of generation efficiency over long distances. This technology has been demonstrated by Siemens Energy with the use of gas-insulated switchgear (GIS), as opposed to air-insulated switchgear (AIS), for DC-operated offshore platforms [8]. Comparable AIS needs up to 95% more space than GIS [8].

Cost Optimisation Strategies. Gazelle Wind Power Ltd (Gazelle) recently unveiled its unique platform design with significant weight reduction, 75% less mooring length, and 50% reduction in mooring loads due to pitch reduction [10]. The Gazelle platform's modular and expandable component design makes manufacturing and assembly quick and easy. Because components are more compact and lightweight, less room is needed in shipyards and harbours, which reduces the demand for cranes. The Gazelle platform is a floating platform that can be transported to a location more easily and affordably.

Various studies have been carried out to demonstrate cost optimisation efforts through engineering and procurement activities in projects. Some of these efforts are still applicable to offshore wind projects. Applied knowledge from oil and gas projects is used in offshore wind projects. Because the offshore wind industry is still growing, and the activities are operated on a project-by-project basis, there is not much literature on cost optimisation strategies in the industry. However, a study by the Crown Estate [4] explains the cost reduction pathway of offshore wind projects. The study reveals that cost reduction can be achieved through technology and supply chain. The main areas of cost reduction include introducing wind turbines with increased capacities, increased rotor sizes, improved blade design and manufacturing, and improved drive train design. According to the study’s report, adopting new-generation turbines will generally cut LCOE by roughly 17% [4]. LCOE is the amount of revenue (from whatever source) needed to generate a rate of return on investment throughout the life of the wind farm that is equal to the discount rate [3].

Before the Crown Estate [4] study, some other studies had been carried out. Fuglsang and Thomsen [9] investigated a large offshore wind farm project in Denmark by carrying out numerical optimisation towards obtaining an optimum wind turbine design. The work aimed to reduce manufacturing and installation costs to make offshore wind farms more competitive compared to onshore wind farms. The study concluded that an 11% cost reduction was achieved from optimising offshore wind turbine design as against a 3% cost reduction from onshore wind optimisation [9]. In 2008, Elkinton, Manwell, and McGowan published a study on the use of optimisation algorithms for offshore wind farm micrositing to achieve a reduction in the cost of energy. Five optimisation algorithms were used to optimise offshore wind farm layouts to minimise the cost of energy. It was concluded that optimising offshore wind farm layouts to reduce energy costs requires applying an optimisation algorithm to an objective or cost function [6].

Ashuri et al. [1] presented a study on multidisciplinary design optimisation of offshore wind turbines by considering design constraints including stresses, deflections, modal frequencies, and fatigue limits along different points on the blade and tower while minimising LCOE as the objective function. The study concluded that when compared to the baseline National Renewable Energy Laboratory (NREL) turbine, the LCOE was reduced by 2.3% due to the application of the integrated technique [1]. Kallehave et al. [14] conducted a study on optimising the design of a monopile structure, as it was considered the most prevalent design of offshore wind. By modelling the soil structure, applying structural damping, carrying out fatigue damage assessments, and addressing shell buckling, it was concluded that a cost savings of 10 – 25% is possible based on the overall reduction of steel tonnage, which is closely related to cost [14].

Another notable study by Röckmann, Lagerveld, and Stavenuiter [17] focused on the collaboration between the offshore wind industry and the offshore aquaculture sector. It was stated that cost reduction in the operations and maintenance (O & M) costs could be achieved if these two sectors worked together. The study concluded that combining offshore wind energy production with offshore aquaculture offers chances for all actors (the government, the wind sector, and the aquaculture sector) to achieve their various goals and that approximately 10% cost reduction in O & M is feasible [17]. Feng and Shen [7] published a study on non-uniform design optimisation of offshore wind farms to reduce LCOE. The study relied on algorithms in optimizing an existing uniform design of an offshore wind farm in Denmark, as the case study. Non-uniform wind farms have multiple types of wind turbines and hub heights. It is possible for wind farm developers and designers to further explore the practical design space for offshore wind farms and achieve even lower LCOE by taking into account non-uniform design choices using various types of wind turbines [7].

As presented in this section, previous studies have effectively utilised engineering and optimisation techniques to reduce the cost of offshore wind energy. However, none of these studies have taken advantage of procurement data analytics, which is the primary focus of this paper. The following section will provide a detailed explanation of the methodology adopted in this paper to address this research gap.

2 Methodology

This research focuses on using generated procurement data of wind turbine components, marine vessels, and export cables to explore the cost optimisation opportunities in offshore wind projects. The procurement data was obtained from primary data sources. Ten (10) offshore wind projects in the UK were selected to show respective cost-saving opportunities from the data analytics workflow created using Alteryx. The Cross Industry Standard Process for Data Mining (CRISP-DM) [14] methodology has been adopted in this research. The CRISP-DM methodology was chosen because it is widely used in the data analytics industry to simplify data mining and related projects. The methodology involves six (6) sequential phases: business understanding, data understanding, data preparation, modelling, evaluation, and deployment. These phases answer the questions around what a business needs, what type of data is needed to achieve the business needs, how the data is organised for modelling, what modelling technique should be adopted, how the model's performance is evaluated, and how the business accesses the results. The CRISP-DM workflow is presented in Figure 3.

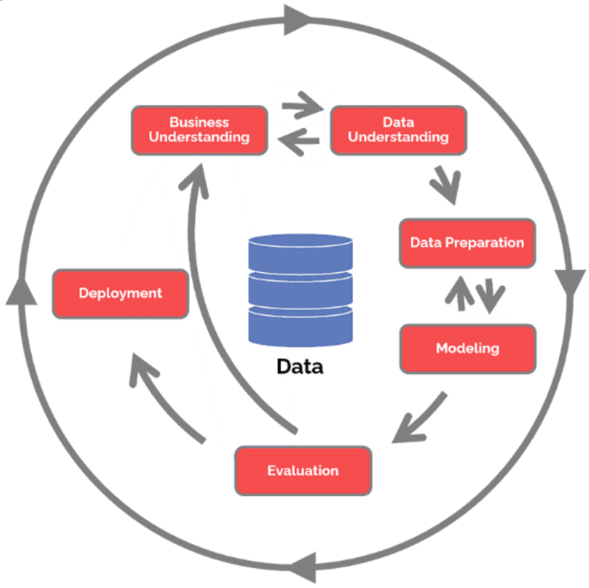


***Figure 3**: CRISP-DM Workflow [15]*

2.1 Data Understanding

It is understood that prices of items are usually found on quotations during procurement processes. Due to this fact, assumptions were made about the prices of items and the delivery timelines. It was assumed that all other project management scopes, including engineering, had been addressed, as the emphasis was only on procurement processes. This research has captured distinctive features of ten (10) offshore wind projects in the

UK, including the developer's name, year of operations commencement, capacity, water depth, number of turbines, turbine capacity, overall cable length, and distance from shore. A vendor database was created that showcases the features of 20 vendors. The features captured include vendor database code, expertise rating in offshore wind projects, expertise rating in oil and gas projects, location of the vendor, and the number of years of business relationship.

Table 2, Table 3, and Table 4 describe the features of the wind turbine quotations, marine vessel quotations, and export cable quotations respectively.

***Table 2**: Wind Turbine Procurement Data Features*

S/N	Feature	Description
1	Vendor Code	Unique code assigned to each vendor on the database
2	Quotation Code	With the understanding that a vendor can quote for more than one item, this is the unique code assigned to each quotation submitted
3	Turbine Name	Name of the wind turbine quoted for
4	Rated Power	Rated capacity of the wind turbine in MW
5	Rotor Diameter	Diameter of the wind turbine rotor in metres
6	Swept Area	The area being swept under the wind turbine blade in square meters
7	Price	The quoted price of supplying the wind turbine, in GBP
8	Delivery Timeline	How long it would take to deliver the wind turbine upon contract agreement, in days
9	Incoterm Code	Applicable procurement responsibility sharing code
10	Location of Item	Location of the wind turbine, which is either outside or within the UK.

***Table 3**: Marine Vessel Procurement Data Features*

S/N	Feature	Description
1	Vendor Code	Unique code assigned to each vendor on the database
2	Quotation Code	With the understanding that a vendor can quote for more than one item, this is the unique code assigned to each quotation submitted
3	Crane Capacity	Lifting capacity of the vessel's main crane, in tons
4	Boom Radius	The maximum reach of the vessel crane when boomed up, in meters

5	Deck Size	The size of the vessel deck, in square meter
6	Maximum Speed	The maximum speed the vessel can travel, in knots
7	Accommodation Size	The quantity of bed space on the vessel
8	Operational Water Depth	The water depth at which the vessel can operate, in meters
9	Dynamic Positioning	The level of capability of the vessel to maintain its position automatically
10	Propulsion Type	How the vessel propulsion system works
11	Location of Item	Location of the marine vessel, which is either within or outside the UK
12	Day Rate	The daily charter rate of the vessel, in GBP
13	Delivery Timeline	How long it would take to deliver the marine vessel upon contract agreement, in days

Table 4*: Export Cable Procurement Data Features*

S/N	Feature	Description
1	Vendor Code	Unique code assigned to each vendor on the database
2	Quotation Code	With the understanding that a vendor can quote for more than one item, this is the unique code assigned to each quotation submitted
3	Price per km	The price of the export cable per unit km, in GBP
4	Incoterm Code	Applicable procurement responsibility sharing code
5	Location of Item	How long it would take to deliver the export cable upon contract agreement, in days
6	Delivery Timeline	Location of the export cable, which is either within or outside the UK

2.2 Data Preparation

While the registered address of a vendor is important to compliance with the Supply Chain Development Statement (SCDS) submitted by developers to Crown Estate, the location of each item quoted is equally important. SCDS is a document submitted by developers to demonstrate support for a sustainable offshore wind sector by highlighting ambition figures to be spent at each project stage. The document clearly explains the commitment and the ambition figures to be spent within and outside the UK. Compliance with SCDS translates to compliance with the local content requirements of the project. Items to be shipped into the UK will likely require more lead delivery time than items available within the UK. Due to this, the research considered item location as an influencing factor on item cost and delivery schedule. In addition, applying various Incoterm codes was considered another influencing factor to the overall cost and schedule. The Alteryx workflow was built by carrying out feature engineering on the vendor attributes, the location of the items, and the applicable Incoterm codes. Feature engineering transforms raw observations into desired features using statistical or machine-learning methodologies [11].

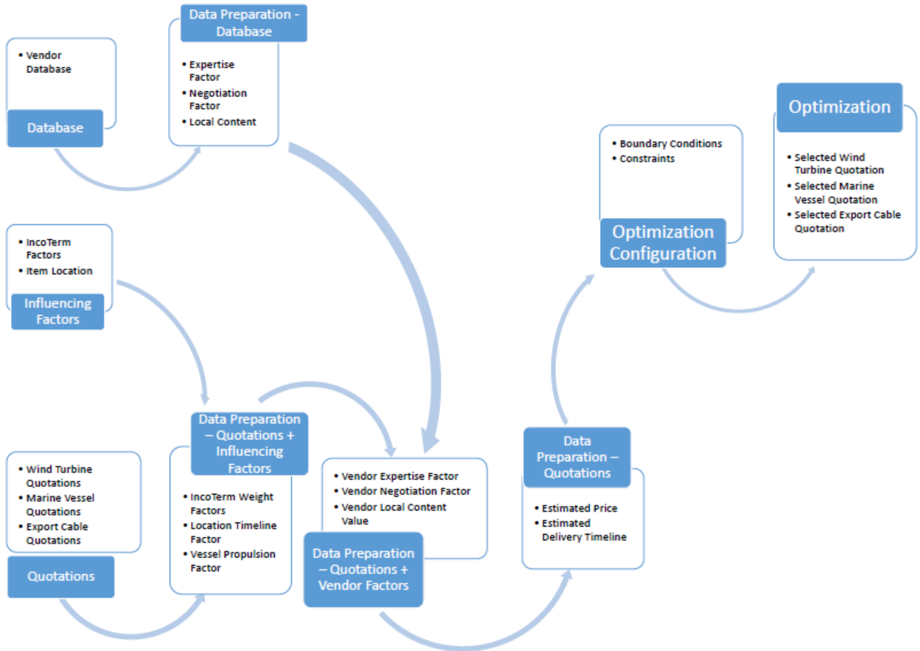


Figure 4: Cost Optimisation Workflow

Figure 4 shows the high-level process flow chart of the cost optimisation workflow. The chart shows that the optimisation process starts with extracting data from the respective wind turbine, marine vessel, and export cable quotations. The data from the quotation streams are prepared by calculating associated Incoterm weight factors, location timeline factors, and vessel propulsion factors, as applicable to each of the quotations based on input from the influencing factors. Further data preparation is done by bringing in the expertise factors, negotiation factors, and local content value from the vendor database. At the end of the data preparation phase, prices and delivery timelines for the respective quotation stream are estimated, which now serve as the inputs for setting the optimisation boundary conditions and selecting the quotation price as the objective function. The project constraints are fed into the workflow to check which quotation from the respective wind turbine, marine vessel, and export cable data streams meets the conditions at the lowest price possible. Finally, the workflow output is the optimised solution with the selection of a quotation for each wind turbine, marine vessel, and export cable quotation.

2.3 Modelling

Upon completing the data preparation of the quotations, the three quotations were configured for the optimisation process. The objective of the workflow is to select respective vendors and quotations meeting the established constraints for each of the ten projects selected while minimising the cost and delivery timeline of the wind turbines, marine vessels, and export cables. The data modelling configuration was done by setting the lower bound of the selection to 0 while the upper bound was set to 1. This type of problem is a binary problem, as either a quotation is selected based on the established constraint conditions or another quotation is selected based on the same conditions. The Alteryx optimisation tool requires an objective function, which in this case, is the cost of the item being minimised. The objective function is named the "coefficient", while the descriptive feature of the chosen quotation is named the "variable". In the case of this research, the quotation code was selected to be variable because of instances whereby a vendor submitted more than one quote for an item.

2.4 Evaluation

Modelling the procurement data by iterating through different scenarios as established by the constraints for each project resulted in the selection of specific quotations submitted by a vendor. The Alteryx workflow checks through the data points of each quotation and identifies the best quotation meeting the constraints and at a minimal cost for each of the wind turbine quotations, marine vessel quotations, and export cable quotations. If no solution is feasible based on the constraints set, the workflow would terminate with an error, otherwise, cost optimisation is achieved by selecting the quotation fulfilling the requirements.

2.5 Deployment

The deployment of the Alteryx workflow provides an interactive interface for achieving cost optimisation in offshore wind projects and viewing the recommended quotation within the Alteryx interface. A report of the solution is generated to demonstrate how the recommended quotation has fulfilled the requirements. In the traditional bid evaluation, quotations are usually put side-by-side for assessment. This research adopted the use of Alteryx to simplify this process and saves much time that would have been spent in traditional evaluation, which is prone to human errors in most cases. An analytic app was developed from the Alteryx workflow, which takes inputs from the user to generate the output reports. The inputs include the vendor database, the procurement quotations for the wind turbine, marine vessel, and export cables, and the established constraints for each project. Figure 5 is the analytic app user interface, while the Appendix presents the complete Alteryx workflow, demonstrating the backend of the app.

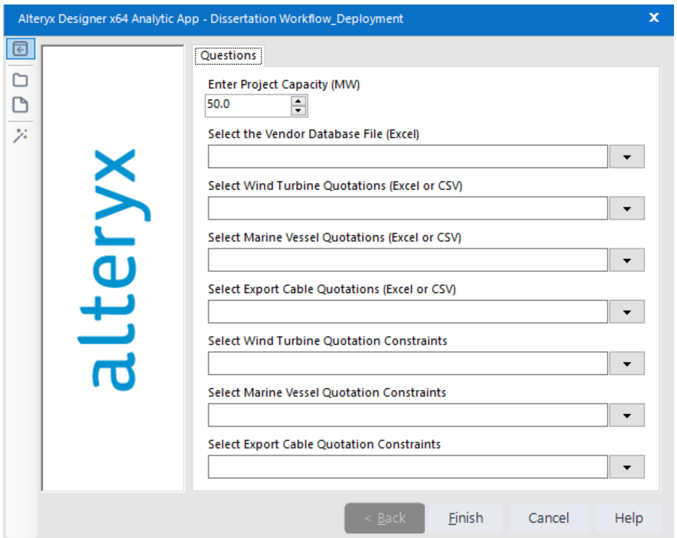


Figure 5*: Analytic App User Interface*

3 Results and Discussions

3.1 Vendor Selection

This subsection presents the outcome of the optimisation procedure, leading to the selection of vendors based on the quotations meeting the constraints of each offshore wind project. The results are presented in the form of tables and the features captured include the project name, project code, developer's name, project's constraints, selected quotation, vendor's name, and the cost of the item. Table 5, Table 6, and Table 7 showcase the selected vendors for each of the ten offshore wind projects, for the supply of wind turbines, marine vessels, and export cables respectively.

Wind Turbine Quotations. As presented in Table 5, the output of the optimisation workflow includes selected quotations that meet the constraints established for each project. These constraints are set to maximise the expertise rating of the vendor, which shows the technical strength of the vendor. Maximising the negotiation factor makes it easier for the developer to negotiate further with the vendor. The local content value shows if the vendor is registered in the UK or not. Each project aims to reduce the quantities of turbines to be installed based on the budgeted amounts and acceptable delivery timelines based on the schedule. In the example demonstrated in this paper, VEN006 is the selected vendor to have met the established constraints for most of the projects based on the quotations submitted to supply wind turbines.

Marine Vessel Quotations. Table 6 shows the selected quotations for the ten offshore wind projects based on the established constraints. The dominant vendors on the list include VEN010, VEN019, and VEN003. Orsted, which owns four of the ten projects, can negotiate better with VEN010 and VEN003 based on the selection.

Export Cable Quotations. Cost optimisation of the export cable quotations produces VEN002 as the vendor selected for most projects based on the constraints. Similar to the wind turbine and marine vessel quotations, it can be noted that the configuration of the constraints determines which quotation is to be selected, regardless of how less expensive or how early the delivery timelines are. Table 7 highlights the selected quotations.

***Table 5**: Selected Wind Turbine Quotations*

COST OPTIMIZATION: WIND TURBINE QUOTATIONS												
S/N	Project Name	Project Code	Developer	Capacity (MW)	Constraints					Selection		
					Expertise Factor	Negotiation Factor	Local Content	Schedule (Days)	Qty of Turbine	Quotation	Wind Turbine Vendor	Value
1	Barrow Offshore Wind Farm	BAROWF	Orsted	90	>= 0.5	>= 0.5	<= 1	<= 900	<= 29	Q2V10	VEN010	£ 33,000.00
2	Robin Rigg Offshore Wind Farm	RRGOWF	RWE	174	>= 0.5	>= 0.5	<= 1	<= 800	<= 50	Q2V10	VEN010	£ 33,000.00
3	Ormonde Offshore Wind Farm	ORMOWF	Vattenfall	150	>= 0.5	>= 0.5	<= 1	<= 950	<= 27	Q3V01	VEN001	£ 42,000.00

4	Greater Gabbard Offshore Wind Farm	GGAOWF	SSE and RWE	504	>= 0.5	>= 0.5	<= 1	<= 1000	<= 110	Q3V01	VEN001	£ 42,000.00
5	Westermost Rough Offshore Wind Farm	WEROWF	Orsted	210	>= 0.5	>= 0.5	<= 1	<= 900	<= 30	Q2V01	VEN001	£ 47,300.00
6	Hywind Offshore Wind Farm	HYWOWF	Equinor	30	>= 0.5	>= 0.2	<= 1	<= 900	<= 4	Q3V06	VEN006	£ 43,000.00
7	Aberdeen Offshore Wind Farm	ABDOWF	Vattenfall	96.8	>= 0.5	>= 0.2	<= 1	<= 900	<= 10	Q2V06	VEN006	£ 60,000.00
8	Hornsea 1 Offshore Wind Farm	HO1OWF	Orsted	1200	>= 0.5	>= 0.2	<= 1	<= 900	<= 150	Q3V06	VEN006	£ 43,000.00
9	Kincardine Offshore Windfarm	KINOWF	KOWL	49.5	>= 0.7	>= 0.2	<= 1	<= 800	<= 5	Q2V06	VEN006	£ 60,000.00
10	Hornsea 2 Offshore Wind Farm	HO2OWF	Orsted	1300	>= 0.4	>= 0.2	<= 1	<= 900	<= 150	Q2V06	VEN006	£ 60,000.00

***Table 6**: Selected Marine Vessel Quotations*

COST OPTIMIZATION: MARINE VESSEL QUOTATIONS														
S/N	Project Name	Project Code	Developer	Constraints							Selection		
				Deck Size (sq.m)	Crane Capacity (Tonnes)	Accommodation Size	Expertise Factor	Negotiation Factor	Local Content	Schedule (Days)	Quotation	Marine Vessel Vendor	Value
1	Barrow Offshore Wind Farm	BAROWF	Orsted	>= 850	>= 750	>= 60	>= 0.5	>= 0.5	<= 1	<= 250	Q1V10	VEN010	£ 50,000.00
2	Robin Rigg Offshore Wind Farm	RRGOWF	RWE	>= 950	>= 800	>= 80	>= 0.5	>= 0.5	<= 1	<= 320	Q1V19	VEN019	£ 85,000.00
3	Ormonde Offshore Wind Farm	ORMOWF	Vattenfall	>= 700	>= 750	>= 65	>= 0.5	>= 0.5	<= 1	<= 300	Q1V19	VEN019	£ 85,000.00
4	Greater Gabbard Offshore Wind Farm	GGAOWF	SSE and RWE	>= 850	>= 800	>= 70	>= 0.5	>= 0.5	<= 1	<= 600	Q1V19	VEN019	£ 85,000.00
5	Westermost Rough Offshore Wind Farm	WEROWF	Orsted	>= 650	>= 750	>= 60	>= 0.5	>= 0.5	<= 1	<= 400	Q1V10	VEN010	£ 50,000.00
6	Hywind Offshore Wind Farm	HYWOWF	Equinor	>= 450	>= 650	>= 50	>= 0.5	>= 0.5	<= 1	<= 300	Q1V10	VEN010	£ 50,000.00
7	Aberdeen Offshore Wind Farm	ABDOWF	Vattenfall	>= 400	>= 650	>= 50	>= 0.5	>= 0.3	<= 1	<= 250	Q1V10	VEN010	£ 50,000.00
8	Hornsea 1 Offshore Wind Farm	HO1OWF	Orsted	>= 500	>= 680	>= 75	>= 0.5	>= 0.3	<= 1	<= 300	Q1V03	VEN003	£ 55,000.00
9	Kincardine Offshore Windfarm	KINOWF	KOWL	>= 500	>= 600	>= 60	>= 0.6	>= 0.3	<= 1	<= 280	Q1V10	VEN010	£ 50,000.00
10	Hornsea 2 Offshore Wind Farm	HO2OWF	Orsted	>= 500	>= 680	>= 80	>= 0.4	>= 0.3	<= 1	<= 300	Q1V03	VEN003	£ 55,000.00

***Table 7**: Selected Export Cable Quotations*

COST OPTIMIZATION: EXPORT CABLE QUOTATIONS										
S/N	Project Name	Project Code	Developer	Constraints				Selection		
				Expertise Factor	Negotiation Factor	Local Content	Schedule (Days)	Quotation	Export Cable Vendor	Value
1	Barrow Offshore Wind Farm	BAROWF	Orsted	>= 0.5	>= 0.5	<= 1	<= 250	Q1V02	VEN002	£ 2,750,000.00
2	Robin Rigg Offshore Wind Farm	RRGOWF	RWE	>= 0.5	>= 0.5	<= 1	<= 350	Q1V02	VEN002	£ 2,750,000.00

3	Ormonde Offshore Wind Farm	ORMOWF	Vattenfall	>= 0.5	>= 0.5	<= 1	<= 180	Q1V07	VEN007	£ 3,240,000.25
4	Greater Gabbard Offshore Wind Farm	GGAOWF	SSE and RWE	>= 0.5	>= 0.5	<= 1	<= 300	Q1V02	VEN002	£ 2,750,000.00
5	Westermost Rough Offshore Wind Farm	WEROWF	Orsted	>= 0.5	>= 0.5	<= 1	<= 250	Q1V02	VEN002	£ 2,750,000.00
6	Hywind Offshore Wind Farm	HYWOWF	Equinor	>= 0.5	>= 0.5	<= 1	<= 200	Q1V12	VEN012	£ 3,000,000.00
7	Aberdeen Offshore Wind Farm	ABDOWF	Vattenfall	>= 0.4	>= 0.5	<= 1	<= 290	Q1V02	VEN002	£ 2,750,000.00
8	Hornsea 1 Offshore Wind Farm	HO1OWF	Orsted	>= 0.4	>= 0.4	<= 1	<= 250	Q1V02	VEN002	£ 2,750,000.00
9	Kincardine Offshore Windfarm	KINOWF	KOWL	>= 0.6	>= 0.3	<= 1	<= 250	Q1V02	VEN002	£ 2,750,000.00
10	Hornsea 2 Offshore Wind Farm	HO2OWF	Orsted	>= 0.4	>= 0.3	<= 1	<= 250	Q1V02	VEN002	£ 2,750,000.00

3.2 Areas of Cost-Saving Opportunities

Looking at the results obtained from the cost optimisation workflow, it is evident that the selection of quotations and vendors is based on the fulfilment of the established project constraints. This subsection identifies areas of cost-saving opportunities in the projects, for the supply of wind turbines, marine vessels, and export cable. The areas are listed below:

- Contracting – This is an area of cost-saving in that each project has specific constraints that are represented with numerical values using inequalities. The quotations submitted by the vendors are checked against the constraints while making reference to the details of each vendor in the vendor database. Key features to help with the selection include the expertise factor, negotiation factor, and the local content factor. Looking closely at the project constraints for each of the ten offshore wind projects in Table 5, Table 6, and Table 7, the negotiation factors are set to be 0.5 and above for most of the projects. The negotiation factor ranges from 0.1 to 1.0, representing 10% and 100% chances of negotiating further with the vendor respectively. 0.5 (50%) indicates that each project wants a vendor with at least a 50% chance of engagement for further negotiations. This shows the likelihood of negotiating further with the selected vendors after the optimisation processes. Similar to the negotiation factors, the expertise factors for most of the projects are set to 0.5 and above. This factor also ranges from 0.1 to 1.0 signifying the technical strength of the vendor. 0.5 value of the expertise factor is a preference for a vendor that is neither a novice nor a high-level expert in the business. The local content factor is a representation of whether the vendor is registered in the UK or not. The value each vendor carries suggests how a developer can structure the contract to be issued and how it has to fulfill the local content requirements. A local content factor value of 1 implies that the vendor is registered in the UK. As presented in Table 5, Table 6, and Table 7, quotations of vendors meeting the constraints of these three features (expertise factor, negotiation factor, and the local content factor) are good for consideration of long-term contracts. By agreeing to long-term contracts with these vendors, the developers can have some prices fixed based on the project commitments. Such vendors can be approached for future supplies at lower rates than what they had quoted at the initial stage before carrying out optimisation.

- Collaboration – This is another area of achieving cost reduction on the projects. Considering that the six distinctive developers of the ten offshore wind projects collaborate, there are possibilities of getting better deals from their respective vendors, who possibly could have an established relationship with other developers based on the agreed prices. Some of the selected quotations and vendors presented in Table 5, Table 6, and Table 7 are repetitive upon meeting the requirements of the established constraints. In Table 5, VEN006 is the most selected vendor with two of its quotations selected for five projects belonging to four distinct developers. If these developers collaborate, VEN006 can reduce its prices for the supply of wind turbines for these five projects. VEN010 is the most selected vendor for the charter of marine vessels, as presented in Table 6. The vendor has one of its quotations selected for five projects belonging to four distinct developers. This also presents an opportunity for the developers to collaborate to reduce costs by engaging this vendor. For the supply of export cables, VEN002 is the vendor selected for eight of the ten projects, as presented in Table 7. These eight projects belong to four distinct developers. The developers can benefit from lower prices as a result of such collaborations should they have similar project requirements e.g., proximity of project sites, similar turbine rating, or similar item specifications. Some developers, who are also big players in the oil and gas industry could use their relationship with other oil and gas operators to benefit from lower prices of vessel hire based on having similar operations within fields of proximity.

- Reusing Components – In a bid to reduce environmental waste and reduce costs, some components can be reused on other projects after completing useful lives on the project of deployment. As VEN006 is the most selected vendor for five projects presented in Table 5 for the supply of wind turbines, components from the five projects can be used interchangeably as long as the item specifications are similar for respective developers. An example of this is reusing some components of wind turbines based on the make and specifications after proper assessment. This approach applies to VEN010 and VEN002 for marine vessel hire and the supply of export cables respectively, as presented in Table 6, and Table 7 respectively. Developers can procure specific items from vendors based on specific needs on individual projects.

4 Conclusion and Recommendations for Future Research

Considering various studies that have been carried out on cost optimisation in offshore wind projects, this research has demonstrated that utilising data analytic approaches presents further opportunities for optimising project costs in the offshore wind industry. Owing to the forecasted cost reductions in offshore wind projects, exploiting available data reveals hidden insights in such data, which developers can use in submitting more competitive bids in future renewable energy auctions. Furthermore, the procurement phase of any project is crucial to the timely delivery of the project. By carrying out feature engineering on quotations submitted by vendors, developers, and even contractors, we can better understand which quotation contributes to complying with the local content requirements of SCDS. Moreover, understanding the IncoTerm codes is imperative to managing associated risks. This research has demonstrated that even though a quotation may be the least expensive option and with the earliest delivery timeline, adopting feature engineering reveals the true cost and delivery timeline of any submitted quotation.

Creating an analytic workflow similar to the Alteryx workflow built for this research presents time-saving opportunities for developers in selecting quotations and vendors that meet the project constraints at the lowest cost possible. Traditional bid evaluation in engineering projects involves procurement buyers, discipline engineers, and quality officers, at a minimum. The bid evaluation team checks the submitted quotations by vendors for the best deals meeting the established project constraints. This exercise requires expertise, takes significant time, and is prone to human errors. Running an analytic workflow prevents such errors and ensures accurate results always. Developers can now rely on low-code or no-code analytic solutions in optimising procurement costs, which obviously can be adopted in other phases of offshore wind projects.

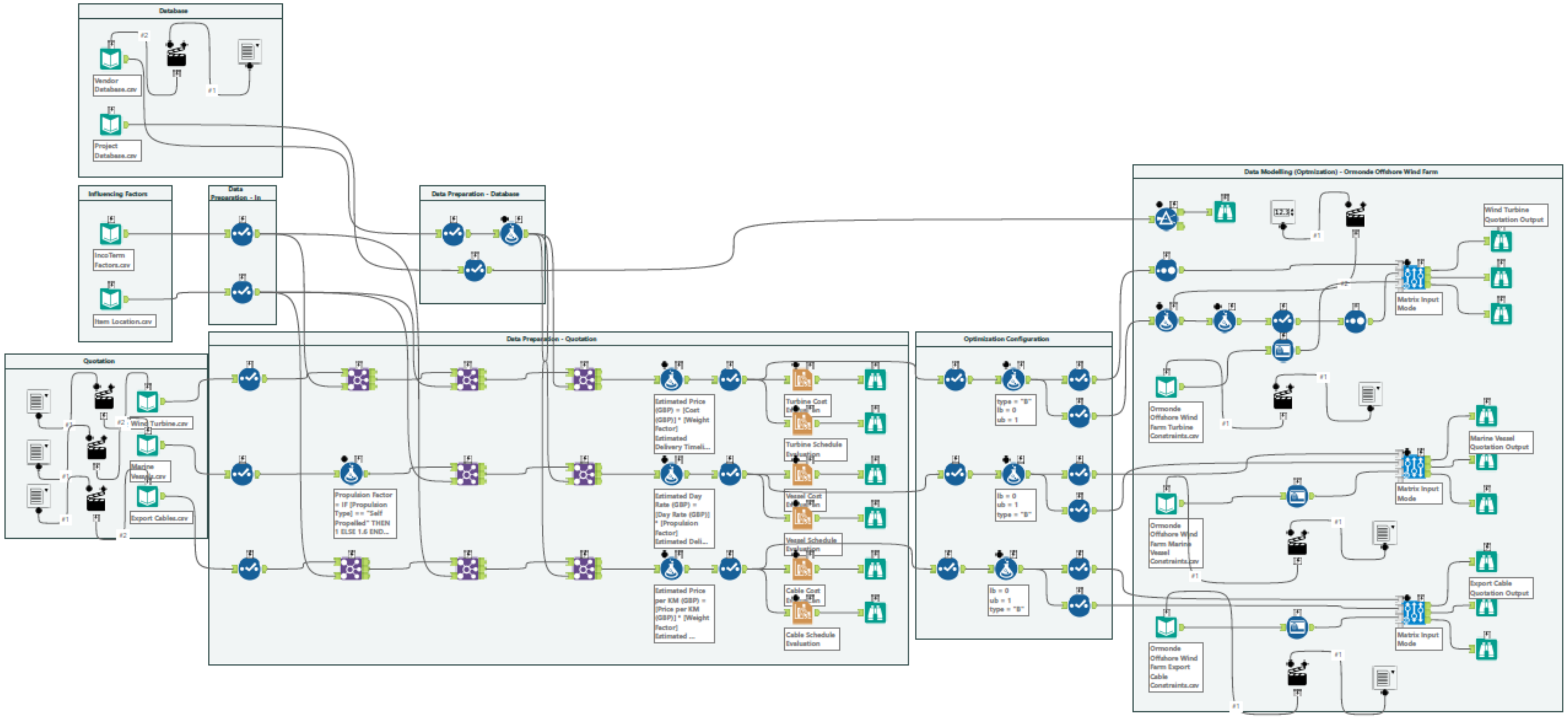
While it has been demonstrated that running an analytic workflow is an effective way of optimising cost, this research has also demonstrated that using an analytic App makes running a workflow more user-friendly. With an analytic App, anyone with computer literacy can select input information and files, including project capacity, vendor database, quotations, and project constraints. The App user can easily obtain reliable cost-optimisation results from the quotations that have been inputted. Finally, this research has demonstrated that making data-driven decisions based on analytical insights supports the digital transformation journey of any organisation.

Using data analytics, this research has focused on procurement activities of offshore wind turbines, marine vessel hiring, and export cables in the UK offshore wind industry. Due to this scope, some recommendations are being made for future studies. There are numerous other components of an offshore wind farm besides wind turbine, marine vessel, and export cable like nacelle, rotor, tower, turbine foundation, offshore substation, onshore substation, operations base, array cable, cable protection, etc. With procurement cutting across the six elements of the offshore wind supply chain**,** which include Development and project management, Wind turbine supply, Balance of plant supply, Installation and commissioning, Operation, maintenance, and service (OMS), and Turbine Decommissioning, it is recommended that future studies focus on how cost optimisation can be achieved through procurement activities of all these elements. This research has used generated procurement data instead of actual data. Even though cost optimisation results will always be accurate, developers tend to appreciate the results more when actual procurement data is used for the analytic workflow. However, it is recommended that actual procurement data is collected for cost optimisation processes in future studies using a data analytic approach.

References

1. Ashuri, T. et al., 2014. Multidisciplinary design optimization of offshore wind turbines for minimum levelized cost of energy. Renewable Energy, 68, pp. 893–905.
2. BEIS, 2020. Electricity Generation Costs.
3. BVG ASSOCIATES, 2019. Guide to an Offshore Wind Farm. Available from: www.thecrownestate.co.uk.
4. Crown Estate, 2012. Offshore Wind Cost Reduction Pathways Study.
5. Department for Energy Security & Net Zero, 2023. Energy Trends March 2023. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1147249/Energy_Trends_March_2023.pdf [Accessed 2 Jun 2023].
6. Elkinton, C.N., Manwell, J.F. and Mcgowan, J.G., 2008. Algorithms for offshore wind farm layout optimization. Wind Engineering, 32(1), pp. 67–83.
7. Feng, J. and Shen, W.Z., 2017. Design optimization of offshore wind farms with multiple types of wind turbines. Applied Energy, 205, pp. 1283–1297.
8. Fischer, S., 2021. Cutting offshore costs. [online]. Available from: https://www.siemens-energy.com/global/en/news/magazine/2021/cutting-offshore-cost.html [Accessed 10 Jun 2023].
9. Fuglsang, P. and Thomsen, K., 1998. Cost Optimization of Wind Turbines for Large-Scale Offshore Wind Farms.
10. Gazelle, 2023. LIGHT, AGILE, FAST. [online]. Available from: https://gazellewindpower.com/technology/ [Accessed 10 Jun 2023].
11. Harshil, P., 2021. What is Feature Engineering — Importance, Tools and Techniques for Machine Learning. [online]. Available from: https://towardsdatascience.com/what-is-feature-engineering-importance-tools-and-techniques-for-machine-learning [Accessed 7 Aug 2023].
12. IEA, 2019. Offshore Wind Outlook 2019: World Energy Outlook Special Report. Available from: www.iea.org/t&c/.
13. IRENA, 2022. Renewable power generation costs in 2021. Available from: www.irena.org.
14. Kallehave, D. et al., 2015. Optimization of monopiles for offshore wind turbines. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 373(2035).
15. Nick, H., 2023. What is CRISP DM? [online]. Available from: https://www.datascience-pm.com/crisp-dm-2/ [Accessed 19 Aug 2023].
16. Piotr, B., 2022. Renewable Electricity – Analysis - IEA. [online]. Available from: https://www.iea.org/reports/renewable-electricity [Accessed 1 Jun 2023].
17. Röckmann, C., Lagerveld, S. and Stavenuiter, J., 2017. Operation and maintenance costs of offshore wind farms and potential multi-use platforms in the Dutch North Sea. In: Aquaculture Perspective of Multi-Use Sites in the Open Ocean: The Untapped Potential for Marine Resources in the Anthropocene. Springer International Publishing. pp. 97–113.

Appendix I



Alteryx Cost Optimisation Workflow with Analytic App