UTS UNIVERSITY OF TECHNOLOGY SYDNEY

ASSIGNMENT COVERSHEET

UTS: ENGINEERING & INFORMATION TECHNOLOGY

SUBJECT NUMBER & NAME	NAME OF STUDENT(s) (PRINT CLEARLY)	STUDENT ID(s)
48550 Renewable Energy Systems	Jake Vulic	98124199

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NAME OF TUTOR	TUTORIAL GROUP	DUE DATE
Dylan Lu	-	24/10/2018

ASSESSMENT ITEM NUMBER & TITLE
Individual Assignment

☑ I confirm that I have read, understood and followed the guidelines for assignment submission and presentation on page 2 of this cover sheet.
☑ I confirm that I have read, understood and followed the advice in the Subject Outline about assessment requirements.
☑ I understand that if this assignment is submitted after the due date it may incur a penalty for lateness unless I have previously had an extension of time approved and have attached the written confirmation of this extension.

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Statement of collaboration:

Signature of student(s) JVulic **Date** 24/10/2018

✂ -

ASSIGNMENT RECEIPT

To be completed by the student if a receipt is required

SUBJECT NUMBER & NAME	NAME OF TUTOR

SIGNATURE OF TUTOR	RECEIVED DATE

Renewable Energy Systems (48550) Individual Assignment – Design of a Practical Renewable Energy System

Jake Vulic (98124199), *Student, Faculty of Engineering and Information Technology – UTS*
24/10/2018

***Abstract*— In the following paper, a hybrid renewable energy system has been designed. It consists of a combination of both solar and wind power generation and is intended to reduce the strain on existing power generation infrastructure in New South Wales, particularly regarding the heavily prominent coal fired power stations. The total system has been designed to have an overall power generation capacity of 100 MW with an 8 MWh/4 MW energy storage solution. It is to be located in one of the three priority zones for renewable energy identified by the NSW government, the central west energy zone.**

***Index Terms*— Energy storage, lithium ion battery, power transmission, renewable energy, solar energy, solar PV, wind energy, wind turbine.**

I. Introduction

THIS document is a design proposal for a practical renewable energy system which is intended to be implemented in New South Wales, Australia. As follows it is separated into the following sections: renewable energy source and location identification, system specifications, system topology, system components, system performance and evaluation, design conclusion and feedback, and references.

Section II following this introduction consists of an analysis of the best renewable energy sources for use in NSW and where to locate them. Section III outlines the major specifications of the renewable energy system. Section IV details the planned topology for each subsequent component of the power generation scheme. Section V goes into further details about which specific components will be used and how much they will cost. Section VI is the conduction of an overall evaluation of the system and its performance. Section VII consists of a conclusion on the final design and my feedback on the assignment. The final section, section VIII, is a reference list, where all research information used in this paper can be found.

II. Renewable Energy Source and Location Identification

Within NSW, the most prominent sources of large scale renewable energy generation are by far solar and wind powered (with the possible exception of the Snowy Mountains Hydro Electric Power Scheme). According to the Australian Energy Market Operator (AEMO) "there are currently 618 MW of committed large-scale wind and solar projects in the region" (AEMO 2018). A breakdown of these wind and solar powered energy plants can be seen in Table 1.

TABLE I
Current and new wind and solar powered energy generation projects in NSW (AEMO 2018)

	Project	Capacity (MW)	Commercial operation date
Large-scale solar	Coleambally Solar Farm	180	Oct 2018
	Beryl Solar Farm	98.4	Winter 2019
Large-scale wind	Crookwell 2 Wind Farm	91	Winter 2018
	Bodangora Wind Farm	113.19	Summer 2018-19
	Crudine Ridge Wind Farm	135	Summer 2019-20
Generator upgrades	Bayswater Power Station	100	2019-2022

It is clear why we in Australia have identified both wind and solar powered sources to be two of the most dependable methods of renewable energy generation. The immense amounts of high intensity solar radiation received in Australia when compared to other countries, coupled with the vast regions of open land we have at our disposal allow for greatly increased viability when it comes to these two energy sources. It is for these reasons which I have decided upon designing a hybrid renewable energy system consisting of both wind and solar power with energy storage, in order to increase their reliability.

Now that the energy sources have been chosen, a location for this new renewables plant must be decided upon. I believe that the best course of action for the design of this power station begins with locating it in one of the three priority renewable energy zones which have been identified by the Berejiklian government of NSW. It has been stated that these three zones have a potential capacity of roughly seven times the coal fired plants in New South Wales, with the government stating in a submission to the AEMO that these regions "could unlock 77,000 megawatts of new generation capacity" (Hannam 2018).

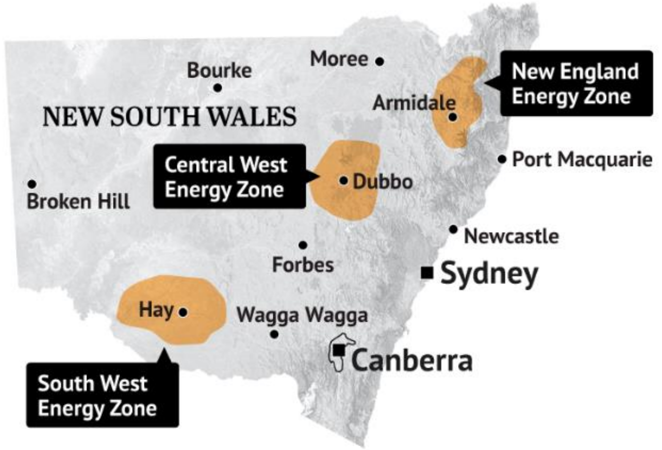

Fig. 1. Priority renewable energy zones chosen by the government of NSW (SMH 2018).

These three priority regions (as seen in Figure 1) are referred to as the South West Energy Zone, centered around Hay, the Central West Energy Zone, centered around Dubbo, and the New England Energy Zone, centered around Armidale. I believe that one of these three zones stands out as the best alternative for this project due to its central location and the fact that it is the closest in proximity to Sydney, which is Australia's largest city with a population of over 5.1 million people and an immense demand for energy. Utilising a new renewable energy system in the central west zone will allow us to provide power to Dubbo and its surrounding area, whilst also giving the greatest possibility of transmitting electricity to Sydney with minimal losses over the transmission process when compared with the other two zones.

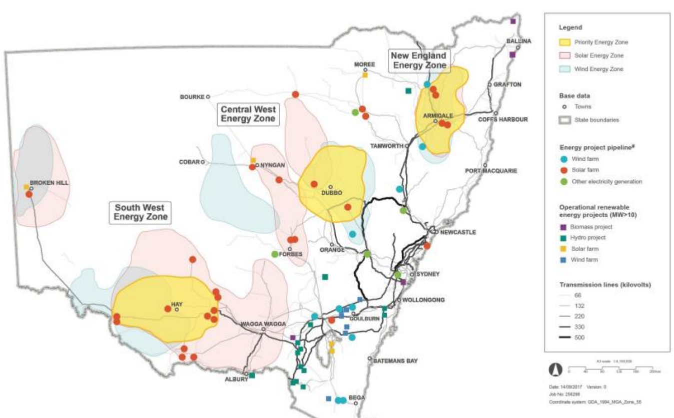

Fig. 2. Map of potential NSW energy zones and existing infrastructure (AEMO 2018)

An analysis of the central west energy zone has identified both "strong solar resources" as well as "moderate to strong wind resources" predominantly around the western region of the zone. If we locate the hybrid renewables plant in the south-western part of the zone, we will be able to take advantage of existing high voltage transmission lines which travel to Sydney and its surrounding area, minimising the overall infrastructure costs associated with this project.

III. System Specifications

The goal of this project is to implement a practical design of a hybrid solar and wind powered electricity generation system with a capacity of 100 MW. This system is being planned with the intention of complementing the existing AC grid, with a large portion of the generated power being transmitted to Sydney via existing transmission line infrastructure in order to reduce the heavy reliance on current coal fired power stations. Our renewable energy system will be favoured towards wind power, with the capacity split ratio being 3-1. This will mean that our plant will have a capacity of 75 MW of wind power generation and 25 MW of solar power generation. We also intend to implement 8 MWh/4 MW of battery storage.

As seen in Figure 3 below, the required storage for combined wind and solar powered systems is far less than either one of these systems alone due to the complementary nature of these two sources when used in conjunction with one another. This allows us to see a great reduction in the cost of required battery storage.

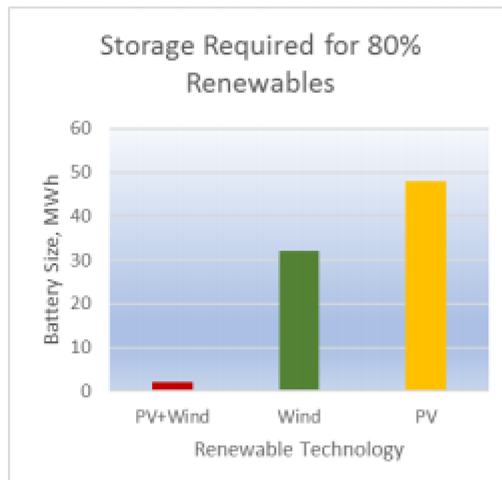

Fig. 3. Required battery storage for combined wind & solar systems versus wind & solar alone (Windlab 2018)

For the purpose of simplicity in this project I have drawn similarities between my own design and other existing hybrid energy systems of a similar size and nature. One of the projects I will be taking comparisons from is the Kennedy Energy Park.

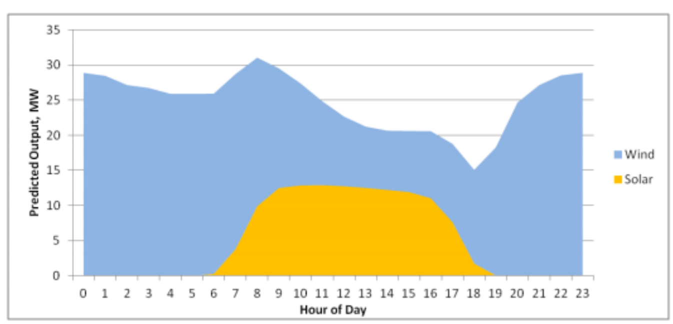

Fig. 4. Wind and solar generation profile at Kennedy over the course of an average day (Windlab 2018)

The Kennedy Energy Park (KEP) is 58% of the size of my proposed system with roughly the same ratio of wind-solar resources, as such it can be expected that the output power generated in my design will be 70% larger than what can be seen in Figure 4. Taking this into account, we can estimate an average power generation of 35-40 MW/h from wind sources and 8-10 MW/h from solar sources (taking into account a 50% capacity factor). Using these figures we are able to estimate an average daily power yield of 1032-1200 MW. This will in turn allow for the production of over 400 GW of power over the course of an average year.

Another aspect of this project which must be addressed is the predicted lifetime of our renewable energy system before a major upgrade or rebuild will be required to take place. An average wind turbine is expected to have a lifespan of about 25 years, with some extending even further than this depending on the level of stress on the turbines and how often maintenance is carried out. The photovoltaic (PV) modules which will be used in our plant must be guaranteed to have a degradation rate of no more than 0.5% of rated power per year. When taking into consideration the 25 year average lifespan of the wind turbines, it can be expected that our PV panels will still be operating at 88-90% efficiency, having lost only around 10-12% of their rated power generation capacity in this time frame. With the conduction of regular maintenance on the wind turbines, it is reasonable to expect the renewable energy system as a whole to still be operating at around or above 80-85% power efficiency after a 25 year period, at which point it will be necessary to implement a major system upgrade in order to ensure the conservation of efficient energy production capabilities.

As stated above, our system will include 8 MWh/4 MW of available energy storage. The combination of wind and solar power together allows for a much smaller energy storage solution to be implemented due to the complementary nature of the two systems. If for example we were to implement a solar powered plant alone, we would need a much larger battery storage facility due to the fact that there are 12 hours of the day where the PV modules are producing essentially no energy (50% capacity factor). As such, a larger storage solution is vital to ensure that power is still available over the course of the night. However, the pattern that follows is highly convenient, as typically when the sun sets we see a rise in wind speed and thus the associated energy produced by our turbines (as shown in Figure 4). This allows us to improve the viability of our solution with as little as 4% of the total capacity of the power plant in energy storage. It is intended for this battery storage solution to be Lithium Ion based, due to their high levels of energy density and cost effective manufacturing expenses.

IV. System Topology

A. Wind Powered Generation Topology

The first thing to consider when looking at the topology of the wind turbines is whether they will be Horizontal Axis Wind Turbines (HAWT) or Vertical Axis Wind Turbines (VAWT). Seeing as VAWT are typically only used in small systems and are for the most part not commercially viable, we will not be going into much detail about them and will instead be discussing HAWT. HAWT are the most commonly used type of wind turbine and have the following advantages and disadvantages.

Advantages include:

- Turbines positioned at a greater height allow for the probability of faster wind speeds.
- Blades sit outside of the center of gravity of the turbine making it more stable.
- Tower height allows for them to be placed on uneven ground, offshore or even among trees above the tree line.
- Majority of HAWT are self-starting.

Disadvantages include:

- Large systems can be complicated and expensive to install/maintain.
- Often considered aesthetically unappealing by locals.

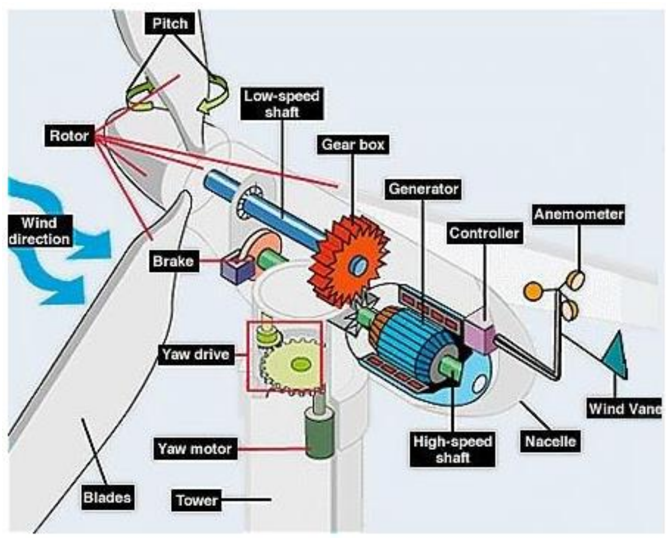

Fig. 5. HAWT components (Turbines info 2018)

Now that we have decided upon the use of HAWT, we must determine the number of blades which will be most efficient and practical in our application. When considering the mechanical stability of wind turbines in large systems, those with an even number of blades are typically avoided. Similarly, one bladed turbines can be equally unstable and thus require a counter weight to function, making them more complex than they are efficient. Thus the most viable option, without having the additional cost of five or more (oddly numbered) bladed turbines, is a three bladed system. The 'Danish' three bladed turbine concept is for these reasons the most commonly produced and implemented in the world for large scale applications.

The final major aspect of topology I will address is the height of the turbines and the length of the blades which will be used in this application. Basing our design on similar projects which have been undertaken in Australia, our turbine will have a maximum height of 198 m and a rotor diameter of 126 m.

B. Solar Powered Generation Topology

Below is a list of the proposed infrastructure for the solar powered part of the renewable energy farm.

- 100,000 crystalline silicon solar PV modules standing roughly 3-4 m high and angled at 25-30°, with tempered high transmittance cover glass.
- 12-14 inverter stations and step-up transformers (converting the generated DC power into AC for transmission).
- 1-1.5 kV weatherproof DC junction boxes.
- Structural panel support frames.

The solar panels will also include 30 year weather protection, in order to ensure they last for the entirety of their expected productive life.

C. Energy Storage System Topology

The energy storage system will comprise of a combination of 25 large industrial scale lithium ion batteries. Each one of these batteries is said to be powerful enough to provide enough energy to allow for an average home to run for 90 days. The combination of these 25 batteries will allow for approximately 8 MW of power storage, as stated previously in the report.

D. Power Transmission Topology

As we will be using mostly existing power transmission infrastructure, we need only transmit the power generated to the nearest substation. In order to do so we will step up the voltage to 110 kV using transformers, the electricity will then be transmitted using Aluminium Conductor Steel Reinforced (ACSR) cable. This cable has been chosen due both its low cost and weight, as well as its high conductivity and tensile strength, making it one of the most efficient cables for power transmission for its price.

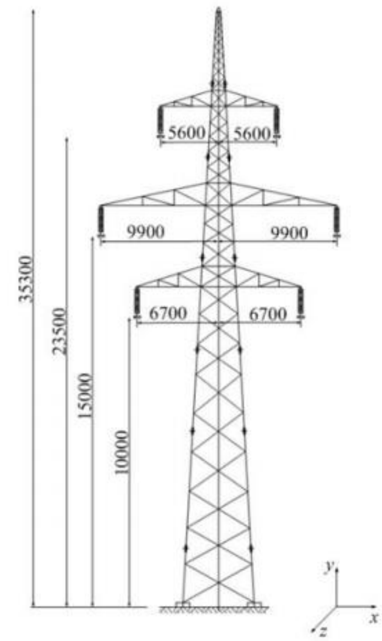

Fig. 6. Transmission line tower design

The transmission line tower design which will be used can be seen above in Figure 6. The lines will also be using a double conductor circuit arrangement with bundled conductors. This will allow for a greater level of reliability and efficiency when transmitting power to the substation.

V. System Components

Now that we have the basic foundations laid out for the overall system topology, we can begin to select and cost more specific system components.

A. Wind Powered Generation Components

Based on our system specifications and design topology, we have decided to use an onshore wind turbine model manufactured by Enercon, known as the E-126. This model has a rated power of 7,580 kW, meaning that we must use a total of 10 of these turbines in order to reach our 75 MW capacity goal for the wind powered segment of our system.

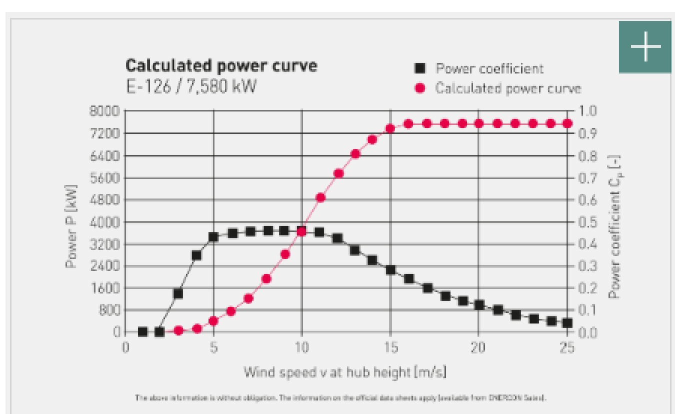

Fig. 7. E-126 power curve (Enercon 2016)

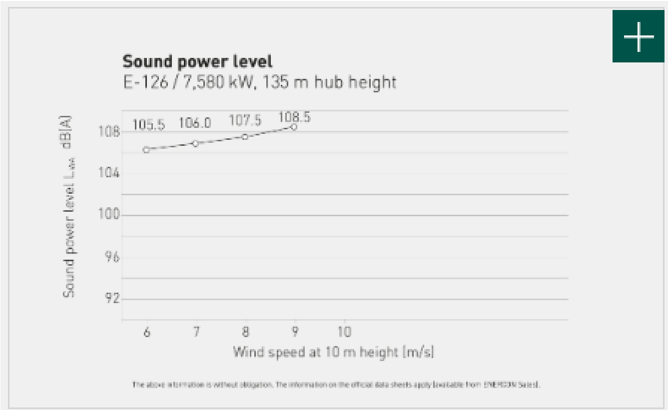

Fig. 8. E-126 sound power level (Enercon 2016)

As can be seen in Figure 9 below, the cost of the wind turbine itself makes up 64% of the total installed cost. With the price of a single E-126 unit costing $14 million, we have calculated the associated total installation costs to be $3.5 million, with an additional $1.54 million for the grid connection. This leaves us with a total installed cost of $19.04 million per unit, which when scaled up by a factor of 10 to incorporate all turbines gives us a cost of $190.4 million.

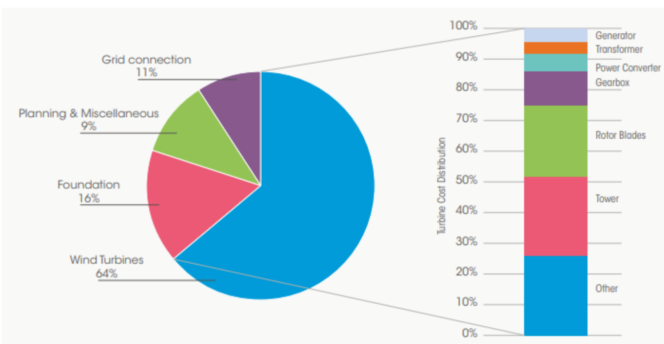

Fig. 9. Cost breakdown of a wind turbine and associated power system (IRENA 2012)

B. *Solar Powered Generation Components*

With each 250 W solar panel costing $0.75 per watt, the capital cost of each solar panel is expected to be $187.50. Multiplying this by the 100,000 solar panels needed to meet our specification gives us a cost of $18.75 million for just the solar panels. Based off the construction of previous systems such as the Gullen solar farm, we estimate all remaining associated costs (installation, inverter stations, transformers, junction boxes, etc.) to be $56.25 million. Thus the total installed cost of this system will not exceed $75 million.

C. *Energy Storage System Components*

The cost of our 8 MWh/4 MW energy storage system has been broken down as follows, and will be sourced through South Korean company Kokam. The total cost (installation inclusive) per lithium ion battery is $450,000. Multiplying this with the calculated need for 25 batteries to obtain the optimum amount of energy storage required leaves us with a total energy storage system cost of $11.25 million.

D. *Total Cost*

The total estimated cost of the project is calculated below in Table II. It is expected to be $276.65 million AUD.

Table II
Total estimated cost of fully installed and operational 100 MW hybrid renewable energy system

Expense	**$/kW (AUD)**	**Total (AUD)**
Wind turbines	1,866.67	140,000,000
Installation cost of turbines	466.66	35,000,000
Grid connection cost of turbines	205.33	15,400,000
Solar panels	750	18,750,000
Installation, grid connection and misc. cost of panels	2,250	56,250,000
Energy storage system	-	11,250,000
Total		**276,650,000**

VI. System Performance and Evaluation

As was evaluated in Section V, the total cost for the construction and implementation of the proposed hybrid solar and wind powered renewable energy system is $276.65 million. Excluding energy storage, this equates to only $2.65 per watt capacity, which is significantly cheaper by almost $1 than the historical cost of the construction of typical coal fired power plants, which is roughly $3.5 per watt. This goes to show how far technology has come in regards to renewable energy systems, as they are now becoming more and more affordable to construct on larger scales. As we continue to fund the research and development of renewable energy and associated power systems, they will move further and further towards economies of scale, allowing for the cleanest and most cost effective energy production possible.

When taking into account the expected lifespan of the power plant, the total cost sums to as little as $110.66 per kilowatt of capacity each year. I believe these costs to be very affordable for a large scale renewable energy plant with storage facilities.

VII. Design Conclusion and Feedback

The final design concept consists of a hybrid renewable energy system based primarily on wind power generation, with a secondary aspect in solar power generation and a relatively small energy storage solution. These two renewable energy sources have been chosen due to their particularly strong viability and reliability in Australia. The plant is to be located in the central west energy zone, one of three priority zones for renewable energy production identified by the government of New South Wales. The proposed design consists of 10 7.58 MW E-126 wind turbines and a solar array consisting of 100,000 solar PV modules. The combined total capacity of these resources is 100 MW (75 MW from wind generation and 25 MW from solar generation), with 8 MWh/4 MW of lithium ion battery storage. The total cost of the project has been estimated to be $276.65 million AUD.

This project was a definite challenge for me. I underestimated the amount of work involved. In addition to my prior knowledge of renewable energy systems from both my undertaking of this subject and other sources, I was required to conduct vast amounts of research in order to equip myself with the knowledge and information required to tackle the questions proposed in the assignment. I definitely learned a great deal from this assignment, not only about the concepts and theory behind renewable energy systems (particularly in regards to solar PV, wind and energy storage) but also about how to realise a design which you have created and planned in order to bring it to life via costing and other methods. One thing I would ask for future students is not overlapping the individual and group assignments (if at all possible), as I found myself unable to make a proper start on this assignment until we had completed the group assignment. All in all the content involved in and concepts behind the assignment were interesting and for the most part enjoyable. I also would have liked to have had more time to take a look into using at least one of the two software packages you recommended. Thank you.

VIII. References

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IX. Biography

Jake Vulic (ATAR 89.95) was born in Sydney, Australia, on December 12, 1996. He graduated from St. Patrick’s College, Strathfield, and studied at the University of Technology, Sydney.

His employment experience included Kmart Ashfield, Officeworks Five Dock, and Sekisui Foam Australia. His special fields of interest included renewable energy systems.

Mr. Vulic is currently studying a Bachelor of Electrical Engineering (Honours) with a Diploma in Professional Engineering Practice.