# Environmental impacts of a renewable energy source: The case of a Turkish wind farm

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It is a well-known fact that the usage of renewable energy sources reduces the environmental impacts substantially. However, obtaining energy from these sources can also cause certain negative environmental impacts. The data of The World Bank indicates that only 4.8 % of the electricity produced in Turkey is of renewable origin (The World Bank, 2014). The strategic plan covering 2015 to 2019 prepared by Turkish Ministry of Energy and Natural Resources states that financial incentives will be taken to encourage renewable energy investments in Turkey (MoENR, 2017). Wind farms are among the most prominent renewable energy sources for Turkey.

Although there are literature studies involving the environmental impacts of wind farms (Ozoemena et. al., 2018; Garrett and Rønde, 2013; Rashedi et. al., 2013; Uddin and Kumar, 2014; Vargas et. al., 2015) through life cycle assessment methodology, it is a well-known fact that the evaluations are case specific and a sound appraisal must rely on site-specific data. On the other hand, in Turkey, only few number of life cycle assessment studies are performed on actual data obtained from the site. Among these studies there is not any one conducted on a wind farm by adopting the actual data. This issue emphasizes the importance of this study.

In this context, the objective of this study is to apprise the environmental impacts of a full-scale Turkish wind farm via life cycle assessment methodology. It is a pioneering study as data obtained from an actual wind farm is used.

The wind farm is an onshore one located in Marmara region near the city Istanbul. Total installed capacity of the wind farm is 47.5 MW and it has 2.5 MW Nordex wind turbines. The farm started generating energy in 2014. In 2016, the monthly average energy production of the farm is 13600 MWh.

The system boundary covers material extraction, part production, construction, operation and maintenance and decommissioning phases of the wind farm. The functional unit is 1 kWh electricity produced. GaBi software is used for modelling and Professional database is used for background data. CML is used for converting emissions into environmental impact categories. A life time of 25 years is assumed for the wind farm. At the end of this time span wind farm is assumed to be dismantled. After decommissioning half of the metals are assumed to be recycled, the rest of the materials will be disposed through appropriate routes: i) materials such as plastics, concrete and wood are directed to a landfill; ii) lubricant wastes generated during the service life is also sent to a landfill; iii) Metal parts of electrical equipments are recycled and plastics are disposed to landfill; iv) half of the steel, aluminum and copper used in several components of the wind turbines will be recycled and the rest will be sent to a landfill.

Landfill and recycling facilities are assumed to be 50 km away from the wind farm and transportation will be performed by trucks.

Life cycle assessment is conducted by following ISO 14040 standards. The investigated impact categories are global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), ozone layer depletion potential (ODP), abiotic depletion potential elements (ADP elements), abiotic depletion potential fossil (ADP fossil), freshwater aquatic ecotoxicity potential (FAEP), human toxicity potential (HTP), marine aquatic ecotoxicity potential (MAEP), photochemical ozone creation potential (POCP), and terrestrial ecotoxicity potential (TETP).

Manufacturing of main components divided into two parts: i) fixed parts manufacturing including tower, electrical equipment and cabling; ii) moving parts manufacturing including rotor, yaw system and nacelle. Rotor comprises of three parts, rotor hub, rotor shaft and three blades. Yaw system is formed from three parts, yaw bearing, drive and brake. Nacelle consists of six parts, main bearing, gearbox, generator, brakes, frame and nacelle cover. Within fixed parts, tower is manufactured in Aegean Region of Turkey and transported to wind farm by trucks. Cables are manufactured in Central Anatolia Region and transported to wind farm by trucks. Electrical equipment of fixed parts and within moving parts, rotor, yaw system and nacelle are manufactured in Germany and transported to wind farm by sea shipment. For installation of wind turbines, steel wires and anchor cages are also used along with concrete. In this stage, steel wires are manufactured in Aegean Region of Turkey and transported by trucks, while anchor cages are manufactured in Germany and transported by sea shipment. Plastics for cable conduits and wood for timber are also used in installation stage. In the base scenario, lifetime is planned as 25 years. At the end of service life, wind farm is assumed to be dismantled. Electrical equipment is seperated into metal and plastic parts, each of them has half of total weight. Metal parts will be recycled and plastic parts will be sent to landfill. Recycling ratio is 90% in the baseline turbine. The other materials such as concrete, plastics, wood are directed to landfill. Lubricant waste is sent to landfill during the service life. The environmental impacts of the investigated wind farm (Table 1) are in accordance with the literature values. The main contributor to ADP (element), ADP (fossil), AP, EP, GWP, MAETP, POCP and TETP is steel in tower. PVC in cables is the main source of FAETP. Steel in foundation tower has the highest contribution to HTP. Transportation of main components is the main contributor to ODP. The secondary contributor to ADP (fossil), AP, MAETP, POCP and TETP is steel used in the foundation. Concrete C35/45 is the second contributor to EP and GWP. Electronic ballast in electrical equipment has the second highest contribution in ADP (element). For FAETP, HTP and ODP categories, the secondary contributors are copper wire in cables, steel in tower and organic coated steel in yaw system, respectively. The tertiary contributor to ADP (fossil), AP, POCP is concrete C35/45 in foundation. Steel in foundation is the tertiary contributor to EP and GWP. Aluminium ingot in cables has the third highest contribution in HTP and MAETP. Copper wire in generator is the third contributor to FAETP, while copper wire in cables is the third source of TETP. For ADP (element) and ODP, the third contributors are glass fibres in rotor blades and transportation of materials by trucks used in tower manufacturing, respectively. The environmental impacts are evaluated by changing the recycling ratio of steel, aluminium and copper at the end of life stage. These recycling ratios are 80, 70, 60, 50, 20 and 0%. It is determined that when the recycling ratio of metals decreases, the environmental impacts are going up. ADP (element) and ODP slightly increases with lower recycle ratios. ADP (fossil), EP, FAETP and HTP values moderately goes up, when the recycle ratio decreases. However, AP, GWP, MAETP, POCP and TETP values significantly grow by lowering the recycle ratios. The environmental impacts are also evaluated with different life times (±5 years). When lifetime increases, values of environmental impacts also arises or vice versa. ADP (element), ODP, TETP values barely decline, when the life time decreases. However, ADP (fossil), FAETP and POCP values moderately decrease with the shorter life times. Final scenario is based on transport of main components such as rotor, nacelle, yaw system, anchor cage and electrical equipment. In base scenario, this transport is supplied by shipment, because these components are manufactured in Germany. Built scenario is about changing the manufacturing location. This location is assumed in Aegean Region of Turkey, and transport will be performed by trucks. As a result of this change, it is determined that there is no change in ADP (element). There is an increase in ODP, while the values of other impact categories slightly decrease.

Table 1. Environmental impacts obtained for all life cycle phases

| Environmental Impact | Total | Part production, construction | Operation&maintenance | Decommissioning |
|---|---|---|---|---|
| ADP element(kg Sb -Equiv.) | 7.27E-08 | 8.31E-08 | 7.07E-11 | -1.05E-08 |
| ADP fossil (MJ-Equiv.) | 6.07E-02 | 7.76E-02 | 2.50E-02 | -4.18E-02 |
| AP (kg $SO_2$-Equiv.) | 1.15E-05 | 2.49E-05 | 1.78E-06 | -1.51E-05 |
| EP (kg $PO_4$-Equiv.) | 1.55E-06 | 2.53E-06 | 1.36E-07 | -1.12E-06 |
| FAEP (kg DCB -Equiv.) | 3.38E-05 | 4.80E-05 | 8.89E-06 | -2.31E-05 |
| GWP (kg $CO_2$ Equiv.) | 4.11E-03 | 7.76E-03 | 5.31E-04 | -4.19E-03 |
| HTP (kg DCB Equiv.) | 1.01E-03 | 1.73E-03 | 5.55E-05 | -7.75E-04 |
| MAEP (kg DCB Equiv.) | 4.07E-01 | 8.37E-01 | 3.20E-02 | -4.62E-01 |
| ODP (kg R11 Equiv.) | 6.34E-13 | 6.00E-13 | 2.00E-15 | 3.20E-14 |
| POCP (kg Ethane-Equiv.) | 8.66E-07 | 2.70E-06 | 2.25E-07 | -2.06E-06 |
| TETP (kg DCB -Equiv.) | 2.86E-05 | 6.04E-05 | 8.48E-07 | -3.26E-05 |

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