Feasibility study on wind energy harvesting system implementation in moving trains

Venera Nurmanova1 · Mehdi Bagheri1 · Toan Phung2 · Sanjib Kumar Panda3

Abstract Feasibility study on implementing wind energy harvesting system on moving train is discussed in this study. Wind turbines installation over the train roof is suggested and analyzed from different aspects. Practical aspects of wind energy utilization are discussed, and challenges are highlighted. Calculations of wind power generation for wagon roof mounted turbine are provided, and air drag of turbine is discussed. Simulation study is performed in SolidWorks environment to explore air drag influence of wind turbines on moving train. Analytically, the generated power is compared to mechanical power required to overcome the extra air drag caused by wind turbines over the train wagons. Wind power generation over the train wagon is discussed and simulated. Economical profit of the suggested design is also discussed in detail. The fuel economy and resultant decrease of the carbon dioxide emission have shown the reasonableness of investments on wind turbine implementation on the passenger trains. The payback period calculations for different scenarios are also discussed at the end.

Keywords Air drag · Ducted turbine · Energy saving · Moving train · Wind power

1 Introduction

Global warming challenge along with fossil fuels depletion caused that governments as well as researchers pay serious attention to the renewable and green energy resources in recent years. Therefore, the proportion of vehicles driving on renewable sources of energy is rapidly increasing. In addition, implementation of alternatives gives an actual opportunity to consumers to become independent from fossil fuel resources and market issues. Despite the fact that electric and hybrid cars are becoming routine transportation vehicles, implementation of green energy in larger vehicles (buses, planes) is still innovative.

Nevertheless, different researches are being conducted regarding the utilization of wind and solar energy on trucks, buses and trains [1]. It is a common practice to manufacture vehicles which utilize alternative sources of energy such as biogas, ethanol, compressed and liquefied natural gas instead of conventional fossil fuels. However, usage of wind or solar energy system in moving objects is considerably innovative technique and requires feasibility study on various prospective such as mechanical design and power output capabilities.

This study focuses on wind energy power generation on moving trains. Since the speed of the air flow facing the wind turbine blades is equal to speed of the train, hence kinetic energy of that air might be utilized for electricity generation [2]. The simulation of the wagon with wind power system unit installed on its roof will be conducted. The unit includes horizontally aligned vertical wind turbine, gearbox and generator, along with battery storage unit which will be installed inside the wagon. Air flow simulations will be conducted in order to define the optimum location for the wind power generation unit, so to minimize the undesired air reluctance. The economic and ecological profit of implementing wind turbines on roof of train will be discussed. The power gen-
eration capabilities of the wind turbine will be assessed for further estimation of feasibility of proposed model.

2 Theory

Vast majority of vehicles on alternative fuels in the US used propane and compressed natural gas, whereas in last two decades due to technological development more vehicles switched to biofuel, ethanol fuel blend and electricity. It should be noted that the proportion of electricity-driven vehicles increased significantly over the past 5 years [1].

Although automobile utilizing of renewable sources such as solar energy or biofuel in car have become a widespread practice, there are several successful projects introducing solar energy into other fields of transportation such as aviation and railways. Implementation of renewable energy on moving train is quite innovative approach. Considering the total fuel consumption of the train, the power generated by available renewable resources seems to be insufficient. Therefore, numerous researches are being conducted in order to investigate possible scenario to reach maximum utilization of alternative energy on the train.

According to [3–5], renewable sources such as wind, solar and biomass (human waste) are considered to be the most efficient supplementary resources for generating power in the train. Particularly, it is supposed to use the roof of the train wagon for installation of solar panels or wind turbines. However, there are some challenges such as additional air drag created by mounted turbine over the train roof. As the other alternative, the human waste can undergo digestion process and further is used as a biofuel [6–8]. The development of alternative energy generation for rail transportation system has been widely discussed and started in India, where roof of trains are already covered by solar panels, and couple of states has connected wind turbine generators to electric train overhead lines [4,7,9].

The highest wind turbines have the tower made from concrete and steel structure in order to increase its strength, as all the supplementary components such as gearbox and generator are installed at the top of the tower in a nacelle. Shorter wind turbines of about 20 m usually have all the electrical components installed on the ground near foundation. Majority of commercial wind turbines have 3 blades, however in rural areas or small-scale installations number of the blades might be increased. There are two major types of wind turbine:

- Horizontal Axis Wind Turbine (HAWT)—the axis of the blades rotation is horizontal to the ground, beneficial at high altitudes, it is one of the most widely used and commercialized types;

- Vertical Axis Wind Turbine (VAWT)—the axis of the blades rotation is vertical, used at lower altitudes [10].

The equation of energy generated by wind turbine is common for all tower designs and is expressed by (1) and is derived using Newton’s second law and momentum theory [3]:

$$ W_{total} = \frac{1}{2} \rho A V^3 C_p $$

where $\rho$ is the density of air in kg/m$^3$, $A$ is area swept by blades in m$^2$, $V$ is the wind speed in m/s, and $C_p$ is the power coefficient, which value can reach maximum 0.593 (also known as Betz limit) for ideal turbine [4,11].

In addition, there are parameters, which overcome alternations due to change of geographic position. For example, the change in altitude and ambient temperature has an impact on the air density [5]. The relation can be expressed as:

$$ \rho = \frac{P}{RT} $$

where $P$ is the atmospheric pressure in kPa, $T$ is the ambient temperature in K, and $R$ is a gas constant and is equal to 0.287 kPa m$^3$/kg K for air.

It was discussed before that the kinetic energy of the wind is converted into mechanical energy of the blades, which in turn rotate shaft of the turbine. At this stage, it is crucial to understand that the rotation of the turbine shaft is not enough to generate electricity in proper level, in other word the number of rotations per minute should be increased to reach optimum turning point of generator and produce energy [12–14]. Therefore, gear system or in this case called gearbox is implemented in order to increase the angular velocity of the generator rotor shaft and reduce the torque by using conservation of momentum principle [6,15].

There are several factors need to be taken into account while designing the overall system. For example, the instability of wind speed, change of air density according to the altitude, size and weight of the additional structure and created supplementary air reluctance are considered as some of those factors. These issues contribute to make the entire task more complex and raise the question of project feasibility both in practical and economical point of views.

In order to minimize this negative effect from air reluctance, the mechanical design of the structure should be modified. First of all, the wind turbine itself is the primary step to start the design of the wind power generation unit. In order to eliminate any confusion, it is important to primarily clarify the difference between wind turbine and the windmill: the first one converts mechanical energy into electrical,
whereas in a windmill the mechanical energy is directly used by machinery [10, 16, 17].

It is suggested to use VAWT for this study due to following reasons:

- beneficial at high wind speed which is typical for moving train;
- robust structure as HAWT will produce significantly more air drag;
- HAWT’s blades are more likely to undergo mechanical damage due to high thrust;
- blades of the HAWT must be adjusted to wind direction by using pitch system, which is not required for VAWT;
- the starting torque for VAWT is higher compared to HAWT;
- in case of VAWT, additional components such as gearbox and generator are combined into more compact structure [7, 18].

Basically, electricity generated by renewable sources of energy such as wind and solar is usually stored in batteries, due to the fact that wind speed and solar radiation varies throughout the operation cycle. Nevertheless, the problem of fluctuations of generated power can be avoided by enhancing the design. For instance, it is a well-developed practice to implement parabolic solar cells in order to concentrate solar energy or even introduce sun-tracking capabilities through system of sensors and motors [3–5, 19–22]. Wind turbines can also be improved by modifying the conventional design, such as pitch and yaw systems to adjust the blades of the turbine according to direction of the wind and enhance the aerodynamic properties of the structure [3].

Sufficiently, high wind speed is enough for VAWT, this can be guaranteed by implementation of duct, which will concentrate and guide the air flow directly to the blade of the turbine. The additional component ducted around the turbine is also called augmenter, and it basically amplifies the wind speed and directs the air flow toward blades. Similar technique has been used for HAWT, since it allows avoiding the relatively expensive angle adjustment system. Figure 1 represents the conceptual design of this mentioned approach [8].

Recent studies and empirical data show an augmenter or simple duct will significantly improve the efficiency and net power generated by wind turbine. According to study of researchers from Croatian University in Rijeka Frankovic and Vrsalovic [9], this kind of modification increases the energy output by the factor of approximately 3–3.5. On the other hand, duct will create a shelter from precipitation and other mechanical damage, thus decreasing the necessity for frequent repairing works and will be used for the proposed model.

### 3 Proposed model

Mechanical and electrical features of the model were designed in order to optimize the existing engineering decisions and maximize the efficiency of the wind power generation system. Wind energy will be applied as a supplementary source for the train’s conventional diesel power.

It is known that during the train movement, the air vacuum will be produced at the sides and the back of the wagon. Therefore, an air with the speed equal to moving vehicle’s velocity will rush to these vacuums in order to fill that vacuum. Basically, the kinetic energy of that air can be used for generation of electricity. In other words, the energy of the wind will be transformed into mechanical energy of the blades of the wind turbine and further by connecting the rotor of the turbine to generator shaft, transferred into electrical energy according to principle of electromagnetic induction.

The roof top of the train was chosen for installation point due to higher wind speed and less obstacles. Moreover, the area of the top is sufficient to locate all components of the system, including wind turbines, gearboxes, and generators, and consequently decreasing the necessity of long wiring.

It is proposed to install five rows of turbine-pair on the train, each having height of 30 cm and length of 1 m. As the length of the wagon is approximately 26 m [23], the distance between every unit is sufficient enough to maintain the preferred air speed level at each unit (see Fig. 2).

Close-up sectional view of mounted unit containing wind turbine, gearbox and generator is illustrated in Fig. 3. The form of the shelter is bell-shaped streamlined body, in order to decrease the air drag exerted on the structure.

It should be noted that the type of the wind turbine is horizontally aligned VAWT with seven flat blades, which enables exploitation of extremely high wind speed available at the wagon roof. The chosen wind turbine type also satisfies area restrictions, since conventional wind turbines will require larger separation distance.
Fig. 2 Conceptual design, ten wind turbine units are installed on the wagon roof. The distance between each row of wind power unit is maintained as 5 m in order to maintain similar wind speed at inlets.

Fig. 3 Wind power system. The aluminum shelter has horizontal gaps from both sides, equal to the length of the wind turbine. These gaps function as a duct, which guarantees the preferable air flow pattern and speed regardless of the direction of the wind speed.

The duct gaps are advised to be located on the inner side of the shelter, rather than at the outer side [9]. It can be explained by fact that the wind speed and direction there tends to be more sufficient and the existence of undesired wake rakes is more likely to occur at the edges of the wagon roof. The visualization of this postulate is provided later through simulation of the air flow.

Unlike traditional three bladed horizontal wind turbines, VAWT rotates at significantly higher angular speed. Nevertheless, it is suggested to use gearbox to regulate the shaft rotational speed and ensure the desired operating speed of generator rotor. The most commercialized types of generator are induction generator (IG) and permanent magnet synchronous generator (PMSG). Both generators operate at fixed rotational speed while being connected to the grid. In spite of economic feasibility of IG, it is strongly recommended to use more efficient PMSG, which in turn does not require additional capacitor for power factor correction [3,4]. Due to existence of brushes in dc PMSG, which requires high maintenance and frequent repairing works, the ac PMSG with electronic rectification is likely to be suitable type of generator. The generator diameter is limited by 25 cm, and generator-gearbox pair is not exceeded 40 cm in total.

4 Analytical calculations and simulations

4.1 Route simulation

It was noted that there are several parameters which have impact on the power output. Therefore, in order to conduct realistic simulations, the number of input values was increased. For instance, since it was decided to simulate the route connecting two Kazakhstani cities Astana (north) and Almaty (south), significant change in altitude has been taken into account as it significantly affects the value of air density.

There are fast and slow train routes running between Astana and Almaty, and the difference is in number of stops (stations) the train performs. The faster route has five passenger stations, while slower route has 11 stations. [11].

Fast route Astana–Almaty (1200 km, 5 stations):

- The route simulated for the period of: 04.10.2016–05.10.2016;
- Trip duration: 12 h 40 min = 760 min = 45,600 s;
- Average speed: 94.7 km/h = 27 m/s.

Slow route Astana–Almaty (1200 km, 11 stations):

- The route simulated for the period of: 04.10.2016–05.10.2016;
- Trip duration: 18 h 49 min = 1129 min = 67,740 s;
- Average speed: 63.8 km/h = 17.7 m/s.

Since the time parameter is measured in seconds, the corresponding simulation times for fast and slow route in Simulink are 45,600 and 67,740 s respectively. As the meteorological data is available at exactly specific train station at certain time point, the air temperature and density values for intermediate locals were estimated through mathematical interpolation method.

4.2 Analytical estimation of drag

The installation of the additional structure on the top of the train will increase the air drag exerted, which in turn will increase the power required in locomotive to overcome that extra drag force. Therefore, it is quite important to estimate the amount of air reluctance. The mathematical expression of the drag force is given by:

\[ F_D = \frac{C_D \rho AV^2}{2} \]  

- Air density, average value for current location \( \rho = 1.2 \) kg/m\(^3\) [12];
- \( V = 17.7 \) m/s, average speed of train [11];
Drag coefficient of the passenger train \( C_{D,\text{train}} = 1.8 \) \[24\];

drag coefficient of streamlined shelter \( C_{D,\text{shelter}} = 0.09 \) \[13\];

drag coefficient of flat blade vertical axis wind turbine
\( C_{D,\text{turbine}} = 0.75 \) \[14\];

Frontal area of the train \( A = 14.44 \text{ m}^2 \) \[23\].

Since the drag force is function of speed squared, it was suggested to use RMS value; however, for calculation of the drag, the average train speed was used since it is larger than RMS in both fast and slow routes (27 m/s against 26.5 and 17.7 m/s against 16.6 m/s, respectively).

The train frontal area that is facing the air flow was estimated by dividing the actual shape of the front side into several rectangles and trapeziums. The value of drag force exerted on train with no additional installations and power necessary to overcome it are calculated below. The speed used in calculations is 17.7 m/s; hence, the drag force exerted on train and power \( W_{D,\text{train}} \) necessary to overcome it are obtained as:

\[
F_{D,\text{train}} = \frac{1.8 \times 14.4415 \times 1.2 \times 17.7^2}{2} = 4.89 \text{ kN} \quad (4)
\]

\[
W_{D,\text{train}} = F_D \times V = 4886 \times 17.7 = 86.5 \text{ kW} \quad (5)
\]

The similar calculation might be conducted for new model by simple summation of drag force on train and streamlined aluminum shelter, since wind turbine, gearbox and generator are all located under it. However, it should be taken into account that the existence of holes or gaps on the surface of the body increases the air reluctance; therefore, to consider the worse-case scenario, the air drag caused by shelter \( (F_{D,\text{shelter}}) \) and wind turbine \( (F_{D,\text{turbine}}) \) was calculated separately and then integrated. The gearbox and generator are not included in calculations as they are fully covered by shelter. The height of the shelter is 0.3 m, and the length is 1 m, the wind turbine is 0.6 m long. That gives the frontal area of 0.3 and 0.6 m², respectively.

Drag force created due to installation of ten shelters from which each is 1 m long and power needed to resist it are as follows:

\[
F_{D,\text{shelter}} = \frac{0.09 \times 0.3 \times 1 \times 1.2 \times 17.7^2}{2} \times 10 = 50.75 \text{ N} \quad (6)
\]

\[
W_{D,\text{shelter}} = F_D \times V = 50.75 \times 17.7 \approx 0.9 \text{ kW} \quad (7)
\]

Drag force created due to ten items of 0.6 m long wind turbine and consequent value of power required are obtained as:

\[
F_{D,\text{turbine}} = \frac{0.75 \times 0.3 \times 0.6 \times 1.2 \times 17.7^2}{2} \times 10 = 253.8 \text{ N} \quad (8)
\]

\[
W_{D,\text{turbine}} = F_D \times V = 253.8 \times 17.7 = 4492 \text{ W} \approx 4.5 \text{ kW} \quad (9)
\]

As a result, the drag force created due to installation of ten units on top of the train and mechanical power necessary to resist it are as follows:

\[
F_{D,\text{units}} = 50.75 + 253.8 = 304.55 \text{ N} \quad (10)
\]

\[
W_{D,\text{units}} = F_D \times V = 304.55 \times 17.7 \approx 5.4 \text{ kW} \quad (11)
\]

The total drag force exerted on train with ten units installed on the roof and mechanical power required to overcome it are as follows:

\[
F_{D,\text{total}} = 4886 + 304.55 \approx 5.2 \text{ kN} \quad (12)
\]

\[
W_{D,\text{total}} = F_D \times V = 5191 \times 17.7 \approx 91.9 \text{ kW} \quad (13)
\]

Table 1 summarizes the calculations carried out above. It is observed that the amount of power required to overcome the air resistance increases by 5.9% with installation of ten units of proposed wind power system. The power required for the train with installed wind turbines to overcome the air drag is 97.9 kW.

### 4.3 Simulation studies

The proposed model was built in several software environments. The conceptual design itself was created using AutoCAD, while aerodynamic flow analysis was conducted in SolidWorks, and the simulation of the entire system was carried out using MATLAB Simulink.

MATLAB Simulink model of the system is illustrated in Fig. 4. Basically, the wind speed and air density are both matrices, where \( m \) is the duration of the trip in seconds. Since
Fig. 4 MATLAB Simulink model. The wind speed and air density are variables that change over time and are presented as matrices. In order for variable profiles to be readable by Simulink, all data are presented via .mat file.

Fig. 5 SolidWorks flow simulation for simple wagon. Simple wagon with no installations was put in improvised air tunnel in SolidWorks environment and the horizontal component of the force was measured.

Fig. 6 SolidWorks flow simulation for wagon with turbines. Ten units of wind power system were allocated accordingly, and the similar flow test was carried out.

the longest route Astana–Almaty is 67,740 s, such matrices are quite challenging for software to process. On the other hand, the route Astana–Aktau is approximately equal to 1 day 21 h 45 min, which is equal to 164,700 s.

The flow simulations are illustrated in Figs. 5 and 6. Since the train movement is in X-direction, correspondingly the X-component of the drag force was estimated and noted. It was expected that the analytical and simulated values of drag coefficient and drag force will not be similar. Therefore, it was decided to focus on percentage value by which the drag force will increase when ten units are installed on the roof.

From the flow simulation presented, it is observable that the air flow is more intense with ten units installed on the train. This is beneficial due to fact that the denser air flow going through the designed duct on the shelter will tend to increase in wind speed. On the other hand, the wind speeds at the inlets of the improvised ducts are similar. In order to maintain the accuracy of simulations, the solver field parameters were not changed for both geometries.

The net force is estimated to be 13,828 and 14,034 N for simple wagon and for wagon with ten wind power units installed, and this difference is resulted in additional air drag caused by wind power unit.

5 Results and discussions

5.1 Simulation results

The wind speed, air density and generated output power are displayed in Figs. 7, 8 and 9. Unlike air density which does not fluctuate significantly, change in wind speed has a notable impact on output power value. Nevertheless, the air density varies in range between nearly 1.26–1.3 kg/m$^3$ for both routes. The acceleration and deceleration values of 0.5 and 0.3 m/s$^2$ for fast and slow routes, necessary stopping distance (54 and 59 s for fast and slow route, respectively) were assumed based on standards and according to train’s moving speed and length [23].

It should be noted that during stop times, the power at the turbine output will become zero. On the other hand, there is a possibility to implement a supplementary device which will inject air directed to turbine blade from compressed air storage and will maintain a stable and continuous power output. Nevertheless, this is out of the scope of this study and is subject for further studies.

The measured values for estimation of additional drag are presented in Table 2. The increase in pressure is expected...
Fig. 8 Wind speed profiles for slow (blue) and fast (red) route. The difference in wind speed is significant. A zero wind speed regions correspond to train stops and is subject for further studies (colour figure online)

Fig. 9 Output power profile for fast route. The stopping stations correspond to zero output powers. This is power generated during 1 h of operation, and its average value during train movement is equal to 1005 W for fast route. Output power profile for slow route. This is power generated during 1 h of operation, and its average value during train movement is equal to 285 W for slow route

since the surface area facing the air flow is larger when ten wind power units are installed on the roof. However, it is notable that the drag force increased by slightly 1.5% for total force and by 2.8% for surface force, whereas analytical estimation has shown 5.9% rise. Nevertheless, during the mathematical solution of the problem, the worst-case scenario was assumed. In addition, the air density values used for analytical and software simulation were constant and variable respectively.

Discrepancy between software and numerical solutions of additional drag can be explained by the fact that the drag coefficient for train, wind turbine, and shelter used in calculations were not estimated experimentally for the specific solids, but taken from the existing literature [13,14,24], whereas SolidWorks simulations considered the shape and materials used for every part of the model.

5.2 Wind turbine output power

In any case, even if ten units are installed on train, the output power per one-way trip will be 126.7 and 56.46 kW for fast and slow routes, respectively. Noting that these amounts of power are enough to overcome on air drag and also supply energy to the load.

It is quite common to express the electrical power in per units in industry. Therefore, in order to make the comparison of the power output for different cases, it was decided to take the power of one turbine per entire train as a reference. Table 3 represents the power generated by wind power units at different scenario.

5.3 Economic and environmental profit

The profit from the proposed model might be considered from several prospective:

- Fuel economy;
- Carbon dioxide emission reduction;
- Taxes for greenhouse gas emission.

According to information provided by JSC “National Company Kazakhstan Temirzholy”, there are currently 550 locomotives in total and 250 in service available. Financial profit of installing ten units on train is presented in Tables 4 and 5. However, it is recommended to primarily familiarize with the following conversions:

- Cost of the fuel: 1 ton of diesel = 28.56 gallons = $43.791 [11];
- Carbon dioxide emission: 1 gallon of diesel = 10.15 kg of CO₂ [25];
- Taxes for carbon dioxide emission: 1 ton of CO₂ = €135 = 135 × 374.54 = $151.643 [26];
- Electrical power to amount of fuel equivalency: 600 kWh/day = 12.28 gallon of diesel = 0.43 ton of diesel = 126.93 kg of CO₂;
- Fuel economy per day: 0.43 ton of diesel = $18.83/day;
- Profit from carbon dioxide emission decrease: 126.93 kg of CO₂ = $19.25/day.

Table 2 SolidWorks data for flow simulation

| Local parameter | Wagon | Wagon + turbine units |
|-----------------|-------|-----------------------|
| Pressure (Pa)   | 101,642 | 101,643 |
| Total force (N) | 13,828  | 14,034 |
| Surface force (N) | 10,251  | 10,546 |
| Increase in force | 1.5% for total force | 2.8% for surface force |

1 Quoted in 2017 [11].
2 Quoted in 2017 [25].
3 Quoted in 2017 [26].
### Table 3  Power output for fast and slow routes

| Route          | One unit per train (kW) | Ten units per train (kW) | Ten units per wagon (MW) |
|----------------|-------------------------|--------------------------|-------------------------|
|                | Fast | Slow | Fast | Slow | Fast | Slow |
| Power output per trip | 12.67 | 5.65 | 126.7 | 56.46 | 3.17 | 1.41 |
| Per units      | 1    | 0.45 | 10   | 4.46  | 250.2 | 111.3 |

### Table 4  Financial gain for the fast route

| 250 Turbines | Saved amount (tons) | Economy (USD) |
|--------------|---------------------|---------------|
| 3.17 MW output power | | |
| Diesel 2.57  | 112.74             |               |
| CO2 0.74     | 112.88             |               |
| Total Day    | 226                |               |
| Total Year   | 81,867             |               |
| 62,500 Turbines | Saved amount (tons) | Economy (USD) |
| Diesel 641.67 | 28,096             |               |
| CO2 185.99   | 28,221             |               |
| Total Day    | 56,460             |               |
| Total Year   | 20,551,440         |               |

### Table 5  Financial gain for the slow route

| 250 Turbines | Saved amount (tons) | Economy (USD) |
|--------------|---------------------|---------------|
| 1.41 MW output power | | |
| Diesel 1.14  | 49.99               |               |
| CO2 0.33     | 50.21               |               |
| Total Day    | 99.75               |               |
| Total Year   | 36,699              |               |
| 62,500 Turbines | Saved amount (tons) | Economy (USD) |
| Diesel 285.41 | 12,497              |               |
| CO2 82.74    | 12,553              |               |
| Total Day    | 25,488              |               |
| Total Year   | 9,127,700           |               |

Basically, the power output per single trip from the ten units installed on each wagon of all trains available on service will be approximately equal to 3.17 and 1.41 MW for fast and slow routes respectively. However, the additional air drag of 5.9% should be taken into consideration. Table 4 shows that for the fast route annual profit will be $81,867 if wind power generation unit is implemented on only one train (250 turbines in total) and $20,551,440 if units are mounted on all 250 trains in service (62,500 turbines in total). Similarly, Table 5 shows that for the slow route, financial gain per annum will be approximately $36,699 and $9,127,700 for one train and all trains in service respectively. The annual profit for the fast route is approximately 2.3 times higher compared to slow route. In case the wind power system is implemented in both types of trains (fast and slow route) the annual income will be $118,566 and $29,679,140 for single train and for all trains currently in service respectively. The cost of single wind power unit is estimated at approximately $500, and for ten units on single train consisting of 25 wagons it will cost $125,000 in total. The notable fact is that the cashback time is quite reasonable for both cases. Moreover, in case of slow route trains were integrated with wind power system, the investment made will be recovered in slightly more than 3 years. This numbers are promising and enthusiastic for renewable energy project. During calculation of payback period, maintenance fairs and running cost have been neglected. Authors mainly focused on power output and environmental efficiency and overall technical feasibility of implementing wind turbines on moving trains. In any case, as the project proceeds, the economic feasibility of proposed model will be estimated more thoroughly.

### 6 Conclusions

The scope of this study was to conduct the feasibility study on implementation of wind energy system on moving trains. Suggested model was examined in several prospective. At first, the overall power generation capability of the wind energy unit was estimated. Afterward, the mechanical challenges caused by installation of the unit on top of the train were analyzed both mathematically and through simulation. Finally, the ecological and economical assets that might be gained in the result of realization of the project were calculated. Simulations of the designed unit installed on the roof of the train have shown less additional air reluctance compared to analytical solution of the drag problem. Nevertheless, the simulation of the wind power system demonstrated the capability of the system to overcome the excess air drag and supply certain amount of electricity to the load as well. Another important benefit is related to reduction of greenhouse gas emission and fuel economy. The approximation of necessary investment and the payback period has also
given positive feedback on feasibility of the proposed renewable energy unit; however, there could be many practical aspects need to be taken into account in practice. It is worth reminding that meteorological conditions and geographic characteristics of the route have a significant impact on wind power output. Therefore, since Astana–Almaty route connects northern and southern parts of the country, the simulation of other routes, for instance, Astana–Aktau (north-west) where ambient temperature, air density, and altitude undergo through dramatic changes is likely to enhance the feasibility assessment of the proposed model. Furthermore, the idea of compressed air storage, which will be used during train acceleration, deceleration, and station stops is quite promising and is likely to solve the issue of intermittent power generation. Calculation of payback period can be improved by clarifying the specifications of all trains currently available and through finalizing the model and price of required components as well as their exact amount. Recall that negotiations with local manufacturers are likely to reduce the cost of the wind power unit.

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