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Estimation of Vehicles Movements as a Sustainable Energy Source in Some Main Roads in Iran

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Abstract- Rising demand for electricity energy and problems associated with using fossil fuels has led to the exploitation of renewable energy resources. Vehicle's motions can be used as a renewable energy resource. This paper examines the application of vehicle movement energy on a road as a renewable energy source and a remarkable mechanism for extracting the energy. The mechanism is called pedal power plant. The pedal power plant is a hydraulic system that is adapted from an offshore energy extraction system called Oyster. The pedals push down and compress operating fluid while cars crossing them. High-pressure fluid is stored in a high-pressure reservoir. Then, it discharges to a turbine or a hydraulic motor to drive a generator, generates electricity. The power plant performance depends on its efficiency, number of pedals and number of cars. Therefore, preliminary design of the system required a busy road, suitable number of the pedals with high efficiency of the system. Comparison between harvested energy from vehicles movement with a solar and a wind power plant in the same regions, shows that for main roads with average 6.7 million traffic load in a month, the pedal power plant with 20 pairs of pedals and efficiency of minimum 0.5 can extract 820 kWh electricity per month which is equivalent to generate electricity from 720 m^2 panel area of a solar power plant. Although in the same areas, the wind current does not meet the minimum requirement of a wind power plant. Besides to store the electricity from solar power plant it should either be close to a national grid network or required batteries storage unit which in turn is not economical.

Keywords Energy harvesting converter, Hydraulic system, Pedal power plant, Renewable energy, Vehicle movements.

List of abbreviation			
η	Overall Efficiency of a power plant	g	Gravity acceleration
W_0	Input work to a power plant with a pedal in a cycle	m	Total mass of a car
$\eta_{mechanical}$	Mechanical subsystem efficiency	t	Energy Duration
$\eta_{hydrulic}$	Hydraulic sub-system efficiency	P	Power
$\eta_{electrical}$	Electrical subsystem efficiency	η^{PV}	Total efficiency of Photovoltaic System
N	force of Wheel on road	A_0	Panel Area of a Photovoltaic module
d	Electrical output energy of a power plant with a pedal in a cycle	S_0^{PV}	Annual average solar energy received by a Photovoltaic module
m	Electrical output Energy of passing of a car axle from a pair of pedals	$P_{0,in}^{PV}$	Annual average solar power received by a Photovoltaic module
$E_{0,Car}$	Electrical output energy of passing a two-axle car from a pair of pedals	$P_{0,out}^{PV}$	Annual average of output electrical power from a Photovoltaic module
d	Predesigned Displacement of the pedal in a cycle	E_0^{PV}	Annual average of output electrical energy from a Photovoltaic module

1. Introduction

Energy consumption is growing due to population growth, rising consumption intensity in industries, agriculture, transportation, household, and other sectors. Moreover, fossil fuels are not renewable and dramatically can harm life environment by causing some phenomena such as greenhouse effects, climate change, melting of ices, acid rains, etc. Given these constrains, fossil fuels cannot respond to the increased demand for the long term [1]. There are required non pollutant and environmentally friendly renewable energy. Many researchers are focused on natural renewable energy sources such as wind, solar, geothermal, and tidal power in past three decades [2, 3]. Some other researchers study recycling ambient waste energy such as undesirable mechanical vibration and abandoned heat. These process is called energy harvesting, and it has been considered for low-powered electronic devices [4].

Utilizing renewable energy resources is in conjunction with economic factors. Investors seeking more profit, although, the renewable energy resources are free, they are looking for ways to reduce total cost of energy harvesting by finding more inexpensive, available and unlimited resources and designing innovative renewable energy converters with higher efficiency [5]. There are other resources of energy that are not as famous as the above resources, and their number is increasing. Energy of vehicles movements on a road is one of these sources, particularly in a motorway.

In some countries, at an entrance of motorways, to pay the toll, each car should derive at a certain speed through a specified route. Lighting for the surrounding area of motorway entrance, devices for controlling and kiosks to sell the toll, all of these consumers require electricity energy, which should be supplied by the electricity national grid. The idea of using the potential energy of vehicles movements on the road was recently introduced as a new source of renewable energy.

The energy source is renewable and can be exploited as long as vehicles drive on that road. Unlike natural renewable resources such as wind, sun, waves and sea tidal currents that are limited to certain places and times, the vehicle's motion exists in all days and nights of a year. Different mechanisms have been proposed to exploit this resource, but so far none have been used in practice. Cause of not deploying this source of energy may be categorized as a lack of a proper low-cost mechanism in construction, installation, and operation. In addition, practically the system should be safe and not disturb the traffic.

Site selection is one of the very important parameters, to make the power plant more beneficial. Highroads entrance is the best location to construct the pedal power plant. Economic feasibility study of the pedal power plant for a road is required statistical traffic data, which is not usually available or it may be purchased. Once knowing the annual traffic data of the road, the Potential of the route for extracting energy is predictable. Extracted energy from traffic may be used in the same place as an economic point of view. All consumers of electricity may consume the generated power which in turn is an advantage of the system for the remote areas from the national grid.

Although previous researchers have investigated several mechanisms for extracting energy from traffic and discussed their performance and features. Proposed systems convert traffic energy into electricity have different mechanisms such as electromagnetic, mechanical and piezoelectric. In 2013, Sheng Wei et al. [6] pointed out that the output voltage produced by Piezoelectric is steadily increasing at the speed of walking.

There are many studies on harvesting electricity from road by piezoelectric material. Papagianakis et al. [7] 2016, studied the energy extraction system performance that was composed of an array of piezoelectric components on pavement. Several samples of the system have been built for experiments in the laboratory as well as freeways. The test results of one unit of the system, with piezoelectric cross-sectional area equal to 0.001556 m^2, in a period of one year, in a freeway with an average 30,000 daily traffic at an average speed of 40 km/h, showed that the extraction capacity was about 241 watts per year for a unit. This system is expensive and lead to costly electricity generation. Saleh Gareh et al. [8] deployed a single circle shaped piezoelectric to generate electricity in high way. Due to very low outcome they advised to use multiple arrays along the highway.

A speed bump for generating high-voltage electricity has been designed and tested at the laboratory by Zhang et al. [9] in 2016. The proposed speed bump was an electromagnetic system that produces current with an average of 55.2 voltages, once the vehicle speed was 40 km/h. the current can be used to provide the required power of the tunnel's lighting. Those devices cannot be installed randomly on the road network but should be implemented in decelerating sites only, such as urban road crossings, pedestrian crossings, and main road exits [8]. In 2012, Ting et al. [10] presented the details of a mechanical system. That was proper to install in areas of freeways that need to reduce the speed of traffic. The system consists of a combination of piston units, a collection of electricity and energy storage equipment. Each piston plate has 136 pistons with 3 cm diameter and a course of 3 cm. Total system efficiency was estimated equal to 41 percent according to their theoretical and experimental results. The system is not recommended for the main road due to slip.

Ramadan et al. introduced, in 2015, a mechanical speed bump power generator system that consists of mechanical parts (including rollers, springs, pinion and rack gear) and electrical components (including generator and electrical circuits) [11]. Following experimental tests, Ramadan et al. found that increasing the weight of a vehicle would increase the extractable power. Consequently, the system is capable to generate electricity at a rate of 37 watts per kilogram of vehicle's mass at each passing vehicle.

In this study, a brief of the pedal power plant idea is discussed. Then, its performance evaluated, using statistical data in some selected routes. Finally, the performance of the pedal power plant for the selected routes has been compared to the efficiency of solar and winds power plants in the same areas.

2. Problem and method description

2.1. Pedal power plant concept

Pedal power plant is a new hydraulic system for harvesting energy from roadway traffic. The idea is adapted from Oyster Wave Energy Generator, which converts the ocean wave energy into electricity [12, 13]. Generally, Oyster contains a massive floater that oscillates by wave action. A schematic view of Oyster converter shows in Fig 1.

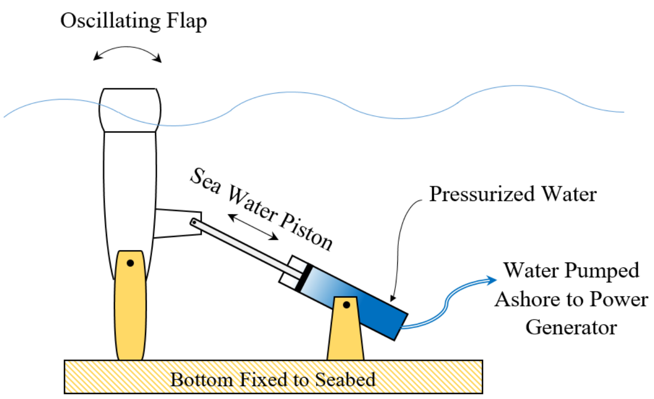

Fig 1. Oyster Wave Energy Generator concept

Weight of car on a pedal is a source of energy, as the same as the wave load on a floater of the Oyster to extract the wave energy source.

Although, huge floater is used in the Oyster to absorb energy from ocean waves, the numerous small panels are used to extract energy from vehicles. The system containing a pedal, spring, cylinder and piston, high and low pressure reservoirs, hydraulic motor or turbine and a generator.

Schematic view of a pedal power plant is shown in Fig 2. When the car wheel touches the pedal, it pushes the pedal down and operating fluid is compressed by piston attached to the pedal. The high-pressure fluid is stored in a high-pressure reservoir and discharges, with specific flux, to a turbine or a hydraulic motor through the control valve. Then, the generator rotates by turbine or motor and generating electricity. Low pressure fluid from turbine or motor flows into low pressure reservoir. Once the car wheel crossed the pedal, it returns into original position by a spring which is mounted under the pedal. In returning of the pedal to the original position, the operating fluid suck from the low-pressure reservoir into the cylinder and the system is ready for the next cycle.

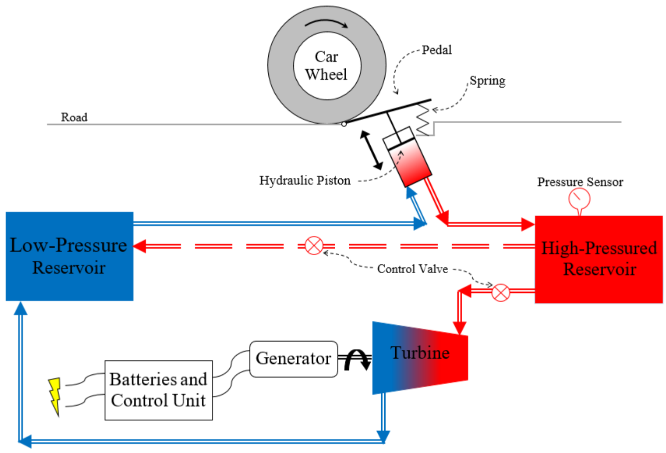

Fig 2. Overview of the Pedal Power Plant proposed for a wheel (Red line showing high pressure fluid and blue line indicates low pressure fluid)

One of the advantages and innovations of the system is the possibility of storing high-pressure fluid like a battery as shown in Fig 2. The pressure and flux of the fluid control steady and smooth running of the generator.

The operating fluid prefers to be a liquid rather than a gas. In most areas at ambient temperature and environmental conditions, hydraulic oil has better efficiency. It is possible to set up a set of pedals on the vehicles' path, all connected parallel to the tank, to store more energy as shown in Fig 3.

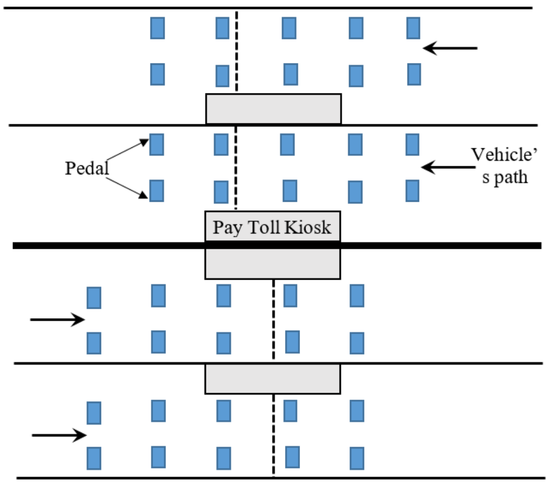

Fig 3. A set of 20 pedals pair in a motorway pay toll (Top view)

There are two important parameters that influence efficiency of injection of fluid into high-pressure reservoir: distance between two pedals and speed of the vehicle passing through the pedal. If the vehicle speed is too high or distance of consecutive pedals are too short, there is not enough time to fill the cylinder and less fluid is injected into the high-pressure reservoir. In general, distance between two consecutive pedals and speed of a car should be estimated by required time for filling the cylinder.

2.2. Evaluation of minimum extracting energy and generating electricity

The pedal power plant is an energy converter system that converts mechanical energy to electricity. The power plant is divided into three main sub-systems:

1) Mechanical system that includes a pedal, a spring and a rod connecting pedal to piston,

2) Hydraulic system that includes a piston and cylinder (an actuator), interfaces and a hydraulic turbine or motor

3) Electrical system that includes a generator, interfaces and a control system.

Total efficiency of the pedal power plant defined as follows [14]:

$$\text{Efficiency} = \frac{\text{Useful output energy of the device}}{\text{Total input energy of the device}} \qquad (1)$$

Total efficiency of the pedal power plant is calculated from the productivity of the three subsystems. The efficiency of each subsystem is also proportional to efficiency of its constituent parts, as defined in the formula (1). Therefore, the total efficiency is:

$$\eta = \frac{E_0}{W_0} \qquad (2)$$

$$E_0 = \eta \times W_0 \qquad (3)$$

$$\eta = \eta_{mechanical} \times \eta_{hydrulic} \times \eta_{electrical} \qquad (4)$$

Where: η is the total efficiency of the power plant, $\eta_{hydrulic}$ is the hydraulic sub-system efficiency, $\eta_{mechanical}$ is efficiency of the mechanical subsystem and $\eta_{electrical}$ is efficiency of the electrical subsystem.

To estimate output energy, a power plant with one pedal is considered. Also, a wheel is assumed to pass through the pedal. Work of weight force of car that applies through a wheel passage to the pedal during a cycle is equal to W_0 (notice that each parameter with subscript of "0" relates to one pedal or one module). One of the most important factors in the energy converters is their efficiency. The system efficiency could be determined by experimental tests. The system that Ting et al. [10] have presented and introduced in literature review is the most similar system to the pedal power plant and results of Ting et al [10] is used to estimate the efficiency. They divide their system into four sub-systems including 1) piston plate, 2) hydraulic storage, 3) hydraulic transmission and 4) electric generator. According to their test results, the piston plate efficiency is $\eta_P = 0.9038$, hydraulic storage efficiency is $\eta_S = 0.950$, hydraulic transmission efficiency is $\eta_T = 0.58$ and electric generators efficiency is $\eta_G = 0.830$. Total efficiency of system is obtained from multiplication of the sub-systems efficiency and is about 0.498. It can be said that $\eta_P \times \eta_S \times \eta_T \simeq 0.5$ is equivalent to $\eta_{mechanical} \times \eta_{hydrulic}$ in the pedal power plant. It is likely that the hydraulic and mechanical system of the pedal power plant can be more efficient. If assumed $\eta_{mechanical} \times \eta_{hydrulic} \simeq 0.6$ and $\eta_{electrical} \simeq \eta_G = 0.83$, total power plant efficiency will be equal to:

$$\eta = 0.6 \times 0.83 \simeq 0.5 \qquad (5)$$

Output energy (E_0) is also related to (W_0) that may be calculated as follow:

$$W_0 = N \times d \qquad (6)$$

As shown in Fig 4, the displacement of the pedal is and "d" it is assumed to be 10 cm in a cycle. "*N*" is the wheel's force. It is equal to One quarter car weight and can be calculated as follow:

$$N = \frac{1}{4} \times m \times g \qquad (7)$$

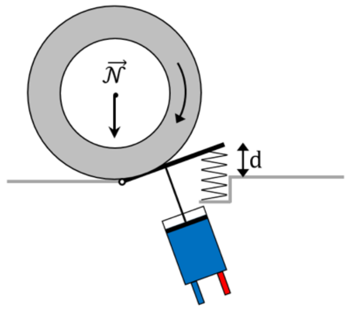

Fig 4. Effective factors in total input work

Where "g" is the gravity acceleration (9.81 $\frac{m}{s^2}$) and "m" is the total mass of a car. The lightest popular vehicle in Iran is a car with total mass of 915 kg. This weight is assumed as criterion of calculating output power. With these assumptions, one can calculate input work and the generated electricity from formula (7), (6) and (3), as follow:

$$N = 2.208 \text{ [kN]} \qquad (8)$$

$$W_0 = 0.221 \text{ kJ} \simeq 6.139 \times 10^{-5} \text{ [kWh]} \qquad (9)$$

$$E_0 \simeq 0.110 \text{ kJ} = 3.056 \times 10^{-5} \text{ [kWh]} \qquad (10)$$

The gained energy by a pedal in one cycle is equal to $0.110 \text{ kJ} = 3.056 \times 10^{-5}$ kWh . It must be emphasized that this estimation is for one pedal and one wheel passing through it. Considering the fact that car's axle has two wheels, to generate minimum energy; a pair of pedals should be used instead of one pedal. Thus, extracted energy from passage of a car axle over a pair of pedals in one row, $E_{0,Axle}$, is twice value of E_0 ($E_{0,Axle} = 2 \times E_0$). The pair of pedals should be in one row so that the wheels of each axle of the car pass over them simultaneously. In addition, each pair of pedals will be pressed by wheels of each axle in turn; it means by passing a two-axle car from a pair of pedals, each pedal is pressed twice so extractable energy from passing a car over a pair of pedals , $E_{0,Car}$, is twice $E_{0,Axle}$ ($E_{0,Car} = 2 \times E_{0,Axle}$). $E_{0,Car}$ is the lowest value of extractable energy from passing a car. Table 1 shows the energy generated by passing one wheel on one pedal, passing one axle on a pair of pedals, and passing a car with two axles on a pedals pair consequently shown in Table 1.

Table 1. Energy from passing a wheel on a pedal, one axle on a pair of pedals, and a car on a pair of pedals

$E_0 = 0.110$ kJ $= 3.056 \times 10^{-5}$ [kWh]	The energy generated by passing a wheel on a pedal
$E_{0,Axle} = 2 \times E_0 = 0.221$ [kJ] $= 6.112 \times 10^{-5}$ [kWh]	The energy generated by passing an axle from a pair of pedals
$E_{0,Car} = 2 \times E_{0,Axle} = 4 \times E_0 = 0.442$ [kJ] $= 12.224 \times 10^{-5}$ [kWh]	The energy from passing a two-axles car from a pair of pedals

The minimum energy that can be obtained from passing a car with two axles is $0.442 \text{ kJ} = 12.224 \times 10^{-5}$ kWh. Minimum output energy of pedal power plant in a rout is calculated by multiplying number of traffics in $E_{0,Car}$. Output energy can be used to determine the electrical power generated for selected rout per month and year. Monthly or annual output power is calculated from the energy of power plant divided by the duration of the operation time:

$$\text{Output Power} = \frac{\text{output energy}}{\text{time duration}} \quad (11)$$

3. Results and discussion

3.1. Road traffic statistics and extractable energy estimation

One of the most important factors affecting capacity and output energy of a pedal power plant is the number of cars in selected site. The traffic load is required to evaluate the output energy from the pedal power plant installed in the selected road. Statistical information of traffic obtained from the Road Administration [15]. Traffic data of selected routes is classified so that it can be useful for estimating output energy in one year (March 2017 to February 2018).

The selected routes and the locations of the traffics counters are presented in Table 2. The routes names were renamed, for the easier reminding. Selected routes that have been provided with the location of traffic counter are expressed in Table 2. The monthly traffic statistics for the selected locations from 1st of March 2017 to the end of February 2018, shows in Table 3. The statistic consists of all vehicle type such as light, semi-heavy and heavy vehicles [15]. Graphical of passing cars number for each month show Fig 6.

Table 2. Selected routes and locations for counting

Selected Route	Counter location	Renamed Route
Tehran-Karaj motorway	Old toll collection	A
Tehran-Saveh motorway	Toll pay No 1	B
Tehran-Qom motorway	Toll pay	C
Tehran-Pardise highway	Toll pay	D

Fig 5. Tehran city and selected routes

Table 3. Number of cars on selected routes in 2017-2018 million per month [15]

Month \ Route	A	B	C	D
1	7.06	3.56	3.62	1.36
2	7.49	3.73	3.62	1.55
3	7.05	3.39	3.92	1.48
4	7.06	3.56	3.13	1.36
5	7.46	3.55	3.62	1.78
6	7.37	3.86	3.93	1.71
7	6.20	4.41	4.41	1.50
8	6.06	4.60	3.62	1.54
9	6.18	4.02	3.71	1.52
10	6.36	3.72	3.68	1.42
11	5.71	3.98	3.10	1.36
12	6.20	4.58	3.26	1.49
Total	8.02	4.70	4.34	1.81
Annual Average	6.68	3.91	3.61	1.51

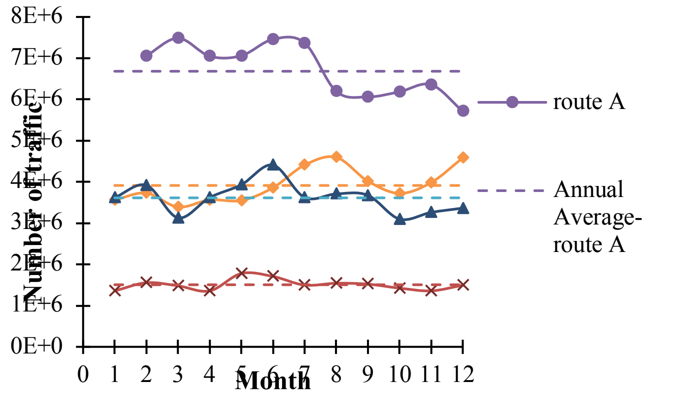

Fig 6. Monthly traffic in routes for 2017- 2018

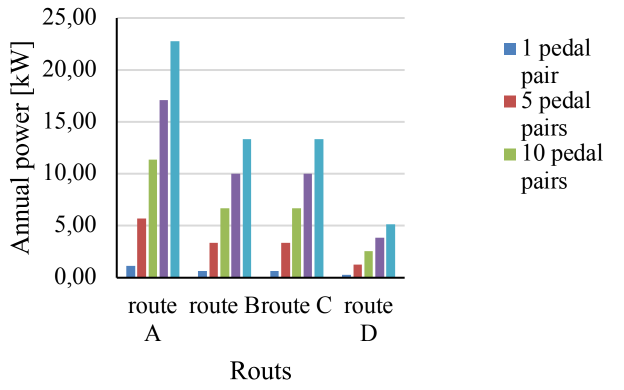

Fig 7. Total extractable power on selected routes within one year

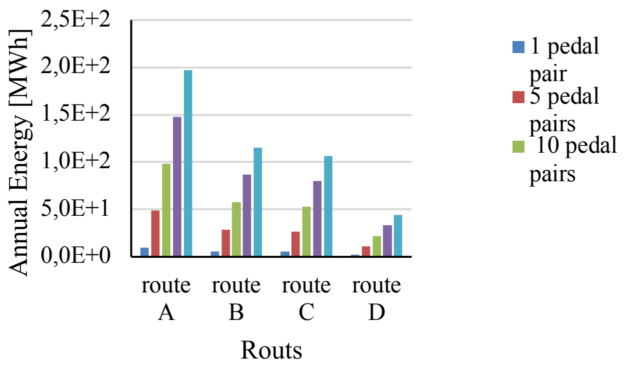

Fig 8. Total extractable energy on selected routes within one year

To evaluate minimum extractable electricity from a plant with a pair of pedals for each selected route in Table 1, the total number of traffic shown in Table 3 for each month is used. To increase the generated electricity capacity of each route a set of the pedals pair should be used. Therefore, the total generated electricity compute from the minimum extracted electricity multiplied by the deployed pedals' set number.

To evaluate minimum extractable electricity from a plant with a pair of pedals for each selected route in Table 1, the total number of traffic shown in Table 3 for each month is used. To increase the generated electricity capacity of each route a set of the pedals pair should be used. Therefore, the total generated electricity compute from the minimum extracted electricity multiplied by the deployed pedals' set number. The computed power for each path shows in Table 4 for various numbers of pedals pairs.

Increasing pedals pair's number increases power output, it shows in Table 4. The output power significantly increases for more than 10 pedals pairs. The output power and the extracted energy are shown in Fig 7 and Fig 8 for the different number of the pedals set

Table 4. Total extractable energy and power on selected routes within one year

Number of pairs of pedal	A		B		C		D	
	Power [kW]	Energy[MWh]	Power [kW]	Energy [MWh]	Power [kW]	Energy [MWh]	Power [kW]	Energy [MWh]
1	1.14	9.85	0.67	5.77	0.62	5.32	0.26	2.22
5	5.70	49.23	3.34	28.83	3.08	26.62	1.28	11.09
10	11.4	98.47	6.67	57.66	6.16	53.23	2.57	22.18
15	17.09	147.70	10.01	86.49	9.24	79.85	3.85	33.28
20	22.79	196.93	13.35	115.32	12.32	106.47	5.14	44.37

3.2. Advantages of the Pedal Power Plant system

A thermal power plant, roughly creates 0.0008 tons of CO2 for producing each kWh electricity [16],[17]. Pedal power plant can avoid significant amount of harmful greenhouse gas. Amount of CO2 gas shows in Table 5 and Fig 9 that pedal power plant, with various numbers of pedals pairs, prevents to produce.

Table 5. Amount of CO2 by pedal power plant with various number of pedals pairs

rout / pairs of pedals	A [ton]	B [ton]	C [ton]	D [ton]
1	7.88	4.61	4.26	1.77
5	39.39	23.06	21.29	8.87
10	78.77	46.13	42.59	17.75
15	118.16	69.19	63.88	26.62
20	157.54	92.26	85.18	35.49

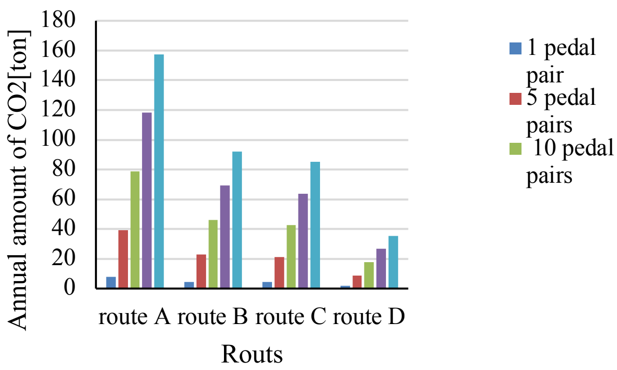

Fig 9. Reduced CO2 production due to the use of various numbers of pedals pairs in selected routs

Performance of a photovoltaic and wind turbine renewable power plants were chosen to compare with the pedal power plant performance. The location of installation for all is assumed in the same area.

3.3. Equivalent Photovoltaic systems

Public and governments can use photovoltaic power plants in places where the national grid is not available, like pedal power plant [18]. Iran is a country with 300 sunny days in more than two thirds of its territory and an average radiation of 4.5 to 5.5 kWh per square meter per day [19, 20]. In general, it can be said that the parameters affecting output power of a photovoltaic power plant are amount of sunshine hours, total radiation, photovoltaic system efficiency and solar panel area.

Annual average of total sunshine hours at a month in Iran has estimated 250.79 h [21, 22]. A popular commercial solar panel which has middle cost and performance is selected. The selected panel has efficiency of 17.4% and frame area of 1.18 m^2. An inverter with efficiency of 90% was selected to convert power from DC to AC. Miscellaneous inverter losses were assumed to be 5%. So, total efficiency of considered Photovoltaic System is about 15% [20, 23].

According to GIS maps, average annual amount of radiation energy in Tehran is about 5 kWh per square meters per day [19, 20]. Given that the average hours are about 251 hours per month, the annual average solar energy and power on frame area of $A_0 = 1.18\ m^2$ is:

$$S_0^{PV} = 5\frac{kWh}{m^2.day} \times 365\ day \times 1.18\ m^2 = 2153.5\ [kWh] \qquad (12)$$

$$P_{0,in}^{PV} = \frac{E_{0,in}^{PV}}{t} = \frac{2153.5\ [kWh]}{251\ [\frac{h}{month}] \times 12\ month} = 0.715\ [kW] \qquad (13)$$

Output energy and power of one module (photovoltaic panel) with area of $A_0 = 1.18\ m^2$ is equal to:

$$E_0^{PV} = E_{0,in}^{PV} \times \eta^{PV} = 2153.5\ [kWh] \times 0.15 = 323.03\ [kWh] \qquad (14)$$

$$P_{0,out}^{PV} = P_{0,in}^{PV} \times \eta^{PV} = 0.715\ [kW] \times 0.15 = 0.1073\ [kW] \qquad (15)$$

According to extractable electricity from a car passing through a pair of pedals $(12.224 \times 10^{-5}\ kWh)$, if the number of traffics in a route was 2.64 million per year (or 7,240 per day or 21,72,000 per month), the performance of a pedals pair will be equivalent to a solar panel. To compare the performance of the pedal power plant with the photovoltaic system in selected routes, solar panel area (or number of modules) needed to generate equivalent extractable energy by the pedal power plant with different number of pedals in road A to D are presented in Table 6.

Table 6. Equivalent solar panel area to generate same energy as pedal power plant with different number of pedals pairs for selected routes

Number of pairs of pedals	A		B		C		D	
	Module number	panel area [m^2]	Module number	panel area [m^2]	Module number	panel area [m^2]	Module number	panel area [m^2]
1	31	35.9	18	21.1	17	19.4	7	8.1
5	153	179.7	90	105.3	83	97.2	35	40.5
10	305	359.5	179	210.5	165	194.4	69	81
15	457	539.2	268	103	248	291.5	103	121.5
20	610	719	357	421	330	388.7	138	162

The routes with very busy traffic, to produce equivalent electricity energy large solar panel area (many modules) should be used as shown in Table 6. The equivalent photovoltaic power plant will be more expensive than the pedal plant. In addition, power generation by the photovoltaic panel is limited to sunny hours throughout the day, and electricity storage is only possible with batteries. Batteries can cost a lot and reduce efficiency [24]. So, the generated electricity and the storage in photovoltaic plants are very costly. It is not comparable with the pedal power plants, particularly for the area far from the national grid.

Therefore, it can be said that construction of the pedal power plant in routes with heavy traffic is more cost-effective than photovoltaic power plants. Notice that in photovoltaic power plants, amount of instantaneous energy production depends on atmospheric conditions. Therefore, it does not necessarily coincide with peak energy consumption during the day, month, and year. If only source of electricity is a photovoltaic power plant, power consumption peak should be provided by the power plant. Therefore, in this point of view, photovoltaic power plants may need to be much larger than estimated in Table 6.

3.4. Equivalent Wind turbines

To build a wind power plant in an area, the potential of the area must be evaluated firstly. This evaluation involves examining erection site in terms of annual average wind speed, wind direction, and turbulence intensity. In accordance with operating conditions and technical instructions of the Renewable Energy Agency, wind turbines with a capacity of fewer than 100 kW, which are classified as "small wind turbines", require at least average annual wind speed of 4.5 m/s. Turbines with capacity of more than 100 kW to 1 MW is known as “commercial turbines” and require average annual wind speed of more than 6 m/s [19, 25].

In Tehran province, Hesarak, Lateyan and Kahrizak stations are close to the locations of traffic counting at routes A, B and C respectively and for route D is not available information. The available wind speed data for the same areas is presented in Table 7.

Table 7. The wind speed in the same location as selected route [19, 26]

Route	Station	Average annual wind speed [ms^{-1}]		
		Height 10 m	Height 30 m	Height 40 m
A	Hesarak	4.09	4.36	4.53
B	Lateman	3.17	3.57	3.71
C	Kahrizak	3.02	4.04	4.2
D	not available	not available	not available	not available

The average annual wind speed shown in Table 7, for all areas is less than 4.5 m/s except for the A location. The annual average wind speed of the rout A is closed to criterion 4.5 m/s at a height of 40 m from the ground. Therefore, for the selected routes and locations, wind is not a reliable source of energy and there is no extraction capability.

4. Conclusion

The road traffic is a renewable source of energy, which is more reliable, consistent, clean and economical. The pedal power plant is a convertor of energy, which converts the road traffic into electricity. A brief explanation of the system has informed in the paper. The most important characteristic of the power plant includes simplicity, low-cost construction, commissioning, operation, maintenance and close to the consumer, particularly in a remote area.

The performance of the power plant depends upon a site selection area. Due to evaluate the performance of the power plant, in the research some main roads of Iran selected, as shown in Table 1. The monthly statistical data of traffic in each route has collected for one year. To estimate harvesting energy of the vehicles' movement of each route, the collected data used.

The collected data of selected routes with a monthly average traffic load of 1.5 million to 6.7 million vehicles, shown the pedal power plant with a pair of pedals generates 2.2 to 10 MWh electricity. For the same power output quantity, from a solar power plant is required 8 to 36 m^2 panel area, depends upon the site location.

By increasing number of the pedals pairs to 20, output electricity increases from 44 to 200 MWh, which in turn, the panel area of equivalent the solar plant becomes 160 to 720 m^2. The research has shown that winds potential is not significant for the same area.

The pedal power plant is more reliable and consistence than wind or solar power plant. It is more environmentally friendly and prevents from producing harmful gases.

Future studies can be focused on efficiency improvement of devices, costs of maintenance and operations for the pedal power plant. Construct a prototype pedal power plant for data acquisition and improvement of devices.

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