



Wind energy harvesting from transport systems: A resource estimation assessment



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HIGHLIGHTS

- Harvesting wind energy from aerodynamic losses of heavy vehicles is investigated.
- The energetic rationale complies with emerging sustainable energy policies worldwide.
- Measured correlation of wind speeds with traffic flow allow fitting to any motorway.
- Traffic related wind drops could affect transient behavior of the energy conversion device.
- The harvestable energy is calculated from traffic-induced wind resource estimation.

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ABSTRACT

Many recent patents worldwide address the concept of harvesting wind energy from aerodynamic losses in motorways, however the mechanics of a specific device dedicated to the task has never been described. The lack of a characterization of the energy resource likely explains why the international market is still to acknowledge any technology related to the concept. Here, an experimental activity is presented to investigate the flow field generated by traffic in motorways and eventually develop an innovative technology that complies with emerging energy policies. In the case of traffic source, the energetic rationale seems to have a double motivation: there will always be an optimal energy supply associated with an increment in transport demand and, contrary to other renewables, the transport aerodynamic losses belong to a source of costs, making them a remarkably sustainable energy source. After a thorough analysis of the correlation between truck flow and wind speed classes, the characterization of a resource indicator for time of wind above a cut-in speed is given, with an account for the effects of traffic clusters and traffic related wind-drops. We demonstrate how during weekdays daytime hours the traffic-generated resource can allow an energy conversion beyond a threshold possibly permitting a positive energetic balance of the system. A study on the effect of traffic related wind-drops is also carried out to investigate how the issue could be relevant in the transient behavior and ultimately in the performance of a mini wind turbine in the kW-range. While many findings relate to the motorway site where the campaign was sited, fitting of the experimental data to the generic motorway case permits to explore a complete range of traffic flows.

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1. Introduction and motivation

By the end of the last decade a considerable number of patents (i.e. [1–3]) appeared on the worldwide scene, addressing the idea of harvesting wind energy generated by traffic. To the best authors' knowledge, none of the inventions describe the mechanics of a

brand new device dedicated to the task. Furthermore, a scientific study to assess the selected resource has never been performed, although it is known that traffic-induced wind properties are quite different from atmospheric wind, to which existing turbines are dedicated. The lack of characterization of such energy resource could explain why the market is yet to acknowledge any technology related to the cited patents. We report the results of an experimental activity started in 2010, whose final objective is to investigate the flow field generated by traffic in motorways and

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to eventually develop an innovative technology to comply with novel energy policies being established, e.g. in the Far East [4].

It is known that atmospheric and traffic contributes to the flow field occurring near motorways can hardly be distinguished [5]. However, it is necessary to assess to what extent an aero-generator is fed either by ambient or traffic, in order to correctly estimate the energy balance. To this end, as an entry point we decided to study a streamlined system presenting the simplest energetic contributes. Hence, among the possible scenarios (motorway, railway, waterway or airside flow in airports), we addressed the general case of ground vehicles impacting air in a straight motorway segment, in the absence of any other obstacle that could modify the flow field (i.e. tunnel exits, urban canyons).

From an economical viewpoint, the idea of harvesting wind energy from traffic can be linked to energy policies making development more sustainable in the transport sector. While mentioning the optimal level of renewable energy supply in general, Munasinghe defines it as the quantity at which the costs of the new (marginal) plant are exactly equal to the avoided costs connected with fossil generation, including environmental damage [6]. Fig. 1 illustrates the proposed case of traffic-induced wind energy, the rationale of which is supported by the following two evidences:

1. There will always be an incremental optimal quantity of energy supply, associated with an increment in transport demand. In fact the costs saved today include fossil generation connected with transport systems but even in a more sustainable future, when transport systems will eventually not rely on fossil generation, an optimal supply will still remain because of permanent aerodynamic losses. Here the cost of wind energy supply is cautiously assumed to balance the cost of future transport power source;
2. Contrary to other renewables, the aerodynamic losses are themselves a source of costs, inherent in any transport demand. Aerodynamic losses are thus a remarkably sustainable potential energy resource, which would still be present in transports not

relying on fossil generation. Theoretically, after deduction of the machine efficiency, the energetic loss is positively given back in the transport system balance.

As power consumption of heavy vehicles (i.e. trucks) can be 10 times higher than that of light vehicles, the energetic rationale of a harvesting concept starts from heavy-vehicle loss-repartition analysis. It can be estimated that for a US Class 8 truck the aerodynamic power losses are as much as 25% of the total 382 kW consumed, in average loading conditions and travelling at a constant speed of 105 km/h [7].

A new clean technology would employ aerogenerators positioned close to the road strip (e.g. [1–3]). It can be argued that highway users would perceive such devices as an obstacle, disturbing their free run. It is therefore critical to prove that the aerogenerator is not subtracting power from running vehicles, in the context of an energy balance [16]. Our studies on ground-vehicle induced flows in the presence of a panel obstacle show how drag coefficient deviations from the undisturbed value grow with increases in panel width up to 15% of the truck length, but the additional energy loss is limited to <1.5% of the corresponding loss without any obstacle [8]. Therefore, an ideal energy conversion device would be able to harvest more than 1.5% of the aerodynamic losses (i.e. a 1.4 kW threshold in terms of corresponding vehicle power losses), providing a positive balance of the system.

To place a conversion system the closest to the energy source, one might ask how are the losses distributed in the space surrounding the vehicle. Mattana et al. [8] find on top of the truck a significant net flow oriented in the trailing direction. Because of high turbulence in the space between wheels and pavement, and because the sides are either one lane away (emergency lane) or moving (due to overtaking), the top of the truck becomes the best candidate for positioning the device. In this study, we measured the wind generated from heavy traffic aerodynamic losses through the implementation of an experimental set-up of ultrasonic anemometers (USAs) and videocameras in a straight motorway section: the instruments were placed at the minimum vertical

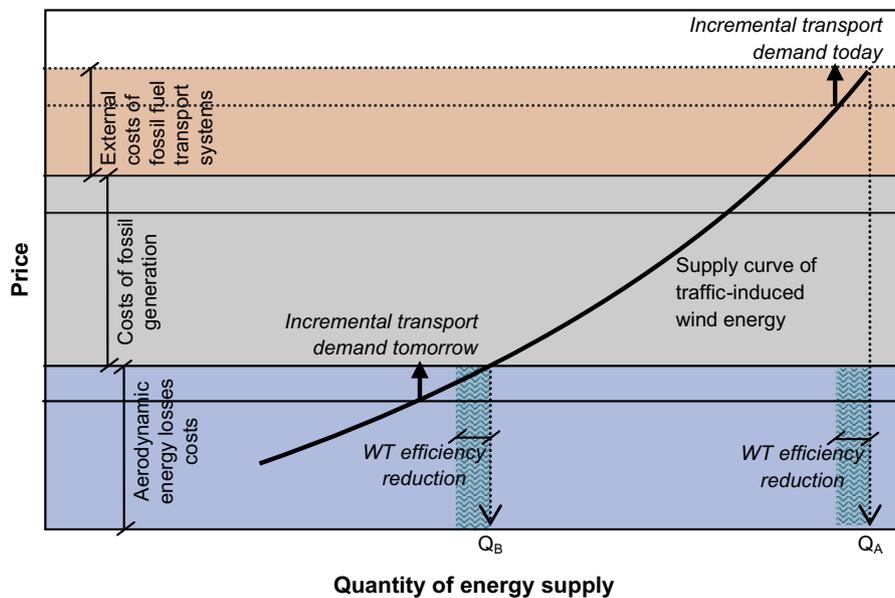


Fig. 1. Optimizing the supply of traffic-induced wind energy by comparing the levels of costs. There will always be an incremental optimal quantity of energy supply (bold curve) associated with an increment in transport demand (vertical bold arrows): in fact today we find Q_A , as we need to sum all the internal and external costs connected with fossil generation, but in a more sustainable future when transport systems will eventually not rely on fossil generation we still find Q_B , as the optimal supply quantity originates from the permanent aerodynamic losses. It is always needed to allow a reduction due to wind turbine efficiency, and cost of wind energy supply is cautiously assumed to balance cost of future transport power source.

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