Environmental Research 165 (2018) 40–45

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Long-term exposure to wind turbine noise at night and risk for diabetes: A nationwide cohort study

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ARTICLE INFO

Keywords:
Wind turbine noise
Diabetes
Epidemiology

ABSTRACT

Focus on renewable energy sources and reduced unit costs has led to increased number of wind turbines (WTs). WT noise (WTN) is reported to be highly annoying at levels from 30 to 35 dB and up, whereas for traffic noise people report to be highly annoyed from 40 to 45 dB and up. This has raised concerns as to whether WTN may increase risk for major diseases, as exposure to traffic noise has consistently been associated with increased risk of cardiovascular disease and diabetes. We identified all Danish dwellings within a radius of 20 WT heights and 25% of all dwellings within 20–40 WT heights from a WT. Using detailed data on WT type and hourly wind data at each WT position and height, we estimated hourly outdoor and low frequency indoor WTN for all dwellings, aggregated as nighttime 1- and 5-year running means. Using nationwide registries, we identified a study population of 614,731 persons living in these dwellings in the period from 1996 to 2012, of whom 25,148 developed diabetes. Data were analysed using Poisson regression with adjustment for individual and area-levels covariates. We found no associations between long-term exposure to WTN during night and diabetes risk, with incidence rate ratios (IRRs) of 0.90 (95% confidence intervals (CI): 0.79–1.02) and 0.92 (95% CI: 0.68–1.24) for 5-year mean nighttime outdoor WTN of 36–42 and $\geq$ 42 dB, respectively, compared to $<$ 24 dB. For 5-year mean nighttime indoor low frequency WTN of 10–15 and $\geq$ 15 dB we found IRRs of 0.90 (0.78–1.04) and 0.74 (95% CI: 0.41–1.34), respectively, when compared to and $<$ 5 dB. The lack of association was consistent across strata of sex, distance to major road, validity of noise estimate and WT height. The present study does not support an association between nighttime WTN and higher risk of diabetes. However, there were only few cases in the highest exposure groups and findings need reproduction.

1. Introduction

Focus on renewable energy sources has increased globally during the last decades, which together with reduced costs has led to an increased number of wind turbines (WTs). WT noise (WTN) has consistently been associated with annoyance among people living by. Schmidt and Klokker (2014), Michaud et al. (2016a), Janssen et al. (2011), Michaud et al. (2016b). Also, reviews and meta-analyses have found WTN to be associated with self-reported disturbance of sleep, (Schmidt and Klokker, 2014; Onakpoya et al., 2015) although recent studies using objective measures of sleep have failed to find an association (Michaud et al., 2016; Jalali et al., 2016). This has raised concern as to whether WTN may increase risk for major diseases.

Recent studies have found exposure to road traffic and aircraft noise to be significantly associated with higher risk of diabetes, (Sorensen et al., 2013; Eze et al., 2017a; Clark et al., 2017) whereas no association was found for railway noise (Roswall et al., 2018). In support of this, traffic noise has been associated with major risk factors for diabetes, including fasting blood glucose, (Cai et al., 2017) glycosylated hemoglobin, (Eze et al., 2017b) obesity (Eriksson et al., 2014; Pyko et al., 2015, 2017; Christensen et al., 2016) and physical inactivity (Roswall et al., 2017; Foraster et al., 2016). The believed pathophysiologic pathways behind noise as a metabolic risk factor are activation of a general stress response and disturbance of sleep, which may lead to reduced insulin secretion and sensitivity, reduced glucose tolerance and altered levels of appetite-regulating hormones (Spiegel et al., 2004; Taheri et al., 2004; Mazziotti et al., 2011; McHill and Wright, 2017). Also, reduced sleep quality and quantity have both consistently been

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https://doi.org/10.1016/j.envres.2018.03.040
Received 5 December 2017; Received in revised form 23 February 2018; Accepted 26 March 2018

shown to increase risk of diabetes (Cappuccio et al., 2010).

Findings on traffic noise and diabetes are not readily applicable to WTN. Levels of WTN are generally much lower than noise from traffic in urban settings. However, WTN has been associated with a higher proportion of annoyed residents than traffic noise at comparable sound levels (Janssen et al., 2011). While people start reporting WTN to be highly annoying at levels from 30 to 35 dB and up, traffic noise is generally not reported as highly annoying at levels below 40–45 dB (Michaud et al., 2016). A potential explanation is that WTN depends on wind speed and direction making it less predictable than traffic noise, where the latter e.g. often abates at night. Also, amplitude modulation may give WTN a rhythmic quality different from e.g. road traffic noise. It has therefore been suggested that the characteristics of WTN relevant for annoyance may be better captured by metrics focusing on amplitude modulation or low frequency (LF) noise, rather than the full spectrum A-weighted noise as typically used in studies of traffic noise (Jeffery et al., 2014). A review from 2016 on LF noise (from various sources) indicated that LF noise was associated with annoyance and potentially sleep disturbance, although it was added that research in this area was scarce and with methodological short-comings (Baliatsas et al., 2016). Lastly, WTs are often placed in rural areas, where the auditory impact of WTs may be more pronounced as compared to more densely populated areas, due to less background noise from traffic, industry and others.

Two studies have investigated associations between WTN and self-reported diabetes: (Michaud et al., 2016a; Pedersen, 2011) A Canadian study of 1238 participants living within 12 km of a WT, among whom 113 reported to have diabetes, found no associations between estimated A-weighted residential WTN and prevalent diabetes (Michaud et al., 2016a). In the second study, results from two Swedish and one Dutch study population(s) were presented. In one of the Swedish study populations (N = 744), A-weighted residential WTN was associated with an odds ratio (OR) for prevalent diabetes of 1.13 (95% confidence intervals (CI) 1.00–1.27) in analyses adjusted for age and sex. However, no association was seen for the other two study populations (N = 1011, ORs of 0.96 and 1.00) (Pedersen, 2011). Both of these studies were cross-sectional, which prevent conclusions on causality and chronological order of events, and with risk of selection and recall bias. No prospective studies have investigated associations between WTN and diabetes.

We aimed to prospectively investigate associations between long-term residential exposure to WTN and risk for diabetes in a nationwide register based study, combining data on WTN, meteorology, WT position and type, residential addresses, development of disease and socioeconomic indicators over the period 1996–2012.

2. Methods

2.1. Study base and estimation of noise

The study was based on the entire Danish population, where all citizens since 1968 can be tracked in and across all Danish health and administrative registers by means of a personal identification number (PIN) maintained by the Central Population Register (Schmidt et al., 2014).

We identified all WTs (7860) in operation in Denmark any time between 1980 and 2012 from the administrative Master Data Register of Wind Turbines maintained by the Danish Energy Agency. It is mandatory for all WT owners to report cadastral codes and geographical coordinates of their WT(s) to the registry. Furthermore, for WTs in operation at the time of data extraction, the register also contained coordinates from the Danish Geodata Agency. In case of disagreement between the recorded geographical locations, the WT location was validated against aerial photographs and historical topographic maps of Denmark. Of the 7860 WTs, we excluded 517 (6.6%) offshore WTs. Furthermore, we excluded 87 (1.1%) WTs with two (or three) different registered locations, for which we were unable to identify the correct location based on aerial photographs and historical topographic maps. Moreover, 314 (4.0%) WTs wrongly recorded in the Master Data Register were assigned new coordinates based on maps and aerial photographs, leaving 7256 WTs for investigation. On the basis of information on height, model, type and operational settings (when relevant) from the register for all WTs each WT was classified into one of 99 noise spectra classes, with detailed information on the noise spectrum from 10 to 10,000 Hz in thirds of octaves for wind speeds from 4 to 25 m/s. These noise classes were made from existing measurements of sound power for Danish WTs (Backalarz et al., 2016; Sondergaard and Backalarz, 2015).

For each WT location, we estimated the hourly wind speed and direction at hub height for the period 1982–2012, using mesoscale model simulations performed with the Weather Research and Forecasting model (Hahmann et al., 2015; Peña and Hahmann, 2017).

The WTN exposure modelling has been described in details elsewhere (Backalarz et al., 2016). In summary, using a two-step approach we first identified buildings eligible for noise modelling defined as all dwellings in Denmark that could experience at least 24 dB outdoor noise or 5 dB indoor low frequency (LF, 10–160 Hz) noise under the unrealistically extreme scenario that all WTs ever operational in Denmark were simultaneously operating at a wind speed of 8 m/s with downwind sound propagation in all directions. In the second step, we performed a detailed modelling of noise exposure for the 553,066 buildings identified in step one, calculating noise levels in 1/3 octave bands from 10 to 10,000 Hz using the Nord2000 noise propagation model (Kragh et al., 2001), taking into account the time varying weather conditions. The Nord2000 model has been successfully validated for WTs (Sondergaard et al., 2009). For each dwelling, the noise contribution from all WTs within a 6000 m radius was calculated hour by hour. These modelled values were then aggregated over the period 10 p.m. to 7 a.m. (nighttime), which we considered the most relevant time-window because people are most likely to be at home and sleep during these hours. We calculated outdoor A-weighted sound pressure level, which is the metric most commonly used in noise and health studies, (Pedersen, 2011; Michaud et al., 2016d). as well as A-weighted indoor low frequency (10–160 Hz) sound pressure level, as LFN easier penetrates buildings, and has been suggested to be an important component of WTN in relation to health (Jeffery et al., 2014).

The quality of noise spectra available for different wind turbine models differed and these spectra were typically only described at certain wind speeds. We therefore determined a validity score that for each night and dwelling summed up information for all contributing WTs on the number of measurements used to determine the WTN spectra class, and how closely the simulated meteorological conditions of each night resembled the conditions under which the relevant WTN spectra were measured.

For the calculation of indoor LFN, all dwellings were classified into one of six sound insulation classes based on building attributes in the Building and Housing register (Christensen, 2011): "1½-story houses" (residents assumed to sleep on the second floor), "light façade" (e.g. wood), "aerated concrete" (and similar materials including timber framing), "farm houses" (remaining buildings in the registry classified as farms), "brick buildings" and "unknown" (assigned the mean attenuation value of the five previous classes). The frequency-specific attenuation values for each of the six classes are shown in (Backalarz et al., 2016).

2.2. Study population

When defining the study population, we identified all dwellings ever situated within a radius of 20 WT heights of a WT as well as a random selection of 25% of all dwellings situated between 20 and 40 WT heights from a WT, thus including all living close to WTs as well as a large population living in the same areas, but with little or no exposure.