Health impact assessment in case of biofuel peat – Co-use of environmental scenarios and exposure-response functions

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\textbf{A B S T R A C T}

Peat will be used more widely for heating in Tartu (Estonia), therefore the potential health effects needed to be assessed. In transition from today’s gas heating to burning of peat, the amount of exhaust gases emitted will increase and more than 100,000 people will be exposed to greater health risks. Based on the peat quality data, the emissions were calculated and their dispersion in Tartu was modelled using the air pollution dispersion and deposition model AEROPOL. The AirQ software, developed by the WHO, was used for calculating the health impacts. The number of years of life lost (YLL) due to the emissions from peat burning was estimated to be up to 55.5 in a year within the population of Tartu (101,000 citizens). However, in perspective, this would be about 28 times less than YLL calculated due to emissions from traffic, local heating etc.

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1. Introduction

Aspects related to economic effectiveness and global and local pollution as well as the politics of sustainable development have to be taken into account when choosing the fuel type in big plants. The rise in the price of natural gas on the global market and geopolitical issues force communities to seek alternative fuels, often local ones. Before new pollution sources are established in towns, it is important to assess their potential effects, particularly on human health. A study focused on the change of fuel type in Tartu (58° 21’ 58” North, 26° 44’ 10” East) in Estonia provides the opportunity to assess future air pollution scenarios and their effect on human health risks.

Peat is an important fuel in Estonia. According to Lappalainen [1], Estonia has vast peat reserves relative to its small area (0.3% of global deposits). Because of large resources and big peatland areas in Northern Europe – peat has been defined as slowly renewable biomass fuel in Finland, Sweden, Estonian and Latvia. Currently, peat accounts for up to 6% of the total fuel consumption for heating in Estonia, but it is increasing [2]. Since peat is a local fuel, the price has been more stable and lower compared to imported fuels. As new technologies allowing for broader use of peat are under

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development (for instance, the pellet industry), there is great concern for the impact it will have in the future [3]. There are now plans to build a new district heating and power station in Tartu using milled peat as the fuel and in the future also to Pärnu. Even peat is not internationally classified as biofuel, its properties and combustion are very similar to biomass, since it is organic matter [3–5]. As peat produces more particulate matter and sulphur dioxide per unit of energy than the gas currently used in big boiler houses [4] and several other biomasses [6], it is important to assess the expected changes in air quality. It is also essential to quantify the possible future threats to public health, since health impacts have been recognized in various situations where different fuels (lignite, coal, oil) have been used in power plants [7].

The current study endeavours to employ scenarios of changes in air pollution exposure simultaneously with available exposure-response functions. In particular, the aims of the current study are to consider information on the fuel quality (peat), model the impact on ambient concentrations, and calculate the years of life lost (YLL) due to this exposure. It also aims to provide a broader perspective by comparing the impact of boiler-house emissions with the effects induced by other sources of air pollution. The analysis aspires to provide insight into further use of the applied methodology for environmental health management and local health impact assessments.

1.1. Health effects of air pollutants

Some air pollutants that occur due to combustion of fuel for heating purposes are obviously harmful, and it has been suggested that they pose the greatest risk, after traffic pollutants [8]. Although people spend most of their time indoors, studies show that in most cases the air quality in a building is very much affected by the outdoor air quality [9]. The research carried out worldwide has focused on evaluating health effects and mortality related to short-term concentrations. It has been shown that mortality significantly varies with daily concentrations of outdoor air pollutants, especially particles [10–12]. Fewer studies have dealt with the effects of moderate long-term particle concentrations that cause most of the YLL due to air pollution. Several epidemiological studies of plausible mechanisms have shown that exposure is mostly associated with respiratory and cardiovascular diseases [13].

It is usually assumed that most of the negative effects are caused by particulate matter [12]. In this case, the particulate matter forms in the condensation processes of peat ash and volatile organic compounds [14]. If peat contains heavy metals (for instance Pb, Cd), they are also found in the particles [15]. It is hard to establish the precise causal relationships that lead to air pollution health effects, because associations are complicated [13]. Fine particulate matter, usually measured as mass concentration with a cut off at 2.5 μm, (PM2.5) can reach the lung alveoli and is likely the dominant factor in health effects [16]. Recently the oxidative properties of pollutants have been established as an important cause of variations in toxicity [17]. However, experts still do not find enough evidence to suggest specific exposure-response assumptions for particles of different origin or composition [12].

1.2. Determinants of the air pollution concentrations

Many factors, such as the number and intensity of pollution sources (traffic, heating, industry), meteorological conditions (wind speed and direction, radiation, temperature, moisture, speed of deposition, chemical reactions), affect the concentration of air pollutants in the atmosphere. Dispersion of pollutants in the air depends mostly on weather. The influence of the same weather conditions on the breathing-level concentrations may dramatically differ for dispersion from ground-level and elevated pollution sources. In general, the air quality in Estonia has been improving due to diminution of industry after the collapse of the Soviet Union [18]. Nevertheless, as the number of vehicles is rising expeditiously in Estonia, the situation will probably be worsening in certain areas in the future [19].

2. Materials and methods

A health impact assessment (HIA) usually integrates scientific results from disciplines such as exposure assessment, toxicology and epidemiology. The air pollution HIA process involves linked stages of emission calculations, air quality assessment, identifying the population at risk, choosing the endpoint and the exposure-response functions, characterizing the background rates of the chosen endpoint and quantification of the health effects.

2.1. Fuel quality information

As the content of peat varies largely, prior to using it as a fuel, the content of ash, sulphur and trace elements etc. must be determined. The database previously compiled by Orru and Orru [20] was used to evaluate the quality of peat presently mined from Sangla and Möllatsi peatlands for future fuel purposes. Additionally 35 samples were taken in 2005 to assess the peat quality at Sangla peatland study area that is intended to be used as fuel for heating in Tartu in the future. Samples were collected from the whole peat section after every 0.5 m per one coring. A detailed description of methods is available in Orru and Orru [20].

2.2. Calculation of future emissions and modelling of concentrations

For emission calculations, at first, the potential power of the boiler houses was taken into account. The quality of peat was assessed according to peat analyses. Assuming that the quality of peat is similar to the commonly used peat, we can use emission coefficients established by Estonian legislation [21]. The emission of pollutants (Mpa) was determined using the following equation:

\[ M_{pa} = 10^{-3} \times P \times q, \text{ g s}^{-1}, \]

where

- \( P \) – the power of the boiler, MWth;
- \( q \) – emission coefficient, g GJ\(^{-1}\).
The air pollution dispersion model AEROPOL [21] was applied to calculate the annual average and maximal hourly average concentrations of pollutants emitted from peat-fired furnaces. The AEROPOL model is based on the classical concept of a plume advected downwind and described by Gaussian distributions in lateral and vertical directions. Convective or inversion conditions depending on input meteorological data, initial rise of heated stack gas, and dry and wet deposition of pollutants are taken into account in AEROPOL. Surfer 7.0 software was used for graphical presentation of the figures.

The assessment of exposure and health impact had to be based on available demographical and base-line mortality data for Tartu [2]. As precise demographical information on the number of inhabitants near the boiler houses was not available, it was estimated for the exposed area using dispersion maps and population density data.

2.3. Assessment of health risk and calculation of years of life lost

The number of YLL induced by fine particles (PM$_{2.5}$ fraction) was calculated using the software AirQ 2.2.3, developed by World Health Organisation (WHO). In current and previous HIAs the relative risks associated with increased levels of PM$_{2.5}$ and PM$_{10}$ have been based mainly on one US cohort study [22] and have assumed the same effects regardless of particle sources [23]. It is likely that the effects and toxicity are related to particle composition, size distribution and sources [12]. The PM components from combustion (metals, PAH, acids) are believed to increase the toxicity, thus the relative risk per mass concentration for local sources in a city could be higher than expected from between city comparisons, as shown in Los Angeles County [24]. Relative risk (RR) is a ratio of the probability of the event occurring among exposed versus others at the reference level of exposure. In addition to the default risk assumption for PM$_{2.5}$, RR = 1.06 (6%) per 10 $\mu$g m$^{-3}$ (recommended RR [22] in the AirQ software), the calculations in this study were made also with RR from the Jerrett et al. study [24], 17% per 10 $\mu$g m$^{-3}$, since the modelled peat combustion particles are assumed to be in the fine particle mode. The software calculates the years of life lost (YLL) due to mortality and gives the results per year per 100 000 inhabitants.

2.4. The base-line air quality

The assessment of base-line air quality was conducted using official air pollution monitoring data. Particles (as PM$_{10}$), sulphur dioxide (SO$_2$), nitrogen dioxide (NO$_2$) and carbon monoxide (CO) were analysed in February–March 2003, May–June 2004 and September–October 2005. Five study areas were chosen: Riia Street (street with heavy traffic), Tamme Street (residential area), Anne Street (block houses area), Jaani Street (town centre) and Turu Street (main crossroad). A mobile air laboratory based in a van (operated by the Estonian Environmental Research Centre) was used. Levels of SO$_2$, NO$_2$, CO and O$_3$ were determined using the UV fluorescence, chemiluminescence, UV-photometry and flame-ionisation methods. PM$_{10}$ was measured using the FH 62-I-R $\beta$-radiation absorption equipment. To collect meteorological data, the Thies Clima 7 m high meteorological mast was used.

3. Results

3.1. Peat quality

Analyses showed that the levels of ash, sulphur and trace elements in peat from the prospective sources for Tartu peat-fuelled boiler houses are lower than Estonian average values and far below the limit values (Table 1). These results confirmed that previously computed calculation coefficients from Estonian legal acts could be used [21].

3.2. Scenarios for heating plant emissions and resulting exposure levels

In the dispersion model the power of the boiler, emission of pollutants, boiler position and the height of the stack were taken into account. Three big boiler houses (BH) presently operate in Tartu: Central BH in the centre of town, Anne BH near a residential area (block houses) and Ropka BH in an industrial area (Figs. 1 and 2). Anne and Ropka BH use mainly wood and gas, and Central BH uses gas. The company that operates the boiler houses has launched peat-mining operations due to plans to burn more peat. They plan to start power production in Central BH, enabling it to operate as a cogeneration plant. The amount of energy produced annually from peat in the future would be 80 GWh (boiler’s max power 18.9 MW) in Ropka BH, 210 GWh (36 MW) in Anne BH and 270 GWh (45 MW) in Central BH. During extremely cold periods when larger amounts of energy are needed, the gas boilers would be used as well. The height of the stacks and the locations would remain as they are now.

The hourly maximum concentrations caused by burning of peat in these boiler houses (with previously given emission coefficients) would be 19 $\mu$g m$^{-3}$ PM$_{2.5}$, 44 $\mu$g m$^{-3}$ SO$_2$ and 65 $\mu$g m$^{-3}$ NO$_2$. This is much more than the maximal annual average concentrations: 1.5 $\mu$g m$^{-3}$, 4 $\mu$g m$^{-3}$ and 1.9 $\mu$g m$^{-3}$, respectively. The dispersion of combustion particles (as PM$_{2.5}$), judged to be the most hazardous from a health point of view, is shown in Figs. 1 and 2. The peaks appear ~600 m downwind in quite a small area (Figs. 1 and 2). As the meteorological

| Table 1 – The content of trace element in peat used for heating in Tartu (mg kg$^{-1}$; ash, %) |
|---------------------------------|----------------|---------------|--------|----------|--------|
| Sangla nowadays | Sangla potential | Möllatsi | Estonian average | Limit value |
| Ash | 4.4 | 6.6 | 3.7 | 6.5 | – |
| S | 0.23 | 0.06 | 0.25 | 0.3 | |
| Cd | 0.04 | 0.1 | 0.05 | 0.12 | 1 |
| Hg | 0.1 | 0.1 | 0.5 | 0.5 | |
| U | 0.3 | 3.7 | 0.07 | 1.27 | 20 |
| Cr | 0.6 | 0.7 | 1.4 | 3.1 | 100 |
| Cu | 2.3 | 2.2 | 4.4 | 4.4 | 100 |
| Ni | 0.9 | 1.4 | 1.4 | 3.7 | 50 |
| Pb | 1.8 | 7.5 | 4 | 3.3 | 50 |
| Zn | 6.7 | 7.7 | 3 | 10 | 200 |
conditions vary, the maximum concentrations usually do not persist for more than a few hours. When the other pollution sources (traffic, local heating etc.) are added, the annual mean concentrations may end up more than 20 times higher than the contribution from the boiler houses.

The air quality in Tartu is measured only once a year during two weeks. This gives only an approximate view of the annual air pollution concentration. According to data from 2003 and 2004, the concentration of pollutants remained below the official limits (Fig. 3). Currently, the biggest problem is the PM$_{10}$ because in conditions of atmospheric inversion, especially in winter, the limit concentrations can be exceeded. The concentrations of SO$_2$, CO, O$_3$, and NMHC were quite low.

### 3.3. Health effect assessment

Estimated concentration of heavy metals in peat was not high. However, the study carried out by Jerrett et al. [24] in Los Angeles indicates that the combustion particles could be more hazardous than particles typically found in outdoor air. Thus, the calculations for boiler-house pollution were still made with RR = 1.17 per 10 $\mu$g m$^{-3}$. According to the population
density and position, about 11,000 inhabitants are living near the boiler houses (Fig. 2). These people are exposed to higher concentrations of peat combustion PM$_{2.5}$ (up to 1.5 $\mu$g/m$^3$). The calculated YLL for this group would be 36 per year (Table 2). Other citizens of Tartu (90,000) would be exposed to lower concentration of peat combustion PM$_{2.5}$ (up to 0.1 $\mu$g/m$^3$). The calculated YLL for the rest of population would be 19.5 per year (Table 2).

Based on monitoring measurements, the average regional background PM$_{10}$ level in Tartu is 9 $\mu$g/m$^3$ out of a total measured level of 37 $\mu$g/m$^3$. According to a meta-analysis the average PM$_{2.5}$/PM$_{10}$ ratio is 0.73 [25], which allows PM$_{10}$ concentrations to be recalculated to PM$_{2.5}$. The calculation of YLL due to the actual particle concentrations induced by all sources was made with a RR of 6% per 10 $\mu$g/m$^3$ on average, which is used as default assumption in AirQ based on Pope et al. [22]. The total YLL induced by all sources (PM$_{2.5}$ concentration 20 $\mu$g/m$^3$) would reach just over 1500 comparatively for the whole population of Tartu in a year (Table 2).

4. Discussion

4.1. Impact of peat burning on air quality

The main health effects caused by burning of peat appear due to formation of particulate matter in combustion processes. Parts of trace elements in peat are bound with particulate matter in exhaust gases, but due to small concentrations and dispersion it does not considerably affect air quality to a large extent. The studies have shown that in combustion processes a lot of fine PM is emitted and several authors have discussed how this fraction has the main role in health effects [16]. Linna and Selin [4] have found that peat with wood is a good combination, as it balances the negative sides of both fuels. It will be probable scenario also in Tartu, as wood waste is largely available.

The contribution from boiler houses to the annual concentrations of pollutants is 15 or even more times lower than contributions from other sources, and currently the affected areas near boiler houses in suburb and industrial regions are sparsely populated. But due to urban sprawl, new residential areas are planned near Anne boiler house.

The main effect is detectable for the smaller area and background concentrations. The 1-h average concentration is much higher and can reach up to 19 $\mu$g/m$^3$ of PM$_{2.5}$. Thus, the effective flue-gas purification systems should be used. The similar height of stacks of Anne and Ropka BH affects the dispersion, though the co-effects can be recognized in the city (Figs. 1 and 2). Because of its high stack (90 m), Central BH affects mainly the background concentration (Figs 1 and 2). Local heating generally can cause very high air pollution concentrations, especially in Tartu, where it constitutes 1/3 of all heating [26]. The stacks of individual houses are low, burning technology is poor, and filters are not used. Currently peat is very seldom used for local heating [27].

<table>
<thead>
<tr>
<th>Table 2 – Calculation of years of life lost.</th>
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<tbody>
<tr>
<td>Type of pollution level</td>
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<td>--------------------------</td>
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<tr>
<td>Induced by boiler houses near boiler houses</td>
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<tr>
<td>Induced by boiler houses in the rest of city</td>
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<td>Induced by all sources</td>
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Fig. 3 – The maximum daily average concentration of pollutants in outdoor air of Tartu ($\mu$g/m$^3$).
4.2. Years of life lost

The appearance of new pollution sources (and their positions) affects the health of the population in the city. Episodes of high pollution levels are driven by meteorological conditions, fuel type, combustion technology and height of stack. The YLL per year calculated due to the annual PM$_{2.5}$ contribution from boiler houses close to these sources is 36 (95% CI = 26–46). For the rest of the population, approx. 90 000, the estimated YLL per year is 19.5 (95% CI = 14–25). It could be possible that the minor increase in their exposure concentration (on average 0.1 mg/m$^3$) to some extent falls below a biological threshold value. When comparing the impact of the boiler-house emissions with the measured air pollution levels in city and the estimated 1539 (403–2682) YLL per year, the difference is impressive. As base-line Estonian mortality is high [2], the influence of air pollution is nevertheless greater. It is also worth considering that the given air pollution level is not very reliable since it is only measured once a year during two weeks, but at least the trend is clear. Our results show that other sources have much greater influence on the city outdoor air quality than boiler houses, even with a scenario in which more polluting peat is used. In Sweden, Jonsson and Hillring [27] have shown that conversion from electrical heating to biofuels or wood-pellets would have no considerable effect on air quality in studied areas. Levy et al. [28] and Pekkanen et al. [29] have determined only minor effects from power plants to air quality in USA and Finland. But López et al. [30] have found in their work that boiler houses could have quite significant influence. Also Krewski et al. [31] have claimed that the emissions from the power plant could increase the mortality estimates, though it seems that the type of fuel can be important and targeted studies are needed.

The confidence interval of YLL is quite wide, indicating that the PM effect on mortality can vary a lot depending on other factors and the population. Effect modification can be explained at least partly by socio-economic and life-style factors. As our study also indicates, the choice of RR matters a lot. Presently, 1.06 per 10 mg/m$^3$ PM$_{2.5}$ is widely used. In combustion emissions the particles are mainly smaller than in the outdoor air, where the coarse fraction is important [32]. Generally PM$_{2.5}$ is thought to be more toxic because it can be inhaled deeper into respiratory system [24]. Thus, the RR for combustion particles could be bigger, which is why we also chose to assume RR to be 1.17. In an HIA worst-case scenario should be taken into account, because it gives the best protection for the public.

Still many uncertainties remain: identifying the exposed group and the extent of individual exposure, selection of the RR as well as the content and fraction of particulate matter. Future extensions could include measurements of particles coming from the stack and epidemiological studies with nearby residents.

4.3. Perspectives

It is difficult to find one single effective way to minimize the health effects of air pollution. The potential impacts should be taken into account in environmental planning and management, urban management, and improvement of combustion technology. These decisions have a benefit-to-cost ratio in the range of 1–5 in the power sector, even in lower income countries like China [33]. The population’s well-being and health should be prioritised and awareness about health effects of pollutants should be improved.

5. Conclusions

1. The amount of YLL per year in the population of Tartu due to PM$_{2.5}$ induced by peat burning is up to 55.5 in one year. Compared to 1539 YLL per year induced by PM from all sources it is not a major air pollution problem.

2. The elaborated co-use of environmental scenarios and exposure-response functions proved to be valuable for HIA. It yielded good quality information for assessment of health impacts in development projects and provided stakeholders with guidelines for proper management of peat and biofuels.

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References


