

OCCUPATIONAL HEALTH AND SAFETY IN WIND TURBINES' MAINTENANCE: AN INVESTIGATION OF MAINTENANCE TECHNICIANS' PERCEPTIONS

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Abstract

The wind energy sector has evolved rapidly in recent years and has led to increased growth in wind farms as well as in new jobs. In the literature, risk factors in "green" jobs are a field of growing interest. The purpose of this study is to investigate the health and safety conditions and contributing factors during wind turbines' maintenance activities. The data collection was done by developing and sending a questionnaire to eight companies, operating in the field of wind turbine maintenance in Greece. Fifty questionnaires were completed by wind turbine maintenance technicians working in 6 out of the 8 companies that participated in the survey. The statistical analysis of the data was performed with LISREL structural equation modeling. The results showed that the mental health of technicians performing maintenance work on wind turbines is affected by adverse ergonomic conditions and increased levels of difficulty and insecurity in the workplace. Health problems associated with extreme fatigue, headaches and hearing problems are affected by both mental well-being of employees and difficulties they face in their work environment. This paper provides the basis for research into occupational health and safety conditions in a relatively new industry, highlighting the potential health and safety effects of wind turbine maintenance activities.

Keywords: wind energy sector, occupational health and safety, maintenance works, LISREL

1. INTRODUCTION

The wind energy sector has evolved rapidly in recent years, due to international policies and national strategies towards investing in renewable energy sources, as a means of environmental protection. Wind power is a clean and renewable form of energy production, which exploits the air of an area for the purpose of producing electricity. The conversion of wind kinetic energy into electricity is achieved through wind turbines; many wind turbines in an area form a wind farm. Wind farms are divided into onshore (installation of wind turbines on land, usually in high altitude areas), and offshore (installation of wind turbines on platforms in the sea).

The development of wind farms worldwide has increased significantly in the last two decades. According to statistics from the Global Wind Energy Council (2019), the total installed capacity worldwide reached 650 GW (Gigawatt) at the end of 2019. Moreover, in 2019 a growth of 19% in new wind power installations compared to 2018 was observed. In terms of cumulative installations, the top five markets at the end of 2019 were: China, the US, Germany, India and Spain, which together accounted for 72% of the world's total wind power installation. In Europe, according to statistics from WindEurope (2019), the new wind power capacity in 2019 reached 15.4 GW, which is 27% more than 2018 but 10% less than the record year 2017. At the end of 2019, there were 205 GW of installed wind power capacity in Europe: 183 GW onshore and 22 GW offshore, which generated enough electricity to meet 15% of the EU-28 electricity demand at that year. Germany is the country with the largest installed capacity in Europe, followed by Spain, the UK, France and Italy. Greek statistics in recent years show that there is a significant growth in the field of wind power, as shown in detail in Figure 1 (Hellenic Wind Energy Association, 2020).

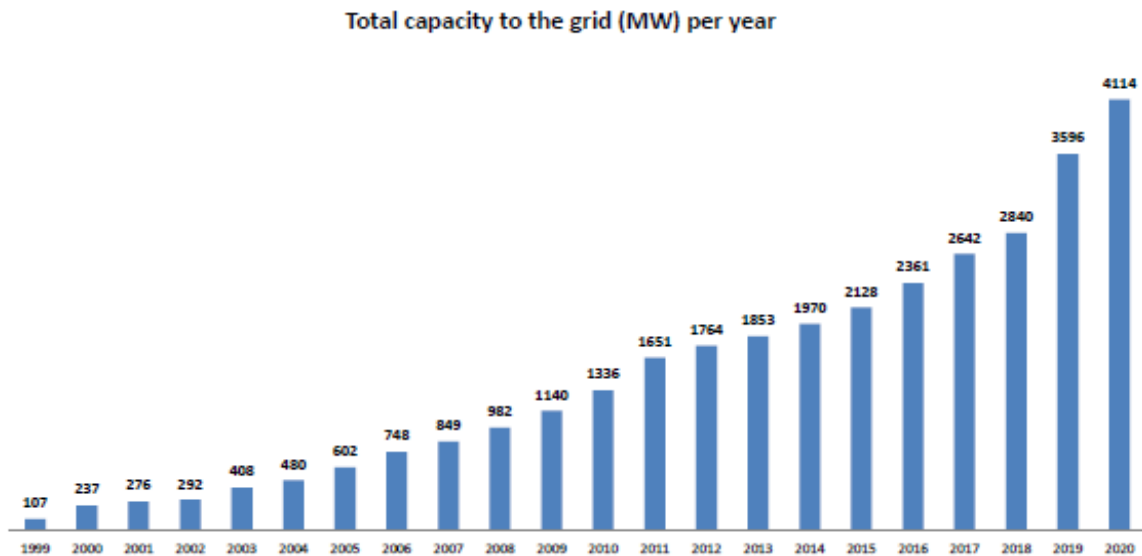


Fig. 1. Cumulative wind power capacity in Greece in years 1999-2020

Statistics on the number of jobs in the wind power sector are also of particular interest, as presented by the International Renewable Energy Agency (2019). While in all sectors of renewable energy technologies, more than 11.4 million persons were employed worldwide in 2019, the wind power sector is estimated to employ more than 1.6 million persons. China has the largest share of jobs in the wind energy sector, followed by Germany and the United States in second and third place, respectively. In the European Union, employment in the wind energy sector in 2017 corresponded to more than 350,000 jobs, while compared to the previous year there was an increase of 15% (EurObserv'ER, 2018).

In this fast-growing branch of the energy industry, workers are required to work with equipment that is technologically evolving over time and following work processes that are constantly revised due to this evolution. They also work mostly in remote work environments, and in conditions that have not yet been adequately researched in relation to their effects on occupational health and safety. In particular, during the period of transfer of the wind turbine components to the site of the installation, during the construction phase of the wind farms, and during the operation and maintenance phase of the wind turbines, workers are exposed to risks that can lead to serious or fatal injuries or long-term illnesses. Thus, occupational health and safety management is becoming a huge asset for all companies in this sector. Moreover, the development of common standards and regulations, and the delivery of appropriate vocational training for employees in the industry, is gradually recognized as a very important factor for employee safety (Steel, 2017).

A study by the European Agency for Safety & Health (2013) gathered available information on occupational health and safety information on the wind energy sector, and identified good practices and challenges for the coming years. In contrast to the extensive studies on the effects of wind turbine operation on public health, this study revealed a lack of scientific research on their effects on the safety and health of workers in the construction and operation of onshore and offshore wind farms.

The present research focuses on factors that, according to the literature, adversely affect the health and safety of wind farm workers, and tries to explore their existence and relevant severity among maintenance employees. The factors examined include the unfavorable ergonomic conditions that characterize the specific working environment, as well as the increased level of difficulty and insecurity due to the nature of the work. The above factors are related to mental health problems, such as depression, nervousness/insomnia, sleep disturbance, and stress, which also lead to worsening of other health problems, such as extreme fatigue, headaches, and hearing problems (Abbasi et al., 2016; Farboud et al., 2013). In addition, the effect of adverse ergonomic conditions on the occurrence and/or worsening of musculoskeletal disorders is investigated (Jia et al., 2016).

2. MATERIALS AND METHODS

Following a thorough literature review, a questionnaire was developed in order to investigate the workers' perceptions on maintenance works in wind turbines in terms of occupational health and safety.

The questionnaire was developed on the online platform Google Drive, thus ensuring the anonymity of the participants, and the ease and speed in its completion. The researchers initially communicated with the health & safety departments of eight companies, operating in the field of wind turbine maintenance in Greece. The selection of these companies was based on their size, high profile and good reputation. A request for participation was sent, together with information on the purpose of the study and a description of the project. From these eight companies, six participated in the survey and 50 questionnaires were answered online. The six participating companies are shown in Table 1.

Enel Green Power Hellas S.A.
Enercon
Enteka
Paralos Energy PC
Rokas/Iberdrola
Siemens Gamesa Renewable Energy

Table 1. Companies participating in the survey

The questionnaire includes 24 questions in total, which are divided into four sections as follows:

- Section A consists of four demographic questions, including sex, age, education, and years of employment.
- Section B consists of ten questions on possible health problems related to specific tasks. Some of these questions were based on the Nordic Musculoskeletal Questionnaire (Crawford, 2007), with the aim of investigating various musculoskeletal problems.
- Section C consists of four questions regarding ergonomic factors in the workplace of wind turbine maintenance technicians. These questions were selected from the research work of Jia et al (2016), according to which there is a link between ergonomic factors and the occurrence of low back pain.
- Section D consists of six questions investigating the subjective evaluation by the respondents, of specific factors in their work, such as the level of insecurity during the work, the adjustment to the requirements in the workplace, etc.

The questions in sections C and D as well as some in section B, have been formulated in such a way that the answer can be given on a scale of 1 to 5, with the smallest number in the answer indicating the most negative version of the question. This format enabled the completion of the questionnaire, and also facilitated the statistical analysis of the results.

The method applied in order to examine complex models of relationships between variables, considering all the model relationships simultaneously, was Structured Equation Modeling (SEM) and the statistical software used to implement the SEM method was LISREL (Mels, 2006). Three hypotheses were formulated by combining questions of sections B, C, and D, related to specific concepts under investigation (see Appendix).

To establish our first hypothesis, we selected questions #5, #8, #10, from section B, which measure the concept of Mental Health problems (MentHeal), questions #21, #22, #23, from section D, which measure the concept of Work Difficulty and Insecurity (WorkDifI), and questions #15, #16, #17, #18, from section C, which measure the concept of Adverse Ergonomic Factors (AdvErgFa). Hypothesis 1

is then formulated: *Some mental health problems of wind turbines' maintenance technicians are affected by the increased level of difficulty and insecurity in the work environment and unfavorable ergonomic conditions observed in the workplace.*

To establish our second hypothesis, we selected questions #5, #8, #10, from section B, which measure the concept of Mental Health problems (MentHeal), questions #6, #7, #11, from section B, which measure the concept of General Health problems (GenHealt), and questions #21, #22, #23, from section D, which measure the concept of Work Difficulty and Insecurity (WorkDifI). Hypothesis 2 is then formulated: *Deterioration of the health of wind turbines' maintenance technicians due to problems caused by their work is affected by possible mental health problems and the increased level of insecurity in the work environment.*

In our work, the deterioration of the health of the employees is described by the intense fatigue, the occurrence of headaches and hearing problems. The work of a technician includes the maintenance of wind turbines to quite high heights (climbing in a height of more than 70m) which provokes intense fatigue. Besides, the replies received in the questionnaire included high rates of discomfort in some parts of the body such as knees, lower back and neck. In terms of headaches and hearing problems, these have been selected after the research of Farboud et al. (2013) in which they are mentioned as related problems from populations located near wind farms.

To establish our third hypothesis, we selected questions #21, #22, #23, from section D, which measure the concept of Work Difficulty and Insecurity (WorkDifI), and questions #15, #16, #17, #18, from section C, which measure the concept of Adverse Ergonomic Factors (AdvErgFa). Hypothesis 3 is then formulated: *The increased level of insecurity and difficulties in the work environment of wind turbines' maintenance technicians is affected by the unfavorable ergonomic conditions observed in the workplace.*

The unfavorable ergonomic conditions inside the wind turbine, is an issue that according to Jia et al (2016) is related to the occurrence of a specific musculoskeletal problem such as low back pain. Therefore, the third hypothesis investigates whether adverse ergonomic factors affect the increased level of difficulty and insecurity observed by the technicians' side.

3. RESULTS

The demographic characteristics of the fifty respondents to our survey are as follows. All participants in the study were men. The majority of them (70%) were aged from 30 to 40 years old and 72% were graduates from technical institutes. More than a half from them (52%) worked as wind turbine maintenance technicians for less than 5 years and 24% of them worked for 5 to 10 years.

The structural model developed and implemented with the LISREL software for the control of the three hypotheses is shown in Figure 2. According to the indicators of good fit in the detailed results for this model, a good fit of the measurement data was observed, which confirms our three hypotheses.

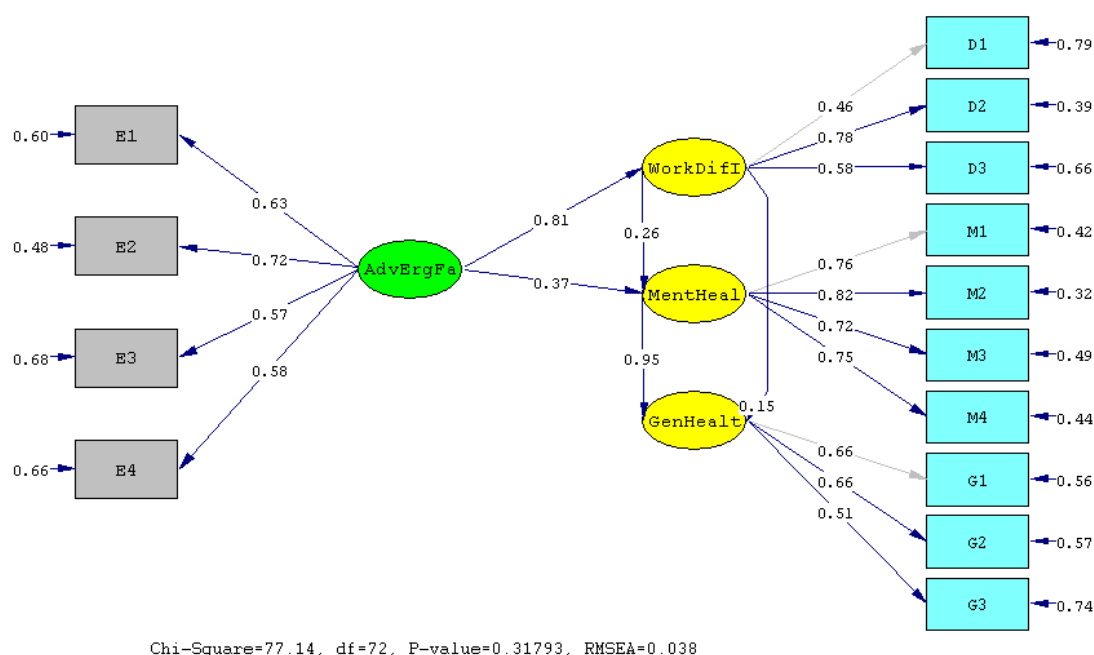


Fig. 2. The structural model expressed in the form of standardized path coefficients

In terms of the answers to the questions of section B, related to the mental and general health problems experienced by the respondents, the main findings concern the phenomena of intense fatigue (Figure 3) and stress (Figure 4), while problems such as sleep disorders, headaches, depression, nervousness, as well as hearing problems, were recorded by a smaller percentage of respondents.

6. To what extent do you think the rates of intense fatigue have risen since you started work as a wind turbine maintenance technician until today?

50 responses

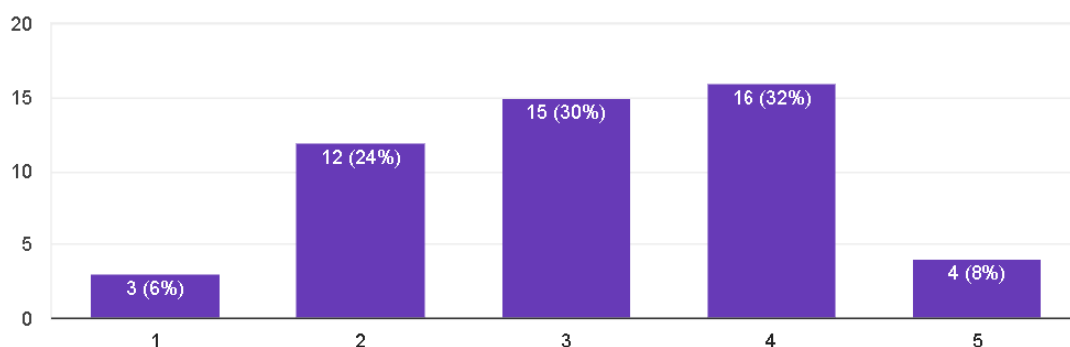


Fig. 3. Results from question 6 (intense fatigue)

8. To what extent do you think stress levels have risen since you started work as a wind turbine maintenance technician until today?

50 responses

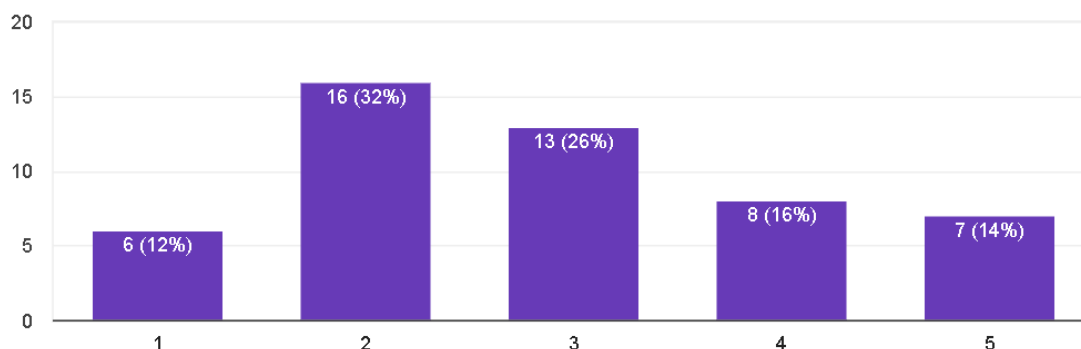


Fig. 4. Results from question 8 (stress)

From the answers to the questions of section C on the adverse ergonomic factors, the main problems identified by the majority of respondents, relate to working in a painful position (deep seat) (Figure 5) and lifting loads (Figure 6).

15. How often do you work with your body in an awkward position such as deep seat?

50 responses

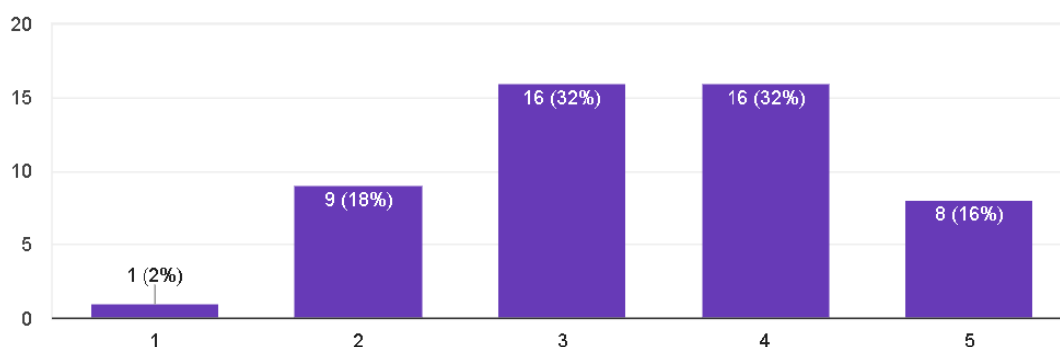


Fig. 5. Results from question 15 (awkward working positions)

16. How often do you perform demanding load lifting during your work?

50 responses

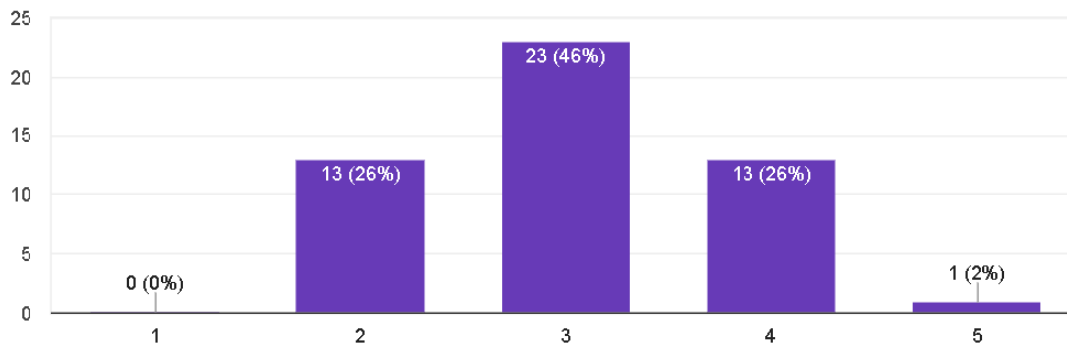


Fig. 6. Results from question 16 (load lifting)

From the answers to the questions of section D, on the subjective assessment of specific factors related to the health and safety of the respondents, the main difficulties identified were related to the limited space (Figure 7) and to the adverse weather conditions (Figure 8).

22. To what extent does the limited space inside the wind turbine contribute to the difficulty of carrying out maintenance work in wind turbines?

50 responses

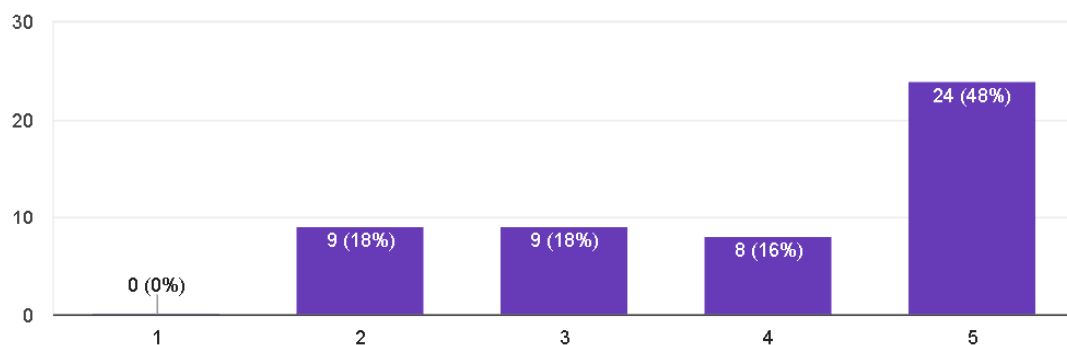


Fig. 7. Results from question 22 (limited space)

23. To what extent do adverse weather conditions contribute to the difficulty of carrying out maintenance work in wind turbines?

50 responses

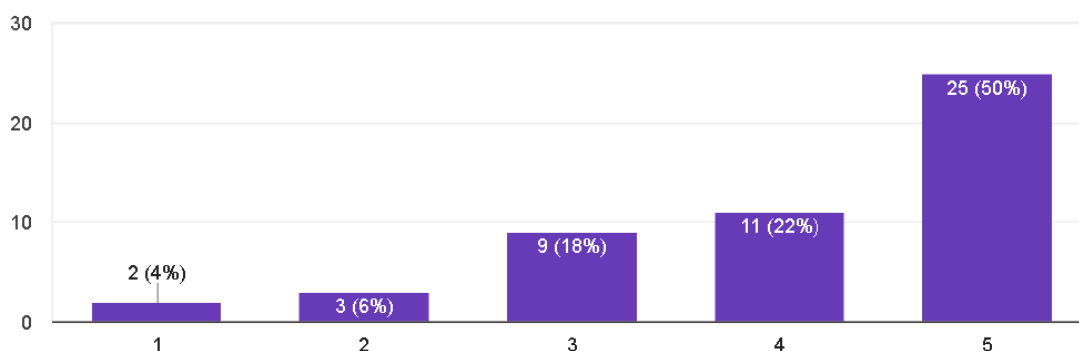


Fig. 8. Results from question 23 (adverse weather conditions)

The positive results of the research include the answers to the questions concerning how the participants evaluate their overall state of health (Figure 9) and the general instructions and training they have received in terms of health and safety at work (Figure 10).

20. At what level do you think your state of health is, taking into account any signs of fatigue in your body? (compared to the period before you start working as a wind turbine maintenance technician)

50 responses

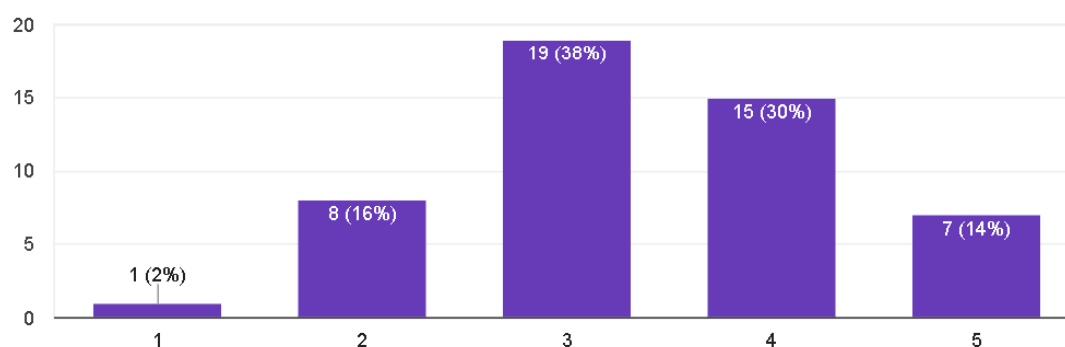


Fig. 9. Results from question 20 (general state of health)

24. How do you evaluate the health and safety written instructions and training provided by your Employer when performing maintenance work in wind turbines?

50 responses

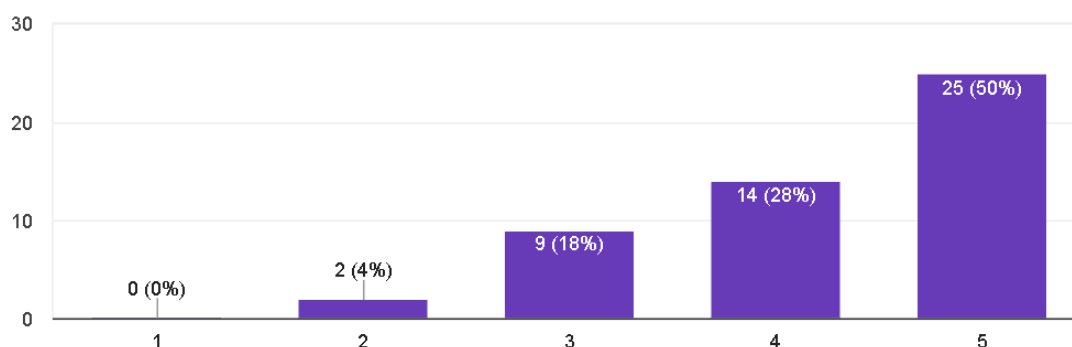


Fig. 10. Results from question 24 (health and safety training)

4. DISCUSSION

The work environment of the wind turbines' maintenance technicians is a demanding one and there are several factors that interrelate. There is a negative impact from the specific working conditions, both on the physical and mental health of the workers performing maintenance work on the wind turbines. Our research focused initially on specific mental health problems such as depression, nervousness, stress, insomnia and sleep disorders. These issues were explored in the research of Abbasi et al. (2016) as health problems of the general population located near wind farms, and we wanted to investigate whether the same problems occurred to wind turbines' maintenance technicians. Our findings, based on the questionnaire responses and relevant analysis, provide evidence that the mental health of workers performing wind turbines' maintenance activities is a complex problem, which is not only affected by the noise factor as shown in the work of Abbasi et al. (2016), but it is also affected by other factors and specifically, as confirmed by the Hypothesis 1, from the unfavorable ergonomic conditions and the increased levels of difficulty and insecurity in the workplace.

The present study also investigated whether the health of the employees had deteriorated during the years of their work as wind turbines' maintenance technicians. The deterioration of their health was described by intense fatigue, occurrence of headaches and hearing problems. The work of a maintenance technician includes climbing at high heights, even more than 70 meters, which results in intense fatigue. Moreover, the respondents' answers revealed additional health issues, such as high rates of discomfort in knees, lower back and neck. Our findings also showed that health problems associated with intense fatigue, headaches, and hearing problems are affected by both mental health problems and the difficulties that the employees they face in their work environment. From Hypothesis 2, it is confirmed that not only populations located near wind farms as mentioned in two previous studies (Krogh et al., 2011; Farboud et al., 2013) but also technicians working in maintenance of wind turbines face similar health problems.

Possible mental health problems relate with the increased level of difficulty and insecurity in the work environment, as well as with the unfavorable ergonomic conditions as tested with the Hypothesis 3. The unfavorable ergonomic conditions inside the wind turbines is an issue that according to Jia et al. (2016) is related to the occurrence of specific musculoskeletal problems, such as low back pain.

Our study results supports previous findings of Jia et al. (2016) who suggested to concentrate on ergonomic factors as well as to psychosocial factors in order to prevent and minimize the occurrence of

back pain among operation and maintenance personnel in wind farms. There is a negative impact from the specific working conditions, both on the physical and mental health of the workers performing maintenance work on the wind turbines.

5. CONCLUSIONS

The objective of this work was to investigate the factors that affect the health and safety of wind farm workers and their interrelation. To our knowledge, there are not enough studies in the relevant literature regarding the effect of the conditions of the specific working environment on the health and safety of workers, since most research articles focus mainly on the effect of the operation of wind farms on the health of general population living nearby.

The work environment of wind turbine maintenance workers contains factors that significantly affect the psychology and physical condition of employees, something that should be taken seriously by companies in the industry, in terms of actions to improve these conditions, but also by occupational researchers and professionals with regard to the follow-up of the investigation of risk factors and occupational safety and health conditions in the wind energy sector.

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APPENDIX. FORMULATION OF HYPOTHESES

HYPOTHESIS 1

B. Employee Health Problems

5. To what extent do you think sleep disturbance rates have risen since you started work as a wind turbine maintenance technician until today?
8. To what extent do you think stress levels have risen since you started work as a wind turbine maintenance technician until today?
10. How often do you experience nervousness and insomnia?

C. Ergonomic Factors in the Workplace

15. How often do you work with your body in an awkward position such as a deep seat?
16. How often do you perform demanding load lifting during your work?
17. How often do you repeatedly hit your knee during your work?
18. How often do you hold one-handed a heavy or bulky object that is not supported elsewhere?

D. Subjective Evaluation of Factors at Work

21. How insecure do you feel during maintenance work inside the wind turbines?
22. To what extent does the limited space inside the wind turbine contribute to the difficulty of carrying out maintenance work in wind turbines?
23. To what extent do adverse weather conditions contribute to the difficulty of carrying out maintenance work in wind turbines?

HYPOTHESIS 2

B. Employee Health Problems

5. To what extent do you think sleep disturbance rates have risen since you started work as a wind turbine maintenance technician until today?
6. To what extent do you think the rates of intense fatigue have risen since you started work as a wind turbine maintenance technician until today?
7. To what extent do you think your headache rates have risen since you started work as a wind turbine maintenance technician until today?
8. To what extent do you think your stress levels have risen since you started work as a wind turbine maintenance technician until today?
10. How often do you experience nervousness and insomnia?
11. How often do you experience hearing problems?

D. Subjective Evaluation of Factors at Work

21. How insecure do you feel during maintenance work inside the wind turbines?
22. To what extent does the limited space inside the wind turbine contribute to the difficulty of carrying out maintenance work in wind turbines?
23. To what extent do adverse weather conditions contribute to the difficulty of carrying out maintenance work in wind turbines?

HYPOTHESIS 3

D. Subjective Evaluation of Factors at Work

21. How insecure do you feel during maintenance work inside the wind turbines?
22. To what extent does the limited space inside the wind turbine contribute to the difficulty of carrying out maintenance work in wind turbines?
23. To what extent do adverse weather conditions contribute to the difficulty of carrying out maintenance work in wind turbines?

C. Ergonomic Factors in the Workplace

15. How often do you work with your body in an awkward position such as a deep seat?
16. How often do you perform demanding load lifting during your work?
17. How often do you repeatedly hit your knee during your work?
18. How often do you hold one-handed a heavy or bulky object that is not supported elsewhere?