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Science Journal of the Malta Chamber of Scientists

Editor-in-Chief: Cristiana Sebu

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# Scope of Journal

Xjenza Online is the Science Journal of the Malta Chamber of Scientists and is published in an electronic format. Xjenza Online is a peer-reviewed, open access international journal. The scope of the journal encompasses research articles, original research reports, reviews, short communications and scientific commentaries in the fields of: mathematics, statistics, geology, engineering, computer science, social sciences, natural and earth sciences, technological sciences, linguistics, industrial, nanotechnology, biology, chemistry, physics, zoology, medical studies, electronics and all other applied and theoretical aspect of science.

The first printed issue of the journal was published in 1996 and the last (Vol. 12) in 2007. The publication of Xjenza was then ceased until 2013 when a new editorial board was formed with internationally recognised scientists, and Xjenza was relaunched as an online journal, with two issues being produced every year. One of the aims of Xjenza, besides highlighting the exciting research being performed nationally and internationally by Maltese scholars, is to provide a launching platform into scientific publishing for a wide scope of potential authors, including students and young researchers, into scientific publishing in a peer-reviewed environment.

# Instructions for Authors

Xjenza is the Science Journal of the Malta Chamber of Scientists and is published by the Chamber in electronic format on the website: http://www.mcs.org.mt/index.php/xjenza. Xjenza will consider manuscripts for publication on a wide variety of scientific topics in the following categories

1. Research Articles
2. Communications
3. Review Articles
4. Notes
5. Research Reports
6. Commentaries
7. News and Views
8. Invited Articles and Special Issues
9. Errata

**Research Articles** form the main category of scientific papers submitted to Xjenza. The same standards of scientific content and quality that applies to Communications also apply to Research Articles.

**Communications** are short peer-reviewed research articles (limited to three journal pages) that describe new important results meriting urgent publication. These are often followed by a full Research Article.

**Review Articles** describe work of interest to the wide community of readers of Xjenza. They should provide an in-depth understanding of significant topics in the sciences and a critical discussion of the existing state of knowledge on a topic based on primary literature sources. Review Articles should not normally exceed 6000 words.Authors are strongly advised to contact the Editorial Board before writing a Review.

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A manuscript for publication in Xjenza will typicall have the following components: Title page, Abstract, Keywords, Abbreviations, Introduction, Materials and Methods, Results, Discussion, Conclusions, Appendices and References.

The manuscript will be divided into clearly defined and numbered sections. Each numbered subsection should have a brief heading. Each heading should appear on its own separate line. Subsections should be used as much as possible when cross-referencing text, i.e. refer to the subsection by the section number.

### Title page

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**Acknowledgements** Collate acknowledgements in a separate section at the end of the article before the references. Do not include them on the title page, as a footnote to the title or otherwise. List here those individuals who provided assistance during the research (e.g., providing language help, writing assistance or proof reading the article, etc.).

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McCreadie, C. and Tinker, A. (2005). The acceptability of assistive technology to older people. *Ageing Soc.*, 25(1):91–110.

**Reference to a Book:**

Brownsell, B. (2003). *Assistive Technology and Telecare: Forging Solutions for Independent Living.* Policy Press, Bristol.

Fisk, M. J. (2003). *Social Alarms to Telecare: Older People's Services in Transition.* Policy Press, Bristol, 1st edition.

**Reference to a Chapter in an Edited Book:**

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The following list will be useful during the final checking of a manuscript prior to sending it to the journal for review. Please consult the Author Guidelines for further details of any item.

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  - Full postal address.
  - Telephone and fax numbers.
- All necessary files have been sent, and contain:
  - All figures are given separately in PDF, SVG, JPEG of PNG format.
  - Caption for figures is included at the end of the text.
  - All tables (including title, description, footnotes) are included in the text and large tables have been given separately as CSV.
  - The reference list has been given in XML, RIS, zotero.splite or BIB file format.
- Further considerations

- Abstract does not exceed about 250 words.
- Manuscript has been ‘spell-checked’ and ‘grammar-checked’.
- References are in the required format.
- All references mentioned in the reference list are cited in the text, and vice versa.
- Bibliographic data for all cited material has been provided.
- Permission has been obtained for use of copyrighted material from other sources (including the Web).
- A PDF document generated from the word processor used is submitted.

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*Editorial*

# Xjenza: the key for a brighter future

**Cristiana Sebu**[*1]
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Dear readers and authors of Xjenza Online, as Editor-in-Chief, I am very pleased to announce the release of the second issue of 2019 of Xjenza Online. I know that the issue came out much later than expected, but both the journal and the world has undergone several changes lately.

In addition to the launch of a brand-new website for the journal, www.xjenza.org, there were also a few more recent key replacements of the members of the Editorial Board. I am glad and grateful that after months of recruitment and training Luke Collins joined our team as Copy Editor. A warm welcome also to Chloe Manning and Ellie Kift as Editorial Assistants. I take this opportunity to thank them all for their time, efforts and assistance.

Under the current circumstances, scientific research is a priority, and so remains our focus in this issue of Xjenza Online, both in the original research we publish and in our news coverage.

The issue opens with an important study by Attard et al. to assess the physicochemical characteristics of biochar from manure generated on three different livestock farms in Malta especially since manure is currently incurring a significant risk in creating environmental pollution. The research reveals that pyrolysis of manure has the ability to render organic nitrogen into inert nitrogen gas and, hence, reduces manure biomass volumes.

The following manuscript by Galea et.al investigates the relationship between air pollution and spontaneous pneumothorax (SP), a sudden onset of a collapsed lung without any apparent cause which occurs frequently in young male asthmatics and smokers. An observational study

on consecutive patients admitted with SP to Mater Dei Hospital from January 2010 to December 2014 indicated that enhanced air pollution seems to increase the incidence of SP.

Next, the article by Bozionelos et al. evaluates the effectiveness of an extended but temporary local network of seismic stations on the Maltese islands to efficiently monitor seismic activity, determine the seismic source, and eventually contribute to the seismotectonic interpretation and seismic hazard assessment. The results of this investigation are instrumental for the future installation of permanent seismic stations on the Maltese islands.

The issue concludes with a news address by Gianluca Valentino, the President of Malta Chamber of Scientists, who on behalf of the recently revamped Council structure is proudly presenting their current plans in order to consolidate a strong voice and vision of the Chamber within the local scientific landscape.

To conclude, I wish you all to stay strong and safe. Let us hope that science will prevail once more, and innovative means of treatment and prevention of the COVID-19 disease will be in place soon. Meanwhile, Xjenza Online will continue to serve the local professional scientific community, to publish high-quality original findings in a peer-reviewed environment, and to help early-career researchers to advance their scientific discourse in the community.

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*Research Article*

# A study to define the physicochemical characteristics of biochar from manure generated on 3 different livestock farms in Malta

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[1b]*Institute of Earth Systems, Department of Rural Sciences and Food Systems, University of Malta, Msida, Malta*
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[3]*Upper Keeping s.r.l., Padova, Italy*

**Abstract.** The amounts of livestock manure produced in Malta surpasses the application rate as stipulated by the Nitrates Directive with the consequence of having an accumulation on farms. In such cases, manure becomes a liability instead of a benefit, incurring significant risk in creating environmental pollution. Pyrolysis of manure is an interesting alternative to land application, as it has the ability to render organic nitrogen into inert nitrogen gas and reduces manure biomass volumes. This technology utilises high temperature, thereby destroying any potential pathogens that may be present in the manure, has the potential of extracting useful energy and generates potentially high value products, e.g. biochar. The functions and application of biochar when used as a soil amendment to improve soil physical, chemical and biological properties depend on its structural and physicochemical properties. Such understanding is crucial for its sustainable use and application. Manure feedstock originating from large ruminant, small ruminant and poultry operations were subjected to a pyrolysis process at 570°C. The starting nitrogen (N) content was repartitioned into inert $N_2$ (59%), whilst 38% was retained within the biochar structure. The biochar physicochemical properties relating to electrical conductivity (EC) values, the accumulation of zinc and the alkaline nature, render the application of this biochar on Maltese soils challenging. Alternatively, this biochar could be used as a solid fuel to dry the incoming manure biomass, and the resulting ash utilised to extract potassium and phosphorus.

**Keywords:** Malta, Manure, Biochar, Pyrolysis

**Acknowledgements.** This research was financed by the Malta Council for Science & Technology for and on behalf of the Foundation for Science and Technology, through the Scheme for the Provision of Proposals aimed at a Holistic Approach to the Sustainable Management of Livestock Manure and Slurry within a Circular Economy Context.

**Author Contributions.** All authors had equal contribution towards this study. Denise Grima Connell, Oliver Fenech and Francesco Berti provided technical and theoretical support; George Attard and Anthony Gruppetta contributed to the analysis of experimental results and wrote the paper. All authors read and approved the final version.

**Conflicts of Interest.** The authors declare no conflict of interest.

## 1 Introduction

Plant agriculture and livestock production follow stoichiometric processes. Nutrient accretion by plants and farm animals to yield food and fibre, depend on the extraction of nutrients from soils that must be replenished on a regular basis to maintain continuous productivity. Traditionally soil fertility was maintained with the incorporation of livestock manure as a source of organic matter and essential nutrients, which contribute towards meeting the crop nutrient requirement and maintain soil integrity. Regions with intensive livestock production generate surplus manure whose application on land will result in the over fertilisation of the agricultural areas risking significant potential negative environmental repercussions. The Maltese livestock sector falls within

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this category, characterised with a very high density of livestock per $km^2$ of arable land. The current Maltese livestock inventory stands at an estimated 13,000 head of cattle, a 2500 sow farrow to finish swine herd, 15,000 small ruminants, 250,000 laying hens, an annual grow out of 2 million broiler chickens, a rabbit doe population of 15,000 and 4100 equines, while the national total available agricultural area for the application of manure generated by these animals is defined at just 11,000 hectares. To mitigate the risk of over application of manure the EU has implemented regulations to safeguard the environment, of which European Commission (1991) is the most important. This directive sets the limits for the application rate of livestock manure, expressed as the amount of nitrogen per hectare of land, established at a maximum of 170 kg of N per hectare. The livestock industry is showing a declining trend, mostly due to improvements in milk yields per cow in the case of dairy cows and to market forces and competitiveness in all the other sectors.

Given the limited agricultural land base available on which grain, fodder and roughage can be cultivated, diet formulations by local feed mills are by default totally dependent on the importation of cereals purchased on global markets. The excreted nutrients resulting from these feeds, with special reference to nitrogen, now in the form of animal manure are in excess to what can be applied to land. The growing concern about environmental consequences of excessive fertilisation from animal manure necessitates the implementation of alternative options. Techniques such as digestion (anaerobic and aerobic) and composting that have a proven track record, especially in Northern Europe, have been proposed to address the challenge of manure accumulation on farms. However, under local conditions, all these techniques have shown some form of limitation. In some cases, these techniques just serve to shift the challenge of the sustainable management of manure up to the next tier without having reached any tangible reduction in nutrients associated with over fertilisation and environmental pollution.

A potentially interesting alternative is the thermochemical conversion of manure into biochar by using pyrolysis (Cantrell et al., 2012). This technology has added benefits such as: a shorter conversion time compared to composting, the absence of non-biodegradable and toxic substances, high processing temperatures that are adequate to neutralise all pathogens potentially found in manure, and the conversion into value-added products (Ro et al., 2010).

The potential processing of manure through pyrolysis with the subsequent recycling of biochar has major advantages over land application:

(i) the energy content of the biomass is capitalised as renewable energy;
(ii) the nitrogen content is mainly transformed into inert $N_2$;
(iii) more valuable components, e.g. phosphate and potassium, are retained in the solid fraction which is dry, odourless and easy to handle.

The functions and application of biochar when used as a soil amendment to improve soil physical, chemical and biological properties depend on its structural and physicochemical properties Angin et al. (2014). Such understanding is therefore crucial for the sustainable use and application of the biochar.

This study evaluates the physicochemical properties of manure produced by the poultry, cattle and sheep sectors on the Maltese Islands and the resulting biochar generated from this manure biomass feedstock during the pyrolysis process.

## 2 Materials and Methods

### 2.1 Farm Selection

The recorded history always makes reference to the fact that Malta does not produce enough grain to meet the needs of its inhabitants let alone to meet the nutritional requirements of the resident livestock. One can safely affirm that this situation is very much the same today as it was back then. National Statistics Office, Malta (2016) states that only 5,290 hectares of arable land are dedicated to the cultivation of livestock fodder, mostly in the form of roughage, such as winter wheat, barley and other similar crops. The harvest meets an estimated 10% of the nutritional needs of the ruminant sector. Hence, the remaining 90% required by the ruminant sector, together with all of the nutritional requirements to feed the monogastric livestock, has to be imported. The grain is procured, normally through international tendering procedures stipulating nutrient limits that have to be met. Due to reasons of economies of scale, the local feed mills act together as a consortium for the procurement of feed grade cereals which are then distributed according to the respective feed mill's market share.

This study assumes that the different herds within the respective livestock sectors do not exhibit significant differences due to feed, animal breed or manure management. Given that:

(1) feed grade grain, irrespective of the feed mill, all originates from the same source;
(2) the fact that there is minimal breed variability amongst herds (cattle are mostly Dutch Frisian, while sheep belong to the local Maltese type);
(3) poultry: most egg layers are imported from a single source as pullets at point of lay, while broilers are supplied from one local hatchery;
(4) manure management is regulated by Justice Ser-

vices of Malta (2007), that provides for the uniform management of manure across the various livestock sectors;

In the opinion of the authors, the selected farms are a true representation of the various sectors.

### 2.2 Manure Biomass Feedstock

Selection of manure types for analysis was based on the quantity of manure generated by the different livestock sectors in Malta. Previous survey results in E-cubed consultants, Adi Associates (2015) were used to identify the main contributors to the generation of manure on Malta and Gozo. Sampling was performed in accordance to the relevant and adapted guiding standards of ISO 18400 series. Following collection, the 50 kg samples were packaged in 60 L drums and shipped under refrigerated conditions (+4°C) to Environlab s.r.l. in Italy for analysis.

### 2.3 Daily Manure

The selected dairy farm is situated to the North-East side of the island within the Magħtab basin. This dairy unit is affiliated with the only Dairy Cooperative (Kooperattiva Produtturi tal-Ħalib) and sources its concentrate feeds from the same coop feed mill. Roughage is mainly alfalfa hay in bales of around 700 kg imported from Spain, which is procured through private importers or through the cooperative itself. The locally produced wheat crop is directly purchased as whole crop bales including straw and ears of grain. The unit houses 412 heads of cattle, of which 221 are females over 2 years.

On average, each milking cow is fed a ration of 13 kg of Special KPH Dairy Pellet Concentrate, 6 kg of Maltese whole crop wheat, 7 kg of alfalfa hay with 1 kg of sugar beet and additional minerals and vitamins, all blended together in a TMR (Total Mixed Ration) mixer and distributor. The remaining herd made up of dry cows, pregnant heifers, young heifers and bulls receive a ration of 5 kg of Standard KPH Dairy Pellet Rations and 5 kg of Maltese whole crop wheat.

The milking herd is kept in a large shed and their excretions are scraped away every 12 to 24 hours and are processed through a drum filter separator (model ROTA 2000). The solid fraction is collected in a manure clamp. The rest of the herd is kept on a dry bed system and the bedding is removed circa three times per year and replaced with fresh bedding. The bedding is mainly low-grade straw but may vary from time to time to include wood shavings, sawdust and shredded paper. The litter is scraped away by a mechanical shovel and deposited in the manure clamp present on farm.

Grab samples were randomly collected from various parts of the manure in the clamp and pooled together to make up a 50 kg manure sample. The “as received” moisture content was measured at 56.4%.

### 2.4 Sheep Manure

The selected unit is situated in the central part of Malta and holds a herd of 302 heads, of which 193 are milking ewes.

The daily ration on this holding includes 800 g of normal sheep pelleted feed supplied by Andrews Feeds Ltd and about 1 kg of Maltese whole crop wheat per head. The milking ewes also receive 1 kg of Andrews Sheep Lactation Pellets, whilst being milked in the parlour.

All animals are housed in sheds on a deep litter system. The manure/bedding matrix is made up of chaff and straw when chaff is no longer available together with the accumulated manure and urine. Fresh bedding is added as necessary to maintain the flock in a dry and clean condition. The litter is scraped away by a mechanical shovel once a year and deposited in heaps in fields adjoining the farm.

Random grab samples were pooled to make up a 50 kg sample of sheep manure collected from this holding directly from the heaps. The “as received” moisture content was determined to be 59.2%.

### 2.5 Poultry Manure

Poultry manure was sourced from two adjacent farms, one being an egg laying unit and the other a broiler operation, both found in the Maghtab basin. Samples from both farms were pooled to make up the representative sample of poultry manure.

The broiler operation has a capacity of 18,000 chicks kept in different sheds. The different sheds carry multi age flocks with a rotation of sheds for slaughter. The grow out cycle is of six weeks after which broilers are shipped out for processing. The feeding regime consists of three different types of concentrate rations, chick crumbs followed by chick starter switching to a standard finisher rations in the last 3 weeks of the growing cycle. All feeds are formulated and compounded at an adjacent feed mill (MCP). The applied bedding is always imported wood shavings. The empty sheds are scraped clean from the litter by means of a mechanical shovel; they are cleaned, washed and disinfected after every cycle. The broiler litter is stored in a manure clamp.

The layer unit has a flock capacity of 40,000 heads. Laying hens are housed in different sheds in cages that are 5 tier high. The feeding regime consists of a standard poultry layer ration in a granulated form produced by Andrews Ltd feed mill. Cages are equipped with manure mats, and sheds are emptied twice a week. Manure is scraped off the mechanical mats and stored in the manure clamp present on farm.

Manure from the broiler farm was two days old, whilst that from the layer farm was collected straight after being deposited in the manure storage area. The pooled

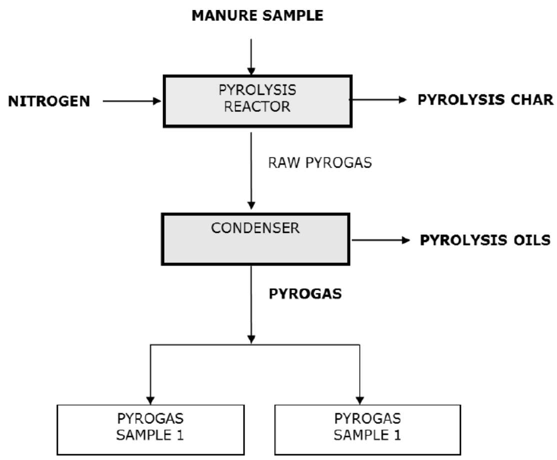


**Figure 1:** Schematic diagram of the pyrolysis process used for this study to produce for producing char (biochar), oils (bio-oil) and pyrogas (syngas).

poultry litter had an "as received" moisture content of 57.6%.

### 2.6 Preparation

Upon receipt of the samples at the laboratory, representative samples from the "as received" manures were prepared by pooling three sub-samples of 2 kg/each, taken from different parts of the received manure sample of 50 kg. Half of the total weight of each manure sample was dried further in an oven at 105°C to reduce its water content before initiation of the pyrolysis procedure.

### 2.7 Pyrolysis system and process

The manure samples were subjected to pyrolysis by means of a pilot test rig consisting of a furnace (reactor), a stack and a bio-oil condenser, as shown in **??**. For each type of manure, a "blank" test was performed to record the evolution of its transformation in time and to calibrate the test rig by using the Flame Ionization Detector (FID) analyser data and the acquisition system for the monitoring of gas flow evolution.

Each manure type was separately tested in a pyrolysis test reactor, which was filled with a weighted amount of dried manure of about 500 g and then put in the preheated oven at 650°C. The temperature during the test was maintained at 570°C. A three litre/min nitrogen flow, controlled by means of a gas flow meter directly connected to the nitrogen gas cylinder, was connected to the pyrolysis reactor as a carrier for the evolving chemical species created by the pyrolysis reaction. The gas flow was sent through a water chilled (4°C) spiral condenser with a collecting bottle for condensed tar. This was followed by two gas bubblers (each filled with 3000 mL of water) leading to the gas sampling line coupling a connection for three litre gas cylinder sampler, two activated carbon cartridges and an on-line gas flow FID analyser used to monitor and record the pyrolysis syngas flow evolution in time.

During each test, a gas cylinder sample was taken at gas flow peak production, while the two activated carbon cartridges were left connected up to the test end. At the end of each test, the biochar residue left in the pyrolysis reactor was weighed and fully characterised.

### 2.8 Feedstock and biochar analysis

Both the feedstock and biochar were tested in an ISO 17025:2005 accredited laboratory, Environlab S.r.l., with accreditation no. 1298. Standard analytical procedures were used and, in the absence of a standard method, inter-laboratory SOPs (Standard Operating Procedures) were utilised. The feedstock material was characterised as received, whilst biochar was collected following each pyrolysis test carried out on individual manure types. Both feedstock and biochar samples were digested for subsequent determination of Sb, As, Ba, Be, Cd, Cr (III), Hg, Ni, Pb, Cu, Se, Sn, Tl, Te, Zn through UNI EN 13657:2004. The concentration of parameters was determined by ICP-OES (Inductively Coupled Plasma - Optical Emission Spectrometry) through standard method UNI EN ISO 11885:2009. Hexavalent Chromium was quantified through method CNR IRSA 16Q 64 Vol 3 1986. Total Organic carbon was analysed by means of standard method UNI EN 13137:2002, whilst hydrocarbon content in the range of C10 to C40 was determined by gas chromatography through UNI EN 14039:2005 + EPA 5021A:2014 + EPA 8015C:2007. UNI EN 15407:2011 was utilised as a method to determine the C, H and N content for elemental analysis. The calorific value was determined through UNI EN 15400:2011. CNR IRSA 1 Q 64 Vol 3 1985 was utilised for the determination of pH. Dry weight (at 105°C) and residue on ignition (at 600°C) were determined through UNI EN 14346:2007 (Method A) and CNR IRSA 2 Q 64 Vol 2 1984, respectively. Analytical results were compared with limits set by the Italian Legislative Decree no. 75 of 29 April 2010 "*Reorganization and revision of the discipline regarding fertilisers, in accordance with Article 13 of Law no. 88 of 7 July 2009*". This Decree is the transposition in the Italian law of European Regulations: Regulation (EC) No 2003/2003 of the European Parliament and of the Council of 13 October 2003 relating to fertilisers; Council Regulation (EC) No 834/2007 of 28 June 2007 on organic production and labelling of organic products and repealing Regulation (EEC) No 2092/91; Commission Regulation (EC) No 889/2008 of 5 September 2008, laying down detailed rules for the implementation of Council Regulation (EC) No 834/2007 on organic production and labelling of organic products with regard to organic production, labelling and control.

Biochar has been included in the Italian Decree no. 75

| $T$ (°C) | Reaction |
|---|---|
| 100–120 | drying |
| 250 | de-oxidation, desulfurisation |
| 340 | aliphatic bond breakage |
| 380 | biochar formation |
| 400 | breakage of C-O and C-H bonds |
| 400–600 | tar formation |

**Table 1:** Chemical reactions that occur at the different temperatures throughout the pyrolysis process.

of 29 April 2010, in an update of Annex 2 - Soil conditioners published in Ufficio Pubblicazione Leggi e Decreti (2010).

## 3 Results and Discussion

The most common ways to extract energy from manure biomass involving thermal process are combustion, gasification and pyrolysis. During the combustion process, the biomass is completely oxidised and converted to heat steam and carbon dioxide. This process is generally associated with environmental pollution issues. The gasification process involves a procedure partly oxidising the biomass, whilst converting the solid fuel to gas. Pyrolysis involves the heating of the biomass in the absence of oxygen. Jahirul et al. (2012) give an extensive technological review on biofuels production through biomass pyrolysis. The process of biomass pyrolysis is very complex, consisting of simultaneous and successive reactions, when heated in an oxygen free environment. The thermal decomposition of organic components commences at 350–550°C and goes up to 700–800°C. Table 1 shows the different chemical reactions happening during pyrolysis at the different temperatures throughout the process. Compounds with long chains of carbon, hydrogen and oxygen break down into smaller molecules, resulting in the production of solid biochar, gases and vapours, that at ambient temperature condense to a dark brown viscous liquid also known as tar/bio-oil. The end product yield is directly related to the conditions of the process, amongst which there are the type of feedstock and its moisture content.

### 3.1 Pyrolysis and the Nitrogen cycle

Animal dung is used to be incorporated into soil to improve and maintain its fertility, but excessive application of manure can lead to serious issues in soil eutrophication, high salt content causing plant toxicity and greenhouse gas emissions (Dagnall et al., 2000; Zhange et al., 2011). Alternatively, it can be considered as a type of renewable energy feedstock when processed through pyrolysis.

In general, the results of this pyrolysis study, agree with those reported by Meesuk et al. (2013), in that the majority of nitrogen in the initial manure biomass was converted into N2 above 500°C. This study indicates that at a temperature of 570°C, of the initial N content present in the original biomass, 59% was released as inert $N_2$, 38% was retained within the biochar structure, 2% released as NO and 1% as $N_2O$. The bulk of the organic nitrogen found in animal manure is in the form of proteins, lipids and polysaccharides (Meesuk et al., 2013), that can potentially be converted into $NO_x$ and $N_2O$ during the pyrolysis process (Thomas, 1997; Tsubouchi et al., 2008; Wojtowicz et al., 1993). The partitioning and transformation of nitrogen into tar/bio-oil, syngas and biochar is a key factor in limiting the formation of $NO_x$ and $N_2O$. The schematic representation showing the N-reduction from biomass and its subsequent portioning during the pyrolysis process is presented in figure 2.

### 3.2 Physicochemical characteristics of manure feedstocks

The results of the different parameters performed on the feedstock are presented in table 2. When "as received" samples of the biomass were analysed to determine the dry matter content, all proved to be relatively wet, as they all contained less than 50% dry matter. This high moisture content is due to the fact that at time of collection the manure had not undergone the necessary time period to cure and go through a process or air drying. Given the relatively dry climate, also during the rainy season, biomass stored in a proper design clamp that allow cross ventilation will undergo a process of natural drying and hence result in higher dry matter content. The amount of "wetness" of the biomass has an adverse effect on the pyrolysis process and on the heating value of pyrolysis bio-oil. Quiroga et al. (2010) reported that on average when poultry manure samples were tested for Heating Values, the energy content on the dry matter basis was on average 4.8 times higher than that obtained from the wet manure, due to the amount of moisture present in the wet form. The high moisture content in feedstock is not desirable, as it will cause a lowering in the operating temperature causing inefficiency of the pyrolysis performance. The amount of energy needed to pyrolyse manure can be divided into drying and sensible heat to raise the dried biomass feedstock to the correct pyrolysis temperature; in this case 570°C. The energy required to dry the feedstock is equal to the amount of heat required to raise the temperature of the wet biomass to 100°C plus the latent heat of vaporisation to remove the water and dry the substrate. In general, a proper pyrolysis process requires a feedstock having a moisture content between 5 to 15 wt%, hence the pre-handling of manure in such a way that it undergoes a thorough drying process to reduce its water content can have significant effects on the operating efficiency for

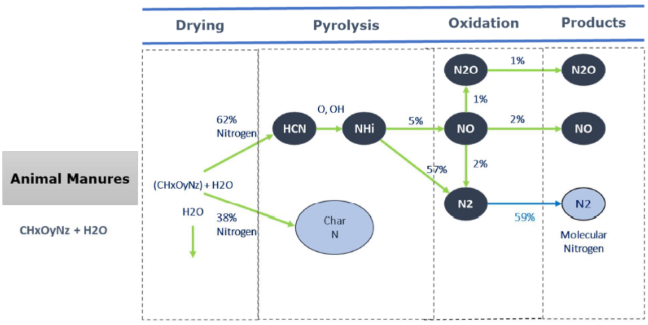


**Figure 2:** Pyrolytic Denitrification Scheme (HCN: Hydrocyanic acid, NHi: the many and different species which contain one NH chemical group as part of their chemical structure, $N_2O$: Nitrous oxide, NO: Nitrogen monoxide, $N_2$: Nitrogen gas).

energy extraction.

The results of the physicochemical analysis on the manure biomass stock show differences inferring that the yield will differ according to type. Table 3 presents differences to the pyrolysis process of different manure types. The table indicates that the three tested samples showed different behaviour, both in terms of final products and in the dynamics of their chemical transformations.

### 3.3 Physicochemical characteristics of biochar

The analytical results of the feedstocks and biochar are in general in agreement with those published in literature (Antal Jr. et al., 2003; Bourke et al., 2007; Keiluweit et al., 2010) in that the resulting biochar harbours a concentration of stable carbon following the removal of volatile matter. The distribution pattern of the products varied according to feedstock type. The sheep manure, composed of faeces that in part contain undigested fibres and urine is continuously added on to the bedding, generally straw in a deep litter barn design. The deep litter is removed on a yearly basis, thus providing an appropriate environment and allowing sufficient length of time for manure and litter to undergo a decomposition process. The cow manure is composed of faeces predominantly containing indigestible fibres of lignin and segregated into a solid fraction following on farm slurry dewatering. In the case of poultry, which is composed of a 50/50 mix of layer hen manure and broiler litter, the lignin fraction would only be present in the broiler litter as wood shavings. The ratio of biochar: bio-oil: syngas released by poultry manure, cow manure and sheep manure was 1 : 1 : 1, 1 : 0.5 : 1.5 and 1 : 4 : 1.7, respectively. This confirms that the different feedstocks are composed of different complexes that have different boiling points. Hence, depending on the respective boiling points, the volatiles released will segregate according to the respective molecular properties into syngas or condense into the liquid bio-oil. Yang et al. (2006) describe the decomposition rate of individual biomass components with pyrolysis temperature; in that hemicellulose is the first to undergo a decomposition peak at about 300°C, followed by cellulose that peaks at about 400°C, while lignin persists with no evident decomposition peak at 500°C. Hence the resulting biochar recovery is highly related to the amount of lignin lattice present in the original feedstock.

The ash content of biochar differed according to feedstocks, with poultry > cow > sheep. This ranking could be assumed to be the combined effect of premix inclusion in diet formulation and the digestive / absorptive efficiency of the various nutrients found in the respective premix. The Electrical Conductivity (EC) values of the biochars from the different feedstocks were also characterised. This reading is a direct indication on the amount of salts present, which can potentially have undesirable effects on soils. The EC values varied from 40,300 to 29,600 $\mu$S cm$^{-1}$. Cantrell et al. (2012) conducted a regression correlation analysis on the relationship between EC and ash content, concentrations of K, Na and (K + Na) and found an extremely low correlation ($R^2$ between $< 0.005$ and 0.13) between % ash and EC, implying that some ash components are insoluble and are incapable of conducting electricity. In contrast, a strong correlation was achieved when EC values were regressed against the concentrations of K, Na and (K + Na) in biochar. In fact, the combined (K + Na) resulted in being the best predictor for biochar EC values. This relationship is of particular significance in the case of Maltese livestock farms, in that most of these farms utilise brackish grown water as potable and/or washing water. This would obviously contribute to increase the salt load in the manures and contribute towards increasing the EC values. Biochar produced from cow manure had the highest EC value among all examined types. Usually the biochar from poultry manure is typically high in EC-influencing elements, generally due to the incomplete assimilation of nutrients by poultry. The higher EC value registered by biochar from cow manure may be due to elements that are exterior to salt content in feed and potable water and the digestive / absorptive capacity of the animal. Often enough, brackish ground water is utilised to wash milking parlours, and the resulting dirty wash water, together with any chemicals that are utilised in the process, being discharged into the manure holding cess pits, thus serving as an additional exogenous source of elements that contribute to additional electrical activity.

In all types of feedstock, the pyrolysis process produced very alkaline biochar (pH > 7), ranging from 11.8 to 12.7; these values are somewhat higher from what is reported by Cantrell et al. (2012) and Singh et al.

| Parameters | Sheep | Cow | Poultry |
|---|---|---|---|
| Dry matter content (%) | 40.8 | 43.6 | 42.4 |
| Moisture content (%) | 59.2 | 56.4 | 57.6 |
| Lower Heating Value (kJ/kg) | 4419 | 5495 | 4267 |
| Carbon (% dm) | 39.2 | 42 | 37.8 |
| Nitrogen (% dm) | 1.7 | 1.2 | 1.3 |
| Hydrogen (% dm) | 6 | 6 | 6 |
| Oxygen (% dm) | 27.5 | 44.7 | 28.5 |
| Chlorine (post-combustion) % w/w | 0.38 | 0.51 | 0.25 |
| Sulphur (post-combustion) % w/w | 0.15 | 0.17 | 0.09 |
| Antimony (mg/kg) | <1.25 | <1.25 | <1.25 |
| Arsenic (mg/kg) | <5 | <5 | <5 |
| Barium (mg/kg) | 15.2 | 9 | 11.8 |
| Beryllium (mg/kg) | <1 | <1 | <1 |
| Cadmium (mg/kg) | <0.25 | <0.25 | <0.25 |
| Cobalt (mg/kg) | <5 | <5 | <5 |
| Chromium (mg/kg) | <5 | <5 | <5 |
| Chromium (VI) (mg/kg) | <1 | <1 | <1 |
| Mercury (mg/kg) | <0.5 | <0.5 | <0.5 |
| Nickel (mg/kg) | <5 | <5 | <5 |
| Lead (mg/kg) | <5 | <5 | <5 |
| Copper (mg/kg) | 7.7 | 9.4 | 18.2 |
| Copper (soluble) (mg/kg) | <10 | <10 | <10 |
| Selenium (mg/kg) | <1.25 | <1.25 | <1.25 |
| Tin (mg/kg) | 1.4 | <0.5 | 0.82 |
| Thallium (mg/kg) | <1.25 | <1.25 | <1.25 |
| Tellurium (mg/kg) | <1.25 | <1.25 | <1.25 |
| Zinc (mg/kg) | 80.5 | 26.2 | 120 |

**Table 2:** Analytical results of the different parameters performed on the manure feedstocks.

| Observations | Chicken manure | Cow manure | Sheep manure |
|---|---|---|---|
| Pyrolysis products distribution | Syngas 30%<br>Bio-oil 36%<br>Biochar 34% | Syngas 51%<br>Bio-oil 15%<br>Biochar 34% | Syngas 26%<br>Bio-oil 59%<br>Biochar 15% |
| Reaction behaviour | Syngas production is high, long lasting and stable from its start to its end. No gas production peaks detected. | Syngas production start is fast, it is short lasting and suddenly falls coming to its end. No gas production peaks detected. | Syngas production is slow, long lasting and quite stable from its start to its end. No gas production peaks detected. |
| Contaminants requiring special attention | None | None | None |
| Other observations | Zinc content in the biochar is quite high. More analytical tests should be carried out to confirm this value, and a Zinc balance inside the farm's perimeter is to be carried out to suggest possible changes in the current feeding practice to potentially reduce Zinc content. | Zinc content in the biochar is quite high. More analytical tests should be carried out to confirm this value, and a Zinc balance inside the farm's perimeter is to be carried out to suggest possible changes in the current feeding practice to potentially reduce Zinc content. | None |

**Table 3:** Behaviour of the different solid manures during the pyrolysis process

| Parameter | Units | Poultry mix | Sheep | Cattle | Italian Fertilisers Decree limit values |
|---|---|---|---|---|---|
| Carbon | % of total dry mass | 26.3 | 51.9 | 43.2 | |
| | *Class 1* | | | | >60 |
| | *Class 2* | | × | × | >30 and ⩽60 |
| | *Class 3* | × | | | >20 and ⩽30 |
| Hydrogen : Carbon (H:C) | Molar ratio | 0.022 | 0.023 | 0.03 | 0.7 |
| Total ash | % of total dry mass | 55.4 | 34 | 44.5 | |
| | *Class 1* | | | | <10 |
| | *Class 2* | | × | | >10 and ⩽40 |
| | *Class 3* | × | | × | >40 and ⩽60 |
| pH value | pH scale | 12.7 | 11.8 | 12.4 | 04/12/20 |
| Electrical Conductivity | $\mu$S cm$^{-1}$ | 31100 | 29600 | 40300 | 1000000 |
| Cadmium | mg/kg | <0.25 | <0.25 | <0.25 | 1.5 |
| Copper | mg/kg | 89 | 98.3 | 40 | 230 |
| Lead | mg/kg | 6.1 | 8.2 | 5.6 | 140 |
| Mercury | mg/kg | <0.5 | <0.5 | <0.5 | 1.5 |
| Nickel | mg/kg | 10.1 | 7.2 | 5.4 | 100 |
| Zinc | mg/kg | 771 | 299 | 586 | 500 |
| Chromium VI | mg/kg | <0.5 | <0.5 | <0.5 | 0.5 |

**Table 4:** Parameters of interest within the biochar generated from bovine, sheep and poultry manure, compared to limit values set in Italian Legislation

(2010) but similar to results obtained by Zhao et al. (2017). Yuan et al. (2011) reported the very strong positively correlation ($R^2 = 0.97$) between pH values and ash content of biochar, hence probably the main cause of each biochar's inherent alkaline pH is due to the minerals involved in the formation of carbonates such as $CaCO_3$ and $MgCO_3$ and the presence of inorganic alkalis such as K and Na. Biochar having high alkaline pH-values has been associated with potential negative consequences on the soil chemistry of low-buffer capacity sandy soils Novak et al. (2009).

In general, pyrolysis tended to concentrate the mineral and heavy metals within the resulting biochar. The concentration profile of the individual components when compared to the raw feedstock manure did not remain constant. Differences in the metal content of the different manure types may be attributed to the specific husbandry practices and to the particular feed provided for each animal type. The concentration of the elements in the feedstock and biochar was in general lower than the listed ceiling concentrations established by the Italian Legislative Decree of the 29 April 2010, no. 75, on fertilisers. The exceptions were cattle and poultry biochar one, that both showed high concentrations of zinc, that goes beyond the acceptable limits. Although animal feeds are regulated, Zn together with or in replacement of Cu is sometimes included in diet formulations. Cantrell et al. (2012) argues that, while the concentration of some heavy metals in biochar decreases with increased temperature, in the case of lead, zinc and copper this was not so; inferring that they are highly stable elements and not prone to volatilisation during the pyrolysis process. The results from this study tend to be in agreement with those reported by Cantrell et al. (2012).

The variations in EC and the level of Zn present in the biochar from the various manure types indicate that, while there may be uniformity in grain procurement and manure handling protocol across livestock farms, there may be situations on particular farms that will contribute to alter the expected physiochemical parameters. Practices such as the use of brackish ground water in lieu of potable water and or wash water, the storing of reverse osmosis reject brine in the slurry pits and the use of different premixes by the feed mills will all have measurable effects on the contents of the stored manure and hence in the resulting biochar.

### 3.4 Recovery

In agreement with results reported in the reviewed literature, this study reports that biochar recovery is positively correlated to ash content but negatively correlated to the manure biomass feedstock volatile matter and nitrogen contents. Volatile matter is released by the feedstock during the pyrolysis process: the more volatile released, the higher are the losses resulting in a lower biochar recovery. Likewise, but in an opposite manner, a high ash concentration results in higher biochar recovery. The sheep feedstock, which had the highest release of syngas and bio-oil and lowest ash content, generated the lowest biochar recovery of 15 wt.% db. Although sheep manure generates the least amount of biochar, on the other hand it appears to be most energy dense when evaluated on the basis of the higher carbon and lowest ash contents. Of particular interest, biochar from poultry manure had the highest ash and the lowest carbon content, correlating well with the literature, that generally classifies poultry biochar as having a poor high heating value. Due to the high ash content, manure biochar may be not viable as a commercial fuel.

Similar to the trend in biochar mass recovery when compared to the original feedstock, carbon recovery also decreased. Changes in carbon content occur simultaneously with losses in hydrogen and oxygen (Antal Jr. et al., 2003). Contrary to trends reported by Cantrell et al. (2012), this study indicates that cow manure generated the most stable carbon that did not decompose following thermal treatment. Lang et al. (2005) noted that higher carbon recovery was obtained from manure-based biochar when compared to pyrolysed lignocellulosic feedstocks, leading Keiluweit et al. (2010) to conclude that pyrolysing manure feedstocks releases less volatile carbon when compared to pyrolysing grasses and wood. Cantrell et al. (2012) justified this observation by arguing that manures had a higher propensity to retain carbon following pyrolysis, due to protective mechanisms involving various inherent metals, that change the bond dissociation energies of inorganic and organic carbon. This mechanism was later supported by White et al. (2011), who showed that treating lignocellulosic biomass with inorganic salt solutions altered reaction pathways, resulting in an increased production of biochar. Nonetheless, one has to factor in the effect of digestive processes when analysing manure and more specifically manure from ruminant animals. The digestive physiological process of ruminant animals involves mechanical breakdown, microbial action and enzymatic activity, all coming together to extract the available cellulose and hemicellulose from the consumed roughage. Thus, manure from ruminant animals will contain plant components that have undergone the full digestive process and resisted breakdown, such as lignin. Xu et al. (2013) suggest that biochar yield has a strong positive correlation with amounts of lignin and mineral content of the feedstock.

Poultry manure yielded the lowest carbon recovery. Commercial poultry flocks are given feed containing a corn - soy bean combination with the inclusion of premix containing vitamins and minerals to formulate diets to meet the specific requirements of the flock. Given that the dietary need of poultry does not require complex fibre, feed is usually formulated to contain minimal amounts of lignin. It so follows that poultry manure will be void of lignin, thereby reflecting in the poor ability of retaining stable carbon following pyrolysis. The poultry manure in this study contained a 50/50 blend of cage layer manure and broiler litter. Hence although the poultry excreta have insignificant levels of lignin, the wood shavings used as bedding in the broiler litter is predominantly lignin, which will contribute towards the recovery of stable carbon.

Table 3 shows that cow feedstock generated the highest amount of syngas and the least amount of bio-oil, while the sheep feedstock behaved in an opposite manner, releasing the highest amount of bio-oil and the least amount of syngas.

### 3.5 Implications for Environmental and Agronomic Management

Maltese Soil Information System (2004) led to the creation of an electronic map of soil properties, with observation points located on a 1 km$^2$ grid across Maltese archipelago. The outcomes of this project highlighted the following issues that are pertinent to this study:

(1) 58% of Maltese soils have low or very low soil organic carbon content ($< 20$ g/kg);
(2) soils are slightly and moderately alkaline (pH between 7.3 and 8.5);
(3) 77% of soils are either loamy, clay loam or clay soils, and have clay content higher than 48%;
(4) heavy metal hot spots have been identified, predominantly in the South of Malta;
(5) soils are non-saline (EC 347 µS cm$^{-1}$); however, in irrigated soils the EC is double (695 µS cm$^{-1}$).

Lehmann (2007) suggested that when applied to soil, biochar having a carbon-rich lattice can be used as an effective C sequestration agent, when its H:C ratio is less than 0.6. Results indicate that biochar from all the different manure feedstock types had a H:C ratio of 0.022–0.03, thus exhibiting a high C sequestration potential, representing an efficient technique for mitigating against greenhouse gas emissions, while also serving as a carbon source to improve the low soil carbon content. The pyrolysis process concentrates minerals that are essential for plant growth such as Potassium, Phosphorus and Sodium, implying that manure-based biochar may be suited for application as an alternative fertiliser. With respect to heavy metal concentrations in biochar, the higher majority fall within the acceptable limits as stipulated by the Italian legislation and would have minimal impact on increasing soil heavy metal concentrations in a singular short-term application. The suitability of biochar as a soil amendment would depend on feedstock selection, initial nutrient concentrations and the resulting nutrient plant availability status. However, the results show EC values of 29,600 to 40,300 $\mu$S cm$^{-1}$, indicating the presence of high levels of salts, which can potentially contribute to increasing soil salinity. In addition, there is the risk of accumulating some individual heavy metals, in particular zinc, that are at high levels both in manure and in the resulting biochar. The alkaline nature of biochar may be of critical concern when applied to Maltese arid soils, due to its high salinity and alkaline nature. These physicochemical properties render the application on Maltese soils of biochar generated from local livestock manure questionable. Further studies need to be undertaken to determine the suitability of manure biochar application onto Maltese soils.

## 4 Conclusions

The need to treat animal manure is driven mainly by the requirements of the Nitrates Directive. Livestock manure in Malta is produced from several sources: cattle, swine, poultry, sheep, rabbits and horses, generating significant amounts of manure and litter. These units do not have the capacity to utilise these materials on site and the quantities generated surpass the application rate to the available arable land as stipulated by the Nitrates Directive. In such cases, manure becomes a liability instead of a benefit, incurring significant risk due to:

(1) need for storage of vast volumes of slurry/manure;
(2) creating environmental pollution and animal health risks, due to the accumulation of manure on farms;
(3) risk due to nutrient concentration and potential nutrient escape causing environmental pollution;
(4) issue of economies of scale in applying a technical solution.

Pyrolysis converts nitrogen into an inert gas and reduces volumes. The thermochemical technology employed in the process utilises high temperature, thereby destroying any potential pathogen that may be present in the manures. Pyrolysis has the potential of extracting useful energy and generates potentially high value products. Lima et al. (2009) claim that: "Chars are normally produced to reduce the volume and mass of a particular feedstock and provide a soil amender that improves the physical and nutritive properties through its ash content of hard, compact soils with a high clay content or highly porous soils with a high silica or sand content." The results show that the biochar produced in this study may not be suitable for use on Maltese soils. The outcomes from this first attempt to define the physiochemical properties of manure and the resulting biochar indicate that further studies involving larger sample size per livestock type are required to verify the physicochemical variations and similarities, in particular the presence of high levels of zinc and EC. Nonetheless, pyrolysis of livestock manures is an interesting substitute to direct land application or incineration. In fact, manure biochar could be potentially used as a fuel to dry the feedstock and the resulting biochar ash can be utilised for the extraction of valuable essential plant nutrients such as potassium and phosphorus. A further economic study on this option will establish the feasibility of the operation.

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*Research Article*

# Environmental Effects on the Incidence of Spontaneous Pneumothorax

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**Abstract.** Spontaneous pneumothorax (SP) is a common occurrence especially in young male asthmatics and smokers. Several studies have shown that this condition occurs in clusters although other reports showed the contrary. There is evidence that clustering of cases occur as a result of severe changes in atmospheric pressure. The literature is however very limited with regards to the relationship between air pollution and spontaneous pneumothorax.
*Methodology*: Observational study on consecutive patients admitted with SP from January 2010 to December 2014. The data regarding dates of admissions, gender, age, residential address, smoking history, relevant medical history and sequential management of the pneumothorax were collected and tabulated. The admission dates were analysed to test for clustering of admissions of patients. The patients were identified by location to assess the incidence of SP in different locations or areas. The Environment and Resources Agency (ERA) of Malta supplied daily particulate data from 3 different sites in the archipelago for the years 2010-1014.
*Results*: There were 112 patients presenting with 134 episodes of SP. The mean age was 29 years and 86.6% were males. No admission date clustering occurred and therefore linkage to atmospheric pressure changes cannot be made. There was however a very significant increase in incidence in patients hailing from the harbour area ($p < 0.00001$). ERA data shows that there was a similarly significant increase in particulate material in the air of the harbour locality when compared to non-harbour areas.
*Discussion and Conclusion*: SP is commoner in men and smokers. There was no evidence of admission day clustering but areas with increased air particulate matter had an increased incidence of patients with SP. Increased air pollution seems to increase the incidence of SP either directly or indirectly.

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## 1 Introduction

Pneumothorax is defined as air in the pleural cavity and spontaneous pneumothorax is the commonest presentation of this condition. Spontaneous pneumothorax is usually classified as primary (no obvious underlying lung disease) or secondary (in the presence of underlying lung condition). Spontaneous pneumothorax has been shown to be commoner in males (Bobbio et al., 2015) and smokers (Bense et al., 1987; Tschopp et al., 2015). Several studies have shown that this condition may occur in clusters (Smit et al., 1997) although others did not show this occurrence (Ayed et al., 2006). There is also some evidence that clustering occurs during moderate to severe changes in atmospheric pressure (Alifano et al., 2007; Schieman et al., 2009; Scott et al., 1989; Smit et al., 1999; Suarez-Varel et al., 2000). Bertolaccini showed that in Turin fluctuations of atmospheric pollutants increased the risk of SP (Bertolaccini et al., 2010). However there is no other research showing that increased air pollution predisposes to SP. Malta is a 30 by 10 km island state at the centre of the Mediterranean Sea (figure 1). Its terrain is flat with no substantial difference in altitude from sea level between different parts of the island. It is very densely populated with 1 350.28 persons per square kilometre and most of the population lives in the north-eastern part of the island. The most air-polluted area in Malta is the region around the main harbour because of the heavy traffic and machinery and

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**Figure 1:** The Geographic position of the Maltese Archipelago at the centre of the Mediterranean Sea (Wikipedia)

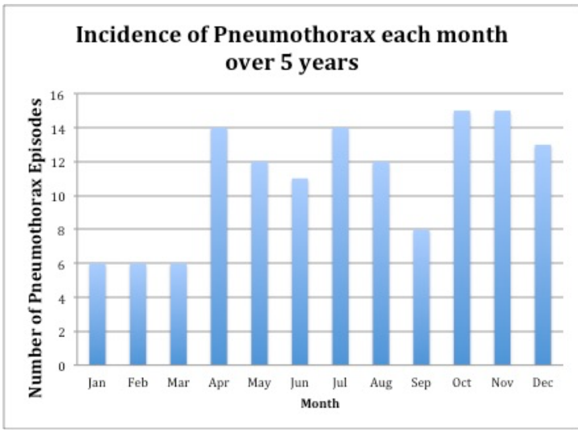


**Figure 2:** The Incidence of Pneumothorax per month over 5 years

the presence during the study of a heavy oil driven power station and the dockyards. In this study we attempt to address the issue of clustering of spontaneous pneumothorax and the possible association of air pollution with this condition.

## 2 Methodology

All patients admitted consecutively with primary spontaneous pneumothorax to the only public acute hospital on the island, Mater Dei Hospital, from January 2010 to December 2014 were included in the study. Patients with primary and secondary spontaneous pneumothoraces were studied but patients with iatrogenic pneumothorax and pneumothorax secondary to trauma were excluded from the study. This data was supplied by the Medical Records Department of the hospital. The data regarding dates of admissions, gender, age, smoking history, relevant medical history and sequential management of the pneumothorax were collected and tabulated. All the chest radiographs taken during these admissions were seen and the size of the pneumothorax assessed by the senior author (J. Galea). The size of the pneumothorax was labelled as small or large as described by British Thoracic Society (2010). If the pneumothorax was less than 2 cm ($< 2$ cm) at the hilum, it was described as small and if it was larger than 2 cm ($> 2$ cm) it was deemed large. The resident locality of the patients was identified from the hospital database and the number of inhabitants in each locality was derived from local council data for 2012. Persons who were not permanent residents on the island were excluded from the study. The harbour area has a concentration of heavy industry related to power generation and shipyards and other heavy machinery. The towns and villages in the proximity of this activity includes Valletta, Floriana, Cospicua, Senglea, Vittoriosa, Marsa, Pietà, Msida, Ta' Xbiex, Ħamrun, Paola, Fgura, Żabbar, Kalkara, Tarxien, Gudja, Għaxaq and Kirkop. All the other towns and villages of Malta were designated as the non-harbour area. People hailing from Gozo would have been managed at the Gozo General Hospital and they were excluded from the study. The year has been divided in two seasons; a wet winter season and a dry summer season. The winter months were from October to March and the summer months were from April to September. The occurrence of pneumothorax for each month was recorded from admission data. The Maltese Environmental and Resource Agency (ERA) supplied the data of daily concentration of particulate matter of less than 2.5 µm (PM 2.5) and less than 10 µm (PM 10) aerosols and the nitrogen oxide air concentration from 2 Malta sites; Msida (a harbour area site), Żejtun (outside harbour area sites) from January 2010 to December 2014. This data was captured using real time air monitoring stations.

## 3 Results

One hundred and twelve patients presented with 134 episodes of pneumothorax. The total mean age was 29 years (median 26) and 86.6% were male. Ninety six (85.7%) patients had a smoking history while 16 (14.3%) never smoked. 57.5% of patients with a first episode of pneumothorax and 79.2% of patients with a second pneumothorax were smokers. There was no statistical difference in the preponderance for sides for first or second episodes of pneumothorax although in both cases there were slightly more left than right pneumothoraces; (1st episode: right 44.3%, left 55.7%; 2nd episode: right 42.9%, left 57.1%).

## 4 Seasonal incidence

Figure 2 shows the number of pneumothoraces each month over the five-year period. Throughout the five years, the mean number of spontaneous pneumothorax

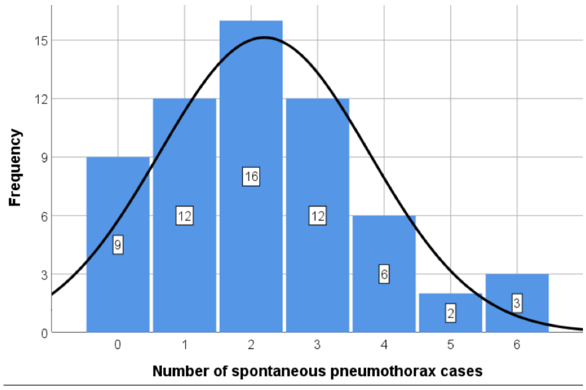


**Figure 3:** Frequency distribution curve of spontaneous pneumothorax patients

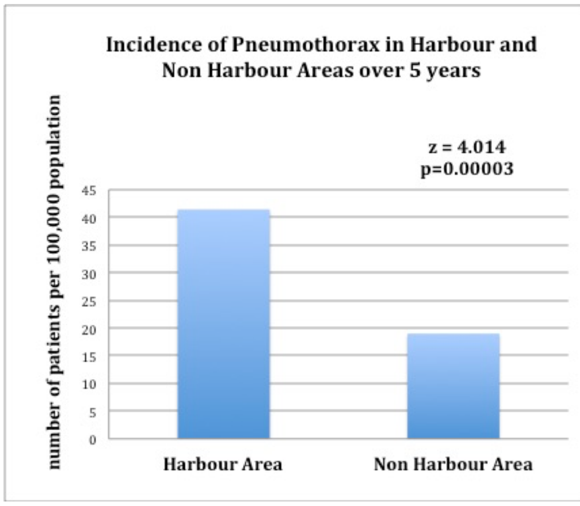


**Figure 4:** The incidence of pneumothorax in the harbour area and non harbour area in Malta

cases is highest in October and November (3.00) and lowest in January, February and March (1.20). Using the Kruskal Wallis test, the difference between the mean frequencies is not significant since the $p$-value (0.293) exceeds the 0.05 level of significance (table 1). Throughout the five years, the number of spontaneous pneumothorax cases per month ranged from 0 to 6. The mean, median and mode are respectively 2.2, 2.0 and 2.0 and the standard deviation is 1.582 (Figure 3). There is therefore no seasonal difference in incidence of spontaneous pneumothorax.

## 5 Clustering

The Chi square test reveals no association between the numbers of spontaneous pneumothorax monthly cases and the year in which these cases occurred since the $p$-value (0.123) exceeds the 0.05 level of significance. If we consider the larger frequencies (4, 5 and 6) of spontaneous pneumothorax monthly cases, these are occurring in all the months excluding February, March and September. If we consider the smaller frequencies (0 and 1) of spontaneous pneumothorax monthly cases, these are occurring in all the months except July (table 2). A method for testing the randomness of observed data is based on the theory of runs. A run is a succession of values which are all above or all below the mean. In other words, the runs test checks the randomness in which the observations vary around the mean. Too few runs indicate definite clustering (grouping), while too many runs indicates that the data alternates too often above and below the mean. The runs test displayed below indicates that the observations are random since the $p$-value (0.258) exceeds the 0.05 level of significance. This implies that there is no clustering of spontaneous pneumothorax cases (table 3).

## 6 Relationship of Pneumothorax to Air Pollution

The incidence of SP in the harbour area over the 5 years studied was 43 out of a population of 103,916 living in the harbour area (8.3 per year per 100,000 population in that area) and 56 out of a population living outside the harbour area of 295407 (3.8 per year per 100,000 population in the non harbour area). This difference is very statistically significant ($p = 0.00003$) (Figure 4). The mean ages for patients in harbour area and in non harbour area were of 28 and 32 years respectively and the difference was not statistically significant. The percentage of male patients and the prevalence of smoking and asthma did not differ significantly between the two regions (table 4).

During the same time period, there was a consistent significant increase in both PM 2.5 and PM 10 and the concentration of nitrogen dioxide ($NO_2$) in the harbour area as represented by Msida compared to non-harbour areas represented by Żejtun (figure 5 and table 5) over the five-year period studied.

## 7 Discussion

Spontaneous pneumothorax was commoner in males and in smokers. Although in several series of SP patients clustering of cases was observed and this was attributed to changes in atmospheric pressure, no clustering was recorded in this study. One explanation for this lack of clustering could be the rather small number of patients with SP. The lack of clustering and the wide distribution of cases compelled the authors to conclude that studying changes in atmospheric pressure during this time period was futile. Analysis of this distribution of cases shows an apparent decrease in incidence in the first 3 months

| Month | Mean number of spontaneous pneumothorax cases per month | Std. deviation | $p$-value |
|---|---|---|---|
| January | 1.20 | 2.168 | |
| February | 1.20 | 0.837 | |
| March | 1.20 | 1.095 | |
| April | 2.80 | 1.304 | |
| May | 2.40 | 1.817 | |
| June | 2.20 | 0.837 | 0.293 |
| July | 2.80 | 1.789 | |
| August | 2.40 | 2.302 | |
| September | 1.60 | 0.894 | |
| October | 3.00 | 2.121 | |
| November | 3.00 | 1.581 | |
| December | 2.60 | 1.140 | |

**Table 1:** Mean number of spontaneous pneumothorax for each month per year

| | Year | | | | |
|---|---|---|---|---|---|
| Month | 2010 | 2011 | 2012 | 2013 | 2014 |
| January | 1 | 0 | 0 | 5 | 0 |
| February | 1 | 1 | 0 | 2 | 2 |
| March | 2 | 0 | 2 | 2 | 0 |
| April | 2 | 4 | 4 | 3 | 1 |
| May | 1 | 4 | 4 | 0 | 3 |
| June | 2 | 2 | 3 | 3 | 1 |
| July | 2 | 2 | 2 | 2 | 6 |
| August | 6 | 2 | 0 | 1 | 3 |
| September | 2 | 1 | 1 | 3 | 1 |
| October | 6 | 3 | 3 | 3 | 0 |
| November | 3 | 2 | 4 | 5 | 1 |
| December | 3 | 4 | 1 | 2 | 3 |

$\chi^2(44) = 55.055,\ p = 0.123$

**Table 2:** The occurrence of spontaneous pneumothorax per month for each year

| | Frequency |
|---|---|
| Test value | 0.072 |
| Cases < test value | 1705 |
| Cases $\geqslant$ test value | 121 |
| Total cases | 1826 |
| Number of runs | 221 |
| $Z$ | $-1.130$ |
| $p$-value | 0.256 |

**Table 3:** Statistical analysis to determine whether clustering of cases occurred

| | Harbour Area ($n = 43$) | Non-Harbour Area ($n = 56$) | $z$-value | $p$-value |
|---|---|---|---|---|
| Gender (Male) | 37 (86.0%) | 47 (83.9%) | 0.2913 | 0.772 |
| Smokers | 27 (62.8%) | 30 (53.5%) | 0.9200 | 0.358 |
| History of Asthma | 4 (9.3%) | 7 (12.5%) | 0.5018 | 0.617 |

**Table 4:** Comparison in the incidence of known risk factors for spontaneous pneumothorax in the harbour and non-harbour area

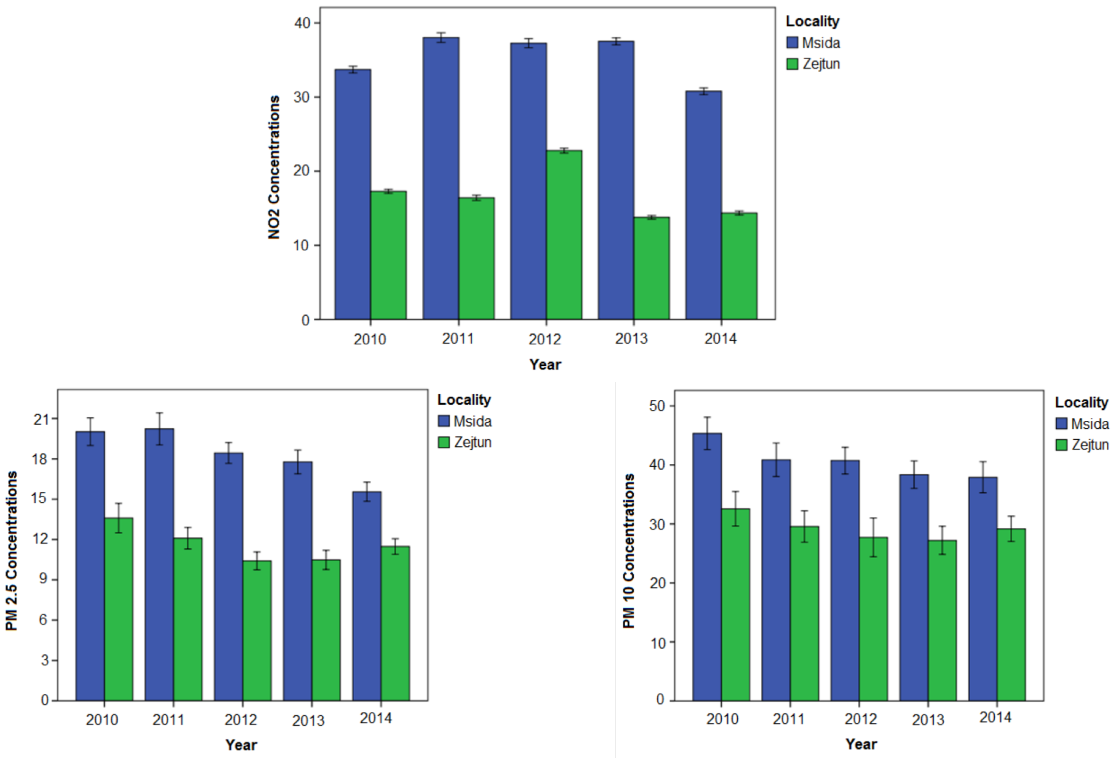


**Figure 5:** Comparison of PM 2.5 (A), PM 10 (B) and $NO_2$ concentration (C) between the harbour area (Msida) and non-harbour area (Zejtun) from 2010 to 2014

| Pollutant | Harbour Area | Non-Harbour Area | $p$-value |
|---|---|---|---|
| Particulate matter 2.5 µm (µg/m$^3$) | 18.3 | 11.8 | $< 0.001$ |
| Particulate matter 10 µm (µg/m$^3$) | 40.6 | 27.5 | $< 0.001$ |
| Nitrogen dioxide (µg/m$^3$) | 36.2 | 9.8 | $< 0.001$ |

**Table 5:** Comparison of concentration of 2.5 µm and 10 µm particulate matter and Nitrogen dioxide between the harbour (Msida) and non harbour area (Żejtun)

of the year over the five-year period but the difference does not reach statistical significance and therefore not deemed important.

The harbour area in Malta is densely populated and has a very high traffic load. During the time of the investigation an oil-fuelled electricity generating power station was located in Marsa at the centre of the harbour area. This was present since 1953 and was decommissioned in 2015 after the end of this study. Data from the Maltese Environmental Resource Agency showed an increased PM levels and NO2 concentration in the monitoring site in Msida (harbour area) when compared to that in the rural Żejtun. This study shows that the difference in incidence of spontaneous pneumothorax between the densely populated, high density traffic and industrial harbour area and the more rural areas is very marked and highly significant. In Balzan et al. (2004), the authors showed that heavy traffic in the harbour area increased the incidence of asthma in Malta. In the current study there was no difference in the incidence of asthma and tobacco consumption in SP patients living in the harbour area when compared to the non-harbour area. Although there are possible unknown confounding factors there is a strong relationship between the quality of the air and the incidence of spontaneous pneumothorax. This association has not been studied before except for a study by Bertolaccini and colleagues who showed increased incidence of spontaneous pneumothorax in patients living in areas in Turin, Italy with a high atmospheric levels of $NO_2$ (Bertolaccini et al., 2010).

The limitations of the study include a small sample size and sampling data of PM10 and PM 2.5 was obtained retrospectively from a third party (ERA) thus making it difficult to ensure that the appropriate calibration and validation of sensors was performed by the testing agency. Some border locations between the two sites maybe problematic because of their equidistance from the monitoring stations (e.g. Gudja, Għaxaq and Kirkop).

In conclusion, the incidence of spontaneous pneumothorax in Malta is markedly higher in locations with higher atmospheric levels of particulate matter of $<$ 2.5 µm and $<$ 10 µm and $NO_2$. This has significant implications from a public health point of view since it provides further local data showing the urgent need to reduce such emissions. There was no clustering of cases in this study.

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*Research Article*

# An augmented seismic network to study off-shore seismicity around the Maltese Islands: The FASTMIT experiment

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**Abstract.** Appropriate planning and deployment of a seismic network is a prerequisite to efficiently monitor seismic activity, determine the seismic source, and eventually contribute to the seismotectonic interpretation and seismic hazard assessment. The evaluation and effectiveness of a local network on the Maltese islands, recently extended by a further six seismic stations for one year, is presented. We investigate the new temporary network's data and site selection quality, utilizing spectral patterns in the seismic data and also evaluate the network's event location performance by relocating a number of recorded events. The results will be significant for the future installation of permanent seismic stations on the Maltese islands.

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## 1 Introduction

The Maltese islands (figure 1) have been affected by several earthquakes in the historical past. The epicentres of these earthquakes were located mainly in the Sicily Channel (bordered by the Sicilian, Tunisian, and Libyan coastlines), in eastern Sicily, and as far away as the Hel-

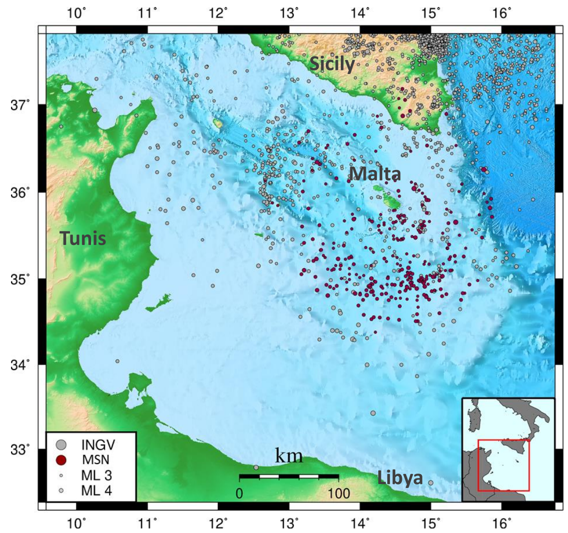


**Figure 1:** Seismicity in the Sicily Channel for the period 1995 – 28 November 2018. Epicentres from INGV (grey dots); Malta Seismic Network (MSN) single station (pre-2014) and MSN most reliable locations for events greater than ML 2.5 (red dots) for the period 1995 until 28 November 2018. Many events appear to be located south of Malta, being focused on the local major tectonic fault zones.

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lenic arc. Contrary to the common belief that Malta is not at risk from earthquakes, some of these events produced considerable damage to local buildings (Galea, 2007). The main damaging events were located in Sicily (1542 $M_w$ 6.6, $I_{max}$ VII on Malta; 1693, $M_w$ 7.4 $I_{max}$ on Malta VII–VIII; 1911 $I_{max}$ Malta VII), Crete (1856, $M_w$ 7.7, $I_{max}$ Malta VII), Ionian (1743, $M_w$ 6.9, $I_{max}$ Malta VII) and Aegean Sea (1886 $M_w$ 7.3, $I_{max}$ Malta VI–VII), where the intensities are on the EMS-98 scale.The risk from seismic hazard is increasing because of the rapid expansion of the construction industry, still not regulated by a national building code.

Because of the unique position of the Maltese Islands in the Mediterranean Sea, and to achieve better earthquake detection in the region, different types of seismographs were installed in Malta since the introduction of seismographic instrumentation at the beginning of the 20th century. A Milne horizontal pendulum seismograph operated in Valletta from 1906 until the 1950s. A vertical long-period Sprengnether seismograph with photographic recording was installed in 1977, operating for some years and then replaced by a three-component short period station with analogue paper recording. The seismograms from these instruments are still preserved by the Seismic Monitoring and Research Group within the Department of Geosciences at the University of Malta, and many of them have been scanned within the SISMOS project (http://sismos.rm.ingv.it). Since June 1995 and until 2014, only one broadband station was operating in Malta at Wied Dalam (Agius et al., 2014). WDD was installed as part of the MedNet program (Boschi et al., 1994). Since 2015, the Malta Seismic Network was set up, initially consisting of only three stations (Agius et al., 2015).

WDD seismic station is located in the south-eastern part of the island, housed in a disused tunnel at a distance of about 900 meters from the coast (figure 2A). WDD is located on Lower Coralline limestone, the oldest of the four main geological formations outcropping on the Maltese archipelago (figure 2B). The isolated installation and quiet environment allow high-quality low noise recordings. It was thus possible to achieve the detection of several local and regional events (Agius et al., 2011) (figure 1). Many of these events occurring close to Malta were too small to be detected by other regional operating stations, and they may have been misclassified or overlooked due to low signal-to-noise ratio. Although the single station location algorithm provides reasonable epicentres, it is unable to determine the depth of the earthquakes, and also suffers from limited accuracy and low precision solutions, especially when the signal-to-noise ratio at the P-onset is low. The significant number of events being detected by the single station, however, highlighted the need to improve earthquake

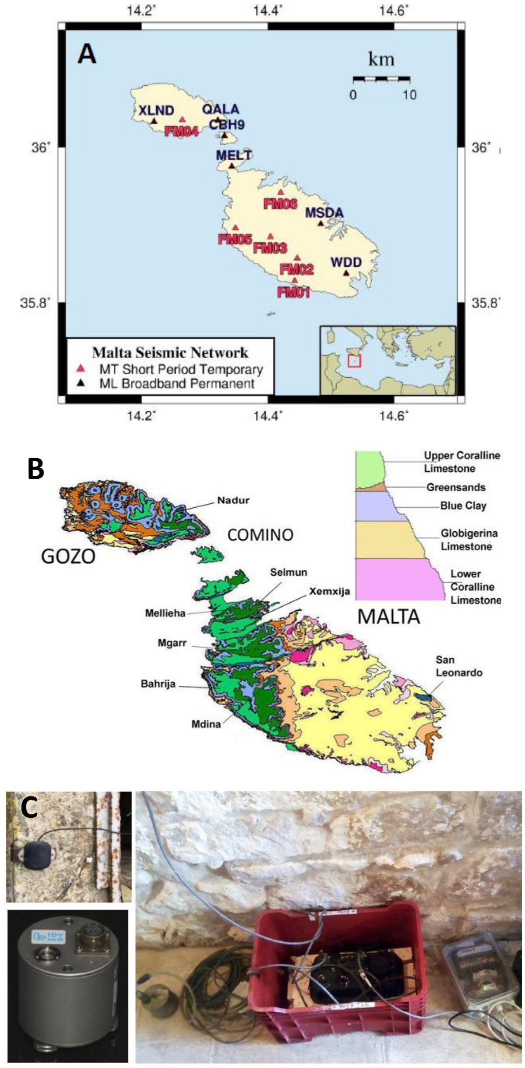


**Figure 2:** **A**: The enhanced seismic network. The stations are depicted with red triangles for the six short period OGS stations and with black triangles for the six permanent stations of Malta Seismic Network. **B**: Geological map of the Maltese Islands after Pedley et al. (1976). **C**: Typical station setup for the enhanced network experiment, here station FM02 inside the farmhouse at Siġġiewi. Top right frame: The GPS receiver placed outside the site. Bottom left frame: The Lennartz seismometer. Right frame: The case holding the data logger.

locations and detectability. Enhancement of the observational capacity was essential for improving the accuracy and precision of the hypocentral solutions, and for identifying active faults in and around the Maltese islands. The Malta Seismic Network was thus established and extended in recent years and currently comprises six permanent broadband stations installed across the Maltese islands (figure 2A, black triangles). The improved detectability (Galea et al., 2018) and the number of the events being obtained by the new network (figure 1), encouraged us to further extend it, and 6 short period temporary stations were installed from June 2017 and operated until September 2018, improving the coverage of the network for more than a year (figure 2A, red triangles). This extension allowed the exploration of the potentials of installing more permanent stations and also helped to test the installation sites. This paper describes the temporary extended network, and evaluates the station quality and performance, focussing on the six temporary stations.

## 2 The FASTMIT Project

The FASTMIT project (Rossi et al., 2016) was funded by the Italian government and coordinated by the OGS (*Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, Sezione Centro Ricerche Sismologiche, Italy*). The main FASTMIT goals are to study the offshore seismicity in the Italian seas as well as in adjacent ones. This is necessary in order to increase the scientific knowledge related to fault systems at sea and their evolution in a broader geodynamic context. Recent studies and observations have highlighted the presence of potential seismogenic and tsunamigenic areas in the Central Mediterranean region, which are not yet well understood and are not fully integrated with seismic and tsunami hazard evaluations (Petricca et al., 2019). During the project, four areas have been investigated (Adriatic Sea, the Taranto Gulf, the Sicily Channel, and the southern Tyrrhenian Sea). In particular, studies have focussed on the improvement of seismic hazard analysis, coastal hazards with a focus on areas in which critical infrastructures are present, or for the evaluation of the hazard associated with off-shore hydrocarbon extraction operations. FASTMIT benefited from numerous other previous and simultaneous research projects and initiatives (e.g., RITMARE, EMODnet–Geology2, EPOS IP, ASTARTE, SHARE, AlpArray). The team consisted of over 60 researchers which provided a pool of different expertise to tackle all the problems related to the mapping and study of the off-shore seismogenic and tsunamigenic structures. Seismic, chirp, and multibeam surveys provided a better definition of the sea bottom and of the tectonic structures beneath it. Moreover, the cross-border (Italy, Austria, Slovenia, Croatia) seismic network CE3RN (Bragato et al., 2014) was strengthened. The temporary array installed in Malta had the main goal to create an international research framework operational even after the end of the project, and more importantly to test and increase the seismic detection capability in the Central Mediterranean and supply useful information to permanent inland networks which, due to their geometry, suffer from a lack of resolution and accuracy both in terms of earthquake location and magnitude threshold in this region.

## 3 New Enhanced Network

From June 2017 to September 2018, in the framework of the FASTMIT project, six short-period stations, equipped with Lennartz sensors and RefTek digitizers, were installed across the Maltese archipelago (figure 2A) and integrated with the permanent Malta Seismic Network. FASTMIT stations were operating offline and data acquisition along with maintenance checks were carried out through frequent visits to the stations. Four of the six stations (FM01, FM02, FM04, FM06) were installed directly on the Globigerina or Lower Coralline limestone. These are the two lower outcropping compact formations lying below the soft and erodible Blue Clay (Farrugia et al., 2016; Pedley et al., 1976). Two other stations, FM03, and FM05, were installed on the Upper Coralline Limestone formation. This compact Upper Coralline limestone represents the youngest formation of the Maltese geological sequence and lies above the Blue Clay formation. Its position, above the Blue Clay, makes Upper Coralline limestone not ideal for seismic station installation, as site amplification (as described further below, figure 8) and alteration in the frequency content of seismic waves is consistently observed (Farrugia et al., 2016). Nevertheless, the installation of these stations was considered useful as a means to evaluate quantitatively, and in more detail, within future studies, the influence of the clay layer on the seismic site response to incoming earthquake waves due to this particular geological setting. Table 1 contains a summary related to the installation of each station. The installation took into account noise levels and the security of the operating conditions. Locations as far away as possible from anthropogenic sources of noise were preferred. Being on a small island, it is in general, challenging to avoid noise from anthropogenic and industrial sources, as well as marine-generated noise from nearby coasts. Nevertheless, sheltered locations offering constant power supply and security for the stations were sought.

## 4 Performance Evaluation

### 4.1 Initial Waveform Inspection

An initial visual inspection of the 24-hour seismogram plots was first carried out to ensure the proper function-

| Station Code | Latitude (°N) | Longitude (°E) | Elevation (m) | Location | Sensor | Digitizer | Outcropping Geology |
|---|---|---|---|---|---|---|---|
| FM01 | 35.8276 | 14.4426 | 128 | Ħaġar Qim temples | Lennartz | RefTek | Lower Coralline Limestone |
| FM02 | 35.8569 | 14.4467 | 95 | Siġġiewi farmhouse | Lennartz | RefTek | Globigerina Limestone |
| FM03 | 35.8845 | 14.4043 | 190 | Mdina – Natural History Museum | Lennartz | RefTek | Upper Coralline Limestone |
| FM04 | 36.0342 | 14.2647 | 105 | University of Malta, Gozo Campus | Lennartz | RefTek | Globigerina limestone |
| FM05 | 35.8959 | 14.3492 | 205 | Baħrija Church - St Martin of Tours | Lennartz | RefTek | Upper Coralline Limestone |
| FM06 | 35.9411 | 14.4208 | 6 | San Mikiel Chapel, Burmarrad | Lennartz | RefTek | Lower Coralline Limestone |
| WDD | 35.8373 | 14.5242 | 44 | Wied Dalam, Birżebbuġa | STS-2 | Quanterra | Lower Coralline Limestone |
| MSDA | 35.9012 | 14.4840 | 48 | University of Malta, Msida Campus | Trillium 120PA | Centaur | Globigerina Limestone |
| MELT | 35.9750 | 14.3430 | 98 | St Agata Tower, Mellieħa | Trillium 120PA | Centaur | Upper Coralline Limestone |
| QALA | 36.0339 | 14.3210 | 92 | Qala, Chapel of Immaculate Conception, Gozo | Trillium Compact | Centaur | Upper Coralline Limestone |
| CBH9 | 36.0140 | 14.3314 | 28 | Comino, Borehole 9 | Trillium Compact | Centaur | Upper Coralline Limestone |
| XLND | 36.0323 | 14.2199 | 15 | Underground Flour Mill, Xlendi, Gozo | Trillium Compact | Centaur | Lower Coralline Limestone |

**Table 1:** Summary of the stations installed during the experiment (FMXX) and MSN permanent stations

ing of a station. Figure 3 shows 24h plots for the day in which the network recorded one of the largest regional offshore events of 1the study period. The ML 3.1 event occurred on the 23rd of November, 2017, at 08:36 UTC, about 50 km SW of Malta, and is marked with a yellow star in figure 3. As shown in the figure, stations FM01 (Ħaġar Qim), FM05 (Baħrija), and FM06 (Salini) are characterised by a lower noise level on this day, making the recording of this event clearer. On the contrary, FM03 (Mdina), FM04 (University of Malta, Gozo Campus), and FM02 (Siġġiewi) appear very noisy during that day. On all the 24h plots, the noise is reduced dramatically during the night, indicating the relationship of the noise with human activity. The highest noise levels are recorded at FM03 in Mdina. Although it is known that light industrial activity was going on close to the station during the day, the noise here continues into the night-time hours, indicating that it may not be all anthropogenic. This effect is probably related mainly to two factors. Firstly, the clay subsurface layer (which, in Mdina, is found only 9 m below the base of the Upper Coralline Limestone, has been observed to cause significant amplification and frequency content alternations (Farrugia et al., 2016)). Secondly, the high noise may be attributed to Mdina's geomorphology. Mdina, being built on a hill, is more exposed to bursts of strong wind during the winter months. The noise at FM04 station, installed within the University of Malta, Gozo campus at Xewkija, on the Upper Globigerina limestone, is most likely related to nearby traffic, maintenance works and farming activity that took place during the station's operating period. Any new station at this site would preferably be located instead on the Middle Globigerina limestone in the basement level of the campus, which is presently being rehabilitated. Noise at FM02 (Siġġiewi) is also likely to be related to local anthropogenic activity, such as farming. At both stations FM04 and FM03, the primary source of noise is very close, mainly agricultural activities taking place in the adjacent field for FM04 (approx. 10 m away) and renovation activities taking place at the building hosting FM03. Nevertheless, during periods when presumably human activity is low, the stations performed well, asit will be shown in the following sections. Low noise levels at FM01 and FM06 are probably because the stations are sited on the compact Lower Coralline Limestone and in quiet areas.

### 4.2 Seismic Noise Analysis

Probabilistic Power Spectral Density (PPSD) plots are here utilized to assess the operation and the ambient noise levels that are recorded at the stations (figures 4 and 9 to 15). The PPSDs are obtained following the approach of McNamara et al. (2004), implemented in the software package ObsPy (Beyreuther et al., 2010), which was used for this study. Following the default method that it is incorporated in the algorithm, PSSDs are computed by analysing continuous traces of recordings in 1 hour windows that move in steps of 30 minutes. Pre-processing of the 1-hour segments includes segmentation into 13 windows that overlap by 75%, truncation to the next lower power of 2, and subtraction of the mean and tapering. After the removal of instrument response, fast Fourier transform (FFT) is applied to all data segments, and PSDs are obtained from the FFT components. Histograms showing the frequency distributions of the amplitudes recorded at each period based on all smoothed PSDs are created. A probability density function is estimated from the histogram for each centre period. The periods are converted to frequencies, so the final plots of PPSDs show the amplitudes most frequently observed at each frequency. An example of PPSD analysis is given in figure 4, in which plots were created for all stations for the one-week period 11-19 May 2018. Above approximately 0.2 Hz, the PPSDs for all stations lie within the new high and low noise model (NHNM-NLNM) of Peterson (1993), demonstrating high performance. At the stations FM01 and FM05, PPSDs appear to touch the NHNM close to 1 Hz. In the case of FM01, this may be due to energetic wave action at the nearby shore, while for FM05, this could be related to the underlying geological conditions, however it needs further investigation. To further examine the performance of the stations, PPSD plots were created for the entire period of the experiment for all the FASTMIT stations (figure 9). Since the sensors are short-period, only the 0.5-60 Hz frequency interval is relevant. The performance seems to be satisfactory for all the stations, with all the PPSD plots generally lying within the high and low noise model (NHNM –HLNM, marked with thick lines on the plot) of Peterson (1993). The only exception is station FM05 where exceedance of the NHNM is partly observed between 0.7 and 3.5 Hz. PPSD curves for FM01 are slightly exceeding the NHNM between 0.6 to 1.5 Hz. This is probably due to the station being located close to the cliff and the sea wave activity. In addition, this exceedance may be linked with the location of the sensor. In spite of the ideal conditions of the site (Lower Coralline limestone and away from human noise sources), the seismometer had to be obligatorily placed on a tiled floor. Moreover, close to the end of the experiment, it was discovered that an irrigation pipe was passing underground, close, and below the instrument. In general, all stations show similar noise frequency characteristics, with a broad peak around 0.5 Hz. FM05 consistently demonstrates a smaller peak at around 5 Hz, which is observable on all subsequent plots.

To investigate the effect of the weather conditions, separate PPSD plots are created for the winter and sum-

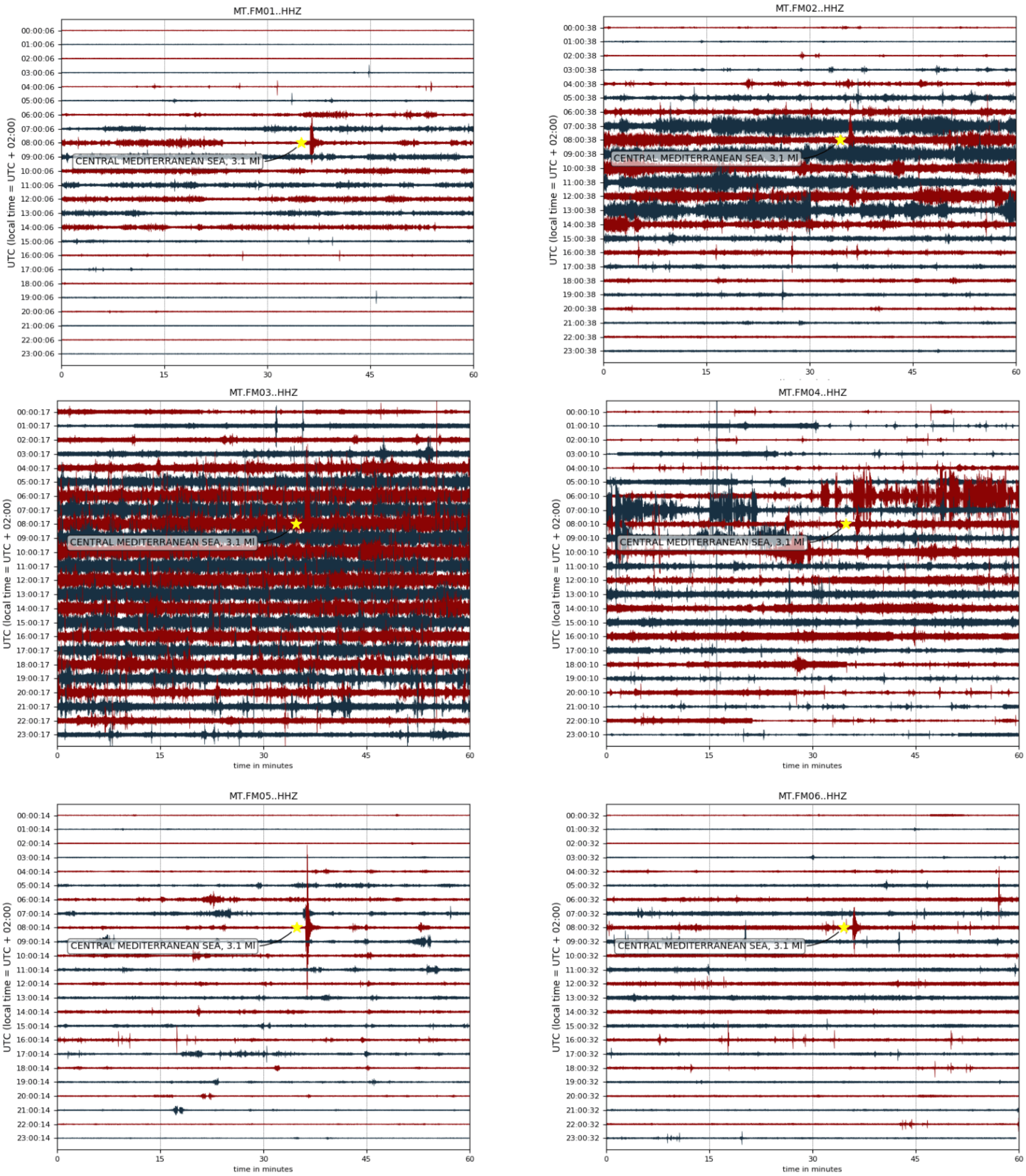


**Figure 3:** 24h waveform plots on the temporary network stations for the 23rd of November 2017. One of the largest offshore regional earthquakes (ML 3.1) during the study period occurred on this day, indicated with a yellow star.

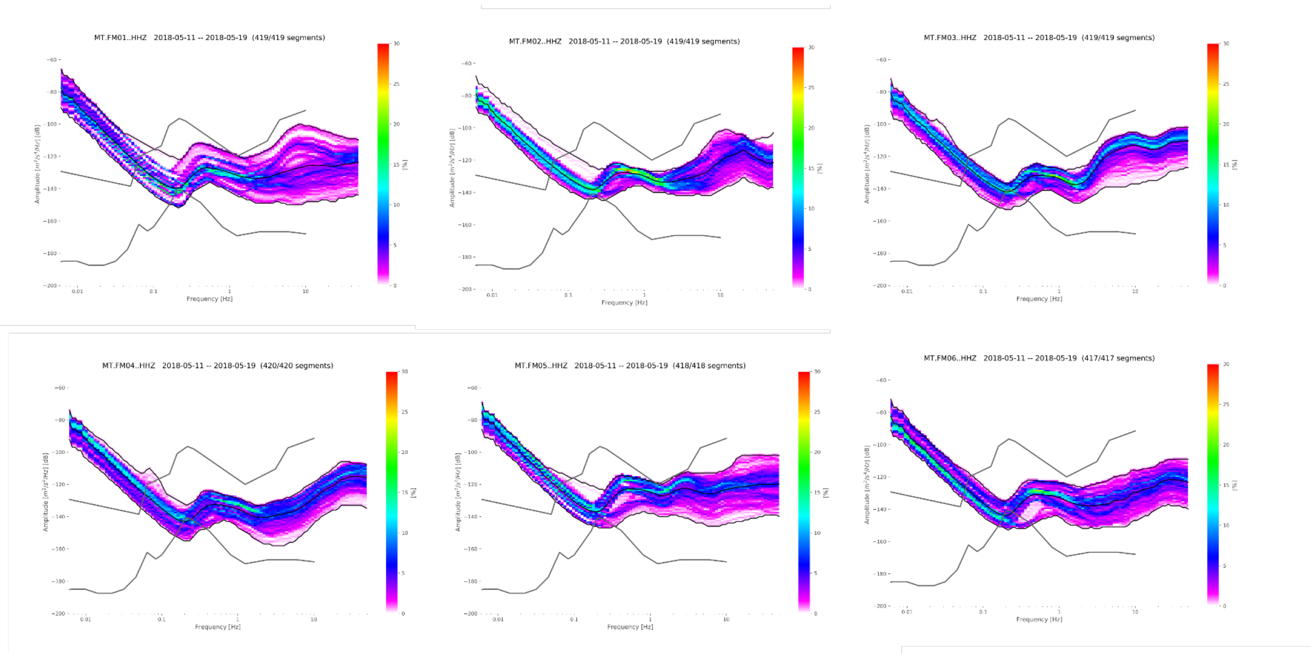


**Figure 4:** PPSD plots for the period 11 to the 19th of May, 2018. The PPSD plots lie within the Peterson noise limits (black curves, Peterson (1993)). Frequencies below 0.5 Hz should not be considered since the instruments were short-period stations.

mer periods (figures 10 and 11, respectively). In general, the mean PPSD curves for all stations are higher in winter than in summer, as expected. The most significant changes between the summer and the winter season are observed in stations FM01 and FM05. FM01 is probably the station most vulnerable to wave action, being close to an exposed coastline. At FM05, the mean curve in winter lies close to the NHNM in the 1 – 3 Hz frequency range. For this station, the NHNM in this frequency range is exceeded during several days, even inthe summer.

To evaluate the anthropogenic effect on noise levels day and night periods are compared separately (figures 12 and 13, respectively). The 24h periods between Mondays to Thursdays are selected to avoid the noise that is created by nighttime activities during the weekends. Then the time periods 01:00 – 04:00 (night) and 16:00 – 19:00 (day) are selected as the most representative of low or high human activity. At all stations, the mean noise level is clearly higher in the daytime than at nighttime at frequencies above 1 Hz, associated with cultural/industrial noise. However, all the stations seem to remain within the noise limits.

To isolate the human activity noise, while focusing on the weather effects, the night periods of winter and summer are compared (figures 14 and 15, respectively). As expected, the summer nights are quieter, as reflected by broader curves reaching lower noise values. The stations most affected are FM02, FM03, and FM06, as at these stations, all curves drop to lower levels. As for the rest of the stations, broader curve ranges from lower to higher noise levels are observed during summer, reflecting the calmer weather conditions. FM01 and FM05, in particular, show a much larger number of low-noise periods during the summer, as expected.

### 4.3 Data availability and Data loss

Figure 5 shows the data availability for the FM stations during the whole one-year period. The sheltered locations selected provided continuous data recordings with only 2 incidents of data loss. At Mdina the flash-card corrupted, causing data loss of one month (figure 5, FM03). At Baħrija (FM05), the station was unplugged by mistake during Christmas celebrations causing one-week data loss (figure 5, FM05).

### 4.4 Earthquake Location

We evaluate the improvement in earthquake location of the new network. Manual picking of the waveforms recorded on the enhanced network was performed for all the events that were detected using the single station location algorithm LESSLA (Agius et al., 2011). The relocation of the events were made using NonLinLoc software (Lomax et al., 2000). The initial results of the relocation are encouraging with small spatial errors, less than 1.8 km on average. The new relocated events detected from all the stations of the enhanced network for the period of June 2017 to September 2018 are shown in figure 6. The relocated events are colour coded according to their depth and scaled according to their local

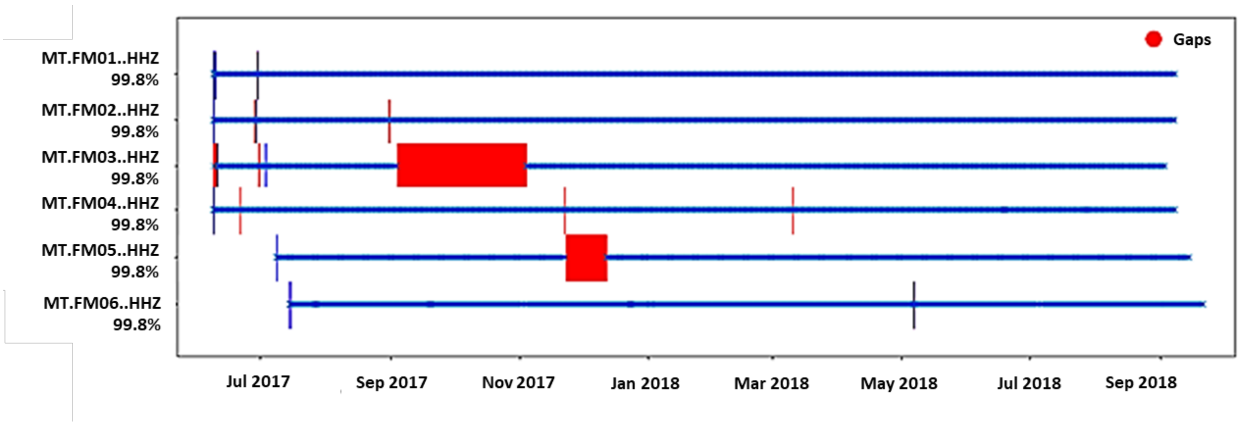


**Figure 5:** Data availability plot for the FM stations. Data gaps are marked with red colour.

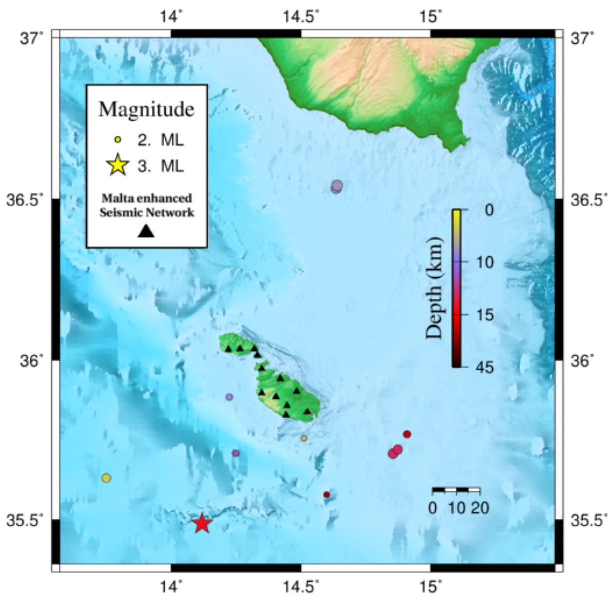


**Figure 6:** Examples of relocated offshore events detected on all the stations of the enhanced network during the period of June 2017 to June 2018. The ML 3.1 event that occurred on 23rd of November 2017 at around 50 km SW of Malta is marked with a red star.

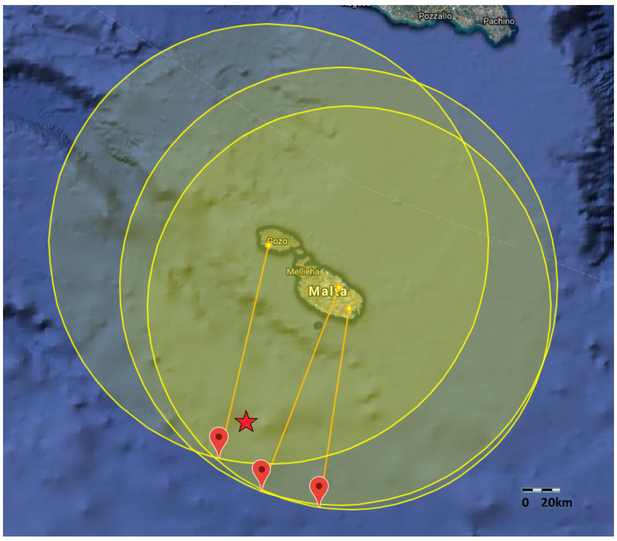


**Figure 7:** LESSLA solutions marked with red markers for the $M_L$ 3.1 November event. NonLinLoc solution is marked with a red star. Besides the fact that LESSLA solutions appear to be toward the same direction, the NonLinLoc event appears to coincide with the direction of the intersection of the circles.

magnitude. The new network enables us to obtain depth estimation, with the initial depths of the events ranging from 3.5 to 12 km. Depth determination is crucial for the identification of active faults and reliable location uncertainties. On the contrary, the single station location is not able to provide depth, and the location uncertainties are empirically assigned by the analyst. As an example of improved location capability, the solution for one of the most significant offshore events during the study period (also indicated on the 24h plots of figure 3, as described above) is compared with the single station location (figure 7). The ML 3.1 event that occurred on the 23rd of November 2017, about 50 km SW of Malta (figures 6 and 7, marked with a red star), had a depth of 14.4 km, as computed by NonLinLoc. In figure 8 (bottom), the waveforms of the vertical component of all the FM stations for this event are plotted. Stations FM03 and FM05 appear to have significant amplification on the waveforms due to the underlying clay layer. In spite of the noise level, a clear identification of P and S arrivals was possible. The solution gave an RMS travel time error of 0.34 s, a 2.1 km horizontal and 1.2 km depth error. LESSLA locations for the stations XLND, MSDA, WDD for the same event differ from each other by up to 20 km (figure 7, red markers). This is partly due to the low signal-to-noise ratio at the P-arrival that introduces errors in single station location (figure 8). Although all LESSLA solutions appear to point to a relatively similar source region, the NonLinLoc event location appears to coincide with the direction of the intersection of the circles and is assumed to be the most accurate solution. The difference in the epicentral distances, between LESSLA and NonLinLoc, might also be explained by the introduction of depth to the estimation of the hypocentral depth.

## 5 Conclusions

To explore the potential of enhancing the ML Seismic Network, we installed six temporary, short-period stations for 15 months, as part of the FASTMIT project, getting very encouraging results. Although the Maltese islands are less than 300 $km^2$ in area, the country benefits in more than one way from having a relatively dense seismic network. Being a small island means that ambient noise from marine sources, as well as inland anthropogenic noise, makes it challenging to find seismically quiet sites. Nevertheless, the PPSD analysis of the additional network stations has shown that most stations have an acceptable noise level that is within the Peterson limits (Peterson, 1993).

In general, such an extended network will provide remarkable improvement in the detection and location of seismic and microseismic activity onshore and close to the Maltese shores. While single-station location by polarisation analysis is adequate, and may even be quite accurate, for locating regional events with a good signal-to-noise ratio at the P-arrival, the algorithm and procedure presently being used may fail for events closer than, approximately 10 km from the station. This network, or a subsequent one, will, therefore, give an unprecedented opportunity for studying the activity of local faults that are known to have generated microearthquakes in the recent past. Together with data from surrounding networks in the Central Mediterranean, it will also provide better location accuracy for more energetic events in the Sicily Channel. Moreover, the location of stations on sites overlying a thick buried clay layer will offer a unique opportunity to perform site spectral ratio analysis in which the response of such a geological setting to earthquake shaking can be directly studied. A more detailed description of the recorded seismicity during 2017/2018 using this network, and showing the above improvement in earthquake detectability, will be the subject of a further study.

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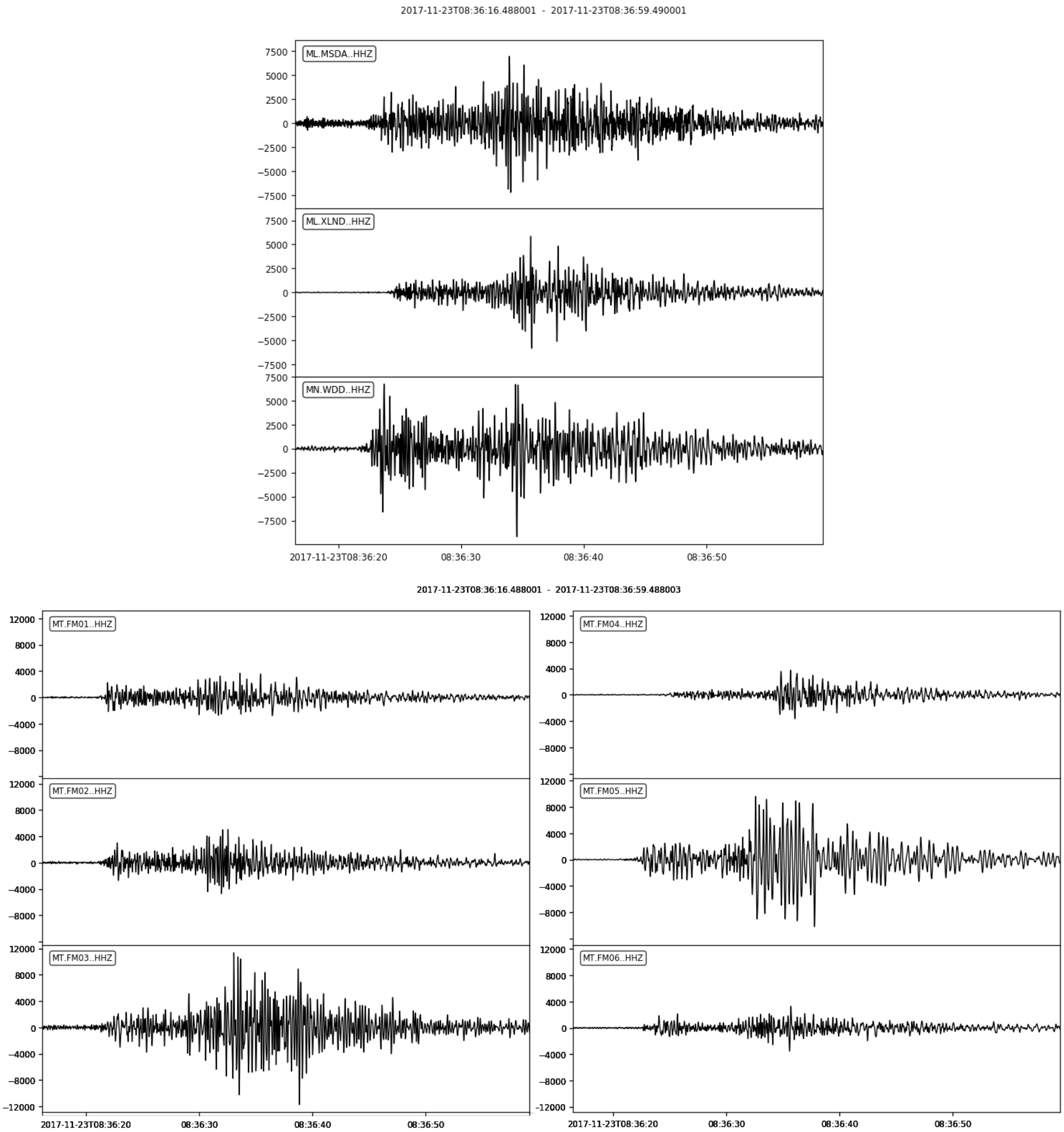


**Figure 8:** Top: Waveforms of the $M_L$ 3.1 event recorded at MSN broadband stations MSDA, XLND, and WDD. In spite of the relatively good waveform quality, noise is present and makes accurate P, S phase, and back azimuth determination difficult, introducing errors in the quality of the solution. Bottom: Vertical component waveforms for the same event as it was recorded at the FM stations. (1-10Hz filter is applied on all waveforms). The S-wave amplification for stations FM03 and FM05, which lie above a buried layer of clay, is evident.

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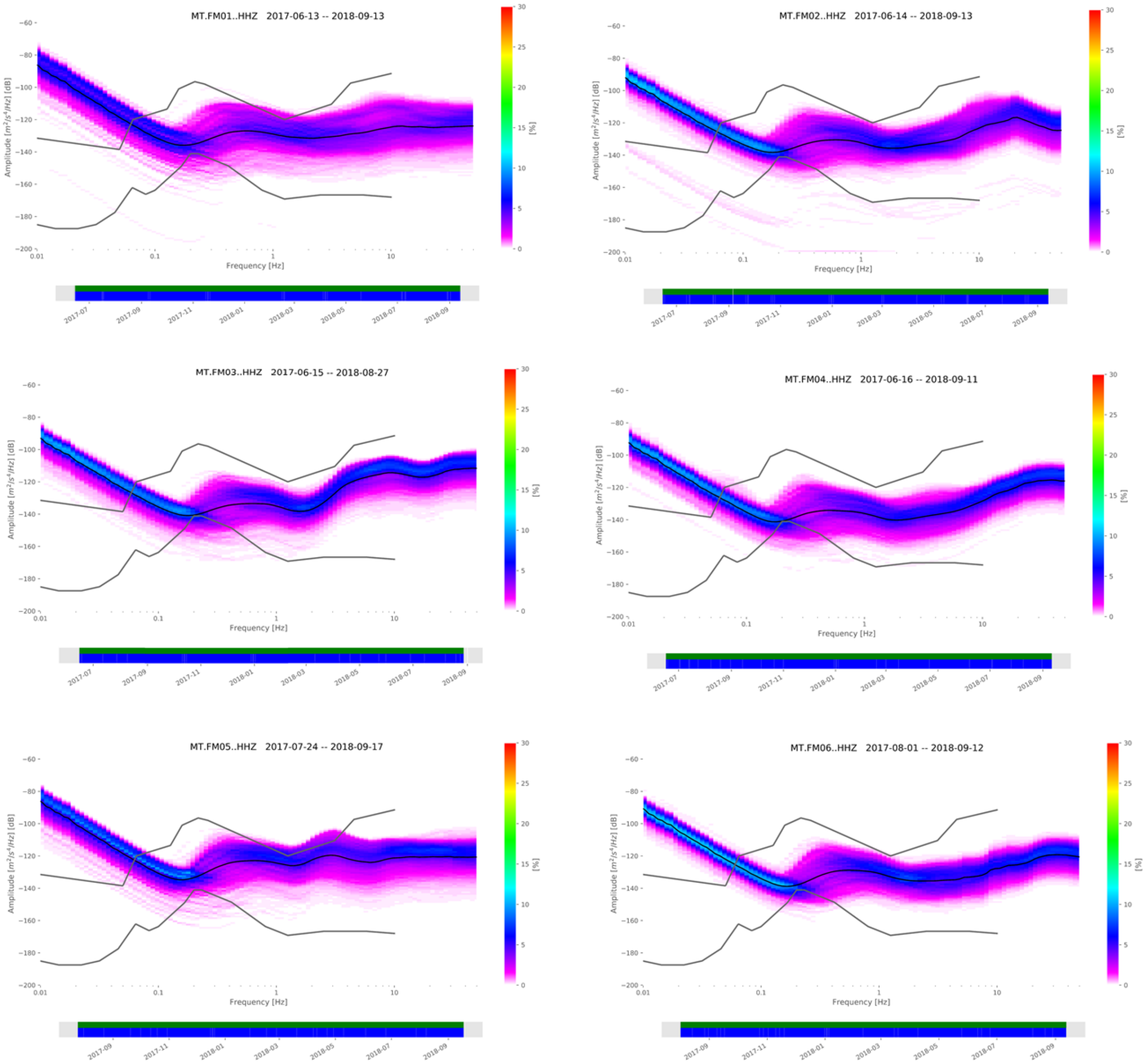


**Figure 9:** Probabilistic Power Spectral Density (PPSD) plots for the duration of the experiment illustrating the overall performance of each station of the FASTMIT network. The PPSDs are obtained by analyzing continuous traces of recordings cut into 1 hour windows at steps of 30 minutes. The PPSDs demonstrate the amplitudes most frequently observed at each frequency (Beyreuther et al., 2010; McNamara et al., 2004). Black curves: Typical upper and lower noise limits (Peterson, 1993), and average values of the PPSD.

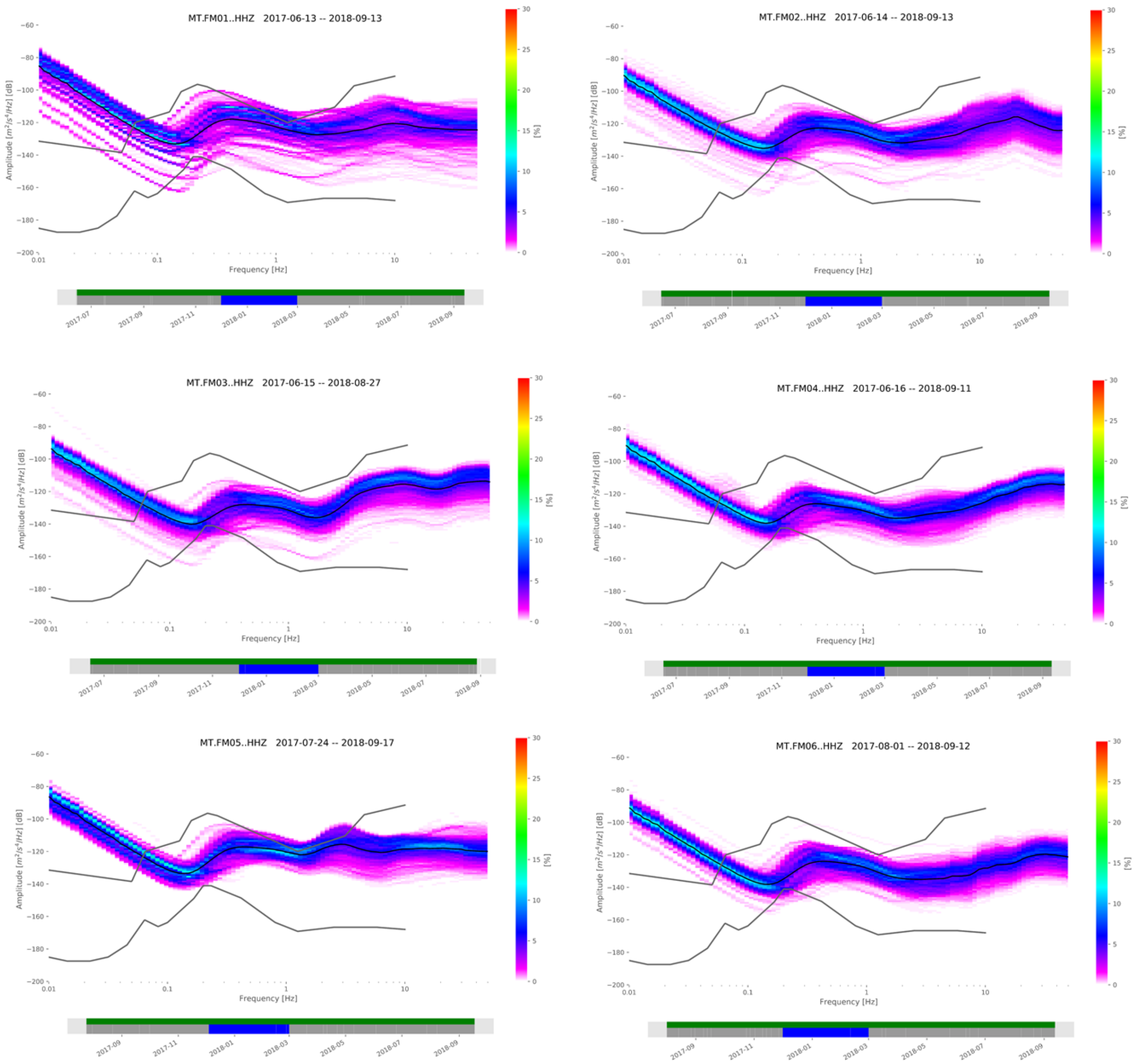


**Figure 10:** Same as figure 9, but for winter time period.

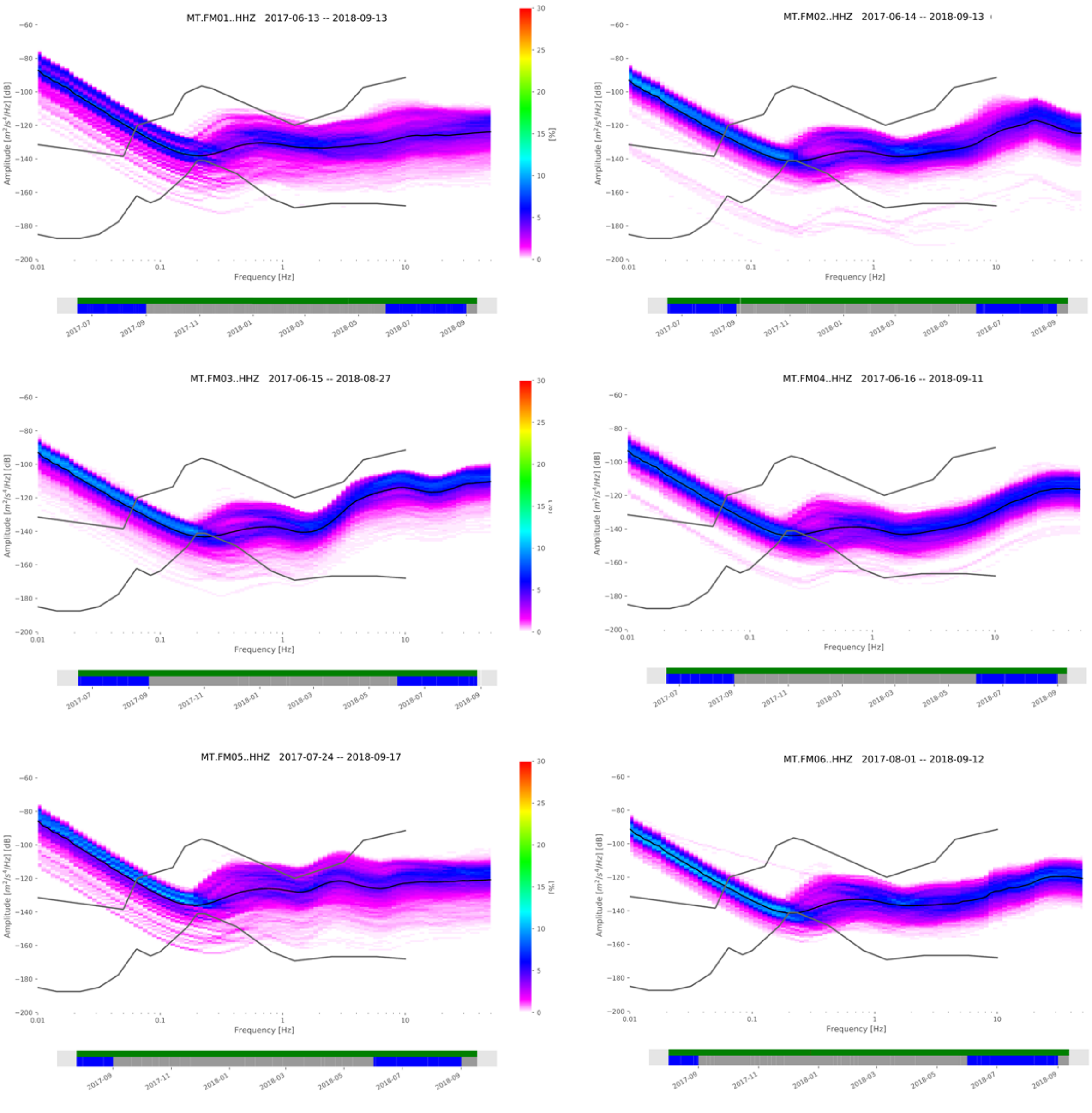


**Figure 11:** Same as figure 9, but for summer time period.

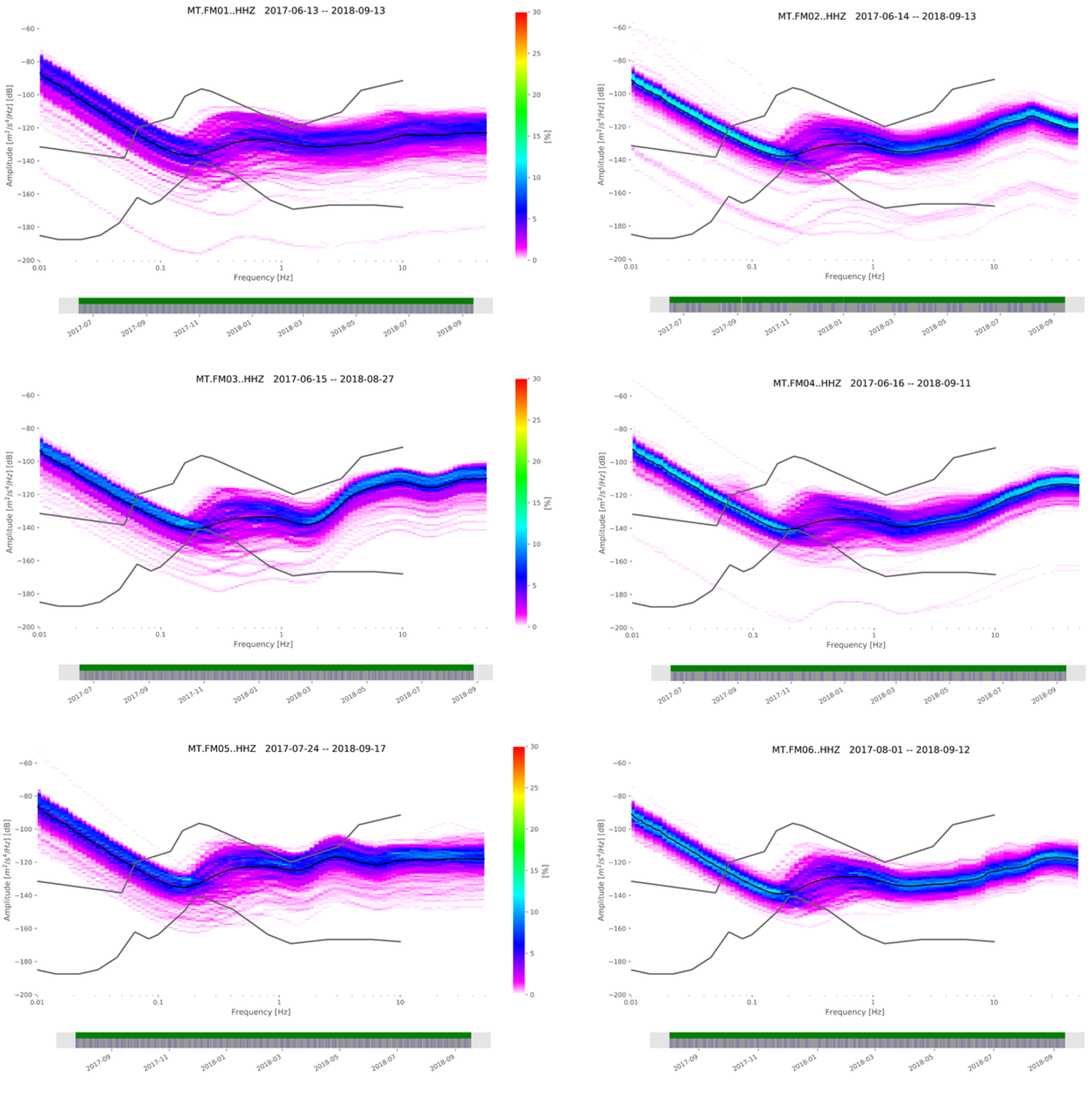


**Figure 12:** Same as figure 9, but for week days.

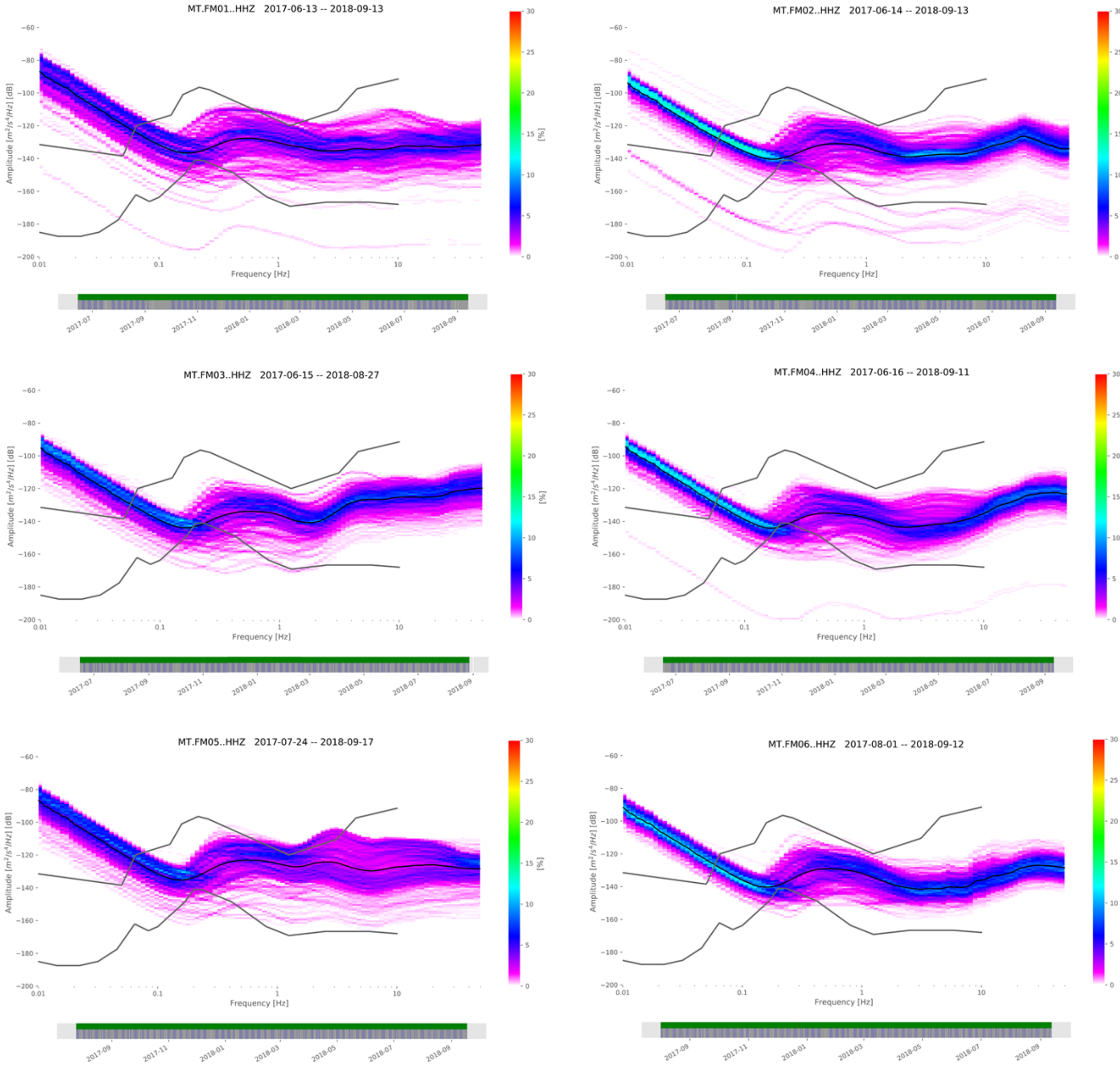


**Figure 13:** Same as figure 9, but for week nights.

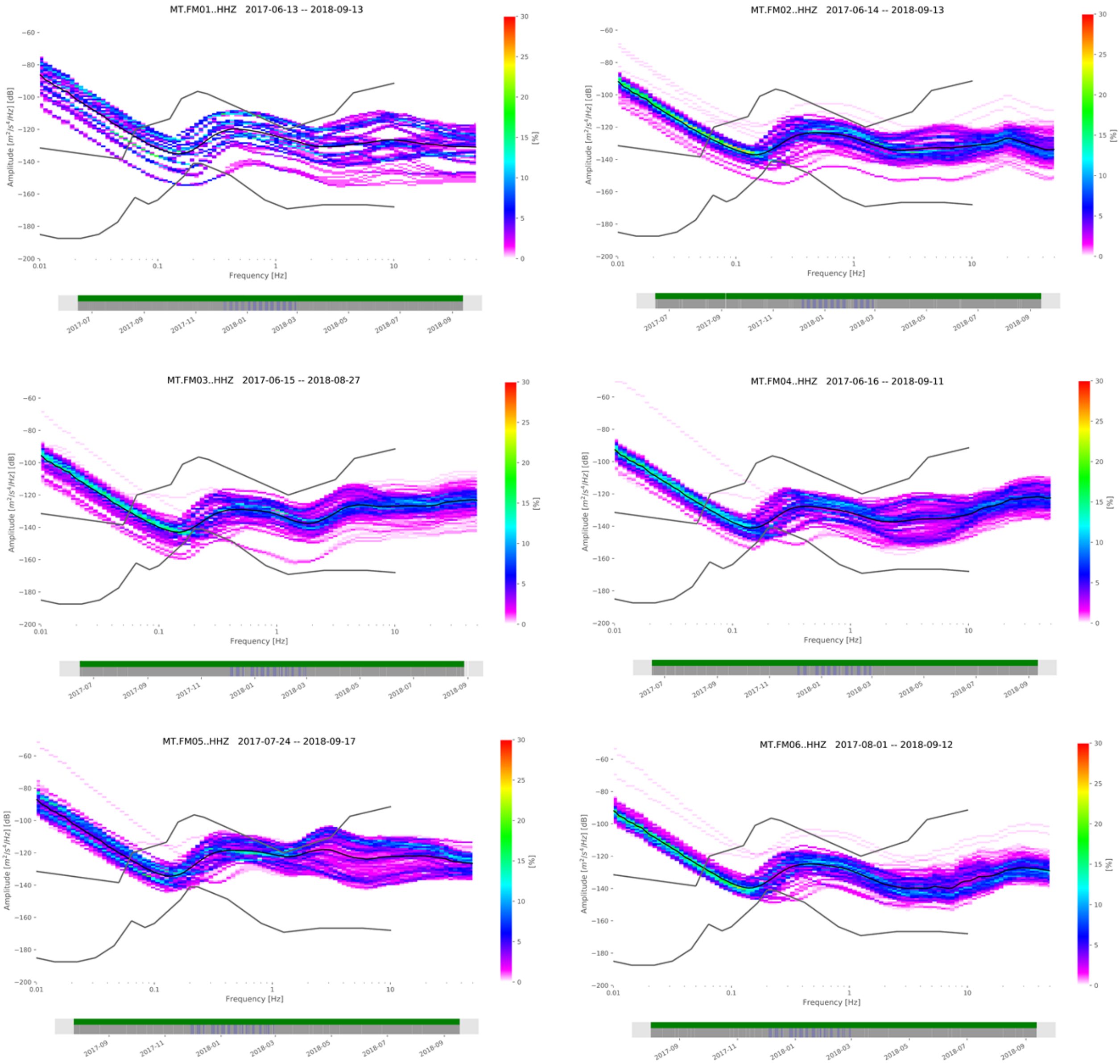


**Figure 14:** Same as figure 9, but for winter week nights.

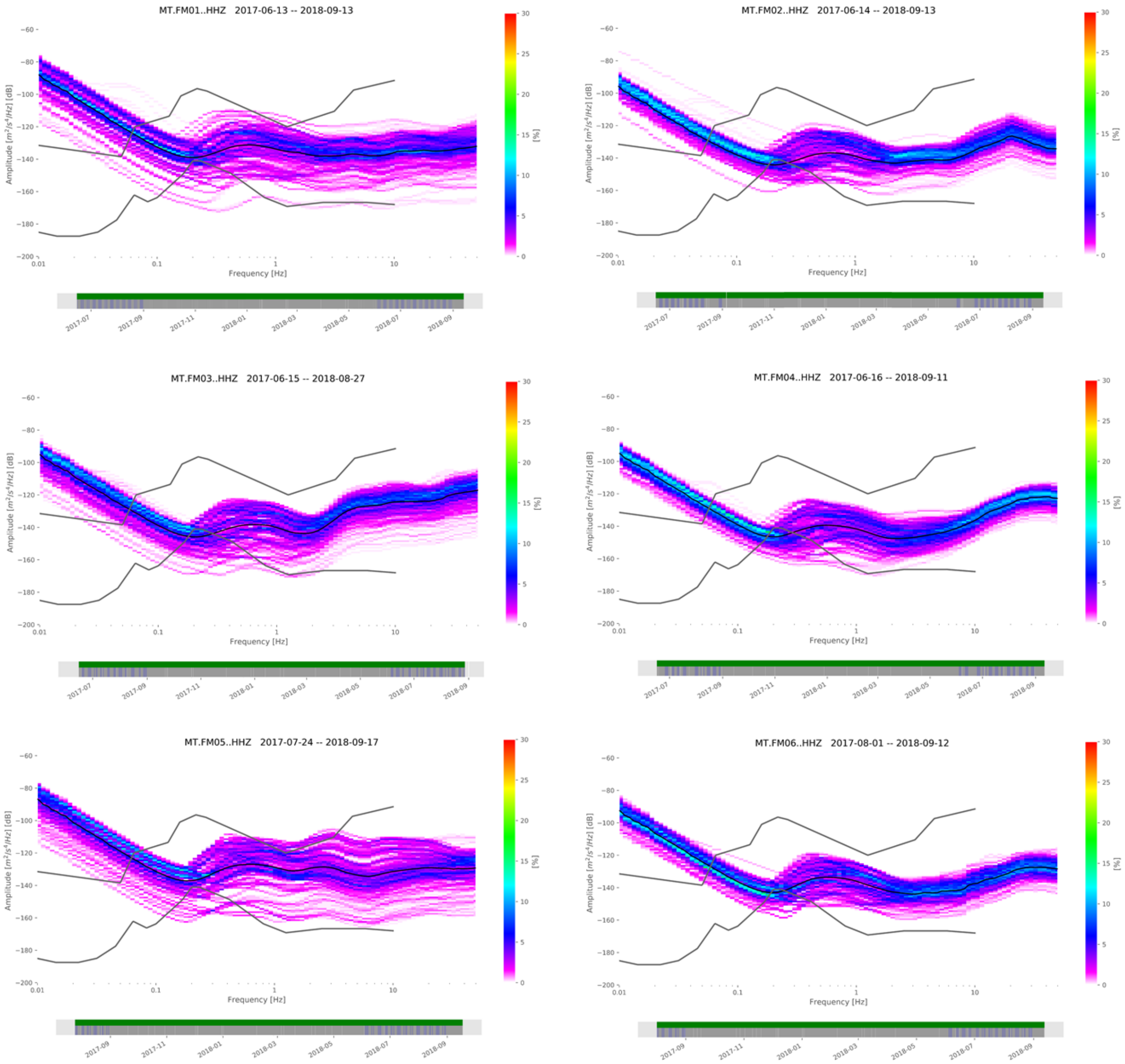


**Figure 15:** Same as figure 9, but for summer nights.

Valentino, G. (2019). *Xjenza Online*, 7:122.

Xjenza Online - Science Journal of the Malta Chamber of Scientists
www.xjenza.org

*News Article*

# A new Council for the Malta Chamber of Scientists

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It is with pride and pleasure that I pen this article as the new President of Malta Chamber of Scientists, whilst extending a warm welcome to my new fellow Council members. The Malta Chamber of Scientists was set up in 1992 at the offices of the Malta Council for Science and Technology, and is an autonomous and professional organization with the specific goals of working towards enhancing the highest levels of education, the public engagement of citizens with science and research, and to foster collaborative networks and promote science and scientists in Malta. It is registered as a Voluntary Organisation with the Malta Council for the Voluntary Sector.

I was initially elected to the Council in 2016 and served in the role of treasurer. My experience in the previous Council allowed me to witness first-hand and support the vast amount of science communication activities that the Chamber is undertaking and supporting, in collaboration with a number of other entities. These include events such as Science in the City, Science in the House, Kids Dig Science, CineXjenza and Malta Café Scientifique. The impact of these activities deserves further study to develop best practices which can be spread both locally and internationally. For example, Science in the City and Malta Cafe Scientifique has inspired the Gozitan counterparts, namely Science in the Citadel and Gozo Café Scientifique, whose setting up was supported by the Chamber. The Chamber will continue to support such initiatives but also policies to encourage more effective science communication and public engagement with research in Malta.

The new youthful Council will inject a boost of much-needed energy and drive to work towards the rest of the Chamber's mission. Following a rebranding exercise, we intend to put a series of new membership benefits in place, including scientific networking events and grants for members.

We will revisit the Chamber's science policy document written a couple of years ago in view of the ongoing changes to the National Research and Innovation Strategy spearheaded by the Malta Council for Science and Technology. In particular, we will embark on a data gathering exercise to better understand the local landscape in terms of public/private spending on R&D, career paths and progression of scientists in Malta (in particular PhD holders and post-docs) and local funding schemes for post-graduate and post-doctoral studies. This will enable us to be in a position to recommend and lobby for evidence-based policies and measures to increase R&D spending from the currently dismal levels of approximately 0.5% of the Gross Domestic Product, and a more balanced approach between fundamental research and close-to-market innovation activities.

The Chamber will continue to support its flagship scientific publication, Xjenza Online. I would like to thank the Editor-in-Chief, Prof. Cristiana Sebu, the Associate Editors, and support staff for their continued effort in maintaining and improving the standard of the journal.

We look forward to working closely with our collaborators and stakeholders, such as the University of Malta and other higher education institutions in the country, the Research, Innovation and Development Trust, other Chambers, STEM student organisations, other scientific associations, government entities, and private industry.

Finally, I would like to close by sincerely thanking outgoing President, Prof. Alex Felice, on behalf of the Council for his vision, the commitment that he has shown to science in Malta, and for his service in the Chamber for the past 28 years.

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