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A Review of Publicly Available Environmental Monitoring Reports for Two 'Open Loop' LNG Regasifiers Operating in Italian Coastal Waters

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A Review of Publicly Available Environmental Monitoring Reports for Two 'Open Loop' LNG Regasifiers Operating in Italian Coastal Waters

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Abstract: This article reviews publicly available environmental monitoring reports for two "open loop" Liquified Natural Gas (LNG) regasification plants operating in Italian coastal waters: Porto Viro (Veneto region, in operation since September 2009) and Livorno (Tuscany region, in operation since October 2013). These plants are key infrastructure for Italy's energy independence. This review was undertaken to assess the effectiveness of the current monitoring programs and suggest potential improvements. Based on the information reviewed, it was found that many of the contaminants being analyzed were consistently below the limits of quantification and did not provide useful data for understanding the potential impact of the plants' emissions. Additionally, this review found that the concentration of oxidizing chlorination residuals (CPOs, TROs) was not being measured, despite its importance in assessing potential harm to marine organisms. This article concludes by recommending the implementation of a peer-review process for both the monitoring schemes and the periodic monitoring reports, and suggests that future monitoring efforts should prioritize the analysis of the most relevant parameters and indicators.

Keywords: LNG regasification; open loop; closed loop; environmental monitoring

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Introduction

In June 2023, Shoreline società cooperativa was commissioned to carry out a 'Study on the development of activities related to offshore energy resources - platforms and regasification plants - and possible interactions with fisheries and aquaculture activities'. The consultancy is part of the 'National Fisheries and Aquaculture Programme 2022- 2024' [1], which was activated by the Ministry of Agriculture. The main objective of the study is to realize a review of the environmental reports, with some suggestions to improve the monitoring program.

There are currently four regasification plants in operation in Italy:

- Panigaglia (Liguria). Regasification capacity: 4 * 10^3 Mm^3, Storage capacity: 10^5 m^3. In operation since 1971. Closed loop plant
- Porto Viro (Veneto)[1]. Regasification capacity: 9.0 * 10^3 Mm^3, Storage capacity: 2.5 * 10^5 m^3. In operation since 2009. Open loop plant
- Livorno (Tuscany)[2]. Regasification capacity: 3.75 * 10^3 Mm^3, Storage capacity: 1.4 * 10^5 m^3. In operation since 2013. Open loop plant
- Piombino (Tuscany). Regasification capacity: 5 * 10^3 Mm^3, Storage capacity: 1.7 * 10^5 m^3. In operation since 2023. Open loop plant

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[1] In June 2023, the Ministry of the Environment allowed the production capacity to be increased from 9.0 to a maximum of 9.6 billion cubic metres per year on a non-continuous basis, without further works on the installation.

[2] In May 2023, OLT Offshore LNG Toscana received approval to increase its annual regasification capacity to around 5 billion cubic metres per year.

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2. Materials and Methods

Environmental monitoring reports from the Porto Viro and the Livorno plants were analysed, as these are the 'open loop' plants that have been in operation the longest. The Panigaglia plant was not taken into account as it uses 'closed loop' technology, while the Piombino plant was concluding its experimental phase at the time of the study.

2.1. The State of the Art

In accordance with European regulations, both plants are subject to:

- Environmental Impact Assessment
- Integrated Environmental Authorisation
- Requirements for the 'Major Accident Hazard'

In addition, since the Livorno plant is located in a vast protected area (Pelagos Sanctuary for Mediterranean Marine Mammals), the SEA procedure - Strategic Environmental Assessment - was followed at regional level.

Besides, voluntary protocols are followed:

- SHEMS - Safety, Security, Health and Environmental Management System (Porto Viro plant)
- EMS - Environmental Management System, and EMAS - Eco-Management and Audit Scheme (Livorno plant)

As part of the assessment of potential environmental effects on the marine environment from offshore production infrastructures, the application of the Marine Strategy Framework Directive is also included. According to what is foreseen for the achievement of GES (Good Environmental Status) for Descriptor 7 ‘alterations of hydrographic conditions’, it is necessary that the environmental monitoring plans drawn up from 2012 onwards for infrastructures subject to EIA, are adapted to the characteristics identified for each of the hydrographic parameters foreseen (currents; temperature and salinity; height of the free surface; turbidity; wave motion; bathymetry and morphology of the seabed). Due attention is paid to the respect of the thermal delta authorized for each plant: the temperature of the incoming seawater is measured continuously in the supply seawater pipe, and the outlet temperature (downstream of the regasification) is measured continuously in the discharge pipe.

In order to prevent the growth and proliferation of encrusting marine microorganisms in seawater circulation systems, sodium hypochlorite (self-produced on board by electrochlorination) is injected into the intake circuit tanks. Seawater is continuously treated with sodium hypochlorite corresponding to a concentration of 0.2 mgL^{-1} active chlorine at discharge. The use of active chlorine entails monitoring of organohalogenated by-products directly related to the plant's activity (mainly trihalomethanes, haloacetic acids, halophenols and haloacetonitriles [2]) in three environmental compartments: water, sediment and biota.

In compliance with the prescriptions foreseen by the authorizations for Porto Viro, ISPRA - the Italian Institute for Environmental Protection and Research drew up the plan and carried out the environmental monitoring activities for the preliminary phase (ante operam) and the site phase. Subsequently, ISPRA carries out the environmental moni-toring activities for the operational phase under the supervision of ARPA Veneto (Agenzia Regionale per la Prevenzione e Protezione Ambientale del Veneto).

For Livorno, marine monitoring is carried out by the company 'OLT Offshore LNG Toscana', the operator of the plant. ISPRA, as part of the technical support activity pro-vided to the Ministry of the Environment and Energy Safety, issues its opinions directly to the Ministry itself, which holds the administrative procedure. The OLT company transmits the annual report containing the environmental monitoring of the area around the Terminal (structured on 4 seasonal campaigns) and carried out according to the EIA prescriptions. This report is structured as follows: - Environmental surveys (water column, sediments, biota, biacustics and noise); - Annual Correntometry Report; - Underwater noise (analysis of the data from the 4 seasonal campaigns for each year).

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In this context, the operators of the Porto Viro and Livorno LNG plants were asked to provide monitoring data on environmental conditions; there was no response from the operators. The Ministry of the Environment responded by indicating the web pages of the portal where the publicly available reports for the Livorno plant alone can be found [3,4]; for Porto Viro, reports were available and downloadable on the website of the Province of Rovigo [5]. Thus, only the reports available on publicly accessible portals were analysed.

2.2. The Concerns

LNG regasification plants are usually proposed in the 'open loop' configuration, whereby seawater is used to heat the liquefied gas. The alternatives, generically referred to as 'closed loop', require higher energy consumption in order not to impact the aquatic environment.

The two technologies entail one the combustion of an additional portion (1%) of the LNG delivered to the plant [6] and therefore higher emissions of CO_2 and NO_x, the other one the cumulative effect of seawater cooling, loss of ecosystem services provided by the marine habitat, destruction of plankton and larvae, selection in favour of resistant bacterial species, and release of toxic substances including residual free chlorine. Of the two forms of pollution, the second involves more concern for a sensitive and limited environment such as the coastal seas, as the release of CO_2 can be mitigated by compensation measures (e.g., reforestation) or eliminated through Carbon-capture systems [33], and the release of NO_x by processes of denitrification of exhaust gases.

The 'open loop' regasification system (ORV) is a technology developed later than the 'closed loop' (SCV), but now widely in use. The regulation of such plants was already tackled by the U.S. Environmental Protection Agency in 2006 (“Liquified Natural Gas Regulatory Roadmap”, [7]). In the same year the report “Annotated bibliography of the potential environmental impacts of chlorination and disinfection by-products relevant to offshore liquefied natural gas port facilities” [8] noted that the toxicity of chlorine-treated seawater effluents is mainly due to oxidising by-products originating in the treatment, rather than residual chlorine in the discharge. In 2008, the potential environmental impacts of ORV are indicated in the document “Examination of the development of Liquefied Natural Gas on the Gulf of Mexico” [9], namely the risk of a reduction of ichthyoplankton and the active chlorine fallout. The EPA emphasized in 2006 [7] that technology choice should be based on a comprehensive assessment of the best available technologies:

> *“When identifying technology-based BPJ [best professional judgment] permit conditions for offshore projects, EPA takes into consideration the various available technology options. Open Rack Vaporization (ORV) uses surrounding seawater at ambient temperature to heat and re-gasify LNG. Submerged Combustion Vaporization (SCV) systems burn a portion of the re-gasified natural gas product to re-heat warming water. Intermediate Fluid Vaporization (IFV), also referred to as 'shell and tube', can operate in either an open or closed loop configuration”.*

Since the operating costs for the entire life cycle of such systems are in any case higher in the 'closed loop' mode of operation, the environmental aspects resulting from continuous use in the 'open loop' mode are of considerable importance and represent the fundamental differentiating factor in the environmental analyses to be carried out by the public administration. Leaving the decision between open and closed loop to plant de-signers is restrictive and potentially dangerous for the environment: since the companies carry out the environmental impact assessment, there is no incentive to find ecologically better but economically less favourable design alternatives.

2.3. Chlorination by-Products

Seawater is disinfected for various purposes. In cooling or heating water circuits, disinfection aims to reduce biofouling and clogging to ensure good heat exchange performance and reduce maintenance [10]. To reduce biofouling, continuous or intermittent chlorination of seawater is usually carried out [10,11], using doses of 0.5-1.5 mg L^{-1} (ex-pressed as Cl2) to achieve a residual oxidant content of 0.1-0.2 mg L^{-1} [12,13].

The chlorination of seawater containing natural organic substances results in the formation of a complex mixture of Chlorination By-Products (CBP). These are mainly:

- Trihalomethanes (THMs): these are the most important group of CBPs generated during chlorination of both fresh and marine waters [14]. Among CBPs, bromoform is the most abundant species found in studies that have searched for CBPs in seawater exposed to chlorinated industrial effluents [12,15–17]. Bromoform, which has been used as a proxy for CBP inputs to the marine environment, is also synthesised in large quantities by phytoplankton and macroalgae [18];
- Haloacetic acids (HAAs): typically, they represent the second largest group of CBP formed in oxidative processes. In seawater, dibromoacetic acid (DBAA) has been observed as the compound with the second highest concentration after bromoform, followed by tribromoacetic acid (TBAA) [19];
- Halophenols (HPs): numerous aromatic CBPs have been detected in samples of chlorine-treated bromide-rich drinking water [20] and in saline wastewater effluents subjected to disinfection [21]. In seawater power plant cooling effluents, 2,4,6-tribromophenol (TBP) was detected as the most important aromatic CBP [15,16].

An extensive study on CBPs in cooling water of power plants has considered 90 cooling water samplings at 10 different coastal power plants in the UK, France and the Netherlands [12]. Subsequently, results of further analyses of these sites were published [13,22]. In addition, several studies have been conducted in the Gulf of Fos [16,17,23] in France where there are several plants discharging chlorinated cooling water (2 power plants, 2 LNG plants, petrochemical plants and steelworks). Further studies on CBPs in cooling water of power plants have been published in South Korea, India and Sweden [24–28]. More recently, Cacciatore et al. 2021 [29] published a study on the distribution of CBPs in water, sediments and marine organisms in the vicinity of Porto Viro plant. Of all CBPs analysed in seawater near the Porto Viro LNG plant, bromoform was the compound most frequently detected.

Studies that have considered the presence of CBP in sediments in the vicinity of chlorinated cooling water discharges from industrial plants are scarce and concern the Porto Viro plant in the northern Adriatic Sea [29], various industrial plants in the Gulf of Fos (northwestern Mediterranean) [17], and a power plant in South Korea [27]. Sediments sampled near the Porto Viro plant were mostly characterised by the presence of HAAs, such as dibromoacetic acid - DBAA, monochloroacetic acid - MCAA, dichloroacetic acid - DCAA, bromochloroacetic acid - BCAA, chlorodibromoacetic acid - CDBA and Dalapon [29].

2.4. Effects of Oxidising Agents Produced by Chlorination on Life in the Marine or Estuarine Environment

Chlorination at low levels introduces oxidising agents into the marine environment in a continuous or pulsed manner which, while effectively preventing biofouling, can also have adverse effects on aquatic life, both through residual oxidising capacity and through the formation of specific CBPs in the marine environment. Chlorine-derived oxidising agents can directly harm organisms by destroying their cell walls or damaging their proteins through oxidation. Secondly, due to the high levels of dissolved organic matter in coastal waters, chlorine by-products can form, including trihalomethanes or haloacetic acids. These by-products have been shown to be very toxic to aquatic organisms. In addition, disinfectants can combine with nitrogen to form chloramine or N-nitrosodimethylamine, both of which have been categorised as carcinogenic [30].

In marine or estuarine waters, the term 'Chlorine-Produced Oxidants' (CPOs) is used because of the high concentration of bromides naturally present in seawater. Bromides, in the presence of residual chlorine, form 'free available bromine' or 'combined available bromine', which can act as oxidants. Thus, CPO indicates the sum of the reactive species of chlorine and bromine. In fresh water, on the other hand, the term Total Residual Chlorine (TRC, or Residual Chlorine, RC) is used, which indicates the sum of the concentrations of the reactive chlorine species. As an alternative to the term CPO, the term Total Residual Oxidant (TRO) is also used. Thus, discharges are generally regulated

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through criteria for the discharge of effluents based on the concentration of CPO or TRO present in the cooling water upon discharge into the sea. A review of the toxic effects of CPO-produced oxidants on marine organisms is reported in the extensive work of 2021 published by the British Columbia Ministry of Environment and Climate Change [31]: it takes into account a total of 173 toxicity data for marine organisms (phytoplankton, molluscs, crustaceans, echinoderms, fish) from the literature. The lowest CPO concentration reported to have a harmful effect on marine fish after an exposure period of more than 2 hours is >23 μg L^{-1}. Thatcher, 1977 [32] recorded 96-hour LC50 values of >23 μg L^{-1} for juvenile pink salmon (*Oncorhynchus gorbuscha*) and CPO of 32 μgL^{-1} for juvenile coho salmon (*O. kisutch*) in laboratory tests designed to simulate chlorinated seawater cooling water.

2.5. Guidelines for Oxidants Produced by Chlorination in Marine Waters

A summary of the guidelines for chlorine in marine waters was published by Batley and Simpson in 2020 [35]. The paper discusses the concentration limits for chlorine in water, above which negative effects on aquatic life can occur. These values have been developed by various environmental agencies, among which:

- US Environmental Protection Agency
- Canadian Council of Ministers of the Environment
- British Columbia Ministry of Environment and Climate Change Strategy
- European Union, trough the European Commission and the European Environment

The essential points are:

- Different organisms have different sensitivities to chlorine. Some marine spe-cies, such as sea urchins, oysters, and clams, are particularly sensitive to the effects of chlorine, even at relatively low concentrations.
- Guidelines vary over time and between regions. They have been updated and modified over the years, based on new research and a better understanding of the effects of chlorine on aquatic organisms. Additionally, guidelines may vary from one region to another, depending on the specific characteristics of local ecosystems.
- Chlorine can have short-term and long-term effects: The effects of chlorine on aquatic organisms can manifest both in the short term (e.g., mortality) and in the long term (e.g., reduced fertility).
- An ‘application factor’ can be used in environmental risk assessment, in order to account for the potential differences between laboratory conditions and re-al-world conditions. The application factor is a multiplier that is applied to the laboratory-derived toxicity values to account for factors such as the presence of other pollutants, temperature variations, and the specific characteristics of the aquatic environment.

The guidelines of the Canadian state of British Columbia [31] take into account **the continued exposure to CPOs**. The chronic toxicity threshold for marine and estuarine aquatic life has been significantly modified from that originally determined by Mattice and Zittel in 1976 [36]. The addition of more recent data to the exposure duration-concentration relationship indicates that marine and estuarine organisms are considerably more sensitive to CPO than originally believed. The chronic toxicity threshold for British Columbia was reduced from 20 μg L^{-1} to 3 μg L^{-1}.

The **acute toxic**ity threshold for marine and estuarine aquatic life in British Columbia [31] has been reduced considerably from that originally determined by Mattice and Zittel in 1976 [36], to account for more recent data. For marine and estuarine situations, the acute toxicity threshold was well defined for exposure periods of less than one minute. However, to avoid any individual sample exceeding a concentration that could be harmful, a maximum criterion of 40 μg L^{-1} CPO was specified, regardless of the exposure period.

3. Review of Existing Reports

Porto Viro and Livorno are the two 'open loop' plants whose reports on the monitoring campaigns are available on public access websites.

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In both plants, the injection of sodium hypochlorite (directly produced on board through electrochlorination) into the intake basins prevents the growth and proliferation of encrusting marine organisms in the seawater circulation systems. As part of the assessment of the potential environmental effects produced on the marine environment, ISPRA releases annual reports for the monitoring campaigns. According to ISPRA, the reports do not return any indications of criticality from an environmental point of view.

For the granting of the Integrated Environmental Authorization, the two plants have also been inspected by ISPRA over the years [2]:

- Porto Viro: 2015, 2017, 2019, 2021
- Livorno: 2017, 2020, 2021

3.1. *LNG Being Actually Regasified at the Two Plants*

The production data of the two plants are reported and analysed. The "Energy and mining statistics - Collection of data on imports, consumption and natural gas balance" are made available by the Ministry of the Environment and Energy Security on a specific web page [34].

It is assumed that the use of seawater - and the consequent effects on the environment - is proportional to the input of LNG regasidfied gas into the distribution network. The tables below represent the data available to date for the two plants under study. We notice that:

- Porto Viro has guaranteed an annual production of more than 59 per cent of its capacity throughout the years 2010-2021 (except for the year 2014: 49%). In the 12 years of operation 2010-'21 it worked at over 70% of its capacity.
- Livorno was most operational in 2019 and 2020, remaining below 41% the other years.

Given this premise, we could consequently assume a different significance of the monitoring findings with regard to the environmental impact related to the operation of each of the two plants.

3.2. *LNG Being Regasified at Porto Viro*

Tables 1 and 2 list the regasification carried out at the LNG plant in order to link the results of the monitoring activities with the actual processes. Annual emission of free chlorine varies from a maximum of 25,520 kg (in 2012) to a minimum of 4,901 kg in 2015: up to 81% less. Figures and details of the data are provided in Appendix A.

Table 1. Import of natural gas for the Porto Viro Plant for a monthly production of 75% or more of its capacity.

Month / Year	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**
2021			X	X		X	X		X			X
2020		X		X		X	X		X	X	X	
2019	X		X	X	X	X	X	X	X	X	X	X
2018			X		X		X		X			X
2017					X	X	X	X	X			
2016									X			
2015	X											
2014												
2013							X					
2012	X		X	X	X				X		X	X
2011	X	X	X	X	X	X	X					X

	01	02	03	04	05	06	07	08	09	10	11	12
2010	X	X	X				X		X		X	X

The highlighted cells indicate a monthly production of 75% or more of the plant capacity, on the basis of an annual production capacity set at 9.0 billion cubic metres.

Table 2. Porto Viro plant: annual emissions of free active chlorine (Cl2) at water discharge, 2010-2019.

Year	Cl2 total mass flow rate at discharge (kg per year)
2019	13,439
2018	No report available
2017	12,859
2016	10,331
2015	4,901
2014	14,707
2013	15,305
2012	25,520
2011	24,727
2010	15,305

3.3. LNG Being Regasified at Livorno

The monthly import data for the plant in Livorno are also recorded in the "Energy and mining statistics"; figures and details of the data are provided in Appendix A. Unlike the other plant, daily production data is available for Livorno: daily data are available on the ENTSOG website. ENTSOG is a body established to facilitate cooperation between national gas transmission system operators across Europe to ensure the development of a pan-European transmission system in line with EU energy and climate objectives.

Daily production data from the Livorno plant were tabulated and compared with the date on which the monitoring campaigns were carried out. The periods during which the plant operated at 75% or more of its daily mean production capacity while the environment was monitored are:

- Year 2022 - Report: E22 (9th annual report)
- Year 2022 - Report: I22 (9th annual report)
- Year: 2020 - Report: P20 (7th annual report)
- Year: 2020 - Report: I20 (7th annual report)
- Year: 2018 - Report: A18 (6th annual report)

Table 3. Import of natural gas for the Livorno Plant for a monthly production of 75% or more of its capacity.

Month / **Year**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**
2021			X	X	X	X						
2020	X	X	X	X		X	X	X	X		X	
2019		X	X	X	X	X	X	X	X	X	X	X
2018										X	X	X
2017					X	X						
2016												
2015												

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The highlighted cells indicate a monthly production of 75% or more of the plant capacity, on the basis of an annual production capacity set at 3.75 billion cubic metres.

Table 4. Output level of the Livorno plant during monitoring activity.

Monitoring campaign ("period")	Day Start	Day Stop	LNG regasification
E22	31/8/2022	23/9/2022	85,88%
P22	31/5/2022	21/6/2022	66,89%
I22	28/2/2022	17/3/2022	81,93%
A21	22/11/2021	17/12/2021	0,00%
E21	30/8/2021	15/9/2021	19,94%
P21	24/5/2021	11/6/2021	74,97%
I21	1/3/2021	25/3/2021	47,51%
A20	10/11/2020	30/11/2020	65,67%
E20	7/9/2020	30/9/2020	44,55%
P20	23/6/2020	10/7/2020	75,24%
I20	3/4/2020	16/4/2020	77,98%
A19	21/11/2019	4/1/2020	53,84%
E19	5/9/2019	4/10/2019	48,26%
P19	30/5/2019	14/6/2019	73,06%
I19	25/2/2019	21/3/2019	63,49%
A18	29/11/2018	21/12/2018	76,52%
E18	03/09/2018	15/09/2018	0,00%
P18	09/05/2018	21/06/2018	0,49%
I18	27/02/2018	22/03/2018	1,85%
A17	14/11/2017	25/11/2017	0,10%
E17	31/08/2017	23/09/2017	19,46%
P17	23/05/2017	03/06/2017	35,62%
I17	21/02/2017	11/03/2017	0,00%
A16	08/11/2016	28/11/2016	0,00%
E16	28/08/2016	8/9/2016	0,00%
P16	17/05/2016	6/6/2016	0,00%
I16	17/02/2016	11/3/2016	0,00%
A15	18/11/2015	6/12/2015	0,00%

The highlighted cells correspond to a productivity level of 75% or more in all the periods under environmental investigation.

3.4. Reading of Reports

Reports on the monitoring activity of regasification terminals were taken into ac-count. Appendix A provides the considerations for the 3 environmental compartments (water, sediment, biota), by monitoring year, for the two plants, as compiled by the authors of the periodic reports. The considerations listed in Appendix A are a direct ex-pression of the authors of the periodic reports.

- For Porto Viro, the reports available and downloadable on the website of the Province of Rovigo [5] were taken into account, with regard to the presence of contaminants in water, sediments and biota, ecotoxicological studies of water and sediments, biomarkers in mussels and fish and the distribution of plankton and benthic populations.
- For Livorno, the company OLT provides the annual report containing the environmental monitoring carried out in compliance with the environmental conditions included in the EIA measure. These reports are available on the website of the Ministry of Environment and Energy Security on the page 'Environmental Impact Assessments and Authorisations' [3,4].

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Of all the material analysed, the elements that are considered particularly critical are listed below:

3.4.1. Livorno: Ecotoxicological Tests on Water Samples

Over time, there is a clear upward trend in the observed ecotoxicological effects. But - according to the reports - this increase is not related to the presence of the terminal, but to oceanographic fluctuations throughout the area. ISPRA's comment regarding the evolution of ecotoxicological responses over time, starting from the reference up to the summer of 2021, without prejudice to the variability of the response attributable to the individual species and the comments in the reports, is an increase in toxicity response over time, probably determined by oceanographic variations throughout the area (a thesis, that of oceanographic variations, for which we have not found elements of in-depth analysis). Cfr. point C1.3 in Appendix A.

3.4.2. Livorno: Zooplankton Incl. Ichthyoplankton

The three components of zooplankton (holoplankton, meroplankton and ichthyoplankton) sampled in summer were compared with the reference station over the nine years of monitoring. The results show that the zooplankton community is significantly different between the Reference and all the other points, with high values for copepod holoplankton and meroplankton, while for ichthyoplankton, although lower, it remains highly significant. The difference observed with the reference point remained almost constant until 2022. This difference is hard to attribute to the operation of the regasifier alone. Cfr. point C2.2 in Appendix A.

3.4.3. Porto Viro: Mussels

The concentrations of CBP in mussels are generally below the limits of quantification, some haloacetic acids (dichloroacetic acid - DCAA, monochloroacetic acid - MCAA, di-bromocloroacetic acid - DBCAA, and chlorodibromoacetic acid - CDBAA) were detected, which were also often found at control stations. Among the halomethanes, chloroform was detected. Cfr. point A3.1.6 in Appendix A.

Slight oxidative effects were observed in some campaigns. Anyhow, biologically relevant effects were excluded in the biomarkers of mussels transplanted in the vicinity of the Terminal and attributable to the operating activities. Overall, no relevant biological effects are highlighted in mussels transplanted in the vicinity of the structure that can be attributed to the terminal's operating activities. Cfr. points A3.1.6 and A3.2.6) in Appendix A.

3.4.4. Porto Viro: Fish

With regard to bioaccumulation in fish, mercury and arsenic show rather high concentrations in the muscle of *Squalus acanthias* both in the vicinity of the terminal and in the control area, in the operational phase, already reported in the blank and site phase for cartilaginous species (cfr. point A4.1.2 in Appendix A). Summary index of biomarker alterations in *Sq. acanthias* shifted to the level ‘moderate’ during the transition from the Reference to the Operting phase of the Terminal (cfr. point A4.1.6 in Appendix A).

When comparing the egg and larvae concentrations, there is still no clear trend in ichthyoplankton in terms of the abundance of eggs and larvae of bony fish (especially anchovies) in relation to the presence of the regasifier (cfr. point A5.8 in Appendix A), indicating the need of further monitoring activities.

Concerning the regasifier in Porto Viro, a separate paper (Cacciatore et al., 2021 [29]) reported chloroform levels in both mussels and fish muscles with higher values in the control stations, which therefore did not indicate a direct relationship with exposure to the plant's discharges. However, a bioaccumulation of some HAAs in particular DCAA in both mussels and fish and MCAA only in mussels was highlighted in the same study. Among the fish, spiny dogfish (*Squalus acanthias*) showed

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higher levels of CBP with compounds similar to those found in the sediment. This result appears to be due to the feeding behaviour of the species, which feeds mainly on benthic fish.

4. Discussion

Overall, many analyses are carried out to search for contaminants that are of little use in understanding the impact of the terminal's emissions, as the concentrations are always or almost always below the limits of quantification. The monitoring of volatile organic compounds (VOCs), for example, shows that organotins in water are almost always below the limits of quantification. On the other hand, the determination of the concentration of oxidising chlorination residuals (CPOs, TROs), which would be important to verify that there are no harmful effects from the summation of all oxidants produced during the chlorination of seawater, is not taken into account. CPOs are considered in the guidelines for marine waters in several countries: United States, United Kingdom, British Columbia, Australia and New Zealand. VOCs and haloacetonitriles were found in sediments and biota below the limits of quantification. The polychlorinated biphenyls - PCBs searched for in the various compartments also do not appear to be linked to emissions from the Porto Viro LNG plant. Based on a critical assessment of the environmental monitoring currently carried out, only the most specific indicators could therefore be selected, which favours a better control of the spatial distribution of pollutants and biomarkers in the area at a distance of less than 200 metres from the plant.

Another important aspect to be considered would be to relate the pollutant's concentrations detected in the water during monitoring to the actual flow rates (hourly and daily at the time of sampling) of the free active chlorine released in the cooling water. The annual flow rates of free active chlorine discharged from the LNG terminal of Porto Viro can vary by up to 81%, as e data show (cfr. Table 2).

Having recognised this, the following operational proposals can be made:

1) **Analytical determinations**. Overall, it is found that many analytical determinations are carried out to search for contaminants of little use in understanding the impacts of emissions from the terminal, with concentrations always or almost always below the limits of quantification. For example, in the monitoring of volatile organic compounds (VOCs), organotins in water are almost always below the limits of quantification.

   The determination of the concentration of chlorination oxidant residues (CPOs, TROs), which would be important to verify that there is no harmful effect due to the summation of all oxidants formed in the chlorination process of marine waters, is not considered. CPOs are considered in the guidelines for marine waters in several countries: the United States, Great Britain, British Columbia, Australia and New Zealand. In sediment and biota, VOCs and haloacetonitriles were found to be below the limits of quantification.

   PCBs sought in the various matrices also do not seem to be relatable to emissions from the LNG plant. Therefore, on the basis of a critical assessment of the environmental monitoring carried out, only the most specific indicators could be selected, favouring greater control of the spatial distribution of contaminants and biomarkers in the area at distances of less than 200 metres from the plant.

2) **Relate analyses to actual wastewater flow rates**. Another important aspect to be considered would be to relate the concentrations detected in the water during monitoring to the actual flow rates (hourly and daily at the time of sampling) of the free active chlorine discharge in the cooling water, whose annual flow rates can vary by up to 81% as evidenced by the data on the quantities of free active chlorine discharged from the LNG terminal.

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3) **Continuation of monitoring plans**. It is assumed that the use of seawater - and the consequent effects on the environment - is proportional to the input of natural gas into the distribution network. It has been found that:
   - the Porto Viro plant ensured an annual production of more than 60 per cent of its capacity throughout the years 2010-2021,
   - the Livorno plant was most operational in the years 2019 and 2020, remaining below 41% the other years.

   Considering the production data, the monitoring results for the Livorno plant cannot justify any request to reduce the intensity of the monitoring plan currently underway. For this plant, it is essential not to deviate from the monitoring action on the marine habitat.
4) **The peer-reviewing of monitoring schemes and periodic reports**. With regard to the monitoring strategy and an overall periodic (five-year) evaluation of the results, it would be useful to be able to identify the best indicators to look for in relation to the specific impacts expected from the emissions produced during the LNG regasification plant's operation; to this end, a critical review of the five-yearly results by an external European scientific body of international relevance could be useful. The critical assessment should be based not only on the compliance of the activities with the planned monitoring plan and on whether or not the legal limits set for individual contaminants are exceeded, but on a selection of the most suitable parameters and indicators for a review of the monitoring and sampling strategies, so as to optimise resources by abandoning the search for contaminants that are not clearly relatable to emissions and better targeting impact assessments to the real quality and extent of the emissions produced.

   This approach is supported, among others, by the Port Environmental Review System (PERS [37]), which promotes the adoption of best practices through certification by independent bodies, thereby enhancing transparency and reliability in environmental monitoring. The PERS methodology, designed for ports and port authorities, offers a framework for environmental management that includes periodic monitoring and the review of environmental reports. The peer review should extend beyond mere compliance with planned monitoring plans and legal limits; it should focus on the selection of the most suitable parameters and indicators to optimize resources. PERS emphasizes the importance of independent verification, transparency, and continuous improvement in environmental monitoring.
5) **Reactivate EIA procedures, opt for 'Closed Loop' if indicated by critical issues**. The need to diversify gas supply sources for the purpose of national energy security can no longer refer to the exceptional conditions of the international context. The situation presented itself with the invasion of Ukraine, but in October 2023 the resumption of the conflict involving Israel indicates a permanent tension for the supply of fossil energy sources.

   The authorisation procedure for regasification plants - even in critical circumstances - cannot automatically lead to the exclusion of the EIA:
   - impacts of the project must be assessed,
   - project alternatives must be considered;
   - there must be a procedure which involves the public,
   - requirements may be imposed to protect the environment and public health.

   In order to preserve marine habitats, operating schemes other than 'open loop' should be implemented as a precautionary measure, in case monitoring findings bring evidence of environmental impact.

Supplementary Materials: The following supporting information can be downloaded at the website of this paper posted on Preprints.org.

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