Optimization of the technical and environmental performance of the renewable energies. Case of the hybrid powerplant "SPPI" of HassiR'mel in the central highlands of Algeria

Sarra Aouadj^{1†}, Soraya Zebirate², Rachid Smail¹, Fethi Saidi³

¹Laboratory of research in Industrial prevention (LRPI), University ChahidmostaphaBenboulaidBatna 2, Batna, Algeria

²Industrial Security and Sustainable Development Engineering Laboratory (LISIDD), IMSI, Mohamed BENAHMED University of Oran 2, Oran, Algeria

³Naval Aero-Hydrodynamic Laboratory, University of Sciences and Technology of Oran 'M-B', Algeria

ABSTRACT

The exploitation of fossil fuels is causing global warming whose negative effects have recently been felt all over the world. Therefore, the search for new sources of energy, renewable and respectful of the environment is crucial for manufacturers. The concept of Best Available Techniques (BAT) presents an adequate solution for manufacturers, for the control, elimination or reduction of the harmful impacts of their activities on the environment. This concept, known as Integrated Pollution Prevention and Control (IPPC), was introduced and imposed from 1996 in Europe. This paper aims to introduce the possibility of transferring the IPPC approach and BAT concepts to Algeria. Therefore, the main objective is to propose some recommendations to optimize the technical and environmental performance of hybrid solar-gas systems, by treating as a case study the first hybrid solar-gas power plant SPPI (Solar Power Plant One) near Hassi R'mel in the south of Algeria. A gap analysis of the Algerian environmental policy compared to the IPPC system, and an assessment of technical and environmental performance of the "SPPI" plant in terms of regulation and BAT are developed in our study.

Keywords: Best Available Techniques (BAT), Environmental Performance, Hybrid Systems, IPPC System, Renewable Energy (RE)

1. Introduction

Energy is the origin of all the socio-economic development of the countries; it constitutes for some the only economic wealth [1]. The main energy sources on earth are fossil fuels. However, the exploitation of fossil fuels causes global warming; whose negative effects have been recently felt all over the globe. Therefore, for a lasting existence, the use of fossil fuels must be reduced. On the other hand, the search for new, renewable and environmentally friendly sources of energy became a necessity [2]. In order to meet all energy needs the research on all the development prospects of different types of renewable energy such as: wind energy, geothermal energy, biomass, and in particular, «solar energy» must be developed.

Over the last few decades, the attitude of governments and industrialists towards environmental protection has changed radically [3]; consequently, the control of environmental impacts has become

a major issue. Manufacturers from now on include the environment in their specifications. In fact, regulation is becoming increasingly demanding, and the costs of non-compliance can be more difficult to bear than implementing environmental options tailored to the context of the industry. In addition, the high cost of the end-of-line techniques with sewage treatment plants, dust collectors and waste collection systems encourage the adoption of cleaner production processes and practices within the industrial process.

It's in this context that comes the concept of Best Available Techniques (BAT) [4-6], whose elaboration presents an adequate solution for the industrialists not only for the control of the harmful impacts of their activities on the environment but also, to be able to prove their good environmental performance. Because the BAT provides a basis, on which the performance of industrial activities can be assessed. This is also a decision-support tool for authorities in terms of environmental authorizations and inspections or controls.

The concept of BAT was introduced and imposed since 1996

This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (<http://creativecommons.org/licenses/by-nc/3.0/>) which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

Copyright © 2021 Korean Society of Environmental Engineers

Received January 30, 2020 Accepted June 24, 2020

[†] Corresponding author

Email: sarah.ing.hse@gmail.com

Tel: +213 542 148 967

in Europe under the framework of the European directive N 96/61/CE [7], so called IPPC (Integrated Pollution Prevention and Control), and revised by the Industrial Emissions Directive (IED) 75/2010/EC (European Commission [EC], 2010) [8]. This directive defines all the principles to be respected for the concerned installations including the adoption of an integrated approach of environmental impacts and the adoption of BAT [9-11].

With the success of the integrated pollution prevention and control (IPPC) in the European Union (UE) and the implementation of BAT, other countries transferred this experience taking into account the specificities of every country and every industrial activity [12]. In the literature, few case studies describe the transfer of the EU approach for the integrated pollution prevention and control to other contexts. One of these case studies is the paper of Miller *et al.* (2008) [13], which includes references to pollution prevention programs in the United States. Zarker and Kerr (2008) [14] describe some pollution programs developed in recent years. Calia *et al.* (2009) [15] considered in their study the pollution prevention programs in the United States, paying attention to a program of a multinational company. Another document is that of Cagno *et al.* (2005) [16] which provides an analysis of over 130 pollution prevention program projects in many companies and countries, with a more detailed attention to the United States. An important contribution is the technical report of the National Center for Environmental Innovation of the United States Environmental Protection Agency Office of Policy, Economics and Innovation (2008) [17], that deals with the description of the IPPC system adopted in the United Kingdom and evaluates its potential of transferability to the legal framework of the United States. The study of Chittock and Hughey [18] relates to the pollution prevention programs in different countries: USA, Japan, Australia, Canada and the United Kingdom. In this regard, a project has been drawn up for transferring the IPPC system to the Mediterranean countries [19, 20]. Our ambition is to transfer the requirements of the IPPC scheme to our country Algeria where the introduction of renewable energies in the sector of electricity production began with a hybrid system "solar-gas" in the first power plant "Solar Power Plant I (SPPI)" in Hassi R'mel (south of Algeria).

The issue discussed in this paper is not to search for the advantages of these systems (hybrid solar-gas systems) and verify their efficiency, because this has been already demonstrated in previous studies such as that of Abdelhamid *et al.* [21]. In fact, the issue is how to optimize those systems to reach a much higher efficiency.

Our contribution is essentially to propose a new combination Renewable Energy- BAT (RE-BAT) for the optimization of renewable energies systems in general and hybrid "solar-gas" systems in particular. In order to serve the subject while verifying the hypothesis of the survey, an analysis of the gaps and differences between the principles and requirements of the IPPC European system and those of the Algerian legal framework must be conducted; as well as an evaluation of the technical and environmental performances of the first hybrid power plant "SPPI".

After getting the results of the two parts of the survey (the analysis of the legal framework and the evaluation of the power plant performances), we will strive to give some recommendations about the techniques used and to draw conclusions for the transfer of the European integrated approach and the implementation of BAT in

Algeria. The next section, is based on an evaluation of the technical and environmental performances of an hybrid "solar-gas" type power plant named SPPI (Solar Power Plant ONE) situated in Hassi R'mel in southern Algeria, in order to present the methodology followed as well as the analysis tools. Then, in section 3, we used the approach followed in the analyses of policies and legislative frameworks to support BAT implementation in the partner countries (Egypt, Tunisia and Morocco), conducted under the framework of the BAT4MED project (Boosting BAT for the Mediterranean Partner countries) [20]. The paper will be closed with some recommendations to improve the technical and environmental performances of the SPPI hybrid solar-gas power plant of the south of Algeria.

2. Methodology and Analysis Tools

The aims tracked in this paper are:

- (1) Define the degree of compliance and respect of the instructions of environmental regulation and BAT for this type of industrial activity.
- (2) Analyze the Algerian legal basis to extract the gaps compared to the European system "IPPC" to implement BAT.
- (3) Introduce the notion of BAT in the evaluation of the companies' performances in Algeria.
- (4) Propose practical solutions for the upgrading of hybrid systems in terms of environment. The aim is to give options for industrialists and authorities for future projects of the Algerian national program of renewable energies development.

2.1. L-BAT Methodology

We used the L-BAT (Local- Best Available Techniques) methodology to evaluate the technical and environmental techniques of the SPPI power plant to compare them with BAT and identify the conformity rate of the SPPI in terms of the Algerian regulation and the BAT of IPPC system of the European Union [22].

We introduced some minor modifications on the methodology to adapt it to the Algerian context. These modifications do not affect the content and the results of the methodology.

In the framework of practical application, steps as illustrated in Fig. S1 structure the general approach used for the evaluation of performances. For every step, a tool was created to complete it.

2.1.1. Adjustment of the L-BAT methodology to the context of the hybrid power plant SPPI

In order to attain the set out objectives, we used the same calculation formulae of the compliance rates of the power plant performance. The adjustments made concern the Environment and Risks Management System review "ERMS".

Fig. S2 illustrates the steps to follow as well as the tools to be used. The definition of the 5 control levels are illustrated in Table 1.

2.2. Analysis Tools

The tools used for the analysis of the gaps and differences between the requirements of the IPPC European system and those of the Algerian legal framework as well as for the evaluation of the

Table 1. Definition of The 5 Control Levels of The Prevention Measures

Classes	Wording	Control levels
A	BAT that figures in the BREF.	Good control
B	Action not referenced in the BREF but consistent with the text of the Algerian regulation.	Average control
C	BAT or measure currently being implemented or medium control of an existing measure	
D	Technique that has similar performances to BAT of the BREF but there is a gap between theory and practice.	Insufficient control
E	Technical Solution non-compliant to the requirements of regulation and/or safety (to be justified).	Largely insufficient control
	BAT or measure currently being implemented and non-compliance to ELV (to be justified)	
	Or	
F	Non-compliance of the application of the measures of regulation.	No control
	Non-compliance in terms of regulation, safety and ELV's requirements	
	Or	
	Measure or technique totally absent	

technical and environmental performances of the first hybrid power plant "SPPI" are as follows:

- Legal texts of the Algerian regulation.
- Reference documents for the BAT so called: BREF (Best REFERENCE documents): our evaluation of the SPPI hybrid power plant performance is the result of the comparison of the techniques used in this power plant with other reference techniques (those whose economic and energetic efficiency as well as their minimal impacts on the environment were verified and validated). These techniques should be listed in some reference documents to facilitate the task for industrialists, researchers and authorities.

Due to the lack of this kind of documentation or a database for BAT in Algeria, we used the reference documents for "BREF" [23] elaborated and published by the European commission in application of the article 16 (2) of IPPC directive [7].

2.2.1. Reference documents on BAT "BREF" used in the analysis

In this paper, we used the requirements presented in two BREFs: BREF of Large Combustion Plants (LCP) and the BREF of Energy Efficiency (EE).

2.2.1.1. Application on large combustion plants "LCP"

The first BREF used as a reference in our analysis is the BREF for LCP published in 2006 (reviewed and republished in 2017) [24]. The parts concerned by our study are summarized in the tableS1.

2.2.1.2. Application on energy efficiency "EE"

The BREF "EE" was published in 2009 and is intended to cover all the issues related to energy efficiency in application of the IPPC directive [25]. The parts of this BREF used as a reference for this study are summarized in Table S2.

3. Analysis of The Gaps and Differences between The Principles and Requirements of The IPPC European System and Those of The Algerian Legal Framework (First Part of The Study)

The IPPC of the European Union is based on 5 principles, all

conceived to achieve a higher level of environment protection as a whole [26, 27]. These principles are presented in the Fig. S3.

Fig. S4 describes the steps of the analysis of the Algerian environmental policy.

3.1. Results of The First Part of The Study (Analysis of The Gaps)

Our analysis of the Algerian system of pollution prevention and control was based on the five principles of the IPPC system. The results of the analysis are summarized in the Table 2.

4. Evaluation of The Technical and Environmental Performances of The First Hybrid Solar-Gas Power Plant "SPPI" (Second Part of The Study)

4.1. Technical and Environmental Diagnosis of The Power Plant

A description of all the main and auxiliary equipments and systems of the SPPI power plant was realized.

4.2. Environment and Risks Management System Review "ERMS"

4.2.1. Completion of a questionnaire related to the « ERMS »

For the ERMS review we tried to conduct a synthesis of all the management measures elaborated by the plant's managers, using a questionnaire prepared for different actors in the SPPI power plant.

The questionnaire includes a list of questions regrouped in 8 different categories:

- Category I: Reduction and Minimization of Atmospheric Impacts.
- Category II: Control and Minimization of Liquid Effluents (Soil and Subsoil protection).
- Category III: Safety-Risks-Fire fighting
- Category IV: Control and Reduction of Noise and Odors.
- Category V: Reduction and Minimization of Wastes Impacts.
- Category VI: Training and Information of the Workers.

Table 2. The Gaps between the IPPC System and The Algerian Environmental Policy

	European system « IPPC »	Algerian environmental policy
Integrated approach	<ul style="list-style-type: none"> - Integrated environmental authorizations « permits » - Update of the authorization conditions - Ongoing monitoring - Adoption of an integrated approach - Consideration of BAT in the issuing authorizations 	<ul style="list-style-type: none"> - Environmental impact study - No update - No ongoing monitoring - Adoption for an approach for each element or aspect of the environment - BAT are not yet implemented or considered in issuing permits in Algeria
BAT	<ul style="list-style-type: none"> - Grouping of BAT in reference documents « BREFs » - Emission Levels Values (ELV) associated to BAT «BAT-AELs » (Article 15, 2. and 3. of the IED directive). [20] 	<ul style="list-style-type: none"> - The absence of reference documents on BAT - General ELVs fixed by the legislative texts
Flexibility	<ul style="list-style-type: none"> - The competent authority could set ELVs that differs from the « BAT-AEL » according to criteria that should be indicated 	<ul style="list-style-type: none"> - The conditions implemented under the principle of flexibility are not applicable in Algeria because the ELV are not based on BAT
Environmental inspections	<ul style="list-style-type: none"> - Emissions must be reported to the competent authority regularly - Implementation of an inspection system of installations. - Elaborate inspection plans - On the basis of these plans, the competent authority must elaborate routine inspections program - Setting a Site's visits frequency - Carry out unscheduled inspections 	<ul style="list-style-type: none"> - Appears in Algerian regulation - Requirement not found - Requirement not found - Requirement not found - Requirement not found - This requirement appears in the Algerian regulation
Public participation	<ul style="list-style-type: none"> - The IPPC system guarantees the right of the public to participate to decision-making in terms of environment 	<ul style="list-style-type: none"> - The Algerian regulation guarantees as well the right of public in terms of environment

- *Category VII: Environment Management (Environmental Management System).*

- *Category VIII: Energy Efficiency.*

The questions were elaborated taking as a reference the legal texts (laws, decrees...) of the Algerian regulation in terms of environment, safety and energy efficiency, in addition to the reference documents on BATs (BREF "LCP" and BREF "EE").

The classification of measures based on control levels is presented in the same questionnaire grid. A color code was used to facilitate the reading of the grid and the interpretation of the results.

→ **The color code used:**

- *Classes A and B: Good mastery or control of the measure*
- *Class C: average control*
- *Class D: insufficient control*
- *Class E: largely insufficient control*
- *Class F: no control*

The Table S5 is an excerpt of the ERMS review grid for the category I "Reduction and Minimization of Atmospheric Impacts". It shows simply the different sections of the questionnaire.

4.3. Results of The ERMS Review

4.3.1. Calculation of the number of prevention measures in terms of control level

For each category and control class, we calculated the number

of prevention measures. The results are summarized in the Table 3.

→ **Interpretation**

The graph of Fig. S3 shows that the majority of the measures of the "ERMS" of the SPPI power plant are classified in the classes A and B "good control". This gives us a first impression about the plant's performance.

In addition to that, we note that there are 7 measures in Class D "insufficient control", this refers to the lack of some prevention measures in the ERMS for the category "Reduction and Minimization of Atmospheric Impacts" and the category "Control and Minimization of Liquid Effluents". Therefore, more attention needs to be paid to these categories by the company's management.

4.3.2. Distribution of prevention measures by class (calculation of the percentage of each class)

We calculated the percentage of the prevention measures of the ERMS for each class of control. Table 4 shows the results.

→ **Interpretation**

The graph of the Fig. S6 completes the graph 5. The largest share belongs to the classes A and B with a percentage of 67%. The class C comes in second position with a percentage of 24%. We notice low percentages (4% and 5%) for the classes D "insufficient control" and F "no control".

Table 3. Number of Prevention Measures for Each Category and Class

Category (environmental and risks objectives)	Total number of prevention measures	Class A	Class B	Class C	Class D	Class E	Class F
<i>Reduction and Minimization of Atmospheric Impacts</i>	23	7	5	4	3	0	4
<i>Control and Minimization of Liquid Effluents (Soil and Subsoil protection)</i>	30	4	12	10	2	0	2
<i>Safety-Risks-Fire fighting</i>	35	0	34	1	0	0	0
<i>Control and Reduction of Noise and Odors</i>	12	2	4	5	1	0	0
<i>Reduction and Minimization of Wastes Impacts</i>	7	0	6	1	0	0	0
<i>Training and Information of the Workers</i>	5	0	4	1	0	0	0
<i>Environment Management (Environmental Management System)</i>	3	1	0	2	0	0	0
<i>Energy Efficiency</i>	25	15	0	9	1	0	0
Total number of measures	140	29	65	33	7	0	6

Table 4. The Percentage of Prevention Measures for Each Control Class

Classes		Class A	ClassB	ClassC	ClassD	ClassE	ClassF
Number of measures	140	29	65	33	7	0	6
Distribution of actions		20.71%	46.43%	23.57%	5%	0%	4.28%

Table 5. Compliance Rates for Each Category

Category (environmental and risks objectives)	Compliance Rate	Minimum acceptable limit for the compliance to regulation and BATs
<i>Reduction and Minimization of Atmospheric Impacts.</i>	52%	75%
<i>Control and Minimization of Liquid Effluents (Soil and Subsoil protection).</i>	53%	75%
<i>Safety-Risks-Fire fighting</i>	97%	75%
<i>Control and Reduction of Noise and Odors.</i>	50%	75%
<i>Reduction and Minimization of Wastes Impacts.</i>	85%	75%
<i>Training and Information of the Workers.</i>	80%	75%
<i>Environment Management (Environmental Management System)</i>	33%	75%
<i>Energy Efficiency</i>	60%	75%

4.3.3. Compliance rate “CR” of ERMS by category

The compliance rate was calculated for each category using the following formula:

$$CR = \frac{\text{Number of classes' (A+B)actions}}{\text{Total number of actions}} \quad (1)$$

The results are summarized in table 8. A representation of these percentages is schematized in the Fig. S7.

→ Interpretation

Through the observation of both tables 4 and 5 we can make the following points:

- The performance of the SPPI power plant looks to be acceptable.
- The compliance rates of the ERMS of the plant by category turn around the minimum acceptable limit (there are 3 values of the CR superior of the limit value and 5 values of the CR inferior of the limit value).
- The power plant has an excellent performance in terms of safety with a CR of 97%. As well as for the category “Reduction

and Minimization of Wastes Impacts” with a CR of 85% and 80% for the “Training and Information of the Workers”

- The Compliance Rates of the categories “Reduction and Minimization of Atmospheric Impacts”, “Control and Minimization of Liquid Effluents”, “Control and Reduction of Noise and Odors” and “Energy Efficiency” are respectively: 52%, 53%, 50% and 60%. Although these CRs are lower than the minimum acceptable limit value (75%), they still are considered acceptable because they exceed 50%.
- The minimal value of the CRs (33%) appears in the category “Environment Management (Environmental Management System)”. This can be translated by the fact that there is a lack of application of the EMS requirements.

4.3.4. Global compliance rate of the power plant

The Global Compliance Rate (GCR) is calculated using the same formula:

$$GCR = \frac{\text{Number of classes' (A+B)actions}}{\text{Total number of actions}} \quad (2)$$

GCR 67%

Table 6. Justification of The Measures Classified in The Classes C, D and F

Reference	Category	Description	Level of control	Justification
Executive Decree N 06-138 of 15/04/2006 Article 5	Reduction and Minimization of Atmospheric Impacts	The atmospheric releases of the SPPI are not captured as near as possible from their source of emission. they are only identified using measure devices placed in the chimneys	D	The atmospheric releases are not important
ED N 06-138 of 15/04/2006 Article 7	Reduction and Minimization of Atmospheric Impacts	The SPPI do not have atmospheric releases treatment installations	F	The atmospheric releases are not important
ED N 06-138 of 15/04/2006 Article 13	Reduction and Minimization of Atmospheric Impacts	The controls made by the concerned services aiming at making sure of the conformity to the atmospheric emission limit values fixed in the annex of ED N° 06-138, are not frequent	D	The controls are made by the environment service of the plant and the results are sent to the competent authority
BREF « LCP »	Reduction and Minimization of Atmospheric Impacts	The plant does not take secondary measures for the reduction of atmospheric releases that aim to reduce or eliminate the atmospheric releases that have already been produced	D	The atmospheric releases are not important
BREF « LCP » & 7.1.7.3.1	Reduction and Minimization of Atmospheric Impacts	The measure of water or steam injection to reduce the NOx emissions is not used in the SPPI	F	The NOx emissions are reduced by using some primary measures such as using treated natural gas, optimisation of the combustion (complete combustion)
BREF « LCP » & 7.1.7.3.3	Reduction and Minimization of Atmospheric Impacts	The technique of Selective Catalytic Reduction (SCR) with ammonia or urea with the presence of catalyser to reduce NOx is not used.	F	
ED N° :06-138 of 15/04/2006	Reduction and Minimization of Atmospheric Impacts	There is no conduit for secondary evacuation of atmospheric releases	F	/
ED N° : 93-160 of 10-07-1993 Article 16	Control and Minimization of Liquid Effluents (Soil and Subsoil protection)	The inspection visits of liquid effluents made by environment inspectors are not frequent	D	The controls are made by the environment service of the plant and the results are sent to the competent authority
REF « LCP »	Control and Minimization of Liquid Effluents (Soil and Subsoil protection)	Extinction waters are not well managed. They are not recovered and treated	D	/
ED N° : 06-141 of 19-04-2006 Article 5	Control and Minimization of Liquid Effluents (Soil and Subsoil protection)	The evaporation pond is not conforme to regulation requirements. It is not equipped with an impermeable material that will withstand environmental factors and chemicals	C	Compliance of the pond : ongoing project.
ED N° : 93-184 of 27-07-1993 Regulation of noise emission	Control and reduction of noise and odors	The results of the sonorous levels evaluation show that the levels of the noise made by engines, machines...etc are higher than the limit values fixed by the law : Between 70 and 98db (A) in the work site (LV ≤ 85dB) [evaluation made by health service of social affairs management – Sonatrach- Hassi R'mel]	D	It is a fluctuant exposition. The workers move (they do not stay in the same place for a long period)
BREF « EE » & 4.3.8	Energy efficiency	No technique used to optimise pumping systems (to save the energy consumed by pumping systems)	D	/

The value of the GCR shows that the global performance of the power plant is acceptable. This concerns the performance of the combined cycle part of the station. The global performance of the SPPI power plant should be assessed without forgetting that it is a hybrid solar- gas power plant with a clean renewable source of energy.

4.4. Analysis of Global Performance of The SPPI (Analysis of The Prevention Measures)

The categories concerned by the classes C, D and F are mainly

the “*Reduction and Minimization of Atmospheric Impacts*”, the “*Control and Minimization of Liquid Effluents*”, the “*Control and reduction of noise and odors*” and the “*Energy efficiency*”.

The measures that belong to the control level « insufficient control » and « no control » are justified by the SPPI management in the Table 6.

4.5. Identification of The Sensitivity of The Local Environment (Consideration of The Local Environment)

The environmental performance of an industrial installation cannot

be effectively defined without taking into account the local context. The results of the study of the installation' environment sensitivity should be taken into consideration (Fig. S8).

4.5.1. Preparation of a questionnaire related to the local context

We note that the sensitivity level was evaluated independently from the intensity of the impacts of the industrial activity that exert pressures on the receiver environment. It consists on analyzing the state of the environment or its vulnerability without considering the industrial context.

The vulnerability levels of the local environment are presented in the questionnaire grid using a color-coding as shown in Table 7.

Table 7. Sensitivity Levels Attributed According to Vulnerability Classes

Classes	Vulnerability levels	Color code
1	Very vulnerable
2	Vulnerable
3	Moderately sensitive
4	A little or not vulnerable

In order to determine the sensitivity level of the local environment or the environment receiving the pressures of the SPPI activities, some criteria should be taken into account. These latter are regrouped in a questionnaire as shown in Table 8.

→ Interpretation of the results of the questionnaire

From the first sight of the results of the questionnaire, we can conclude that the local environment where is located the SPPI power plant is not sensitive or vulnerable (this interpretation was facilitated by the color code) as shown in table 8. The yellow boxes (moderately sensitive), were attributed to the two themes: air and soil.

In the first box, the nature of the sensitive vicinity (presence of installations classified as hazardous in the vicinity) may present an issue, because an accident in one of these installations could be transferred to the others. Consequently, the volume of the human and material damages will increase, as well as for the environment (soil and subsoil contamination, air pollution...etc).

However, this could be justified by the fact that these industrial installations possess powerful safety systems, as safety is a key issue in such plants, reflecting the low frequency of major accidents in this area (north region of Hassi R'mel gas field).

For the second box, it is almost the same preoccupation. It concerns the activities in the vicinity (zone of industrial activities: the power plant of *sonelgaz* of *Tilghemt 220MW* nearby the *SPPI power plant* and the *natural gas processing module* owned by *Sonatrach (module 3)*.

To summarize, we can say that the zone where the SPPI hybrid power plant is located is a Saharan industrial zone, inhabited only by the installations' workers in life bases. In addition to that, it contains only few sensitive environmental elements (desert).

The final result is that more attention must be paid for atmospheric emissions to preserve the workers' health and the population of Hassi R'mel (the distance between the SPPI and the town of

Hassi R'mel is about 6 km). Since atmospheric dispersion is very rapid, air must be considered as a vulnerable element.

5. Conclusion and Recommendations

The goal of our evaluation was not to show the weaknesses of the ERMS system of the SPPI power plant. In fact, our main goal is to prove that the industrialists in Algeria use measures that could be qualified as BAT, but they do not possess neither references of these techniques to be able to compare them to theirs, nor the tools to define their technical and environmental performances.

The main intended objective in this paper is to propose some recommendations to optimize the future projects of hybrid solar-gas power plants in Algeria.

The first point to start with is the minimization of atmospheric emissions. In the SPPI power plant, some primary measures (measures that should be taken to avoid the formation and the production of these emissions), have been taken, such as:

- The use of a treated combustible, whose combustion generates less NO_x and no SO_x.
- The optimization of the combustion by its execution in several stages (staged combustion) with low temperature in the first zone and a sufficient residence time of combustion gases in the combustion chamber for a complete combustion.
- The use of expansion turbine for the recovery of the energy content of pressurized combustible gases.

For this type of emissions, some primary and secondary measures (measures or techniques at the end-of-pipe [27], aiming at reducing the emissions that are already produced) are absent.

The justification given for the absence of a treatment station of atmospheric releases is that the power plant is of medium capacity and the emissions are low. Furthermore, the projects of the Algerian program of RE development are of higher capacity, consequently bigger amounts of releases will be produced. This would require paying a much greater attention at this point. For this reason, the following measures which are qualified as BAT in the "LCP" BREF are recommended:

- (1) Preheating of combustible gas using the waste heat coming from the boiler and the gas turbine (efficient use of the natural resources).
- (2) Water or steam injection as a measure for NO_x elimination: the injection of water/steam can be practiced by injection of a mixture of fuel and water or steam or by injection of water or steam by means of injectors directly in the combustion chamber. The evaporation or the overheating of steam requires a thermal energy, which is then no longer available to heat the flame. Thus, the temperature of the flame decreases and the formation of NO_x is reduced [24].
- (3) Use of Dry Low NO_x technologies: in addition to the benefits for the environment, the low NO_x technologies have several economic benefits:
 - The installation of a modern dry low NO_x burner costs approximately 2 million Euros for a gas turbine of 140 MWth [24].

Table 8. Questionnaire to Evaluate The Sensitivity of The Natural and Human Environment Surrounding The SPPI Power Plant

Themes		Characteristics of the environment of the industrial site	Criteria	
Water	Superficial waters	1. Presence of a waterway in the vicinity? (-) - Type of usage? (-) - Presence and type of aquatic fauna-flora? (-) - Distance between the installation and the nearest waterway? (-)	Waterway quantity. Rate of flow Volume of rejected water by the industrial site. Distance of the site Type of fauna-flora Class of waters' quality	
		1. Presence of network? - Road infrastructure? (+) - Railroad infrastructure ? (-) - Air traffic? (+) 2. Climate conditions : - Dominants winds: <i>the dominant wind comes mainly from the north-east frequently. The sirocco, which comes from the south, can also happen once in a while producing sand storms.</i> - Precipitation : <i>low moisture areas, low rainfall</i> - Nature of sensitive vicinity : industrial zone - Presence of installations classified as hazardous in the neighborhood : (+)	Flow? <i>Low traffic-private road (allowed access only for the workers)</i> Frequency of storms : Storm frequency: low. Annual medium precipitation: 78.5mm Population density : <i>Low density. Area inhabited only by plant workers in living bases</i>	
Soil		3. Presence of protected zone or landscape quality? (fauna-flora) : <i>There are no protected areas or sites of cultural interest within or in the vicinity of the Hassi RMel field, the nearest protected area being the MZab Valley located approximately 60 kilometres southeast (site classified within the UNESCO World Heritage)</i> 4. Nature protection? 1. Presence of cultural heritage? (buildings and urbanism)(-) - Hospitals, schools...(-) - Type of land use or activities in the vicinity? <i>Zone of industrial activities</i>	Nature : (NC) Distance from the site: (NC) Nature (NC) Distance from the site (NC) Type: <i>Power station, Natural gas processing module.</i> Distance from site: 500m	
		1. Existence of risk zones? - Flood zone? (-) - Seisme zone? (-) - SEVESO II Zone (-) 2. Geological context ? <i>The triassic reservoir of Hassi-RMel is an assembly constituted by the superposition of the three levels A, B, & C, with intercalation of clay, of variable thicknesses. The cover is formed by anhydritic and clay loam.</i>	Frequency of occurrence: <i>very low or absent.</i> Nature of the geological formations of the site on which the facility is located? <i>Reservoir A: It is composed of very fine, locally clay sandstone with strong cementation. This layer has 54% of the reservoirs.</i> <i>Reservoir B : Consisting of fine sandstone, more or less clayey. This layer has 13% of the tanks in place.</i> <i>Reservoir C : Composed of fine sandstone, very poorly cemented with many conglomerates. It is the thickest layer with 60 meters.</i>	
Soil	Groundwater	3. Presence of water-table(groundwater) under the site? (+)	Nature of the aquifer : <i>Horizon SENONIAN -TURONIAN</i> Depth of the water-table : 645 m	
		4. Presence of water catchment near the site? (-)	Quantity : NC Distance (<i>is the installation located within the boundaries of these catchments?</i>) : No	
Noise		5. Presence of networks? - Road infrastructure? (+) - Railroad infrastructure? (-) - Air traffic? (+)	Flow? <i>low traffic</i>	

- The new burners offer an advantageous exploitation from an economic point of view, as there are no significant energy losses coming from the combustible losses, or in the form of hydrocarbons...etc.

However, the gas turbines maintenance costs with this technology are 40% higher than the gas turbines without low NOx technologies, this technique presents a good investment in terms of environmental performance of industrial installations [24].

(4) The use of the Selective Catalytic Reduction (SCR):

The process of selective catalytic reduction is widely used to reduce the nitrogen oxide in the gaseous releases of large combustion plants in Europe and other countries as well as Japan and the USA [24].

The process of selective catalytic reduction is a catalytic process based on selective reduction of nitrogen oxide with ammonia or urea in the presence of a catalyst. The reduction agent is injected in the flue gases upstream of the catalyst. The NOx conversion takes place on the surface of the catalyst in a temperature-ranging between (170 and 510)°C by one of the reactions (3) and (6). The catalysts of SCR based on the metal oxides and functioning in the range of temperatures mentioned previously are available in the market and used in many applications [24].

→ With the ammonia as a reduction agent [21]:

→ With urea as a reduction agent [21]:

- (5) Adoption of one or several techniques of CO₂ catchment and elimination from the exhaust gases.
- (6) Elaboration of common systems of waste water and gases: the idea of joining the waste water and gas treatment systems deserves to be studied. This idea could help in having environmental and economic benefits (minimization of the costs of the material, stations' construction, maintenance...etc).

Another point to talk about is the reduction of noise, as the limit values fixed by the law are exceeded although the plant is not of a very high capacity.

On the basis of the obtained results, we propose the following recommendations to improve the technical and environmental performances of the SPPI hybrid solar-gas power plant:

- (1) Putting mufflers of high quality on the chimneys.
- (2) Adding doubling in the support structure of the gas turbine.
- (3) Using as much as possible, the "once through cooling systems", because it was proved that these systems do not generate much noise (BAT).

We always insist on the fact that the SPPI is a hybrid power

plant using a renewable energy source. The evaluation made in this paper is to optimize, by using BAT, the combined cycle part of the hybrid system so that we could propose a combination "RE-BAT".

Author Contributions

A.S. (Ph.D. student) conducted all the experiments and wrote the manuscript. Z.S. (Professor) is the thesis director. R.S. (Associate Professor) and F.S. (Associate Professor) are the thesis co-directors.

References

1. Munu N, Banadda N. Can cities become self-reliant in energy? A technological scenario analysis for Kampala, Uganda. *Environ. Eng. Res.* 2016;21(3):219-225.
2. Asantewaa OP, Asumadu-Sarkodie S. Is there a causal effect between agricultural production and carbon dioxide in Ghana? *Environ. Eng. Res.* 2017;22(3):219-225.
3. Syahirah FKA, Umi FMA, Khairuddin MI. Compilation of liquefaction and pyrolysis method used for bio-oil production from various biomass: A review. *Environ. Eng. Res.* 2020;25(1):18-28.
4. Honkasalo N, Rodhe H, Dalhammar C. Environmental permitting as a driver for eco-efficiency in the dairy industry: A closer look at the IPPC directive. *J. Clean. Prod.* 2005;13:1049-1060.
5. Barros MC, Magán A, Valiño S, Bello MP, Casares JJ, Blanco JM. Identification of best available techniques in the seafood industry: case study. *J. Clean. Prod.* 2009;17:391-399.
6. Silvo K, Melanen M, Honkasalo A, Ruonala S, Lindstrom M. Integrated pollution prevention and control-The Finnish approach. *Resour. Conserv. Recycl.* 2002;35:45-60.
7. Council of the European Union. Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control on [Internet]. c2020. Available from: https://aida.ineris.fr/consultation_document/1031.
8. Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on Industrial Emissions (Integrated Pollution Prevention and Control) on [Internet]. c2020. Available from: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32010L0075>.
9. Council Directive 2008/1/EC of the European Parliament and of the Council of European Commission of 15 January 2008 concerning Integrated Pollution Prevention and Control on [Internet]. c2020. Available from: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:024:0008:0029:en:PDF>.
10. Raya I, Vázquez VL. Sharing experiences to improve pollution prevention and control in the Mediterranean area on [Internet]. c2020. Available from: https://www.researchgate.net/publication/288008143_Sharing_experiences_to_improve_pollution_prevention_and_control_in_the_Mediterranean_area.
11. Daddi T, De Giacomo MR, Frey M, Irlando F, Testa F. The Implementation of IPPC Directive in the Mediterranean Area. In: Environmental Management in Practice; Broniewicz, E., ed. InTech: Rijeka, Croatia; 2011. p. 119-144.

12. OECD. Best Available Techniques (BAT) for Preventing and Controlling Industrial Pollution, Activity 2: Approaches to Establishing Best Available Techniques Around the World [dissertation]. OECD; 2018.
13. Miller G, Burke J, McComas C, Dick K. Advancing pollution prevention and cleaner production—USA's contribution. *J. Clean. Prod.* 2008;16:665–672.
14. Zarker KA, Kerr RL. Pollution prevention through performance-based initiatives and regulation in the Unites States. *J. Clean. Prod.* 2008;16:673–685.
15. Calia RC, Guerrini FM, De Castro M. The impact of six sigma in the performance of a pollution prevention program. *J. Clean. Prod.* 2009;17:1303–1310.
16. Cagno E, Trucco P, Tardini L. Clean production and profitability: Analysis of 134 industrial prevention (P2) project reports. *J. Clean. Prod.* 2005;13:593–605.
17. US Environmental Protection Agency Office of Policy (US EPA). Economics & Innovation. An In-depth Look at the United Kingdom Integrated Permitting System [dissertation]. EPA: Washington, DC, USA; 2008.
18. Chittock DG, Hughey KFD. Review of international practice in the design of voluntary pollution prevention programs. *J. Clean. Prod.* 2011;19:542–551.
19. Regional Activity Center for sustainable Consumption and Production (SCP/RAC). The BAT4MED project identifies the key industrial sectors to work on [Internet]. c2020. Available from: <http://www.cprac.org/en/newsgeneralthe-bat4med-project-identifies-the-key-industrial-sectors-to-work-on>.
20. European commission 2010, 7th framework program, *Boosting BAT in the Mediterranean partner countries* on [Internet]. c2020. Available from: <https://cordis.europa.eu/project/rcn/96938/fact-sheet/en>.
21. Abdelhamid L, Bahmed L, Benoudjit A. Impact of renewable energies – environmental and economic aspects: “Case of an Algerian company”. *Manag. Environ. Qual.* 2012;23(1):6–22.
22. Cikankowitz A, Laforest V. Using BAT as evaluation method of techniques. *J. Clean. Prod.* 2003;42:14–158.
23. European IPPC Bureau. Reference documents on [Internet]. c2020. Available from: <https://eippcb.jrc.ec.europa.eu/reference/>.
24. European commission. Integrated Pollution Prevention and Control Reference Document on Best Available Techniques for Large Combustion Plants on [Internet]. c2020. Available from: https://eippcb.jrc.ec.europa.eu/reference/BREF/lcp_bref_0706.pdf.
25. European Commission. Reference Document on Best Available Techniques for Energy Efficiency on [Internet]. c2020. Available from: https://eippcb.jrc.ec.europa.eu/reference/BREF/ENE_Adopted_02-2009.pdf
26. Cikankowitz A, Laforest V. La directive IPPC : où en est-t-on ? et où va-t-on ?. *Vertigo*, la revue électronique en sciences de l'environnement on [Internet]. c2020. Available from: <https://journals.openedition.org/vertigo/9671?lang=en#quotation>
27. Sonki I. Design for environmental catalysts for VOC removal. *Environ. Eng. Res.* 2000;5(4):213–222.