POLITECNICO DI TORINO

Master’s degree in Environmental and Land Engineering

Master’s degree thesis

ENERGY EFFICIENCY IN THE INTEGRATED WATER SERVICE

The case study of the replacement of the air diffusion system in the biological treatment section of the SMAT plant in Castiglione Torinese, in the context of the White Certificates mechanism

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A.Y. 2021/2022

CONTENTS

TABLE OF FIGURES

TABLES

ABSTRACT

The current geopolitical setup of the European Union, especially following the abrupt escalation of the Russian-Ukrainian crisis that has been ongoing since 2014, has highlighted the need for EU policy to attribute crucial importance to the energy sector. The European Union's energy vulnerability, as well as the need to deal with climate-altering gas emissions, has prompted EU policy to take measures to reduce energy consumption, using energy efficiency as the first tool to deal with the energy and climate crisis. In this context, in Italy, the white certificate mechanism plays a crucial role in promoting interventions to achieve the nation's energy-saving goals. This thesis work first analyzed the socio-economic structure of the European Union and the related risks and policies in the context described above. In particular, an in-depth dissertation on the white certificate mechanism, adopted in Italy, in order to incentivize energy efficiency interventions, is provided. Among the eligible by the mechanism intervention, the case study of the replacement of the air distribution system in the biological treatment tanks, at the SMAT WWTP in Castiglione Torinese, is analyzed. The energy efficiency obligations acquired as a result of the intervention were estimated, using algorithm number 4 found in the operational guide prepared by GSE for interventions that can accrue white certificates. In this context, the necessary parameters were estimated, consistent with the public data available for the plant under consideration. The drafting of the documentation required to obtain the certificates has been provided. In order to have a contextualization in the economics of the plant, the payback period of the investment was calculated, considering the actual data of the outcome of the call for tenders for the replacement of the diffusers and the incoming cash flow resulting both from the energy savings and the incentive. Finally, given the centrality also of the fight against climate change, the reduction of greenhouse gas emissions generated by the efficiency intervention was calculated, according to GHG Protocol.

1 EUROPEAN CONTEXT

In an economic scheme increasingly centered on sustainability and circularity, while also taking into account the goals set by the European Union to combat climate change, the issue of energy conservation is central. An additional problem arose considering Russia's invasion of Ukraine. The deterioration of the political relationship with Russia, linked to this event, underscored the impending need for action regarding energy vulnerability affecting the Member States.

1.1 EUROPEAN ENERGY DEPENDENCE

Since 2013, all the 27 EU countries have been net importers of energy, underlining their great energy dependency (1). Considering the share of energy import dependence, a scheme is given below:

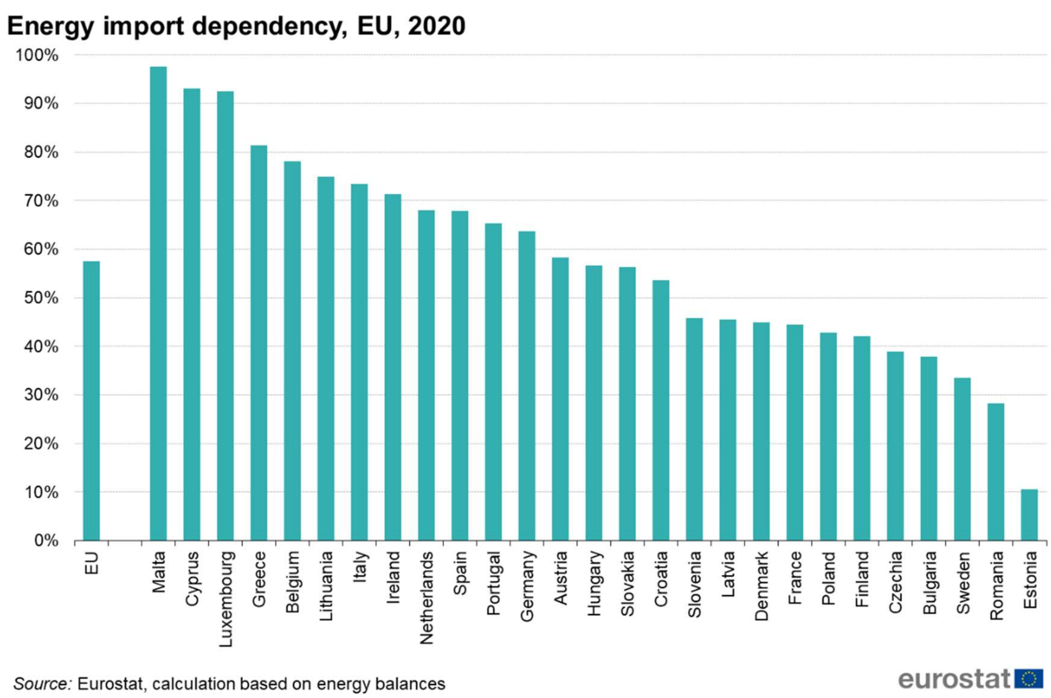


Figure 1: EU import dependence in 2020(1)

The EU depends on energy imports for 58.3% of the total energy required. Considering a more detailed analysis, the less dependent nations are Estonia, Romania, and Sweden, while the more dependent ones are Malta, Cyprus, and Luxemburg, with energy dependence rates of more than 90%. In Italy, this indicator is about 70%.

Furthermore, the main EU energy supplier is Russia, especially considering natural gas as the source. The EU depends on Russia for 24.4% of all its energy needs, according to data updated up to 2020.

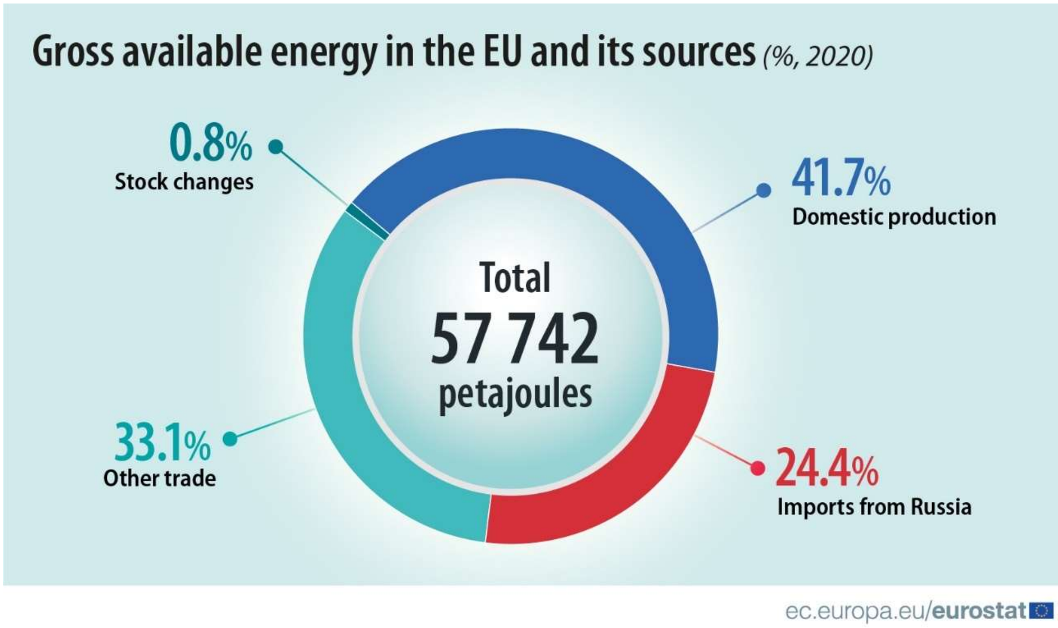


Figure 2: Sources of gross energy available in EU,2020(1)

1.2 EUROPE AND CLIMATE CHANGE

One central theme to deal with is climate change. According to the sixth assessment report of Working Group II of the IPCC (Intergovernmental Panel on Climate Change), our 1.1 °C warmer world is already affecting the natural and human systems (very high confidence)(2). Four are the Key Risks (KR) to which Member States could be exposed, with increasing severity depending on the temperature rise that will occur.

- Key Risk 1: Mortality and morbidity of people and changes in ecosystems due to heat. The number of deaths and people at risk of heat stress will increase two to threefold at 3ºC compared with 1.5ºC GWL (Global Warming Level) (high confidence). Warming will decrease the suitable habitat for the ecosystems as known, in a severe way above 2°C of Global Warming Level (high confidence). Furthermore, fire-prone areas will increase (very high confidence) reducing natural carbon sink capacity (medium confidence)

- Key Risk 2: Heat and drought stress on crops. The production losses in southern Europe will be not replaced by new cultures that can be established in Northern Europe due to the warmer climate (high confidence). The adaptation through irrigation will be limited by water scarcity, especially considering 3° of GWL (high confidence)
- Key Risk 3: Water scarcity. Considering a scenario with 2° GWL in Southern Europe more than one-third of the population will be affected by water shortage. This risk at 3° GWL will double leading to important losses in water and energy-dependent sectors (medium confidence)
- Key Risk 4: Flooding and sea level rise. At the 3°C GWL, the costs of the damages and the people impacted by precipitation and river flooding could double. Concerning Coastal flooding, damages are predicted to be at least 10 times higher by the end of the 21st century, and even more or sooner with current adaptation and mitigation measures (high confidence). Sea level rise poses an existential threat to coastal communities and their cultural heritage, especially after 2100.

Confidence Terminology	Degree of confidence in being correct
Very high confidence	At least 9 out of 10 chance
High confidence	About 8 out of 10 chance
Medium confidence	About 5 out of 10 chance
Low confidence	About 2 out of 10 chance
Very low confidence	Less than 1 out of 10 chance

Table 1: Treatment of uncertainties in IPCC reports

A summarizing sheet of the risk's situation is proposed in the following figure, as support.

Figure 3: Summarized risk associated with climate change in Europe

2 EUROPEAN POLICIES AGAINST ENERGY VULNERABILITY AND CLIMATE CHANGE: ENERGY SAVING AND ENERGY EFFICIENCY FIRST

The European Union has adopted a series of policies to address a clean energy transaction, including the fight against climate change, and simultaneously decrease the energy dependence of Member States. Within these policies, energy efficiency and energy conservation assume a key role.

The European Directive 2018/2002, of 11 December 2018,(3) commonly known as the Energy Efficiency Directive, fixes for the EU countries the goal of achieving a 32.5 % reduction in primary and final energy consumption by 2030 compared to 1990. Projections made in 2007 would result in the expected primary energy consumption of 1887 Mtoe and final energy consumption of 1416 Mtoe. In accordance with the directive, these values must be, in 2030, 1274 Mtoe and 956 Mtoe respectively. Furthermore, Member States are required to achieve cumulative end-use energy savings for the entire obligation period 2021 to 2030, equivalent to new savings each year from 1 January 2021 to 31 December 2030 of 0,8 % of annual final energy consumption, averaged over the most recent three-year period before 1 January 2019.

It is important to introduce another important theme. Nowadays EU is fully devoted to the ambitious goal to reach carbon neutrality in order to deal with climate change issues. As an intermediate step toward climate neutrality, the EU has increased its climate ambitions for 2030, committing to reduce greenhouse gas (GHG) emissions by at least 55 percent by 2030, compared to 1990 emission levels. The EU is working on reviewing its Climate, Energy, and Transport legislation as part of the so-called "Fit for 55” package to align current laws with the goals that have to be reached by 2030 and 2050.

The Fit for 55 package includes proposed legislation on(4):

- <u>EU emissions trading system (EU ETS):</u> the system put a price on carbon production related to different sectors. The companies buy the allowances in order to cover the GHG emissions. The cap on allowances is set, and every year is reduced. With Fit for 55 package the reduction rate passes from -2.2% annually, to 4.2%. Furthermore, new sectors are considered with the maritime transport, road and buildings sector;

- Efforts Sharing Regulation (ESR): with this regulation a target in reducing emissions is set for different important sector (agriculture, small industries, waste, buildings, road transport) that cover 60% of the overall emissions in EU. With Fit for 55, the reduction of emissions passes from -29% to -40% in 2030;
- Land Use, Land Use Change and Forestry (LULUCF): starting from 2018 a no debit rule was applied. Emissions in LULUCF has to be equal to sinks associated with this category. With the package an increase in the removal must be reached, with -310 Mton of CO_2e removed by 2030.
- Alternative fuels infrastructure: an adequate supportive infrastructure for the use of non-traditional fuels has to be guaranteed;
- Carbon Border Adjustment Mechanism (CBAM): with this system the member states has to take into account the emissions not only in the national and European boundaries, but also emissions associated with delocalization of companies. If with ETS the communitarian societies pay the GHGs emissions, with CBAM the emissions are paid also outside, bringing the cost at the same level, avoiding production in area where lower prices are reached through less strict environmental regulations. CBAM is expected in the first phase to be applied to iron and steel, cement, fertilizers, aluminum and electricity;
- Social climate fund: this fund act in financing the use of less impacting technologies and systems for vulnerable categories in the European countries;
- RefuelEU aviation and FuelEU maritime: according to RefuelEU aviation, in the European airport the suppliers have to increase the share of sustainable fuels that they distributes (at least 6% by 2030 and 63% by 2050). Furthermore, the airplanes have to avoid the practice of tankering of extra fuel, in order to reduce the emission related to unnecessary extra weight. Considering FuelEU maritime the vessels above 5000 gross tons, responsible for 90% of GHGs emission in the maritime sector, to decrease the carbon intensity of the energy used up to 6% by 2030 and 75% by 2050;
- CO2 emission standards for cars and vans: starting from 2050 cars and vans have to be zero-emission vehicles;
- Energy taxation: this system works ensuring that the price of energy reflects also the environmental impacts of its production;
- Renewable energy: with the package a new target in share of renewable energyused has to be reached by 2030. The target passes from 32% to 40%;
- Energy efficiency;

- <u>Energy performance of buildings</u>: this sector has a great potential in order to reduce GHG emissions. Less energy used and more sustainable energy, can jointly help in reaching important results.

A summarizing infographic included by the European Council presentation is given below:

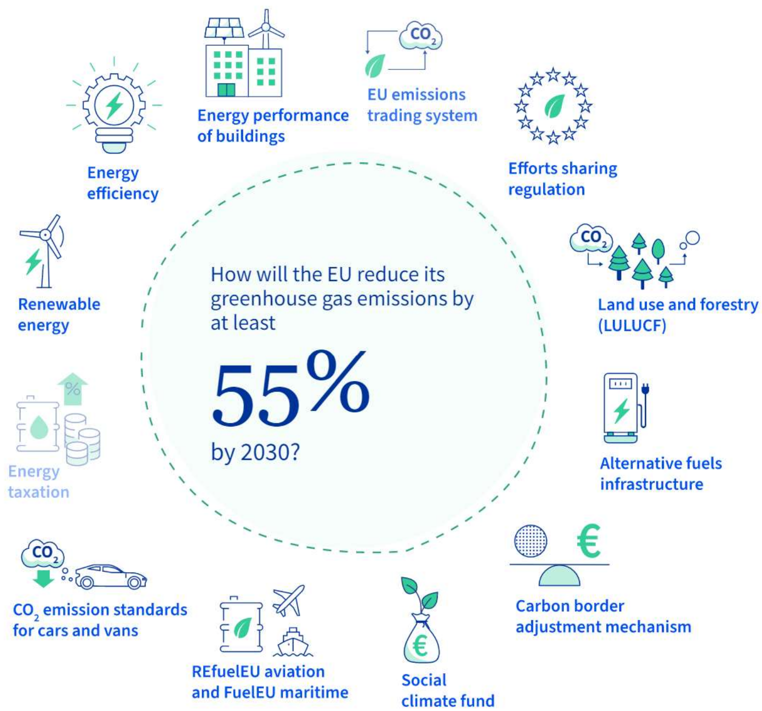


Figure 4: Fit for 55 main sectors of action(4)

As can be appreciated the Energy Efficiency is one of the main actors in Fit for 55 package. The European Directive 2018/2002, was so revised on July 2021 (5) to meet the objectives of the " Fit for 55" package. A more ambitious goal of energy savings was fixed with values of primary energy consumption of no more than 787 Mtoe and final energy consumption of no more than 1023 Mtoe in 2030. These values correspond to an energy consumption reduction of 9% by 2030, compared to the 2020 reference scenario projections. According to this proposal, EU countries must achieve new savings each year of 1.5% of final energy consumption from 2024 to 2030, up from the current level of 0.8%.

In May 2022 In order to respond to the troubles and disruptions in the global energy market resulting from Russia's invasion of Ukraine, the European Commission presented the REPowerUE Plan(6). In this plan, the importance of energy saving and thus efficiency is further emphasized. Energy saving is considered “the cheapest, safest and cleanest way to reduce our reliance on fossil fuel imports from Russia(7)”. The new energy efficiency target passes from 9% to 13%, with an expected primary energy consumption of 750 Mtoe and final energy consumption of 980 Mtoe by 2030.

3 THE WHITE CERTIFICATES

As seen in the previous chapter, Energy efficiency is a crucial theme in the EU agenda.

The mechanism of white certificates (WhC), in Italy, acts to improve energy efficiency among different sectors. The WhCs are Energy Efficiency Obligations (EEOs). The mechanism obliges the distributors of electric energy and natural gas with more than 50.000 final clients to achieve a certain threshold of primary energy saving. This energy saving is quantified by the white certificates, considering that one EEO corresponds to one TOE (Tons of Oil Equivalent) of saving. The certificate is assessed by the GSE (Gestore Servizi Energetici). The GSE reports the savings of the distributors to the GME (Gestore Mercati Energetici) which has the role to deliver the EEOs.

The WhCs can be obtained also by volunteer subjects, typically ESCos (Energy Service Companies) or companies that have appointed a certified energy management expert.

Also, the CAR (Cogenerazione ad Alto rendimento), a high-efficiency cogeneration system can be considered in order to require the WhCs.

Furthermore, the certificates can be also traded through bilateral agreements on a platform managed by GME. The EEOs have so a monetary value established by the market's session.

Energy savings were evaluated through different procedures, during the development of the regulation(8)-(9):

- Standard projects (SPs): the deemed saving approach (Metodo di valutazione standardizzato) is used for these projects. Here the calculation of savings is performed considering the installed units, based on ex-ante survey.
- Simplified monitoring projects (SMPs): these projects use standardized data sheets and require the monitoring of energy consumption. The savings are measured using meters, algorithms, and standardized consumption baseline.
- Monitoring plans (Metodo di valutazione a consuntivo) projects (MPPs): n this project there is a measure of energy consumption before and after the implementation of the project that has to increase energy efficiency. Monitoring plans are widely used for industry and more complex projects.
- Major projects: this method was introduced in 2012. These projects are directed mainly at measures in large infrastructures, in transportation, and for industrial processes

3.1 CRITICALITIES AND CHALLENGES RELATED TO THE COMPLEXITY OF THE WHITE CERTIFICATES SCHEME

White certificates were firstly introduced in Italy in 2001, however, this energy efficiency incentive mechanism has been efficiently applied since 2005. The scheme has led to cumulative energy savings between 2005 and 2017 of more than 26 million toe, generating 62% of energy savings in the industry. More than 6 million tons of CO2 are avoided annually (GSE estimate). Although, the complexity of the mechanism has necessitated the implementation of several substantial changes over time in order to ensure its proper functioning (9).

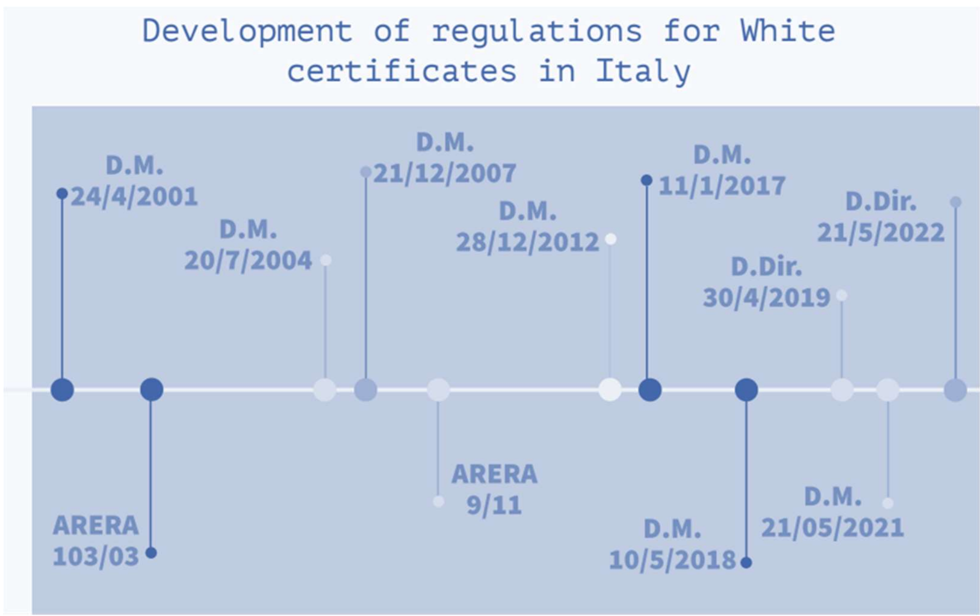


Figure 5: Regulation changes in time for the scheme of WhCs

In the first phase of implementation of the scheme, considering the period between 2005 and 2007, good results in terms of supply performance were reached(9). The results were obtained through the implementation of compact fluorescent lamps (CFLs), low-flow taps, showerheads, and systems to reduce the waste of water in a very simple way.

With the D.M. 21/12/2007, some important modifications were introduced. The obliged subjects were the distributors of electric energy and natural gas with more than 50.000 final clients, instead of 100.000. There was also an increase in the existing targets, in a very optimistic vision, and the extensions of the period of application up to 2009. With this decree, there is also the introduction of volunteer subjects. Furthermore, there was a modification of the flexibility clause: in the previous decree the minimum number of certificates to be recovered in 2 years was 60%, while with the new D.M this percentage passed to 50%, but in just one year.

The 50% of cumulative savings in the period between 2005 and 2010 was reached thanks to CFLs (8). This is quite an impressive result, however, brought different related problems. The increase in the spread of CFLs changed the reference technology bringing a problem of additionality (white certificates are not issued for all energy savings generated by the interventions implemented, but only for the portion that would not have been achieved under normal conditions (business as usual). Furthermore, distributors and ESCOs based the achievement of their results in terms of energy saving on a campaign that distributes lamps and water devices. In this phase, the energy savings were only related to deemed savings. Starting from 2011, there was a decrease in energy savings, due to few projects presented and also because the WhCs lifetime of the project presented in 2005 was ended. The development in technologies and the spreading of CFLs led to exclusion from the calculation of new savings, starting from 2011, this brought an increase in the WhCs price.

There was a necessity to achieve significant results to change from the “civil” sector to the project industry.

An important step in this direction was done by the introduction of the tau coefficient by the ARERA (Autorità di Regolazione per Energia Reti e Ambiente) guidelines introduced in October 2011. The tau coefficient is a “multiplier that awards additional white certificates by remunerating future (discounted) savings over the entire technical lifetime of an energy efficiency measure” (8). Depending on the lifetime of the technical solution implemented in the energy efficiency project, the tau coefficient can assume different values from 1, for a lifetime of 5 years, to 4.58, for a lifetime of 30 years. In this way, projects with longer lifetimes are incentivized, increasing the return on the projects with high capital costs. However, this led to decoupling between effective energy savings and WhCs issued, quite problematic and to difficulty in the management of the controls on the real energy savings achieved by the projects. In the guidelines, was also decided to allow the presentation of proposals after the implementation of the energy efficiency projects. This last action was mainly undertaken in connection with the delay in launching the scheme, despite the existence of a pertinent decree back in 2001.

The D.M. 28/12/2012 introduced some other novelties: new targets till 2016, taking into account the tau coefficient, stopping by the end of 2012 the opportunity to require WhCs for already implemented projects, and flexibility clause extended to 2 years. The reduction of the targets allowed to decrease the decoupling introduced by the tau coefficient partially. However, the undersupply of WhCs with respect to the target was destinated to grow again. Firstly, for the stop of retroactive financing, but also for the reconsideration of the tau coefficient in order to avoid over-financing of industrial projects. This second theme was considered excluding from the scheme the MPPs with a very low payback period. The stop in financing already implemented projects and the changes in the tau coefficient, led in 2013 to a strong increase in WhCs requests, being the last year for the request of already implemented projects. However, in the period between 2014 and 2016, the issued WhCs decreased due to the perceived insecurity of the scheme. Another issue raised from the risk of fraud from SPs, using a very simplified method.

A re-design of the scheme was introduced by the D.M. 11/1/2017. With this decree only two methods to acquire WhCs were accepted:

- Standard Project with sample measure (SPSMs, a mix of deemed savings and metered savings). The calculation of savings is made on the basis of the installed unit, but taking into account also sample measurements performed, ensuring more reliable results for standard projects.
- Monitoring plans projects (MPPs, a type o metered savings), which remain similar to the past, but with additional requirements for the identification of consumption baseline. This must be based on measures of the savings done at least daily after the project implementation, and measurements are required also for one year before the implementation of the project.

The decree also eliminated the tau coefficient but increased the WhCs lifetime. An example: if a project has a lifetime of 20 years, from the previous guidelines, it is characterized by a tau coefficient of 3.36, with the new decree this implies obtaining WhCs with a lifetime of 10 years (instead of 5 years). If the tau associated with the project was 2.26, so WhCs lifetime was 7 (instead of 5 years). It was also introduced the coefficient "K". At the time of submission of the application, the proposing party may request that the volume of WhCs for the first half of the lifetime of the project (time for which the WhCs are recognized) is multiplied by the factor K1=1.2, while for the other half lifetime by K2=0.8. Another important step was done, clearly defining the concept of additionality. The decree defined, as the baseline for additionality, the average market supply. This caused a drop in eligible projects, that together with the elimination of the tau coefficient and SPs, increased the problem of supply for WhCs. As said, huge frauds are done with SPs. These frauds were estimated to amount to 600.000 certificates per year, according to the MiSE and another 700 thousand certificates were frozen as a result of more in-depth checks undertaken by the GSE. This caused a collapse in supply that was not foreseen at the time of the issuance of the D.M 11/1/2017. All this situation led to a skyrocket in the price of WhCs on the market, touching 480 €/certificate in February 2018.

Considering all the discussed issues, a new decree was emanated. The D.M. 10/05/2018 was intended to act on the supply and demand side. For the supply side, there was the abolition of additionality for the improvement of existing facilities, to facilitate participation in the mechanism and controls done by GSE. A ceiling of 250 €/certificate was established for distributor reimbursement, and the GSE decided to release temporary certificates, not related to energy savings, to obligated entities in case of a lack of certificates to cover the minimum targets. Jointly with the flexibility clause extended to two years with a minimum target of 60% already introduced, these measures had the role to maintain a more stable system.

The targets addressed through the different decrees seemed to be too ambitious, so even taking into account the measure to reach the objectives more easily and to stimulate the functioning of the scheme, in 2021 a new decree was issued.

The D.M.21/5/2021 has introduced some other modifications. The targets for the obliged subjects are extended up to 2024, however, the already existing objectives in terms of energy saving are decreased. This measure was taken in order to take into account the residual targets accumulated by the distributors. A change was introduced for 2020.

	National quantitative energy saving targets [MEEO]	**Energy saving in the final use of electric energy[MEEO]**	**Energy saving in the final use of natural gas[MEEO]**
D.M. 11/1/2017	11.9	3.17	3.92
D.M. 21/5/2021	5.08	1.27	1.57

Table 2: changes in targets introduced by the decree of 2021.

These downward targets seem to be in contrast with the aim of PNIEC (Piano Nazionale Integrato Energia e Clima) (Integrated National Energy and Climate Plan). For this reason, a provision has been made in the decree for the Ministry to act promptly to raise obligations in the event of oversupply, something that is also useful because of the expected upward revision of the PNIEC targets. The new decree also introduces an auction system, based on the “pay as bid” principle. Such a scheme could prove to be a useful complement to TEEs for complex and costly projects that are difficult to implement with the current market values of white certificates, in cases where measuring energy savings in the manner provided by TEEs is difficult.

3.2 HOW WORKS THE WHITE CERTIFICATE

As understood the white certificates are instruments to incentivize energy efficiency. Even if the theme is quite complex in this sub-chapter an overview of the functioning of the scheme is proposed.

3.2.1 Subjects involved and their role in the White Certificates mechanism

As first thing, the subject and the roles involved are presented.

The obliged subjects are the distributors of energy carriers (both electric energy and natural gas) that has more than 50.000 end clients. They are subject to a minimum threshold, in time, that has to be reached in terms of energy savings. These values, expressed ad MEEO (Millions of Energy Efficiency Obligation), are defined by the Ministry of Economic Development (Ministero dello Sviluppo Economico - MiSE), jointly with the Ministry of Environment and Land and Sea Protection (Ministero dell’Ambiente e della Tutela del Territorio e del Mare). The share of contribution for each obliged party is fixed by ARERA, according to the amount of energy carrier distributed by each subject. ARERA must communicate to MiSE and GSE (Gestore Servizi Energetici) these data by January 31 each year. ARERA is also responsible for enforcing sanctions in case of noncompliance.

The targets for the obliged parties, according to D.M 21/05/2021, are tabled below:

Year	Energy saving in final uses of electric energy [MEEO]	Energy saving in final uses of natural gas [MEEO]	Total energy saving in final uses
2021	0,45	0,55	1,0
2022	0,75	0,93	1,68
2023	1,05	1,30	2,35
2024	1,08	1,34	2,34

Table 3: Goals in energy saving in final uses of electric energy and natural gas for distributors in different years.

The obliged parties have to reach at least 60% of the target each year, if this percentage of the objective is reached, the residual part of the objective can be compensated in the following two years without sanctions.

As analyzed, the mechanism is not only for the obliged subjects. An important role to ensure the achievement of the final goal of the scheme is covered by the eligible parties.

These subjects are:

- ESCo (ENERGY Service Company) certified UNI 11 352. The remuneration of these certified companies is compatible with the energy savings reached.
- Societies with an expert in energy management (EGE - Esperto Gestione Energetica) certified UNI 11339.
- Societies with management system ISO 50001.
- Temporary groupings and associations of enterprises and groupings of territorial entities can also connote themselves as owning entities.

Another important player in the mechanism is the GSE (Gestore Servizi Energetici). GSE is responsible for the management, evaluation, and certification of savings related to energy efficiency projects. For the evaluation part, GSE can rely on the technical support of ENEA and RSE. GSE has also another important role: the emission of WhCs not related to energy efficiency projects. The targets for the obliged parties are sometimes too ambitious. For this reason, GSE, starting from 31st May till the end of the considered year, under the demand of obliged parties, can emit WhCs at the cost of 260 €/certificate minus the value defined by the mean of the market for the certificate, in the considered year. This contribution has to be between 10 € and 15 €. These certificates can be so acquired at a reasonable price, but the obliged parties, to require this kind of WhCs must already reach the 20% of the energy savings fixed as its target.

Once the obligations are emitted the scheme needs to be supported by a market to exchange the certificates. This market is organized and managed by GME (Gestore Mercati Energetici).

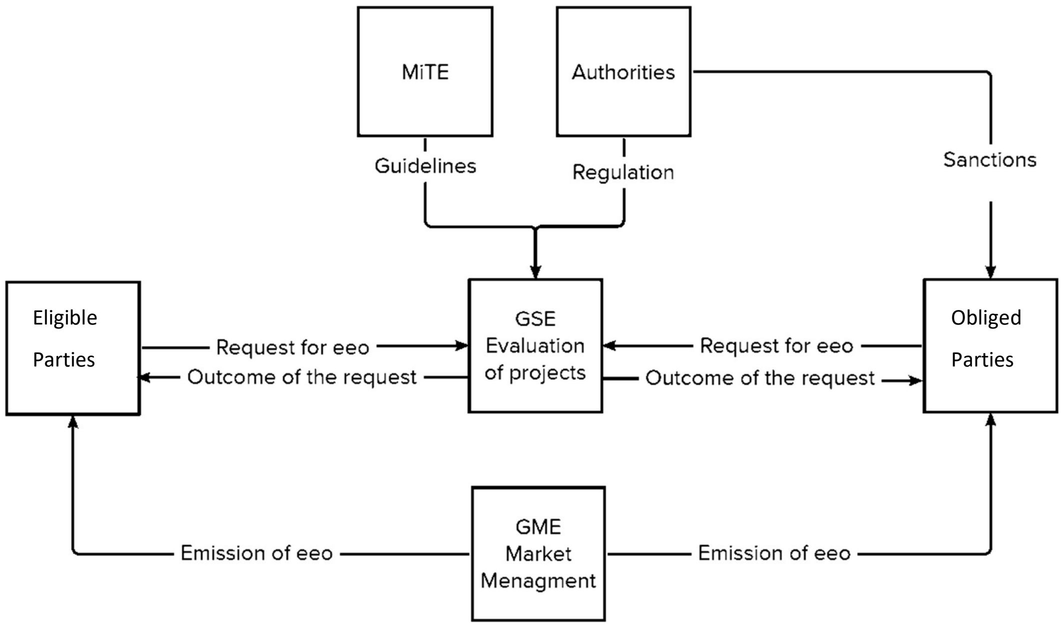


Figure 6: Summary of the involved subjects in WhCs mechanism

3.2.2 Eligible projects and applications for access to the incentive

The eligible project to obtain WhCs are projects that generate additional energy savings.

These savings are defined with respect to baseline consumption. In the decree, the baseline consumption is defined as the primary energy consumption of the technology taken as a reference. In case of substitution of component of the implementation of a new system in an already existing plant, the baseline consumption is based on measurements done *ex ante* the implementation of the project (referred to as a period of at least 12 months). The same is done dealing with totally new facilities.

For each intervention, the lifetime of the project (U) is defined as the time in which WhCs are assigned. This period cannot be more than 10 years, in order to consider the obsolescence of the technology. Energy savings are accounted for over the entire useful life U, starting from the beginning of measurements and in any case not later than 36 months from the date of the start of project implementation.

A list of possible projects, divided into categories of application, is present in Annex 2 of the D.M. 21/05/2021, with the relative lifetime of the projects.

Once the documentation for the request of WhCs for a given intervention is sent to the GSE, the GSE has 90 days for the evaluation. Requests for reporting savings must be submitted within 120 days after the end of the relevant monitoring period.

The project types regulated by the current legislation are two:

- Monitoring Plan Projects (Progetti a Consuntivo – PC);
- Simplified monitoring projects (Progetti Standardizzati – PS).

3.2.2.1 Monitoring Plan Projects - Progetti a consuntivo

In the monitoring plan projects, the additional energy savings are calculated on the basis of the punctual measurements of the characteristic quantities *ex-ante* and after the implementation of the project. This kind of project has to realize an energy saving of at least 10 EEOs in the first 12 months of monitoring.

The determination of the baseline consumption, in order to evaluate the *ex-ante* situation, is performed by the daily measurements of the consumption of the operative variables over a period of 12 months. The monitoring time is chosen in order to appreciate also the weekly, monthly, and seasonal fluctuations of energy consumption. Some exceptions for the prescription of the frequency and duration of measurements can be done if the proponent can demonstrate that fewer measurements can be considered representative. Furthermore, if the measurements, done for less than 12 months or more than daily, are higher than the expected one, reported in the technical sheet of the product, the proponent can decide to use the reference consumption. The proponent has to send to GSE documentation containing:

- information on the proposing party and the owning party, if different than the proponent;

- information on the site where the project has to be done (Address, cadastral code, activities carried out under the project, ATECO code where applicable), including information on the owner or entity that has the availability of the facility and/or site;

- the technical report of the project.

The realization of the project has to be started in maximum of 12 months after the GSE approval.

The requests for the reporting of the energy savings (Richieste a Consuntivo – RC) contain point measurements of post-intervention characteristic quantities that contribute to the quantification of energy savings achieved by the project over a monitoring period. The monitoring period to which each RC refers is annual. Limited to projects characterized by high savings, data may be submitted for semi-annual or three-month monitoring periods.

3.2.2.2 Simplified monitoring Projects – Progetti Standardizzati

For the simplified monitoring projects, the calculation of the energy savings is performed through a standard algorithm, jointly with a direct measurement done on a representative sample. To respect the representativeness, the repeatability of the characteristic parameters, operational variables, and operating conditions of the facilities, buildings, or sites, where the direct measurement is done, must be demonstrated. The direct measurements on the representative sample are done daily for 12 months. As for PC, if the proponent is able to demonstrate that fewer measurements in frequency and duration are sufficient, this reduced set can be used in the definition of the baseline consumption.

So, this method of evaluation can be implemented if:

- The repeatability of the project can be demonstrated;
- The implementation of the standard measurements campaign, as prescribed for PC, is not economically feasible, compared to the economical value of the WhCs associated with the proposed project.

To access the mechanism, the PS has to realize additional energy savings of at least 5 EEO in the first 12 months of monitoring.

In the directorial decree 21/05/2022, the possible admittable interventions and an operative guide with the algorithms for the calculations required are present. This information is regularly updated and viewable on the GSE website.

Standardized Savings Certification Requests (Richieste Standardizzate - RS) allow reporting of savings achieved within a standardized project, over a number of years equal to the useful life of the interventions. They contain post-intervention measurements of the characteristic quantities of the representative sample only, which contribute to the quantification of energy savings achieved by the project over a monitoring period. The monitoring period for individual RSs is annual.

3.2.3 Types of White Certificates

The WhCs emitted are of 4 types:

- Type I: the primary energy savings are reached through the reduction of the consumption of electrical energy.
- Type II: the primary energy savings are reached through the reduction of the consumption of natural gas.
- Type III: the primary energy savings are reached through the reduction of consumption of energy carries other than electrical energy and natural gas, realized not in the transport sector.
- Type IV: the primary energy savings are reached through the reduction of consumption of energy carries other than electrical energy and natural gas, realized in the transport sector.

3.2.4 Auction system and White Certificates market

A new system of rewards for savings through downward auction procedures is created in order to help to reach the 2030 energy-saving targets, taking into consideration the efficacy of the current policies and the need for additional outcomes. The auctions may involve certain technologies or project types, intervention fields, or economic sectors and have as their goal the economic worth of the toe saved. They also use the pay-as-bid criterion. For the incentive period this amount remains unchanged. The economic value placed on the auction basis takes into account the value of the toe saved, as detectable from the price trend of white certificates on the organised market, and the specificities of the technology or project type considered, as well as the positive environmental externalities generated.

4 WHITE CERTIFICATE AND INTEGRATED WATER SERVICE

A dissertation preliminary to the discussion of the case study is useful to contextualize the project in the actual scenario.

4.1 ENERGY CONSUMPTION IN WASTEWATER TREATMENT PLANTS

Wastewater treatment plants have high energetic requirements. The WWTPs installed in Europe are 22.558, which use 15.021 GWh/year (10), more than 1% of the overall electricity consumption in EU (11). Furthermore, the energy cost accounts for 15 to 40% of the total operational cost (12). Considering the described scenario, energy efficiency actions have to be implemented also in this important sector.

The main factors contributing to energy consumption in a conventional WWT plant are typically the aeration in biological treatments (55.6%), primary and secondary settling with sludge pumping (14%), and solids dewatering (7%) (12).

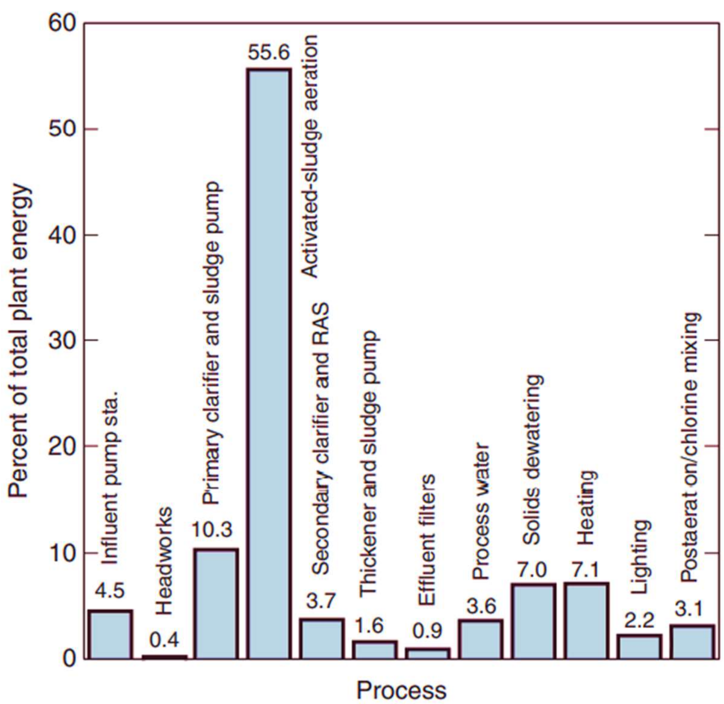


Table 4: plant energy consumption among the different processes involved in WWTP(12)

As discussed above, the main voice of energy consumption is to be attributable to aeration in the biological treatment compartment. The reduction of the impact of this section could be an important achievement in terms of energy savings related to WWTPs.

4.2 SECTORAL GUIDELINES FOR ISSUANCE OF WHITE CERTIFICATES IN INTEGRATED WATER SERVICE

In the White Certificates Operational Guide, approved by the MiTE with the Director's Decree of May 3rd, 2022, specifically in Annex 2.6. several interventions to be carried out in the integrated water service sector are listed.

Water Service	**Plant section of the water service**	**Intervention**	**Project Type**
Aqueduct	Pumping system	Installation or replacement of pumping systems, also accompanied by the installation or replacement of related inverters	PC
	Desalination plant	--	PC
	Potabilizatio n plant	Construction or upgrading of new potabilization plants	PC
	Re-layout of the networks	Implementation of network sections	PC
		Implementation of pumping systems	PC
		Implementation of pumping plant	PC
		Construction of storage tanks	PC
		Contextual construction/decommissioning/replacement of storage tanks, pumping systems, sections of the network	PC
	Network losses	Pressure management and control	PC
		Adoption of active leakage control techniques	PC
		Modification of layouts and large-scale renovation of the infrastructure	PC
	Installation of motors, also together with the installation or replacement of related inverters		PC
Wastewater Treatment	Pumping system	Installation or replacement of pumping systems, also accompanied by the installation or replacement of related inverters	PC
	Oxidative biological treatment	Replacement of production and air distribution systems of compressed air	PC
		Replacement of compressed air diffusion systems	PC
		Replacement of sewage movement systems	PC
		Construction of new biological oxidation tanks	PC
		Ultrafiltration membranes for WWTPs	PC

Sewage	Sludge line	Installation or replacement of new centrifuges	PC
		Installation or replacement of new mechanical dewatering systems	PC
		Installation or replacement of thermal dehydration systems	PC
	Installation of motors, also together with the installation or replacement of related inverters		PS or PC
	Pumping system	Installation or replacement of pumping systems, also accompanied by the installation or replacement of related inverters	PC

Table 5: Intervention on Integrated water services, according to the Annex 2.6 of the operative guidelines.

Another important indication is given by Table 1 present in Annex 1 of the D.M. 11/1/2017 and its subsequent modification:

Typology of intervention	**Lifetime of the project (U)**		
	New installation	Substitution	Integrated efficiency
Electricity, gas, and water network efficiency improvement	-	7	7
Fine bubble systems for WWTPs	7	5	-
Compressed air production systems	7	5	5
Ultrafiltration membranes for WWTPs	7	5	-
Engines, also with the installation or replacement of the inverters	7	5	-
Pumping systems, also with installation or replacement of inverters	7	5	5

Table 6: Table 1 in Annex 1 of D.M. 11/1/2017 with the lifetime of the project according to the type of intervention

The substitution of the compressed air diffusion system has to follow, in the calculation of energy savings for obtaining the WhCs, the Monitoring Plan Project (Progetto a Consuntivo) regulation. The WhCs for this kind of intervention (fine bubble system for WWTPs) are assigned for a lifetime of the project equal to 5 years.

In the intervention of replacement of distribution and diffusion systems of compressed air, the algorithm to be used is the number 4, while the indicator, so the characteristic operative magnitude, the SAE (Standard Aeration Efficiency).

According to algorithm number 4 reported in the guideline the energy savings are calculated as:

Equation 1: calculation of energy savings based on algorithm 4 for wastewater treatment plant

$$RISP = \left(\frac{1}{SAE_{baseline}} - \frac{1}{SAE_{ex\ post}}\right) \times kgO_2 \times f_e$$

Where:

- RISP is the energy saving in EEO
- KgO_2 is the quantity of oxygen present in the volume of the air processed by the production system of compressed air in the ex-post situation and equal to the amount of air in Sm^3 multiplied by 0.285 KgO_2/ Sm^3
- f_e is the conversion factor equal to 0.000187 toe/kWh, in case of withdrawal of electricity from the grid
- $SAE_{baseline}$ is the aeration efficiency referred to the baseline solution equal to the ratio between KgO_2 given and energy consumed for the production of compressed air in KgO_2/ kWh
- $SAE_{ex-post}$ aeration efficiency in operational conditions referred to the ex-post situation in KgO_2/ kWh.

5 CASE STUDY: WHITE CERTIFICATES MATURED FOR THE SUBSTITUTION OF FINE BUBBLE DIFFUSERS IN THE CASTIGLIONE TORINESE WWTP WITH CONSTANT TEMPERATURE APPROXIMATION

5.1 THE WASTEWATER TREATMENT PLANT OF CASTIGLIONE TORINESE: A GENERAL OVERVIEW

The centralized plant of Castiglione Torinese is the biggest Italian Wastewater Treatment Plant (WWTP). This industrial pole allows the treatment of a maximum potentiality of 3,800,000 person equivalent (PE), and an operating capacity of 2,100,000 PE, considering that 1 PE corresponds to 60g of BOD (Biological Oxygen Demand) per person per day, which is equivalent to 200 l of sewage per day. Thus, the mean treated flow rate is 600,000 m^3/day, which means 215,000,000 m^3/year(13).

The plant is composed of two main lines: the water and the sludge line. In the plant space, another area is dedicated to the offices, the support, and maintenance spaces. Finally, there is a photovoltaic plant to provide part of the electric power required by the industrial hub.

Figure 7: map of Castiglione Torinese WWTP(13)

In order to understand the results of the treatments, the input and output parameters of the WWTP are given in the table below.

	Input [mg/l]	Output [mg/l]
Average SST	200	8
Max SST	500	30
Average BOD_5	220	5
Max BOD_5	500	25
Average COD	380	30
Max COD	700	80
Average NH_4	25	2
Max NH_4	40	10
Average N_{tot}	31	8.4
Max N_{tot}	45	14
Average P_{tot}	4.0	0.7
Max P_{tot}	6.5	2

Table 7: Wastewater parameters in input and output in WWTP of Castiglione Torinese(13)

5.1.1 Water Line: processes description

The Castiglione Torinese centralized plant is composed of a section of pre-treatments with grit and oil removal. After the pre-treatments, the water goes into four parallel modules. Within the 4 modules are performed firstly primary sedimentation and then biological treatments. In 3 modules the secondary treatments use a system of intermittent aeration, while in one module there is the application of the step feed aeration. The operations are followed then by secondary sedimentation, filtration, and disinfection.

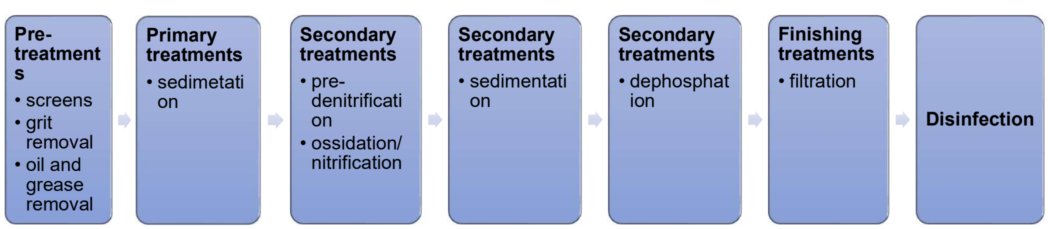


Figure 8: the general flow of treatments in the water line

5.1.1.1 Pre-treatments

The first operations that are carried out in the water line are the pre-treatments. These processes have the aim to reduce and remove great dimension solids, sand, oils, and greases.

Firstly, there are two screening sections for the removal of the great dimensioned solids. This step is fundamental because if not properly performed the great dimensioned solids can interfere with the following treatment steps. The intake of wastewater is continuously monitored with measurements of temperature, pH, Redox potential, ammonia, and TOC (Total Organic Carbon). The screening sections are closed sections and are composed of four lines. Each line is constituted by two hydraulic screening installations, a conveyor belt, and a compaction section. The material removed, after the compaction, goes to the landfill, while the gases are sent to a wet scrubber for the abatement of the odorous substances.

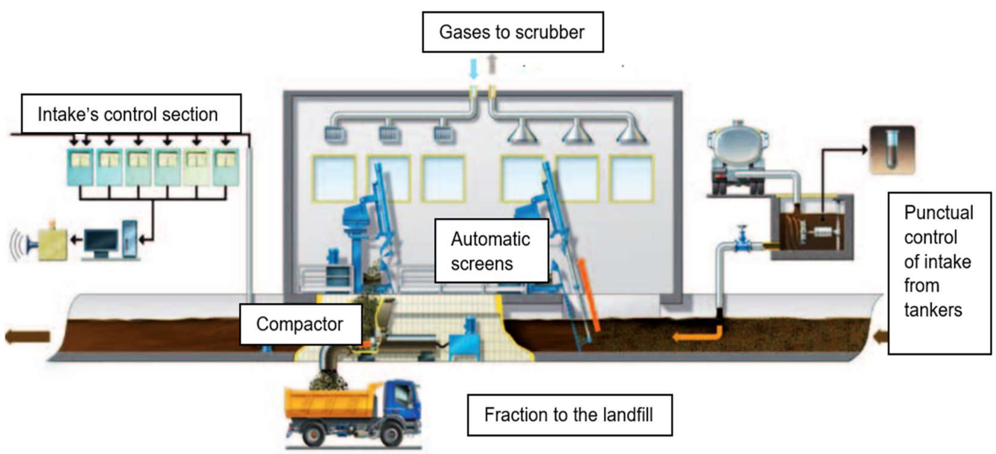


Figure 9: screening section scheme(13)

Another crucial operation in wastewater treatment is grit, oil, and grease removal. In Castiglione Torinese, this step is performed by means of four couples of pools, with to-and-fro bridges, where an increased section allows the decrease in velocity of the flow. In this way part of the sand sediments in the bottom part of the pools. The sands are then brought up, through airlift mounted on the bridges, and sent to further treatments where they are washed and subjected to centrifugal processes to recover the material instead of sending it directly to a landfill. Furthermore, a pre-aeration with centrifugal fans allows the surface skimming of oils and greases. Then, they are removed through a blade on the surface and collected.

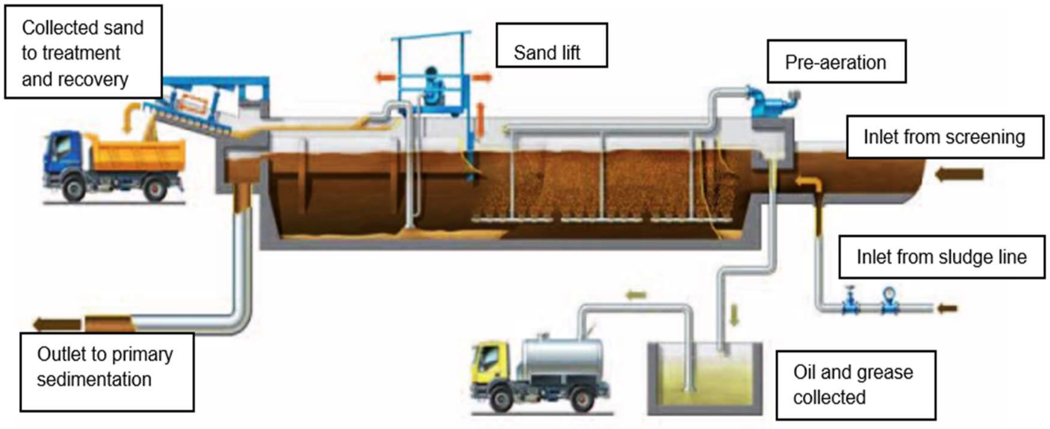


Figure 10: oil, grease, and grit removal scheme(13)

5.1.1.2 Primary sedimentation

Primary sedimentation is a crucial physical process, that thanks to the gravitational forces allow the removal of almost the total suspended solids (TSS). The scum floats on the surface during this treatment and in this way can be removed by skimming. In the considered plant this process is carried out through eight circular basins, equipped with a rotary bridge and a sludge scraper. Thus, the products from the primary sedimentation are the primary sludge and the scum. After the collection, the sludge is sent to the thickening while the scum to further treatments.

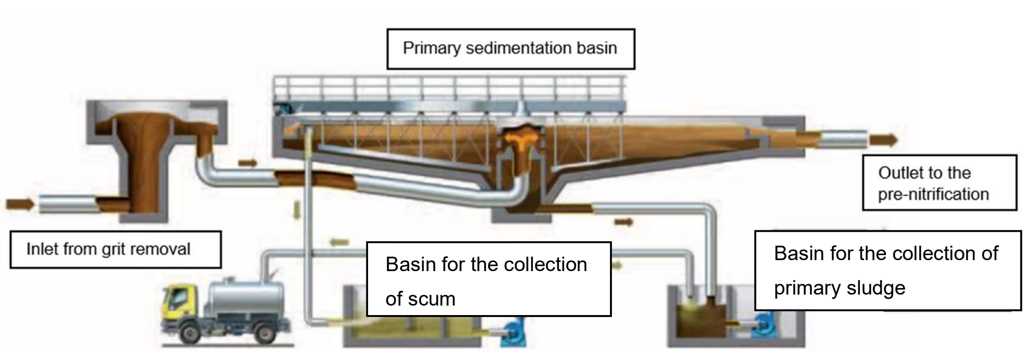


Figure 11: primary sedimentation scheme(13)

5.1.1.3 Secondary treatments: denitrification and oxidation

The aim of secondary treatments is the removal of organic matter and nutrients in the dissolved and suspended form present in wastewater.

After the primary clarifier, the effluent is sent to the treatments of denitrification and oxidation.

Until 2004, the plant consisted of a system that implemented the Modified Ludzack-Ettinger (MLE) process.

In 2004, one module was radically modified. in this module, biological water treatment takes place with a fractional feed system with the effluent fed at three points, simulating a piston flow with alternating zones of aerobic conditions and zones of anoxic conditions. In the aerobic zone, oxidation of organic matter and nitrification of nitrogen takes place. In the anoxic zone, the denitrification process takes place. The alternation of the aerobic and anoxic environment in this case is so in space.

As of 2018, the other three modules of the system were also modified. The configuration implemented in this one is intermittent aeration, with optimized regulation through the use of OSCAR®. In these three modules, there was also the substitution of the nine turbochargers, needed for the aeration. This kind of configuration acts on the creation of an alternation of aerobic and anoxic environments in time.

Serving the oxidation and denitrification compartment are 12 turbocharger and 59.000 microbubble diffusers.

The main reactions that take place in this section of the plant are the following:

- In the aerobic environment the microorganisms (m.o.) decompose the organic matter, according to the following reaction:

  $$C_5H_7NO_2 + 5O_2 \rightarrow 5CO_2 + NH_3 + 2H_2O$$

  Reaction 1: organic matter consumption

  At the same time, the ammonia nitrogen is converted to nitrite (through Ammonia Oxidizing Bacteria (AOB)) and then nitrate (thanks to Nitrite Oxidizing Bacteria (NOB)), with the nitrification process.
  The fundamental reactions that take place are reported.

$$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 4H^+ + 2H_2O$$

Reaction 2: Ammonia oxidation to nitrite

$$2NO_2^- + O_2 \rightarrow 2NO_3^-$$

Reaction 3: Nitrite oxidation to nitrate

$$NH_4^+ + 1.1863O_2 + 0.098CO_2 \rightarrow 0.019C_5H_7O_2N + 0.98NO_3^- + 0.942H_2O + 1.98H^+$$

Reaction 4: total nitrification reaction with the creation of new biomass

- In the anoxic environment, the nitrates and nitrites are transformed into gaseous nitrogen with de-nitrification. In this section, the microorganisms use as a source of oxygen the nitrogen oxides. The metabolic reduction of nitrate in gaseous nitrogen is reported below:

$$2NO_3^- + 12H^+ + 10e^- \rightarrow N_2 + 6H_2O$$

Reaction 5: Total denitrification

5.1.1.4 OSCAR®: Optimal Solutions for Cost Abatement in Nutrients Removal

An important mention must be done to the more recent works on the biological process' section of the plant of Castiglione Torinese with the implementation of OSCAR® (Optimal Solutions for Cost Abatement in Nutrients Removal) in 3 moduli of the plant, with a research program that was started in 2018.

Traditionally in WWTP the Modified Ludzack-Ettinger (MLE) process is implemented. In this process, de-nitrification takes place before the oxidation/nitrification phase. There is an internal recirculation with part of the aerated mixture that goes back into the anoxic basin. At the inlet of the biological treatment, there is also the recirculation of the activated sludge from the secondary clarifier.

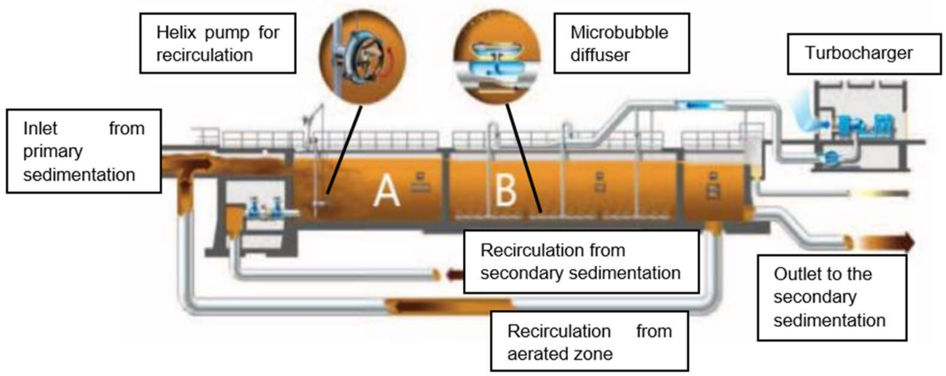


Figure 12: biological process scheme (A: denitrification basin; B: oxidation/nitrification basin)(13)

The Modified Ludzack-Ettinger process (denitrification before the aeration basin) for denitrification in WWTP is widely used but entails some drawbacks:

- It is not able to cope with the variation of nitrogen load in the inlet of the treatment;
- the recirculation of the aerated mixture and the aeration require high energy consumption;
- The recirculation of the aerated mixture leads to a liquor very poor in nitrates.

To overcome the problems, the denitrification process takes place in a single reactor with intermittent aeration. Through a cascade control on different significant parameters (Nitrogen; Dissolved Oxygen (OD)), the aeration is optimized. If there is an increase in the concentration of the ammonia, the aeration is switched on, in order to allow the transformation of ammonia into nitrate and nitrite. On the contrary, if the concentration of ammonia is low, the aeration is stopped, and denitrification occurs. The OSCAR® system is based on these principles. This system was firstly implemented for small WWTP (with capacity < 2.000 PE), and then, through a more complex and integrated approach, also for big plants such as that of Castiglione Torinese (14).

The intermitted aeration is used for plant at low load activated sludge processes (low load F_c= 0.15-0.30 $kgBOD_5$/ kgSSMA·d.

Analyzing in detail the implementation of the system in this plant, different criticalities are taken into account in the installation:

- The intermittent aeration must be done without stopping the turbochargers of the biological treatment basin, in order to avoid damages related to the stress for the ON/OFF routine.

- In the 3 moduli, the joint management of 18 needle valves has to be implemented to regulate the flow, associated with 18 probes for measurement of ammonia-nitrogen and 18 for measurement of OD. This involves dealing with a very complex and potentially unstable system.
- The impossibility to create an out-of-service and so to have a total emptying of the basins.
- A minimum recirculated flow of the aerated sludge has to be maintained, reducing so the possible savings in this section.
- The necessity to deal with an already optimized system that works in a quite efficient way.

To cope with the different constraints and the complexity required, dynamic modeling was used with 4 possible scenarios (14):

- Scenario 1: intermitted aeration with OSCAR ® without recirculation of the aerated sludge.
- Scenario 2: intermitted aeration with OSCAR ® with recirculation of the aerated sludge only in the winter months (November, December, and January).
- Scenario 3: intermitted aeration with OSCAR ® with recirculation of the aerated sludge in 6 months (October, November, December, January, February, and March).
- Scenario 4: intermitted aeration with OSCAR ® with recirculation of the aerated sludge all the year.

The main results with a measure of relevant parameters involved in the biological processes are presented in the table below:

Parameters	**U.O.M.**	**Without OSCAR®**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
COD	mg/l	39.0	43.5	43.5	43.5	43.3
BOD	mg/l	-	12.9	12.8	12.7	12.6
$N\text{-}NH_4$	mg/l	<1	2.3	2.3	2.3	2.3
$N\text{-}NO_3$	mg/l	5.3	4.5	4	3.7	3.1
TKN	mg/l	2.7	4.3	4.3	4.3	4.3
TN	mg/l	8.0	8.8	8.3	8.0	7.4
SST	mg/l	23	19.6	19.6	19.6	19.6

Table 8: parameters obtained through different scenarios with and without intermitted aeration with OSCAR ® in WWTP of Castiglione Torinese.

The aim of the project is to maintain the value of the concentration of TN below 8 mg/l, so the only feasible scenarios are 3 and 4.

In terms of energy saving, another synthetic information is proposed:

Parameters	**Without OSCAR®**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
Energy required (kWh/year)	18,138,456	8,052,697	8,802,559	9,481,799	10,799,957
Cost of energy required (€/year)	2,448,692	1,087,114	1,188,345	1,280,043	1,457,994

Table 9: energy requirements and costs in different scenarios in the plant of Castiglione Torinese (cost of electric energy estimated as 0.135 €/KWh) (14).

As expected, all the scenarios that use the controller led to costs and energy consumption well below the treatment without OSCAR ®.

It is interesting to better understand how the new complex system works. The controller receives as input the measurements obtained with the probes in the basins. Starting from this data, the controller extracts as output a dynamic setpoint of OD required (that is different from a constant value and changes changing the input). The needle valves and turbochargers are so controlled by the setpoint of oxygen and guarantee adequate aeration, without waste of energy, since they are set on the basis of the real needs of the system.

Some data can be also obtained for a long-term period of monitoring. Looking at the period from January 2019 to September 2020 the value of mean TN at the output of the process was 7.8 mg/l, while from September 2020 (month of activation of intermittent aeration through OSCAR ®) to July 2021 was 6.2 mg/l, showing an improvement in nitrogen removal (15).

In conclusion, it can be said that thanks to this controller different advantages can be reached:

- Higher efficiency in nitrogen removal;
- Higher overall efficiency of the biological process itself;
- Lower energy demand;
- Lower generation of secondary sludge;
- Removal of phosphorous also in this section of biological treatment.

5.1.1.5 Secondary treatment: Secondary sedimentation- Phosphate removal

The last part of the biological treatment consists of further gravity separation. The sludge obtained is partially recirculated in the denitrification basin, while the other fraction of the secondary sludge is sent to the sludge line. A further treatment step is performed by adding iron chloride ($FeCl_3$) to the activated sludge to obtain a chemical removal of the phosphates. Then, the effluent obtained from the secondary clarifier is sent to the final filtration.

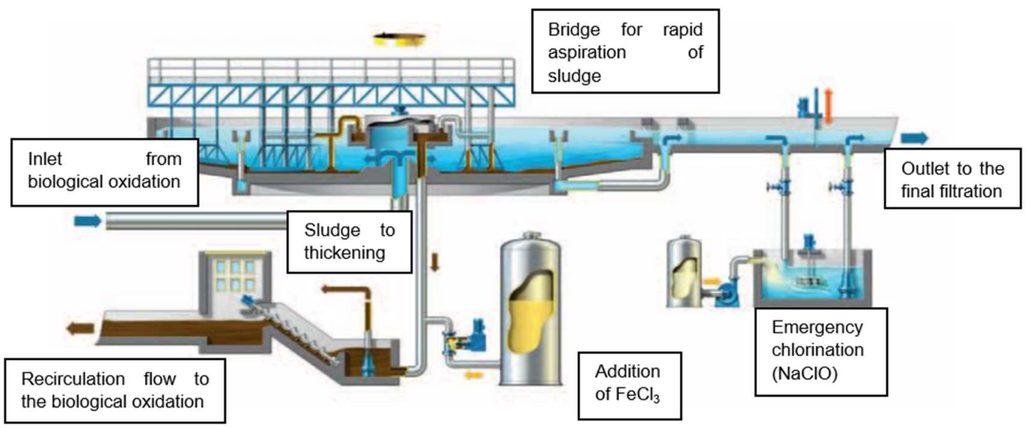


Figure 13: secondary sedimentation and phosphate removal scheme in Castiglione Torinese WWTP (13)

5.1.1.6 Final filtration and industrial aqueduct

This final step is performed by a final filtration to achieve the removal of almost all suspended solids remaining in the effluent. The presence of voluminous components, such as algae, for example, is removed through preliminary screening. The final filtration is performed through the split of the flow in 27 multi-layer filters constituted by a bed in sand and anthracite coal. After this final step, the treated water has characteristics compatible with the ecosystem.

The majority of the flow is discharged into the river, while a part is reused as industrial water (in the industrial aqueduct there is a process of disinfection and the water obtained is mainly used in the Castiglione Torinese plant itself).

The filters are periodically washed through a backwash system: the contaminated water obtained from this operation is so recirculated at the initial stage of the water line, in order to remove contaminants.

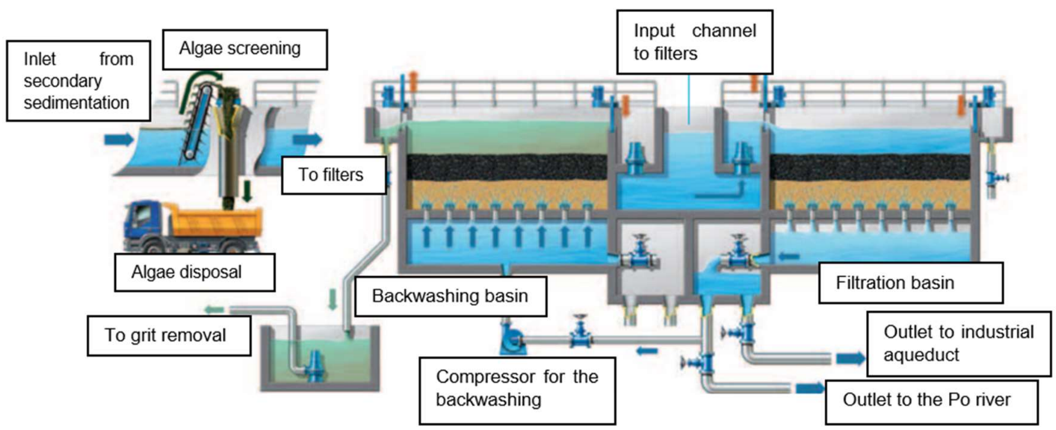


Figure 14: Final filtration scheme in Castiglione Torinese WWTP (13).

5.1.2 Sludge line: process description

In order to increase the concentration, the sludge from the water line is subjected to an initial process called pre-thickening. The output product from this treatment is collected in a storage tank and then sent to the digester, while the wastewater returns to the head of the water line. The digestion stage accomplishes the transformation of organic matter into inorganic matter through the action of bacteria anaerobes that develop at the temperature of 37 - 40 °C. The temperature in the digester is maintained in this range, through heat recovered from the combustion of biogases produced in the process itself. The result of the digestion process is biogas that is composed of 65% of methane and 35% of CO_2 and the process is completed after about 20 days of residence time of the sludge in the digesters. After this residence time, the stabilization is completed. After further thickening in the post-thickening stage, the sludge is sent to the dewatering stage in centrifuges or filter presses. In centrifugation, the sludge is conditioned with organic polyelectrolytes and treated by means of four high-performance centrifuges by subjecting it to a centrifugal force of 3,160 g. Alternatively, the final stage of dehydration takes place in chamber filter presses after conditioning by the addition of ferric salt and lime in order to have precipitation into flakes. In the filter presses, the sludge is subjected to a maximum pressure of 16 bar, allowing it to reach a dry content of more than 40 %. This water tenor allows the use of the product as compost or is compatible with discharge in landfill.

Part of the centrifuged sludge is pumped to the desiccation section consisting of two dryers, that work with indirect heating with diathermic oil, at single stage. The heat transfer fluid, thermal oil, is heated in a methane boiler. The steam produced is condensed with the recovery of 80 °C hot water used to heat the digesters. The unconditioned sludges are sent to the deodorizer and the condensates to the water line head for treatment. The processing time for thermal drying of the sludge is equal to about 6 hours. The final product is in the form of small granules, suitable for recovery by waste-to-energy or use as fuel for cement plants.

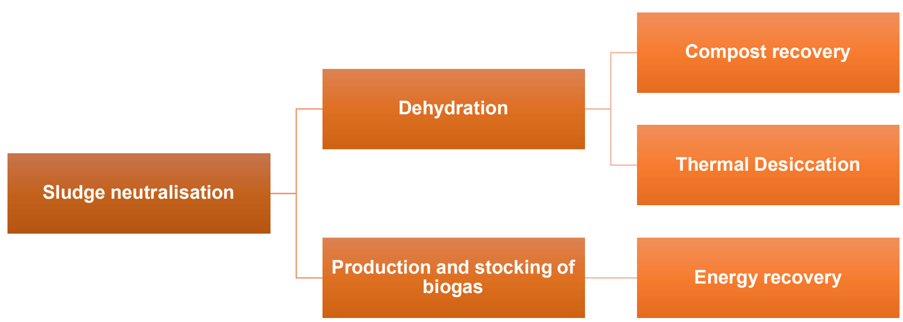


Figure 15: General flow of treatments in the sludge line

5.1.2.1 Pre-thickening

The first operation performed in the sludge line is the pre-thickening. This process is performed in six settling tanks, wherein in the lower part, there is the collection of the pre-thickened sludge, while in the upper part the residual water is collected through an overflow weir. The concentrated sludge is then sent to the anaerobic digestor, while the water is sent back to the water line.

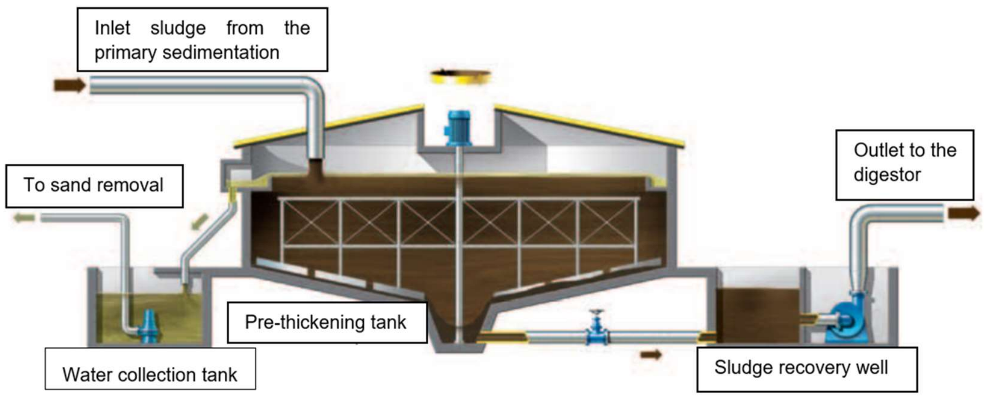


Figure 16: Pre-thickening section scheme (13).

5.1.2.2 Anaerobic digestion and energy recovery plant

The anaerobic digestion is performed in six digestors, with a mixing system constituted by a stirring paddle at the temperature of 37-40 °C (mesophilic temperature range), with a retention time of 15-20 days. The mesophilic range of temperature is maintained through a tubular heat exchanger wherein is circulated water at 80 °C, coming from the co-generator heat recovery system. This system allows the abatement of the organic substances, degraded into biogas, through anaerobic microorganisms.

The main processes that take place during anaerobic digestion are:

- Hydrolysis: the more complex molecules (carbohydrates, fats, and proteins) are transformed into simpler molecules.
- Acidogenesis: the hydrolysis products are transformed into intermediate VFAs (Volatile Fatty acids): Between VFAs part are acetates and part higher VFAs, that need further transformation to be accessible by methanogenic microorganisms. In this step, there is the formation of VFAs and as byproducts ammonia (NH_3), carbon dioxide (CO_2), and hydrogen sulfide (H_2S).
- Acetogenesis: the higher VFAs and other intermediates are converted and there is the production of carbon dioxide, hydrogen, and as a product acetic acid (CH_3COOH).

- Methanogenesis: in the last step there is the formation of biogas. In the plant, the production share is 65-70% for methane and 30-35% for carbon dioxide. There is also the production of solid/liquid residuals.

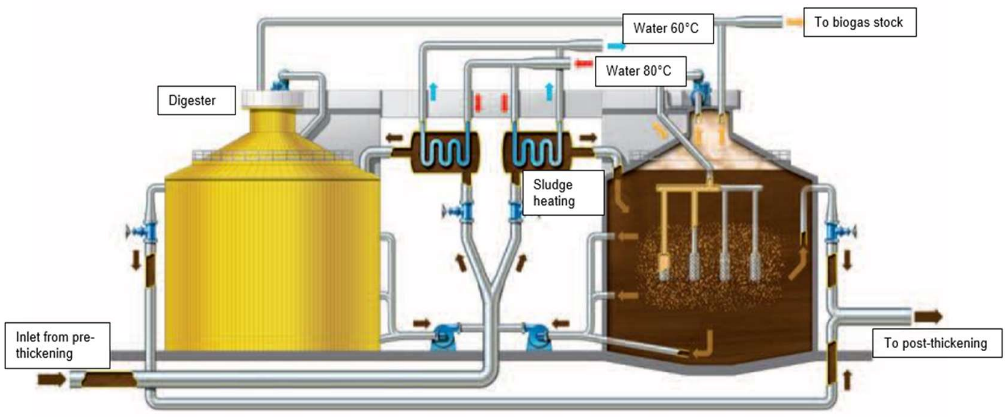


Figure 17: Anaerobic digestion scheme in WWTP(13)

The produced biogas is then compressed and burned in the motor section of the energy recovery plant. In this section, thermal and electrical energy is obtained through co-generation. The thermal energy is used to heat the sludge in the digester and during winter as heating for the offices. Electrical energy constitutes 50% of the electricity requirements of the plant.

5.1.2.3 Filter-pressing

After the stabilization and the post thickening phase, there is mechanical dehydration through the filter-pressing treatment. The sludge is firstly post-thickened, then conditioned through the addiction of lime water ($Ca(OH)_2$) and ferric chloride sulfate ($FeClSO_4$) in 4 tanks. This operation is performed to reach better performance in terms of filterability. Thanks to screw pumps, the sludge is brought to six plate filter presses where the sludge reaches a dry content of 40%.

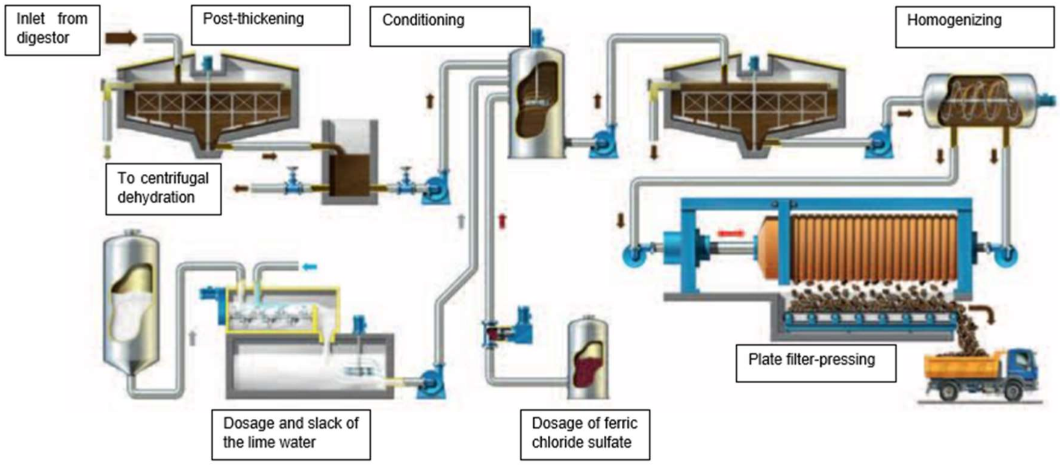


Figure 18: Post-thickening, conditioning, and filter-pressing of sludge scheme in WWTP (13).

5.1.2.4 Centrifugal dehydration

Alternatively, to the dehydration through filter-presses, the sludge can be subjected to centrifugal dehydration. The entering sludge is firstly filtrated through a roto-filter, then conditioned through a polyelectrolyte, a polymeric organic agent that has the scope to promote the aggregation of the residual organic substance in the sludge. The product obtained from the previous treatment's stages passes through four centrifuges and thanks to them reaches a dry content of 24% to 30%.

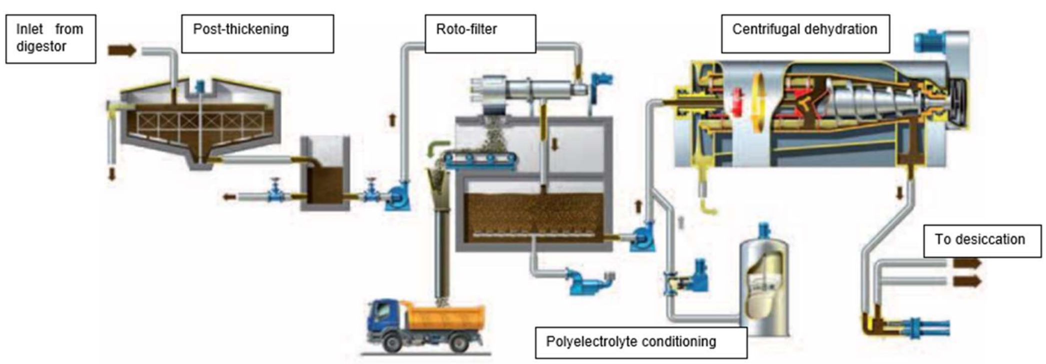


Figure 19: Centrifugal dehydration scheme in WWTP (13).

5.1.2.5 Desiccation

The desiccation section is constituted by two lines: the condensate line and the sludge line.

The sludge with a dry content of 26% is stocked and then sent to the desiccator. The dryers, work with indirect heating with diathermic oil at 2020°C, at single stage. Here the evaporation of a part of the liquid happens.

Dual extraction is provided for each dryer by means of a reversible auger capable of conveying the dried sludge alternatively to the two cooling augers. The heat for the evaporation of the sludge is produced through a boiler, faded with methane.

From the dryers, the vapor and dust are captured and sent to a cyclone where the dust is separated, and the depurated vapor is obtained. The depurated vapor is condensed in a mixture condensation column. In this section, heat recovery is performed through a double-plate heat exchanger.

The condensed vapor is then sent to deodorization.

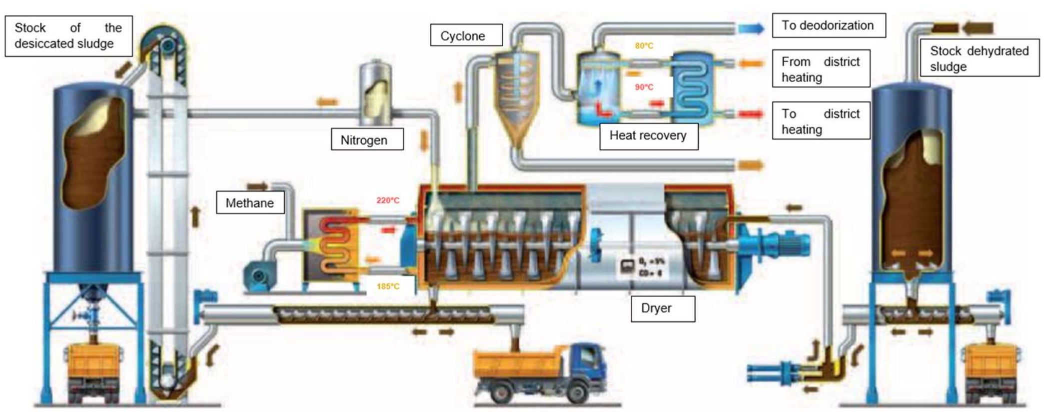


Figure 20: Desiccation scheme of the WWTP (13).

5.1.2.6 Deodorization

The deodorization section in the plant is composed of 3 lines, one for the treatment of the gases from the water line, and two in service of the sludge line.

This process takes place through two subsequent washes in a scrubber. The scrubber contains plastic material. Two subsequent washes are operated in the scrubber. Firstly, a liquid with sulfuric acid is fed, in this way, through the contact between the gas and the acid solution the abatement of the basic pollutants takes place through absorption. In the second step, sodium hydroxide is fed, together with sodium hypochlorite.

5.1.3 Energy production in the plant

An important cost of WWTP is the energy cost. For this reason, in the SMAT plant of Castiglione Torinese, particular attention is given to this component. To reduce electricity withdrawals from the external grid, the plant takes advantage of its ability to self-produce energy. The energy comes from a photovoltaics park and an energy recovery section from the combustion of biogas produced from the stabilization of sludge.

As discussed, along the sludge line there is an energy recovery section consisting of four GE-Jenbacher reciprocating cogeneration engines. These engines were installed in 2009 and with a total nominal power of 8000 KVA (1400 KW electrical power and 1100 KW thermal power for each engine), coupled with alternators. They use biogas produced by the anaerobic digestion of sludge as fuel, and in case of need, can be supplied with methane gas taken from the external grid. The heat recovered from the exhaust gases and the engine cooling circuit is used to heat the process water to bring the sludge in the digesters up to temperature (38°C), and in the winter period, it is also used to heat the office building and technical offices in the plant. The self-produced electrical energy by combustion from the cogeneration unit averages 30.000.000 kWh/year and covers about 50% of the plant's total electrical energy needs while the heat produced covers the plant's total thermal energy needs (16).

To further reduce electricity withdrawal from the grid, a photovoltaic park was installed in May 2011. The park is composed of 4.242 polycrystalline silicon panels having a total useful area of more than 7.000 m^2. The annual production coming from the installation is 1,200,00 kWh (13).

In 2020, a plant was implemented and made operational for the production and sale of biomethane to the grid. The intervention inevitably led to a reduction in self-produced energy from cogeneration. Indeed, in 2021 the self-consumption of energy strongly decreased according to the sustainability report (17).

5.2 ESTIMATION OF THE MATURED WHITE CERTIFICATES

On the basis of the public data given by SMAT, the matured white certificates from the substitution of the diffuser system in the aeration basin can be estimated.

As described the number of diffusers in the plant corresponds to 59000. Considering 4 moduli, for each modulus 14750 diffusers.

The representative configuration of modulus 3 (that has the same functioning of the moduli 2 and 3, and module 4 is provided.

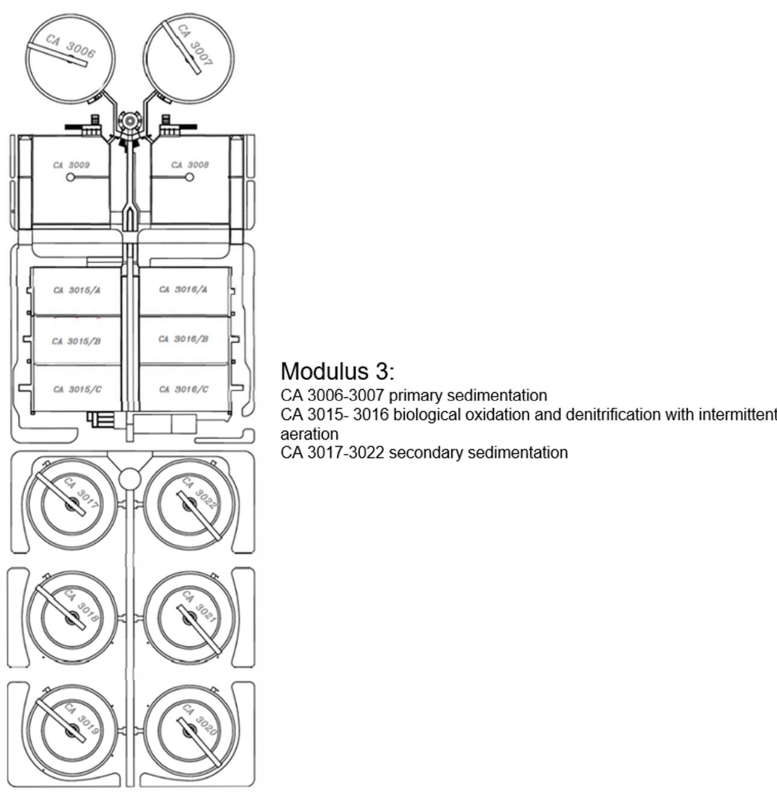


Figure 21: Modulus 3 configuration

As discussed in the moduli 1, 2, and 3 there is intermittent aeration. The concentration of dissolved oxygen in the basin is not constant and changes over time in order to guarantee the desired outcome of the process. No data can be retrieved directly from the plant, but the function time of the turbochargers is equal to 9.8 h/day (14).

A simple model is constructed that describes the OD in the basin, considering as constrain the operating period of the turbochargers.

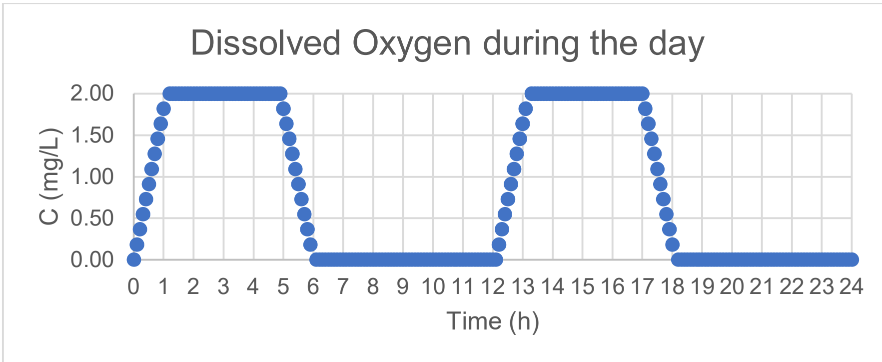
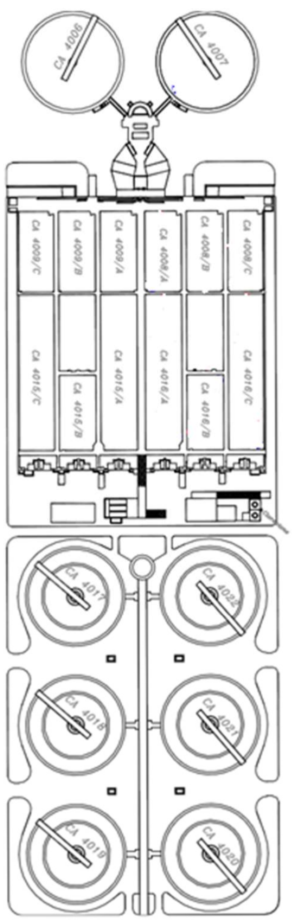


Figure 22: Dissolved Oxygen variation during a day considering intermittent aeration in the basin.

Concerning modulus 4 a step feed configuration is implemented. In this the function time of the turbochargers is equal to 24 h/day.



Modulus 4:
CA 4006-4007 primary sedimentation
CA 4008-4009 denitrification
CA 4015- 4016 biological oxidation and denitrification with intermittent aeration
CA 4017-4022 secondary sedimentation

Figure 23: Modulus 4 configuration.

To the aim of calculation, a temperature in the basin of 17°C is assumed. The site elevation is 304 m. The inlet temperature at the turbocharger is assumed to be equal to 20°C. The Submergence of the diffuser is 5 m.

In the case of the study, Sanitaire Silver Series II diffusers are considered. The area of each diffuser is 0.0421 m^2, with disc material specially blended high-grade EPDM. The selection was done in order to have a material that has elastic and resistance properties adequate with the functioning of intermittent aeration.

Technical data	
Disc material	Specially blended high-grade EPDM
Diameter	178 or 229 mm (7 or 9 in)
Airflow range per disc	0.8-7 Nm^3/h (0.5-4.5 scfm)
Standard oxygen transfer efficiency (SOTE)	Approx. 6.5% per m submergence (2% per ft)
Standard aeration efficiency (SAE)	2.5-6 kg O_2 /kWh (4-10 lb O_2 /hph)

Figure 24: Sanitaire Silver Series II diffusers and technical data.

This device is assumed to be installed in both baseline and ex-post configuration, however, to take into account the downgrading and obsolescence of the technology in the baseline configuration a decreased depth of the diffusers and a further decrease of SOTE are considered.

The number of diffusers per unit area and the diffuser density (DD) is calculated on the basis of the chosen device and of the basin characteristics. It is assumed to be constant in the two cases.

The geometrical characteristics of the aeration tank is taken by SMAT.

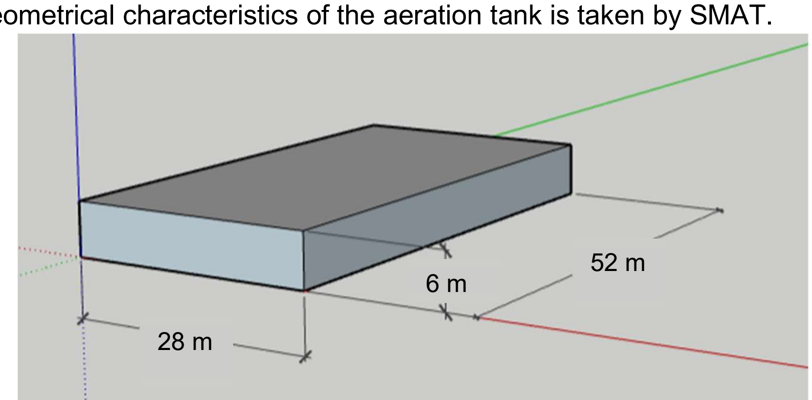


Figure 25: Geometrical features of the biological treatment basin.

The area of the basin is so equal to 1456 m^2.

As discussed, the area of the membrane in the diffuser is equal to 0.0421 m^2.

Equation 2: calculation of number of diffusers per unit area

$$\frac{n_{diff}}{m^2} = \frac{n_{diff}}{Area_{basin}} = 1.71\ \frac{diffusers}{m^2}$$

Equation 3: diffuser density [%]

$$DD\ [\%] = \frac{Area_{diffuser} \cdot n_{diff}}{Area_{basin}} = 7\ \%$$

Another important assumption is done for the Oxygen Transfer Rate (OTR). Considering that the input flow is not changed by the intervention and that the results of treatment have to be reached also in baseline setup, the OTR is assumed to be sufficient for the aim of the plant and so maintained constant for the ex-post configuration.

5.2.1 Estimation of air flow for each diffuser, SOTR, SOTE and OTR in baseline and ex-post configuration

The airflow from each diffuser is assumed equal to 6.5 Nm^3/h in baseline configuration.

$$Q_{diff\ baseline} = 6.5\ \frac{Nm^3}{h}$$

This work is based on public data given by SMAT for this reason the $Q_{diff\ baseline}$ is selected through an iterative process taking into account that the energy demand of the plant in 2020 was 55212 MWh (17) and, according to literature, the energy consumption for aeration in biological treatments is about 50% of this amount (18).

A crucial aspect of the project is the calculation on the SOTR (Standard Oxygen Transfer Rate). SOTR is referred to standard conditions defined so for:

- T=20°C;
- P=1 atm;
- Clean water;
- The concentration of dissolved oxygen is equal to 0 mg/L.

This important parameter represents the rate at which the SOR (Standard Oxygen Requirement) is transferred in water.

The SOTR for each diffuser is calculated as:

Equation 4: Project SOTR calculation

$$SOTR_{baseline} = SOTE \cdot \frac{kgO_2}{m^3} \cdot Q_{diff\ baseline}$$

The standard oxygen transfer rate (SOTR) can be retrieved, considering that, at 20°C and 1 atm (standard condition), there are 0.28 kgO_2 for each m^3 of air. Furthermore, the SOTE (Standard Oxygen Transfer Efficiency) must be considered. The SOTE is the fraction of oxygen supplied to the aeration tank, which is actually transferred or dissolved into the liquid at standard conditions. It is a major design parameter for diffused aeration systems. This parameter is retrieved from the performance curves. In order to consider the obsolescence of the devices the submergence considered is 4 m instead of 5 m.

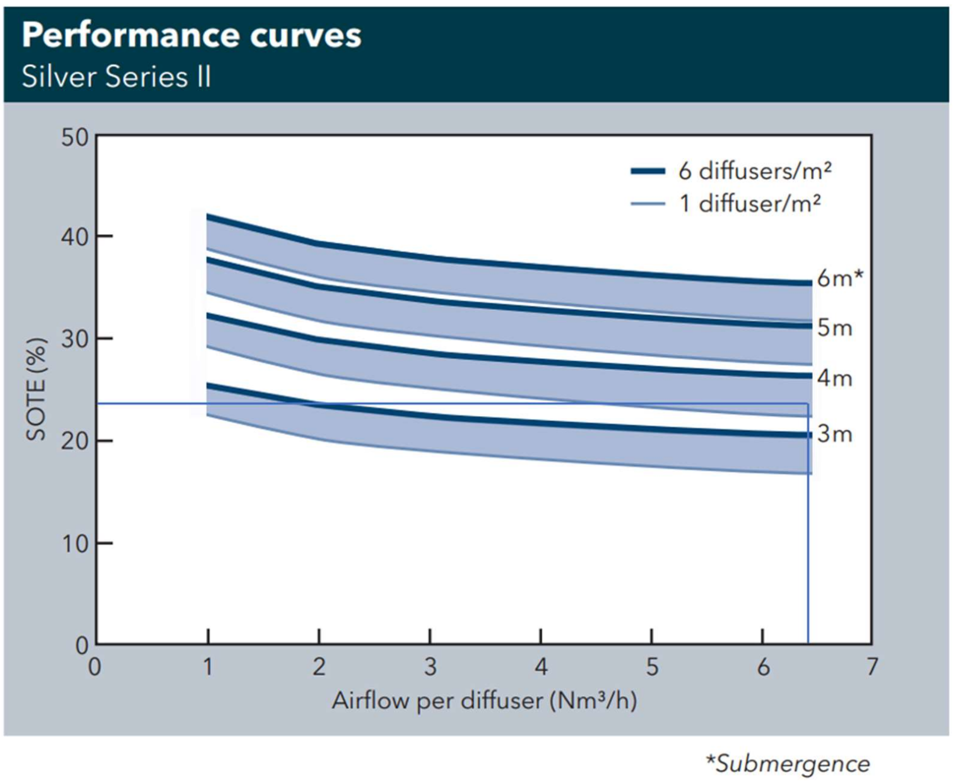


Figure 26: SOTE baseline from performance curves

So, from the curves the selected SOTE is:

$$SOTE_{baseline} = 24\%$$

Once all the terms are known the SOTR can be calculated:

$$SOTR_{baseline} = SOTE \cdot \frac{kgO_2}{m^3} \cdot Q_{diff} = 0.24 \cdot 0.28 \frac{kgO_2}{Nm^3} \cdot 6.5 \frac{Nm^3}{h} = 0.437 \frac{kgO_2}{h \cdot diffuser}$$

To calculate the energy savings from the intervention, the SOTR has to be reported to on-site condition. The calculation of the actual oxygen requirements needs some correction factor that has to be considered to take into account the effect of wastewater with related salinity, temperature, pressure, the depth of the diffusers, but also the desired concentration in the basin and the efficiency of the mixing system in the real condition. To this aim, the calculation of the Oxygen Transfer Rate (OTR_f) has to be considered.

Equation 5: OTR calculation

$$OTR_f = SOTR \left[\frac{\tau\beta\omega C^*_{\infty 20} - C}{C^*_{\infty 20}}\right] [(\theta)^{t-20}] \alpha F$$

With:

$OTR_f = field\ oxygen\ transfer\ rate\ in\ operating\ condition\ \left[\frac{kgO_2}{h}\right]$

$SOTR = oxygen\ transfer\ rate\ at\ standard\ condition \left[\frac{kgO_2}{h}\right]$

$\tau = temperature\ correction\ factor = C^*_{st}\ / C^*_{s20}$

$\beta = relative\ DO\ saturation\ to\ clean\ water = C^*_{\infty\ wastewater}\ / C^*_{\infty\ tap\ water}$

$\omega = pressure\ correction\ factor = \frac{P_b}{P_s} = \exp\left[-\frac{gM(z_b - z_a)}{RT}\right]$

$P_b = barometric\ pressure\ at\ test\ site\ [m] or [kPa]$

$P_s = standard\ barometric\ pressure = 10.33\ m = 101325\ kPa$

$g = acceleration\ due\ to\ gravity = 9.81\ m/s^2$

$M = molecular\ weigth\ of\ air = 28.97 g/mol_{air}$

$z_b = elevation\ b\ [m]$

$z_a = elevation\ at\ sea\ level =\ 0\ m$

$R = universal\ gas\ constant = 8314\ Nmol/mol_{air} K$

$T = temperature\ [K]$

$C^*_{\infty 20}$

$= concentration\ of\ saturation\ of\ the\ oxygen\ at\ sea\ level\ and\ 20\ °C\ for\ diffused\ areation\ \left[\frac{mg}{L}\right]$

$= C^*_{s20}\left[1 + d_e\left(\frac{D_f}{P_s}\right)\right]$

$d_e = effective\ saturation\ depth. Usually, for\ submegence\ about\ 90\%\ it\ is\ considered$
$= 0.21 - 0.44$

$D_f = depth\ of\ disffusers\ in\ basin\ [m]$

$C = average\ DO\ (dissolved\ oxygen) concetration\ in\ the\ considered\ volume\ \left[\frac{mg}{L}\right]$

$\theta = empirical\ temperature\ correction\ factor$

$\alpha = relative\ oxygen\ transfer\ rate\ in\ wastewater\ vs. clean\ water$
$= K_L a_{f\ 20\ watewater}/K_L a_{f\ tap\ water}$

$F = Fouling\ factor$

Considering all the described conditions the different terms to obtain the OTR_f can be calculated:

- $\tau = temperature\ correction\ factor = \frac{C^*_{s17}}{C^*_{s20}} = \left(\frac{9.67\frac{mg}{L}}{9.09\frac{mg}{L}}\right) = 1.064$
- $\beta = relative\ DO\ saturation\ to\ clean\ water = 1,\ considering\ very\ low\ salinity$
- $\omega = pressure\ correction\ factor = \frac{P_b}{P_s} = \exp\left[-\frac{gM(z_b - z_a)}{RT}\right] = \exp\left[-\frac{9.81\frac{m}{s^2}\cdot 28.98\frac{g}{mol}\cdot(304\ m)}{8314\frac{Nmol}{molK}\cdot(17+273.15\ K)}\right] = 0.962$
- $C^*_{\infty 20} = concentration\ of\ saturation\ of\ the\ oxygen\ at\ sea\ level\ and\ 20\ °C\ for\ diffused\ areation = C^*_{s20}\left[1 + d_e\left(\frac{D_f}{P_s}\right)\right] = 9.09\frac{mg}{L}\left[1 + 0.4\left(\frac{5.7\ \mathrm{m}}{10.33\mathrm{m}}\right)\right] = 11.096\frac{\mathrm{mg}}{L}$
- $\theta = empirical\ temperature\ correction\ factor = 1.024$

The elements discussed remain constant in baseline and *ex-post* condition, assuming similar diffusers and being the plant characteristics and incoming wastewater the same.

For the Fouling factor and the relative oxygen transfer rate in wastewater vs clean water, a more in the deep dissertation is needed.

The fouling factor accounts for the loss of oxygen transfer efficiency that results from the buildup or scaling of biological and/or chemical film or deposits on the surface of aeration equipment. Fouling is most experienced on the surface of fine-pore diffusers. The typical fouling factor ranges from approximately 0.5 to 1.0 for this kind of device. Usually, α is instead equal to 0.65. In order to consider the baseline and ex-post configuration, values of αF are retrieved from the literature. Even if in this study the results are considered extendible to the plant of Castiglione Torinese, a specification is needed: the αF factor is an ensemble of parameters very site-specific. Using the off-gas method the direct measurement of the on-site oxygen transfer efficiency can be performed. The off-gas method is based on a gas-phase balance between the oxygen content in a flow of atmospheric air, taken as reference, and the oxygen content in an off-gas withdrawal from the surface of the aeration basin considered. The first reported study is referred to tests conducted in the oxidation tank of an urban WWTP of 3,500 population equivalent (P.E.) located in Tuscany (Italy). Through this experiment, the αF is retrieved for new devices and devices with two years' service.

Test	**Condition**	**αF**
June 2010	new	0.53
May 2012	2 years' service	0.30

Table 10: αF obtained with off-gas method in time

Considering alfa equal to 0.65 as the first approximation, we will obtain so a fouling factor equal to 0.46.

Another study using the off-gas method is reported to have a general overview of the results. The performed tests are done in a local water reclamation plant operating in biological nutrient removal mode, and part of the activated sludge was continuously circulated in the research tank and back to the main plant. Selected diffusers were tested for 1 year in the same process water to quantify fouling effects on diffuser performance. A side stream continuously-fed tank was utilized and 4 diffusers in different materials and with different characteristics were tested at a flux of 1.71 m^3/h/diffuser (19).

Code	Type	Material	Diameter (m)	Length[a] (m)	Surface area (m^2)
Diffuser 1	Porous disc	Ceramic	0.22	—	0.039
Diffuser 2	Disc, small pores	EPDM	0.22	—	0.039
Diffuser 3	Disc, large pores	EPDM	0.22	—	0.039
Diffuser 4	Disc, small pores	EPDM	0.22	—	0.038

Table 11: diffusers characteristics(19)

The diffusers 2 and 4 are more similar to the diffuser selected in this study project.

The obtained results from the measurements are reported in the graph below.

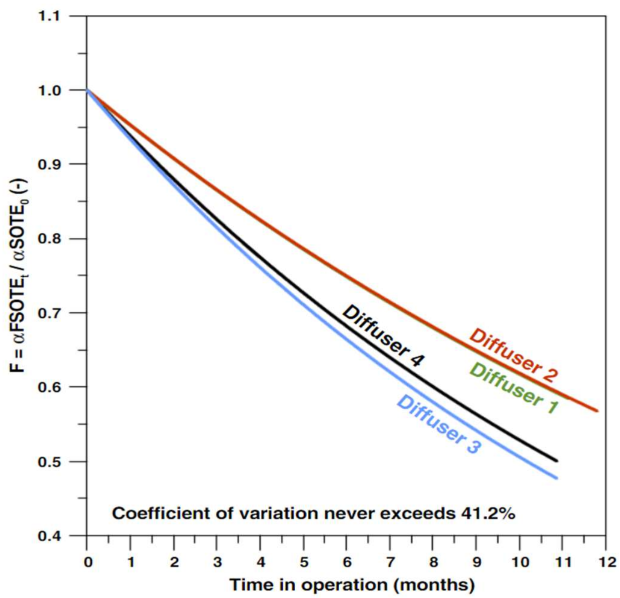


Figure 27: variation of Fouling factor in time considering different diffusers

Scaling the results obtained in the side stream tank to the full-scale process the 12 months corresponds to 5 years, inducing in the testing tank more rapid fouling than in real process conditions.

Looking at the results so, the Fouling factor for diffusers 2 and 4 at 10 months is respectively 0.55 and 0.65.

Considering the different results analyzed in this work a value of fouling factor equal to 0.55 is taken for the baseline situation. So:

$$\alpha F_{baseline} = 0.65 \cdot 055 = 0.36$$

For the ex-post situation the parameters of the first study are considered, so:

$$\alpha F_{ex\ post} = 0.53$$

The obtained results are held also in the Castiglione Torinese treatment plant. The value of αF new was taken for the calculation of the OTR_f ex-post, while the value of αF of the baseline situation was obtained as the mean value of the reported studies.

Once that a reasonable value for $\alpha F_{baseline}$ is taken, the calculation of the OTR_f in baseline conditions can be completed. As already described in the initial hypothesis, the OTR_f remains constant in baseline and ex-post situations:

$$OTR_{f baseline} = OTR_{f\ ex\ post} = 0.124 \frac{kgO_2}{h\ diffuser}$$

Once that OTR_f is known, be taken constant, the $SOTR_{ex\text{-}post}$ can be estimated through the inverse formula of the OTR_f (Equation 5: OTR calculation) :

$$SOTR_{ex\ post} = 0.297 \frac{kgO_2}{h\ diffuser}$$

From this value, jointly with the selection of a proper $SOTE_{ex\text{-}post}$, through an iterative process in which the Q_{diff} and SOTE are varied till convergence of the result, the airflow rate for each diffuser can be calculated, through the inverse formula of Equation 4: Project SOTR calculation, considering, in this case, the real submergence that is equal to 5 m.

The obtained results are:

$$Q_{diff\ ex\ post} = 3.4\ \frac{Nm^3}{h}$$

$$SOTE_{ex\ post} = 31\ \%$$

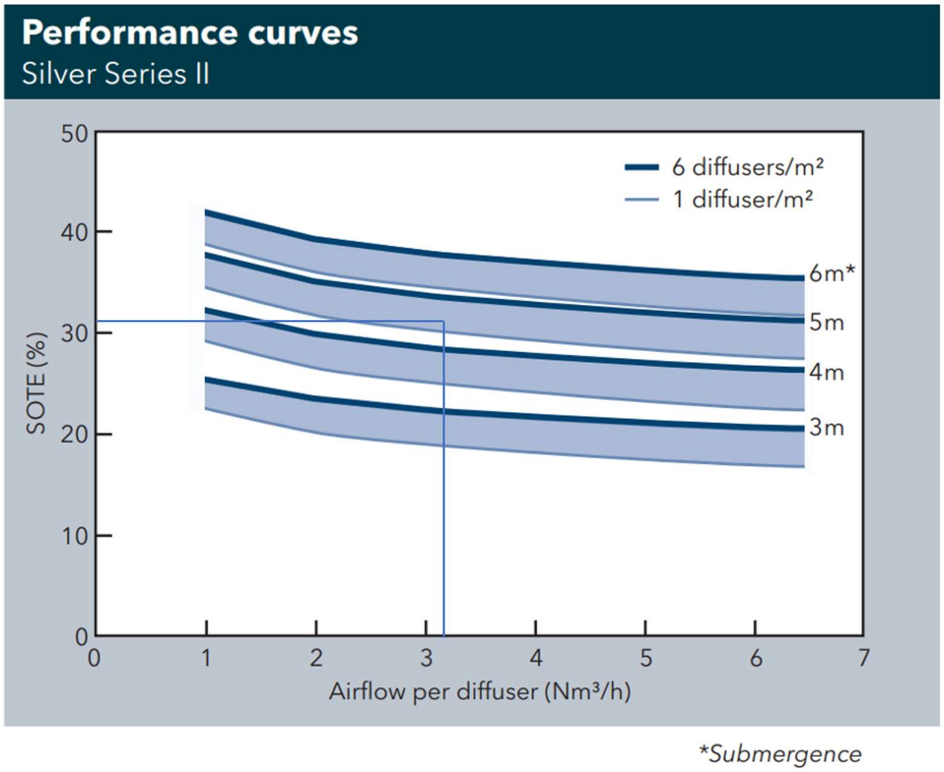


Figure 28: Airflow and SOTE selection for ex-post situation

As can be appreciate a decrease in the air flow and an increase in efficiency is shown after the substitution of the diffusers.

5.2.2 Estimation of transferred oxygen, electric power requirements, Standard Aeration Efficiency and matured white certificates

Once these crucial parameters in both situations are evaluated, it is necessary to differentiate the calculation to evaluate the electric power requirements of the plant. The time of functioning of the turbochargers is not homogeneous in all the moduli. In moduli 1, 2, 3 the intermittent aeration leads to a working time of 9.8 hours, while in modulus 4 the working time is 24 hours. For this reason, a separate calculation is done considering jointly the modulus 1, 2 and 3 and separately the modulus 4.

5.2.2.1 Calculation for moduli 1,2 and 3, working with intermittent aeration

As stated, the diffusers are considered widely spread in the different moduli. For this reason, the number of diffusers present in moduli 1, 2 and 3 is, in this study, assumed to be equal to 44,250.

The transferred oxygen can be so calculated as:

Equation 6: Calculation of the transferred oxygen

$$Tranferred\ Oxygen = OTR_f \cdot n\ of\ diffusers$$

The resulting value obtained is:

$$Tranferred\ Oxygen_{baseline} = Tranferred\ Oxygen_{expost} = Tranferred\ Oxygen = 0.124 \frac{kgO_2}{h\ diffuser} \cdot 44250\ diffuser = 5471 \frac{kg\ \ _2}{h}$$

And considering a daily functioning of 9.8 h (tf), the corresponding Transferred Oxygen in kgO2/day will be:

$$Tranferred\ Oxygen = 5471 \frac{kgO2}{h} \cdot 9.8 \frac{h}{d} = 53613 \frac{kgO_2}{d}$$

The dry airflow that has to be compressed for the injection in the tank is:

Equation 7: calculation of dry airflow

$$Q_{air} = Q_{diff} \cdot tf \cdot n\ diffusers$$

The results are so:

$$Q_{air\ baseline} = 6.5 \frac{Nm^3}{h\ diffuser} \cdot 9.8 \frac{h}{d} \cdot 44250\ diffusers = 2818725 \frac{Nm^3}{d}$$

$$Q_{air\ ex\ post} = 3.4 \frac{Nm^3}{h\ diffuser} \cdot 9.8 \frac{h}{d} \cdot 44250\ diffusers = 1482275 \frac{Nm^3}{d}$$

The required electric power (P_w) used by the turbochargers can be so retrieved:

Equation 8: Calculation of the electric power

$$P_w = \frac{wRT_1}{29.7\ n\ e} \times \left[\left(\frac{p_2}{p_1}\right)^n - 1\right]$$

Where:

$w = weight\ of\ air\ flow\ \left[\frac{kg}{s}\right]$

$R = universal\ gas\ constant\ for\ air = 8.314 \frac{J}{mol\ K}$

$T_1 = absolute\ inlet\ temperature\ [K] = 293.15\ K$

$p_1 = absolute\ inlet\ pressure\ [atm] = 1\ atm$

$p_2 = absolute\ outlet\ pressure\ [atm] = 1.71\ atm$

$n = \frac{k-1}{k}\ with\ k = specific\ heat\ ratio, n = 0.283$

$28.97 = molecular\ weight\ of\ dry\ air$

$e = efficiency$=0.85

Dealing with the same turbochargers, the only term that differs in the equation is the weight of the airflow: this quantity is related to Q_{air}.

After appropriate conversions the power requirements are calculated:

$$P_{w\ baseline} = 2315.7\ kW$$

$$P_{w\ ex\ post} = 1217.7\ \ kW$$

The quantity of used electric energy over one year, considering tf=9.8 h/d will be:

$$Energy_{baseline} = 8283129\ kWh$$

$$Energy_{ex\ post} = 4355827\ kWh$$

As can be appreciated, the calculation of the energy consumption are consistent with the data reported by the study on the implementation of OSCAR® (14), reported in Table 8, referred to the energy consumption of the moduli 1, 2 and 3.

Once the energy consumption is calculated, the SAE (Standard Aeration Efficiency) can be reported:

Equation 9: Standard Aeration Efficiency calculation

$$SAE = \frac{Transferred\ Oxygen}{Energy_{used\ for\ air\ compression}} \left[\frac{kgO_2}{kWh}\right]$$

Considering both situations:

$$SAE_{baseline} = \frac{53613 \frac{kgO_2}{d} \cdot 365\ d}{8283129\ kWh} = 2.36 \frac{kgO_2}{kWh}$$

$$SAE_{ex\ post} = \frac{53613 \frac{kgO_2}{d} \cdot 365\ d}{4161784\ kWh} = 4.49 \frac{kgO_2}{kWh}$$

For the final calculation of the RISP and so of the eeo matured in this plant section, the Equation 1: calculation of energy savings based on algorithm 4 for wastewater treatment plant is reminded:

$$RISP = \left(\frac{1}{SAE_{baseline}} - \frac{1}{SAE_{ex\ post}}\right) \times kgO_2 \times f_e$$

Considering the discussed results:

$$RISP = \left(\frac{1}{2.36 \frac{kgO_2}{kWh}} - \frac{1}{4.49 \frac{kg0_2}{kWh}}\right) \times 53613 \frac{kgO_2}{d} \times 365 \frac{d}{year} \times 0.000187 \frac{eeo}{kWh} = 734.4 \frac{eeo}{year}$$

5.2.2.2 Calculation for modulus 4 working in step feed configuration

The number of diffusers present in the modulus 4 is assumed, in this study, to be equal to 14,750.

The transferred oxygen can be so calculated through Equation 6: Calculation of the transferred oxygen:

$$Tranferred\ Oxygen_{baseline} = Tranferred\ Oxygen_{expost} = Tranferred\ Oxygen = 0.124 \frac{kg\ \ _2}{h\ diffuser} \cdot 14750\ diffuser = 1823.6 \frac{kgO_2}{h}$$

And considering a daily functioning of 24 h (tf), the corresponding transferred oxygen in kgO2/day will be:

$$Tranferred\ Oxygen = 1823.6 \frac{kgO2}{h} \cdot 24 \frac{h}{d} = 43765 \frac{kgO_2}{d}$$

The dry airflow that has to be compressed to be injected in the tank is estimated with Equation 7: calculation of dry airflow:

$$Q_{air\ baseline} = 6.5 \frac{Nm^3}{h\ diffuser} \cdot 24 \frac{h}{d} \cdot 14750\ diffusers = 2301000 \frac{Nm^3}{d}$$

$$Q_{air\ ex\ post} = 3.4 \frac{Nm^3}{h\ diffuser} \cdot 24 \frac{h}{d} \cdot 14750\ diffusers = 1210021 \frac{Nm^3}{d}$$

The required electric power (P_w) used by the turbochargers can be so retrieved by considering Equation 8: Calculation of the electric power.

$$P_{w\ baseline} = 1890.4\ kW$$

$$P_{w\ ex\ post} = 994.1\ \ kW$$

The quantity of used electric energy over one year, considering tf=9.8 h/d will be:

$$Energy_{baseline} = 16559358.6\ kWh$$

$$Energy_{ex\ post} = 8708025.4\ kWh$$

Also in this case, according to Equation 9: Standard Aeration Efficiency calculation, the SAE can be, at this point, calculated:

$$SAE_{baseline} = \frac{43765 \frac{kgO_2}{d} \cdot 365\ d}{16559358.6\ kWh} = 0.96\ \frac{kgO_2}{kWh}$$

$$SAE_{ex\ post} = \frac{43765 \frac{kgO_2}{d} \cdot 365\ d}{8708025.4\ kWh} = 1.83\ \frac{kgO_2}{kWh}$$

Using the Equation 1: calculation of energy savings based on algorithm 4 for wastewater treatment plant, the eeo obtained will be:

$$RISP = \left(\frac{1}{0.96 \frac{kg\ \ 2}{kWh}} - \frac{1}{21.83 \frac{kg\ \ 2}{kWh}} \right) \times 43765 \frac{kgO_2}{d} \times 365 \frac{d}{year} \times 0.000187 \frac{eeo}{kWh} = 1468.2 \frac{eeo}{year}$$

The total number of the white certificates obtained will be so:

$$RISP_{tot} = 2202.6 \frac{eeo}{year}$$

The intervention considered produces energy savings far exceeding the 10 eeo, the lower limit for access to the mechanism of with certificates with PC.

5.2.2.3 Calculation of the energy savings considering a decrease in efficiency

Summing up the power requirements for all the moduli:

$$P_{w\ baseline,tot} = 4206.1\ kW$$

$$P_{w\ ex\ post,tot} = 2211.8\ kW$$

While from the energy point of view:

$$Energy_{baseline,tot} = 24842487.6\ kWh = 24842.5\ MWh$$

$$Energy_{ex\ post,tot} = 13063852.34\ kWh = 13063.9\ MWh$$

The electric energy used in the aeration operation, as the electric power, as calculated cannot be considered constant in a wise evaluation. The expectation is that in the lifetime of the project (25 years), the value of the power in ex-post situation will coincide with the power requirements in baseline condition.

For this reason and in sake of simplicity, a linear increase in the power required is considered in this this study considering as situation at year=0 the ex-post power as calculated in the previous step, while at year=25 the electric power equal to the baseline situation.

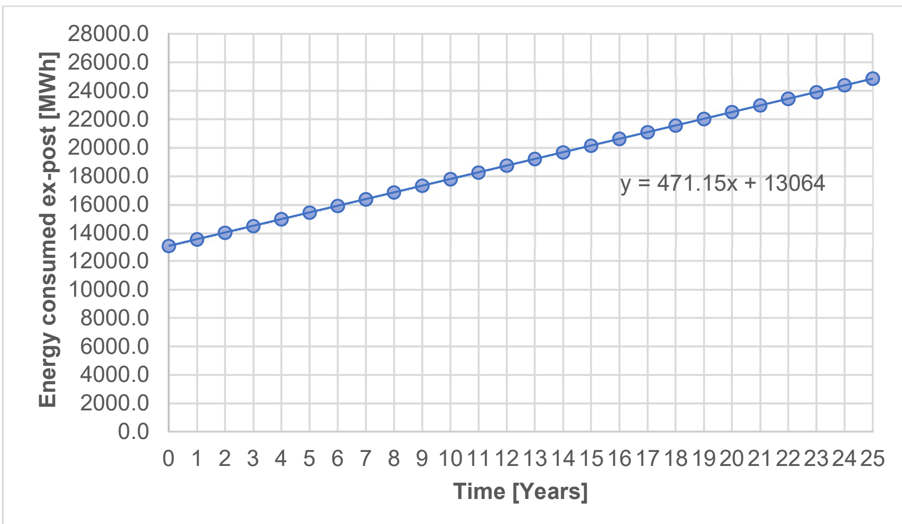


Figure 29: Increase in time of the energy required for aeration

The variation in the used energy between the baseline and ex-post situation is obtained as the difference between the estimated energy requirement for each year and the baseline electric energy used. Considering i the umpteenth year, the saved electric energy will be estimated as:

Equation 10: calculation of the saved energy

$$\Delta MWh_i = Energy_{baseline} - Energy_{expost,i}$$

The obtained results, calculated according to the selected decrease in energy efficiency during time, are reported in the table below:

Year	Energy consumed baseline [MWh]	Energy consumed ex-post [MWh]	ΔMWh
0	24842.5	13063.9	11778.6
1		13535.0	11307.5
2		14006.1	10836.3
3		14477.3	10365.2
4		14948.4	9894.1
5		15419.6	9422.9
6		15890.7	8951.8
7		16361.9	8480.6
8		16833.0	8009.5
9		17304.2	7538.3
10		17775.3	7067.2
11		18246.5	6596.0
12		18717.6	6124.9
13		19188.7	5653.7
14		19659.9	5182.6
15		20131.0	4711.5
16		20602.2	4240.3
17		21073.3	3769.2
18		21544.5	3298.0
19		22015.6	2826.9
20		22486.8	2355.7
21		22957.9	1884.6
22		23429.1	1413.4
23		23900.2	942.3
24		24371.3	471.1
25		24842.5	0.0

Table 12:Calculation of the energy used in ex-post configuration and of the energy saved with respect to baseline consumption

In order to have a more clear visualization of the results, a graph is proposed where the increase in the energy used in ex-post situation is plotted together with the decrease in the energy saved in the estimated lifespan of the part of the plant interested in the study.

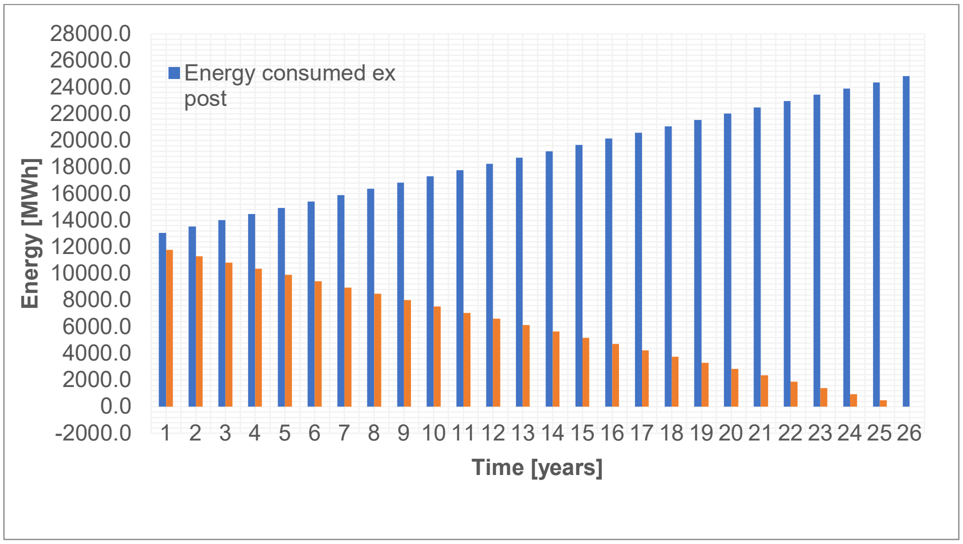


Figure 30: Energy saved, and energy required in ex-post situation during time

6 PROCEDURE FOR OBTAINING WHITE CERTIFICATES

Once the possibility to access to the mechanics of White Certificates is recognized, the procedure to obtain them has to be described.

First of all, in the phase of the presentation of the project, a table with the synthetic data of the project has to be presented, jointly with the device's technical data sheets.

The request has to be performed in two separate procedures, being the descriptive parameters different in modulus 1, 2, 3 with respect to modulus 4.

Descriptive parameters	**u.m.**	**Baseline**	**Ex-post**
SOTR	$kg0_2/h$	0.437	0.297
SOTE	%	24	31
Production system type	--	turbocharger NextTurbo	turbocharger NextTurbo
Air	Nm^3/h	287625	151252.6
Electric power production system	kW	2315.7	1217.7
Air diffusers type	--	micro bubbles diffusers	micro bubbles diffusers
SAE	$kg0_2/kWh$	2.36	4.49
Average annual COD in	mg/l	380	380
Average annual COD out	mg/l	30	30
Average annual Nitrogen in	mg/l	31	31
Average annual Nitrogen out	mg/l	8.4	8.4
Average annual Phosphorus in	mg/l	4	4
Average annual Phosphorus out	mg/l	0.7	0.7
Average annual flow rate treated	m^3	215000000	215000000
Person Equivalent	PE	2100000	2100000

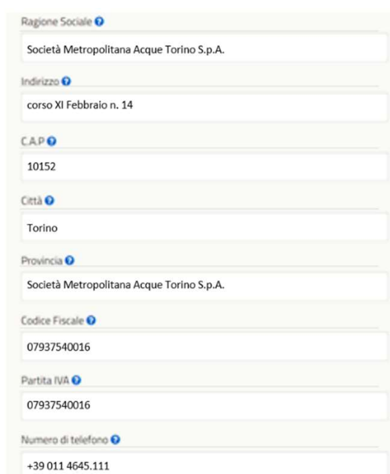
Table 13: Synthetic table required for the access to WhC mechanism for basins with intermittent aeration.

Descriptive parameters	u.m.	Baseline	Ex-post
SOTR	kg0$_2$/h	0.437	0.297
SOTE	%	24	31
Production system type	--	turbocharger NextTurbo	turbocharger NextTurbo
Air	Nm^3/h	95875	50417.52891
Electric power production system	kW	1890.3	994.1
Air diffusers type	--	micro bubbles diffusers	micro bubbles diffusers
SAE	kg0$_2$/kWh	0.96	1.83
Average annual COD in	mg/l	380	380
Average annual COD out	mg/l	30	30
Average annual Nitrogen in	mg/l	31	31
Average annual Nitrogen out	mg/l	8.4	8.4
Average annual Phosporus in	mg/l	4	4
Average annual Phosporus out	mg/l	0.7	0.7
Average annual flow rate treated	m^3	215000000	215000000
Person Equivalent	PE	2100000	2100000

Table 14: Synthetic table for access to WhC mechanism for basins with step feed aeration

Once that the synthetic tables are produced, the company must accredit in the dedicated GSE section. The applications for eligibility of energy efficiency projects, to be sent to the GSE, must be made exclusively through the electronic procedure set up by the GSE.

SMAT plant is a company obliged to have an Energy Manager, for this reason has to accredit as SEM (Society with Energy Manager) and to upload the documentation related to this status. Furthermore, some basic information that cannot be modified are requested in this phase in the pop-up window.



Ragione Sociale
Società Metropolitana Acque Torino S.p.A.
Indirizzo
corso XI Febbraio n. 14
C.A.P
10152
Città
Torino
Provincia
Società Metropolitana Acque Torino S.p.A.
Codice Fiscale
07937540016
Partita IVA
07937540016
Numero di telefono
+39 011 4645.111

Table 15: Accredit data for SMAT

Once that accredit procedure is concluded the company can upload the PC.

The requested documentation in order to present a PC has to include different information.

First of all, information on owner and proponent. In the case study these subjects coincides and the information are the same of the accredit procedure. Through C.F. and P.IVA the system is able to recognize if the company is obliged to have an Energy Manger, as in the case of SMAT. In this situation the documentation containing the appointment of the person responsible for the conservation and rational use of energy (pursuant to Art. 19 L. 09/01/1991, n.10.) has to be uploaded.

Then, information on site and plant where the project has to be implemented. In this case the plant is the Castiglione Torinese WWTP.

6.1 PRESENTATION OF THE MONITORING PLANS PROJECTS (PC)

The technical report of the project has to be reported in the request. In this report has to be considered the minimum content described by GSE for the PC (20) with:

- Description of the context: how and in which way the plant of Castiglione Torinese works (so, a synthesis of the treatment operated and of the main quantitative features of the unit).
- Description of the intervention for energy efficiency: substitution of diffusers with description of the main parameters in baseline and ex-post situation.
- Aim of the project: in the case of study the project is developed in order to decrease the electric energy input in the plant, acting on the aeration system in the biological treatment section. Through this intervention, not only this purpose is reach but benefits in terms of reduction of the carbon footprint of the plant are reached too.
- Type and sector of intervention: in this case the intervention is made on substitution of fine bubble diffusers in WWTP.
- Project implementations start date: the proposing party, in order to enable the identification of the date of the beginning of the work of the intervention, shall provide:
    - Gant Diagram.
    - Documentation with effective starting assessment of each phase of the Gant diagram.

In this study a Gant diagram is hypnotized considering the common phases of a project implementation. Each period in the Gant diagram corresponds to 1.5 months. The monitoring phase, both in ex-post and baseline configuration, is set equal to 12 months as requested by the normative on the white certificates mechanism.

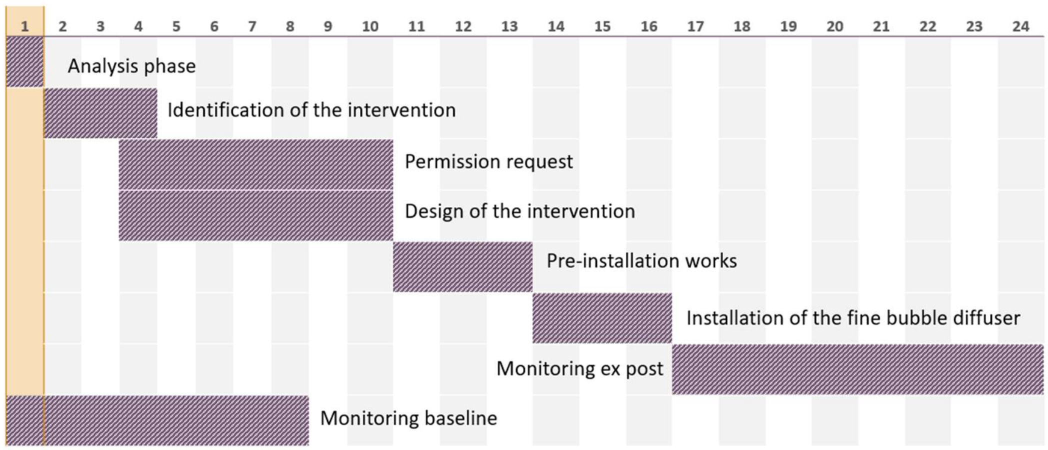


Figure 31:Gant diagram hypothesis for the case study

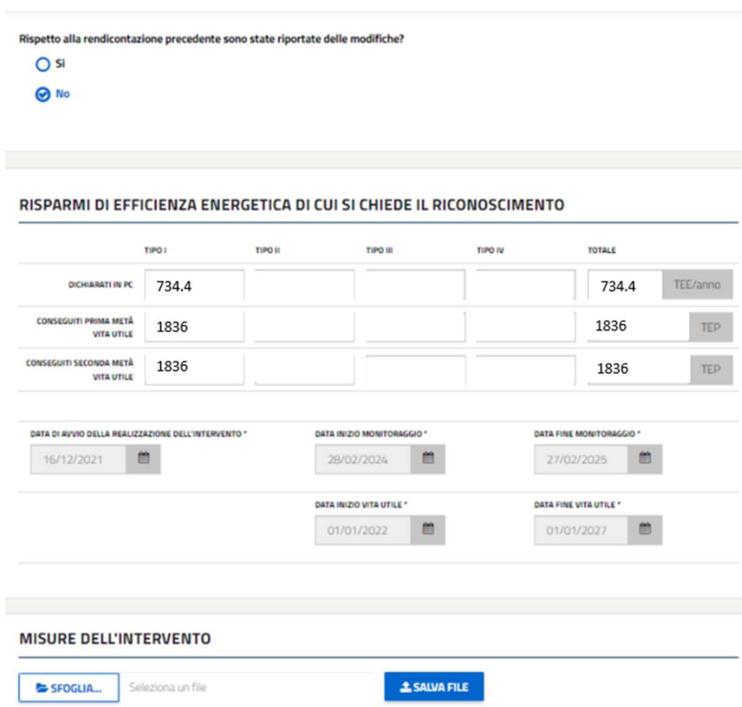
- Monitoring system description. In the SMAT WWTP of Castiglione Torinese, all the monitoring instruments needed in order to consider the baseline and ex-post consumption are available, for this reason no additional campaign and costs for the implementation of monitoring devices has to be considered. No technical information on the implemented devices for the monitoring are public, for this reason this information is not present in this work.
- Energy requirement measured with a daily frequency, for 12 months respectively before and after the intervention. In the case study the baseline and ex-post electricity requirement are estimated, no daily measurements are available.

6.2 REQUEST FOR REPORTING SAVINGS RELATED TO PC (RC)

As discussed in the presentation of the policy framework of the mechanism, GSE has 90 days to complete the evaluation after receiving the supporting documents for WhCs' requests for a specific intervention. Savings reporting requests must be made within 120 days of the conclusion of the applicable monitoring period. Also, the request for reporting saving is done through on-line procedure.

In this procedure the data from the monitoring period has to be inserted, together with data of the beginning of the work to implement the intervention and data of starting and finishing of monitoring plan.

In the case study of the matured eeos are of type 1, being not available real data, present are assumed to be equal to the calculated eeos.AS for the request presentation, also the request for the accounting requires to deal separately with modulus 1, 2, 3 and modulus 4.



Rispetto alla rendicontazione precedente sono state riportate delle modifiche?

- Sì
- No

RISPARMI DI EFFICIENZA ENERGETICA DI CUI SI CHIEDE IL RICONOSCIMENTO

	TIPO I	TIPO II	TIPO III	TIPO IV	TOTALE
DICHIARATI IN PC	734.4				734.4 TEE/anno
CONSEGUITI PRIMA METÀ VITA UTILE	1836				1836 TEP
CONSEGUITI SECONDA METÀ VITA UTILE	1836				1836 TEP

DATA DI AVVIO DELLA REALIZZAZIONE DELL'INTERVENTO * 16/12/2021

DATA INIZIO MONITORAGGIO * 28/02/2024

DATA FINE MONITORAGGIO * 27/02/2025

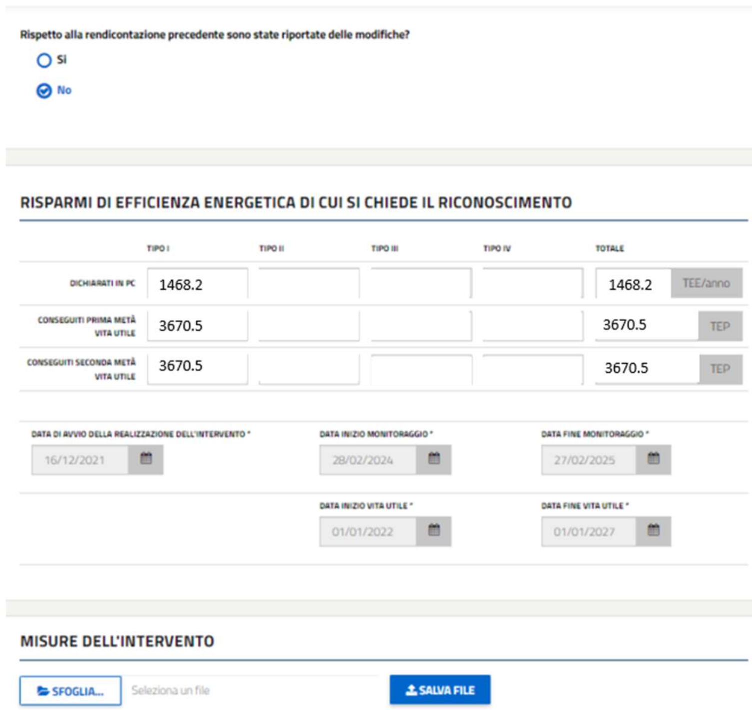
DATA INIZIO VITA UTILE * 01/01/2022

DATA FINE VITA UTILE * 01/01/2027

MISURE DELL'INTERVENTO

SFOGLIA... Seleziona un file SALVA FILE

Figure 32: RC in online platform for modulus 1,2,3 with intermittent aeration



Rispetto alla rendicontazione precedente sono state riportate delle modifiche?

Si

No

RISPARMI DI EFFICIENZA ENERGETICA DI CUI SI CHIEDE IL RICONOSCIMENTO

	TIPO I	TIPO II	TIPO III	TIPO IV	TOTALE	
DICHIARATI IN PC	1468.2				1468.2	TEE/anno
CONSEGUITI PRIMA METÀ VITA UTILE	3670.5				3670.5	TEP
CONSEGUITI SECONDA METÀ VITA UTILE	3670.5				3670.5	TEP

DATA DI AVVIO DELLA REALIZZAZIONE DELL'INTERVENTO * 16/12/2021

DATA INIZIO MONITORAGGIO * 28/02/2024

DATA FINE MONITORAGGIO * 27/02/2025

DATA INIZIO VITA UTILE * 01/01/2022

DATA FINE VITA UTILE * 01/01/2027

MISURE DELL'INTERVENTO

SFOGLIA... Seleziona un file SALVA FILE

Figure 33: RC in online platform for modulus 4 with step feed aeration

Within 90 days from the date of receipt of the requests for verification and certification of savings, the GSE concludes the evaluation and provides feedback to the proposing party.

If the assessment is positive, the GSE authorizes the GME to issue the energy efficiency certificates.

7 ECONOMIC EVALUATION OF THE PROJECT

In order to assess the economic return of the intervention and the goodness of the operation in budgetary terms, an amortization plan and the calculation of the payback period and net present value are proposed in this work.

7.1 INVESTMENT COSTS IN DIFFUSERS SUBSTITUTION AND OTHER COSTS

Considering all the energetic considerations done for the aeration in the biological treatment, acting on the energy efficiency of this particular system could be a key action in order to decrease strongly the energetic demand of the plant, and so the related costs and GHGs emissions.

In order to ensure a constant and optimal efficiency of the air diffusion systems serving the biological oxidation tanks at the SMAT plant in Castiglione Torinese, it was planned to replace the diffusers (59000, at present) and the distribution network at the bottom of the tanks. To this aim, a call for tenders was issued by SMAT published on G.U.U.E. n. S/243, on 15/12/2021, and G.U.R.I. V Serie Speciale Contratti Pubblici n. 144 on the same date.

The project was assigned to a temporary business groping constituted by TORRICELLI S.R.L. as agent for the group and CICLAT TRASPORTI AMBIENTE SOCIETA' COOPERATIVA as principal. The offer accepted on 25/05/2022 was 4.879.972,00 €.

According to the disciplinary in the call for tenders of SMAT and the offer accepted, reduced by 18,824% with respect to the estimation of costs in the disciplinary, the different prices for the operations can be obtained.

Operations	**Costs in disciplinary [€]**	**Costs by the winning company [€]**
Cleaning of the tanks	865000	702172.4
Demolition of existing infrastructure and disposal of waste materials	400000	324704
Supply and installation of air diffusion network	3520000	2857395.2
Supply and installation of electromixers and ancillary works	458000	371786.08

Supply and installation of ammonium, orthophosphate analyzers, and ancillary works	554000	449715.04
Supply and installation of flag recovery systems and ancillary works	53000	43023.28
Various completion works	100000	81176
Safety charges (not subject to rebate) related to services	20000	20000
Safety charges (not subject to rebate) related to the work	30000	30000
Total	6000000	**4879972**

Table 16: Costs for the different operations considered in the call for tenders of SMAT

The percentage attributable to the procurement and installation of the ventilation system, cleaning and demolition work was considered in relation to the total cost. In this way, that percentage is considered for the charges and various completion works costs. This calculated share is 79.6%. Taking these considerations into account, the cost to be included, strictly related to the energy efficiency intervention, will be as follows:

Operation	**Costs [€]**
Cleaning of the tanks	702172
Demolition of existing infrastructure and disposal of waste materials	324704
Supply and installation of air diffusion network	2857395
Various completion works	64613
Safety charges (not subject to rebate) related to services	15919.24
Safety charges (not subject to rebate) related to the work	23878.86
Total	**3988683**

Table 17:Investment costs strictly related to the aeration network substitution

The other cost related to this section of the plant is the maintenance cost. This annual outcome is assumed to be 6% of the cost of supply and installation of the air diffusion network:

$$C_{maintance} = 171443.71 \frac{€}{year}$$

7.2 COST OF ENERGY IN TIME AND REVENUES OF THE INTERVENTION

Once the costs are considered, in order to have a financial evaluation of the project the revenues related must be estimated.

In this particular case, the revenues are the cost avoided due to energy savings. For this reason, the incoming flow, as cost avoided, has a strict dependence on the cost of energy.

The energy market is a very dynamic system, strictly related to a complex system of geopolitical and technological constraints. Considering the complexity of the market a prediction of future energy prices, in order to have a robust estimation of the revenues, is not possible. To evaluate the impact of the cost of energy on the economical evaluation of the investment the costs of electric energy for non-household consumers in the period between 2008 and the second semester of 2022 are considered (21).

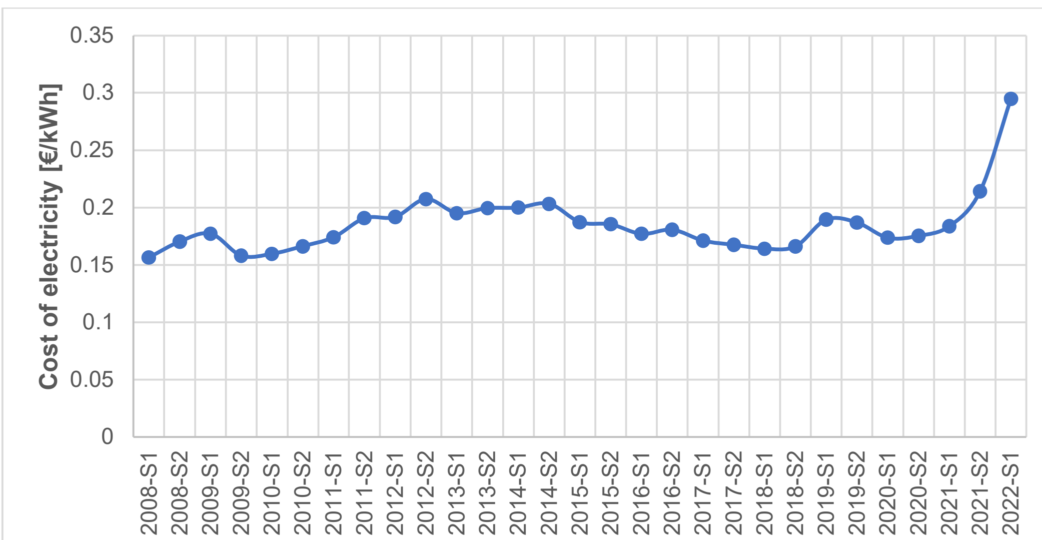


Figure 34: Electricity prices in time in Italy (source of data: Eurostat)

According to the distribution of prices, three energy costs are considered in this work:

$$c_{max} = 0.249\ €/kWh$$

$$c_{average} = 0.185\ €/kWh$$

$$c_{min} = 0.156\ €/kWh$$

A constant value of the price of electricity in 25 years is quite unrealistic assumption. For this reason, another case is considered: the case in which the dynamic of the cost of electric energy in the years between 2008 and 2022 remains equal in the years in which the study would be implemented. As discussed, this is another quite strong assumption, being impossible to predict the market, especially in a time span of 25 years. However, all these cases are considered in order to define a range of possible solutions in the economic evaluation of the project.

$$c_{dyn} = variable\ with\ periodic\ pattern$$

Once the prices of electric energy are set, the avoided cost in the plant can be considered as revenue of the investment and calculated for each year.

Equation 11: Calculation of the revenues from the electric energy saving for each year

$$Revenue_{i,energy\ savings} = \Delta kWh_i \cdot c_{\max|average|\min\ |dyn}$$

The calculated values are summarized in the table:

Year	Revenue min [€]	Revenue max [€]	Revenue average [€]	Revenue dyn [€]
0	1843356.44	3473519.58	2180469.11	1925217.95
1	1769622.18	3334578.79	2093250.34	1896266.07
2	1695887.92	3195638.01	2006031.58	1765782.34
3	1622153.66	3056697.22	1918812.81	1689009.20
4	1548419.41	2917756.44	1831594.05	1805170.10
5	1474685.15	2778815.66	1744375.28	1881754.79
6	1400950.89	2639874.87	1657156.52	1633249.14
7	1327216.63	2500934.09	1569937.75	1673225.82
8	1253482.37	2361993.30	1482718.99	1615110.04
9	1179748.11	2223052.52	1395500.22	1405144.08
10	1106013.86	2084111.73	1308281.46	1264318.72
11	1032279.60	1945170.95	1221062.69	1117038.66
12	958545.34	1806230.16	1133843.93	1011831.89
13	884811.08	1667289.38	1046625.16	1064317.48
14	811076.82	1528348.60	959406.40	904622.74
15	737342.57	1389407.81	872187.63	937343.79
16	663608.31	1250467.03	784968.87	1250467.03
17	589874.05	1111526.24	697750.10	616069.73
18	516139.79	972585.46	610531.34	553077.59
19	442405.53	833644.67	523312.57	460638.86

20	368671.27	694703.89	436093.81	383865.71
21	294937.02	555763.11	348875.04	343841.91
22	221202.76	416822.32	261656.28	282263.20
23	147468.50	277881.54	174437.51	171920.94
24	73734.24	138940.75	87218.74	92956.97
25	0.00	0.00	0.00	0.00

Table 18: Revenues as energy costs avoided in case of variable costs of electrical energy.

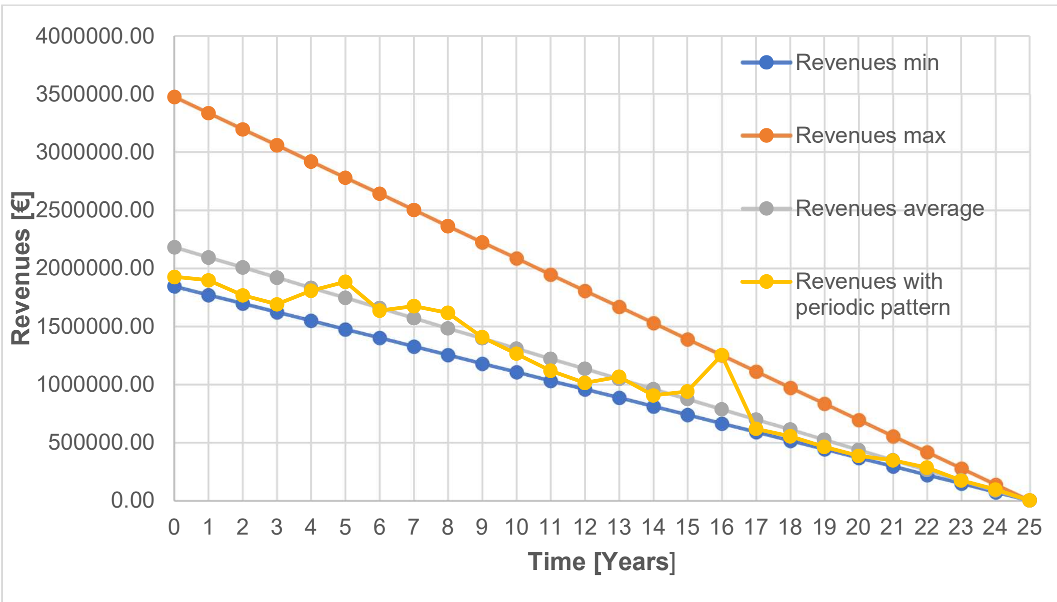


Figure 35: Graph of the revenues obtained by the energy savings in the plant during its lifetime, considering the variable cost of energy.

7.3 CALCULATION OF THE REVENUES FROM THE WHITE CERTIFICATES MECHANISM

The white certificates have a monetary value. Considering this type of PC, the eeo are matured for a period of 5 years and are calculated with respect to the first year of monitoring after the intervention. The market of these peculiar obligations has shown in time great instability (22).

This instability brought the necessity to deal with the problem. In DM 10/05/2018 a cap was defined, in order to decrease the market volatility, at 250 €.

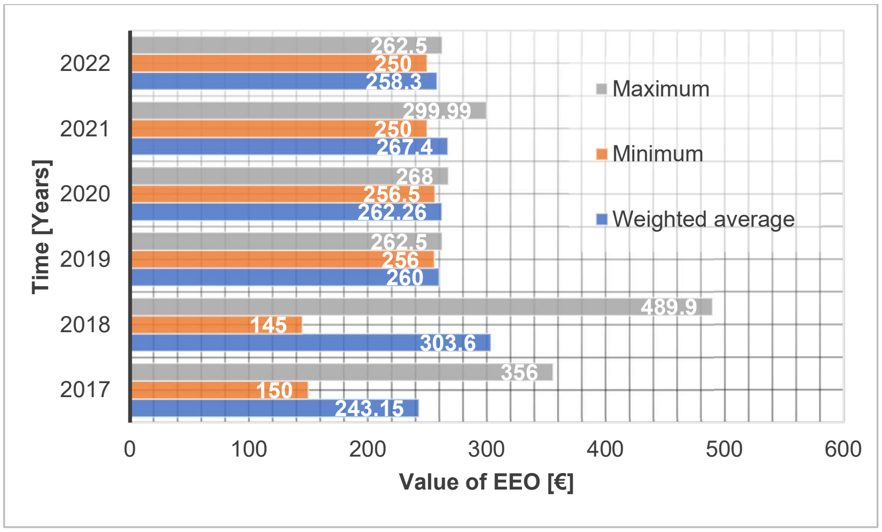


Figure 36: Market of eeo in time

After the great instability of the market in 2018, with an oscillation between 145 and 489.9 €/eeo, the introduction of the modification in the mechanism, brought by the decree of 2018, led to a value for the obligations that remain quite stable, with no significant variation.

On the basis of these observations, the value of eeo assigned in this study (r_{eeo}) is:

$$r_{eoo} = 260\ €$$

Once this value is established, considering the number of eeo calculated with Equation 1: calculation of energy savings based on algorithm 4 for wastewater treatment plant, the revenue from eeo, for each year, can be estimated:

Equation 12: calculation of revenues from eeo

$$Revenue_{eoo} = RISP_{tot} \cdot r_{eeo}$$

$$Revenue_{eeo} = 2311.4 \frac{eeo}{year} \cdot 260\ € = 600972.5 \frac{€}{year}$$

7.4 EVALUATION OF INVESTMENT CRITERIA: DISCOUNTED PAYBACK PERIOD AND NET PRESENT VALUE

Having identified both negative and positive cash flows, the viability of the project must be assessed by pointing out suitable investment criteria.

In this case study, the Discounted Payback Period (PBP) and the Net Present Value (NPV) are considered. All the calculations are differentiated considering the variation in revenues based on the variation of costs as discussed previously.

7.4.1 Discounted Payback Period

The Discounted Payback Period (PBP) is the time that an investment needs to start producing a positive cash flow, so it is the time necessary for a project to repay itself.

The Discounted PBP takes also into account the future value of the cash flow, considering that the actual value is decreased over time. The time value of money is factored in through the discount rate (k). According to the literature a k=4% is taken in this case study.

The calculation of Discounted PBP is obtained with the following equation:

Equation 13: calculation of the Discounted PBP

$$\sum_{t=1}^{PBP} F_{At} - \mathrm{F}_0 = 0$$

Where:

$F_0 = cost\ of\ the\ investment\ [€]$

$F_{At} = \frac{F_t}{(1+k)^t} = discounted\ cashflow[€]$

$F_t = cashflow\ given\ by\ the\ revenues\ minus\ the\ annual\ costs\ [€]$

$k = discount\ rate\ [\%]$

$$t = umpteenth\ year\ between\ 0\ and\ the\ lifetime\ of\ the\ project$$

Considering the actualized cumulative cash flow, Discounted PBP can be obtained graphically, where the function described in the Equation 13: calculation of the Discounted PBP, change in sign.

Once the graph is obtained, the Discounted PBP is retrieved through the solution of the second-degree equation, which well approximates the trend of the Equation 13: calculation of the Discounted PBP.

Considering revenues from energy savings and white certificates incentive matured for the first 5 years of the lifetime of the aeration system, varying the cost of energy as described in the previous subchapters, the obtained results for Discounted PBP will be the following.

Considering the maximum cost for electric energy:

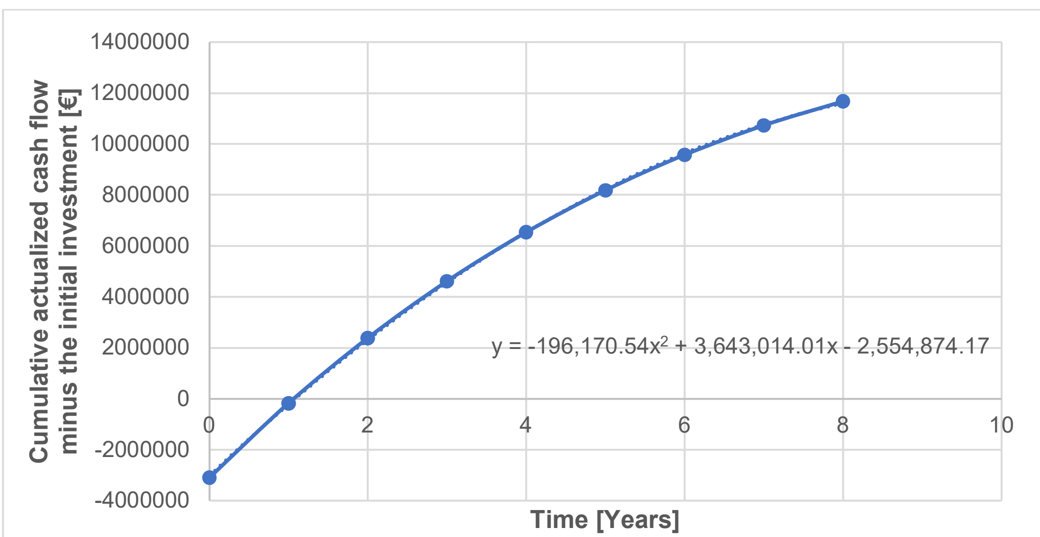


Figure 37:Cumulative actualized cashflow minus the initial investment in time with a max cost of electric energy

$$Discounted\ PBP_{max} = 0.73\ years$$

Considering the average cost:

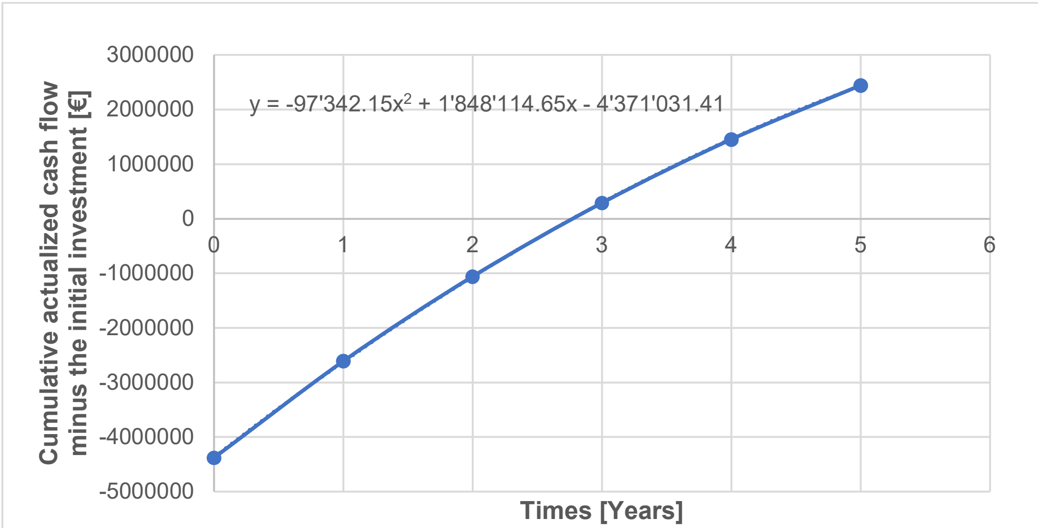


Figure 38: Cumulative actualized cash flow minus initial investment in time with the average cost of electric energy

$$Discounted\ PBP_{average} = 1.76\ years$$

Considering the minimum cost:

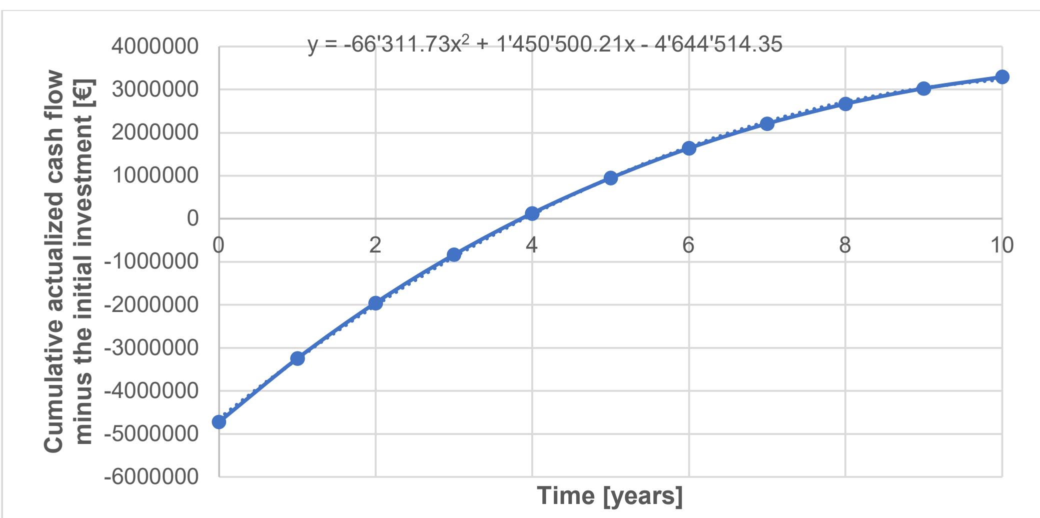


Figure 39: Cumulative actualized cash flow minus initial investment in time with min cost of electric energy

$$Discounted\ PBP_{min} = 2.26\ years$$

Considering that the dynamic of the electric energy cost expressed in the period 2008-2022 will be present in the period of the investment.

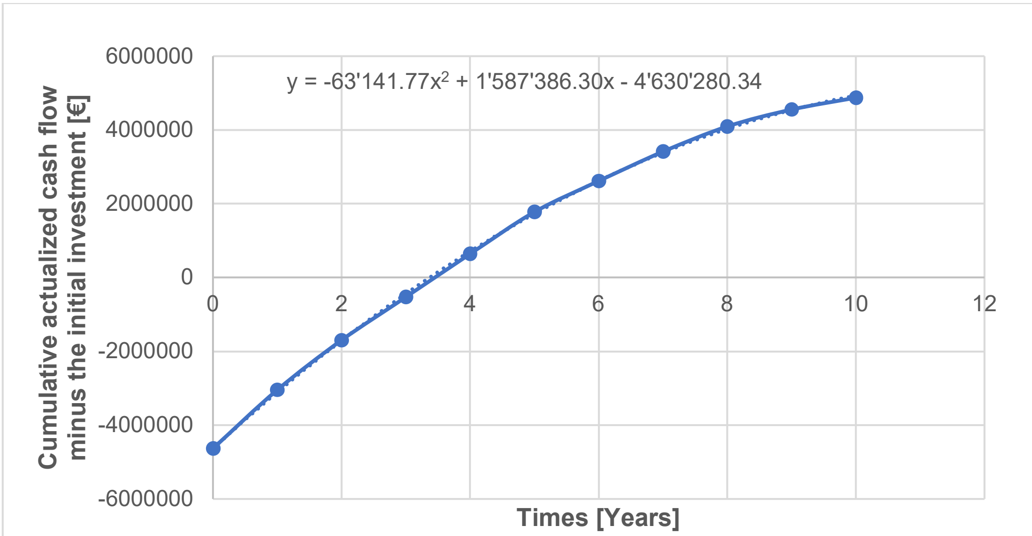


Figure 40: Cumulative actualized cash flow minus initial investment in time with the dynamic cost of electric energy

$$Discounted\ PBP_{dyn} = 2.06$$

According to the obtained results, in case of a very high cost of energy the investment is repaid in less than 1 year, however considering that the maximum cost of energy is related to a very particular historical moment, is more probable that a realistic Discounted PBP time is near to 2 years.

In order to better appreciate the contribution of the mechanisms in terms of repayment of the investment time, the Discounted PBP is also evaluated without the revenues matured through WhCs.

Considering the max cost of energy without WhCs:

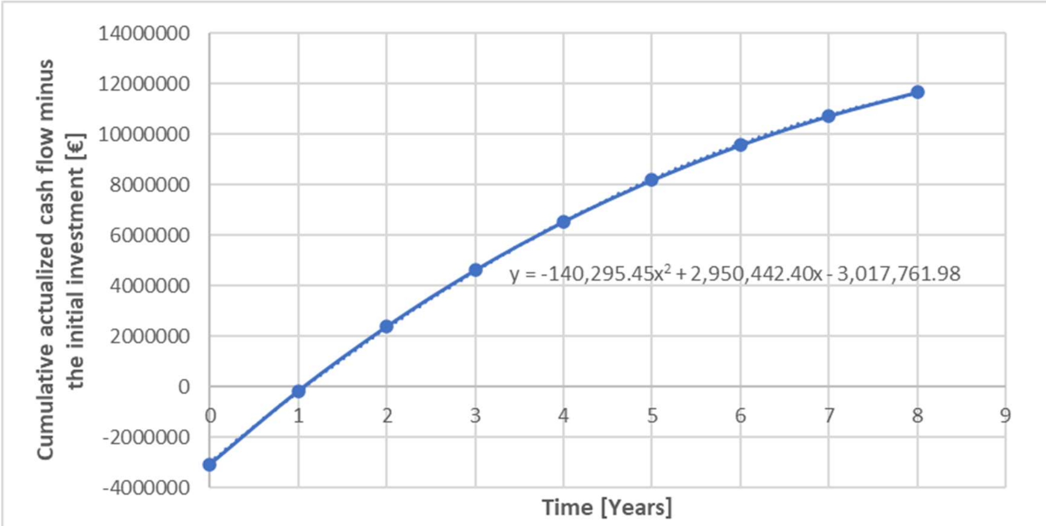


Figure 41:Cumulative actualized cash flow minus initial investment in time with maximum cost of electric energy, without revenues from WhCs

$$Discounted\ PBP_{max} = 1.08\ years$$

Considering average cost of electricity and no WhCs:

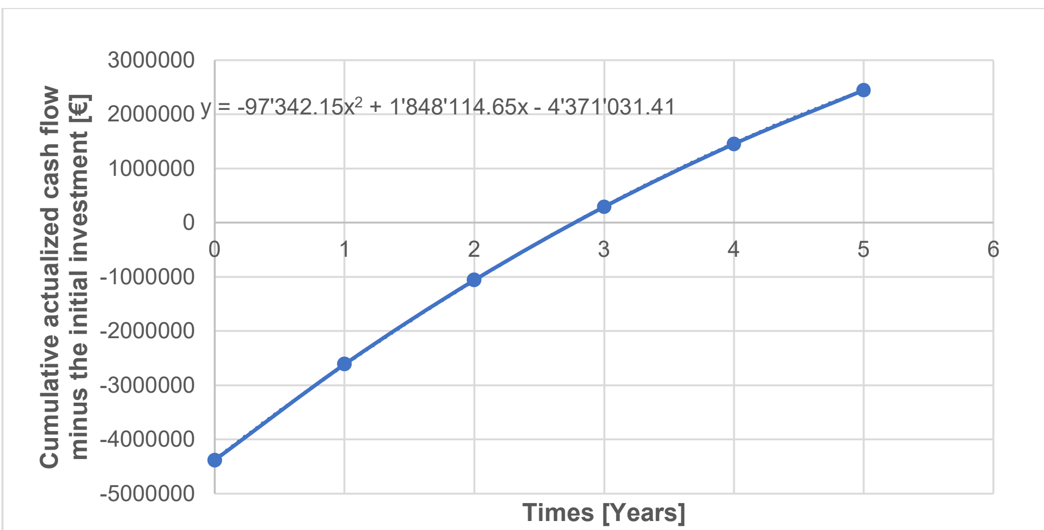


Figure 42:Cumulative actualized cash flow minus initial investment in time with average cost of electric energy, without revenues from WhCs

$$Discounted\ PBP_{average} = 2.77\ years$$

Whit minimum cost of electricity and no WhCs:

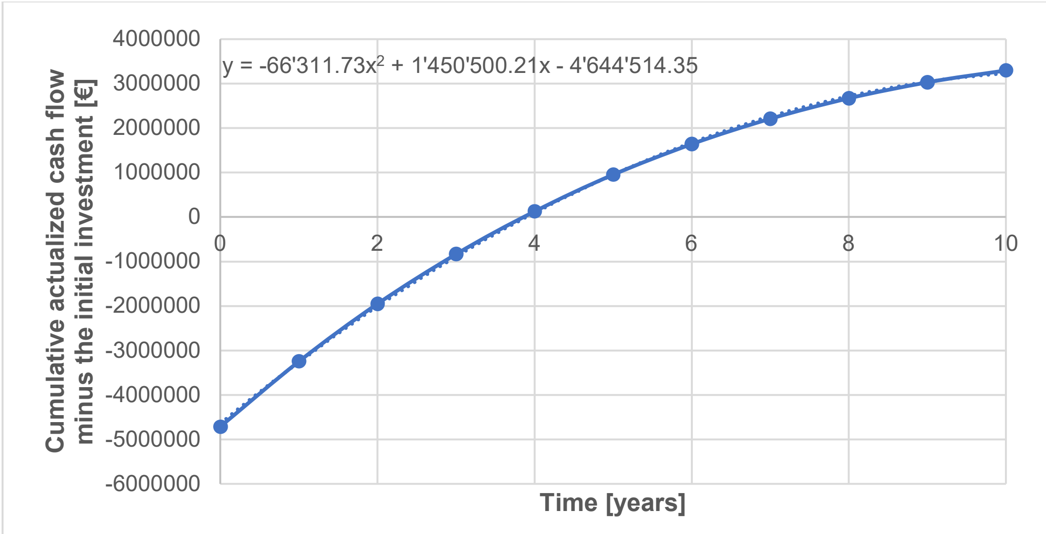


Figure 43:Cumulative actualized cash flow minus initial investment in time with minimum cost of electric energy, without revenues from WhCs

$$Discounted\ PBP_{min} = 3.89\ years$$

While whit a dynamic cost of electric energy, without the incentives:

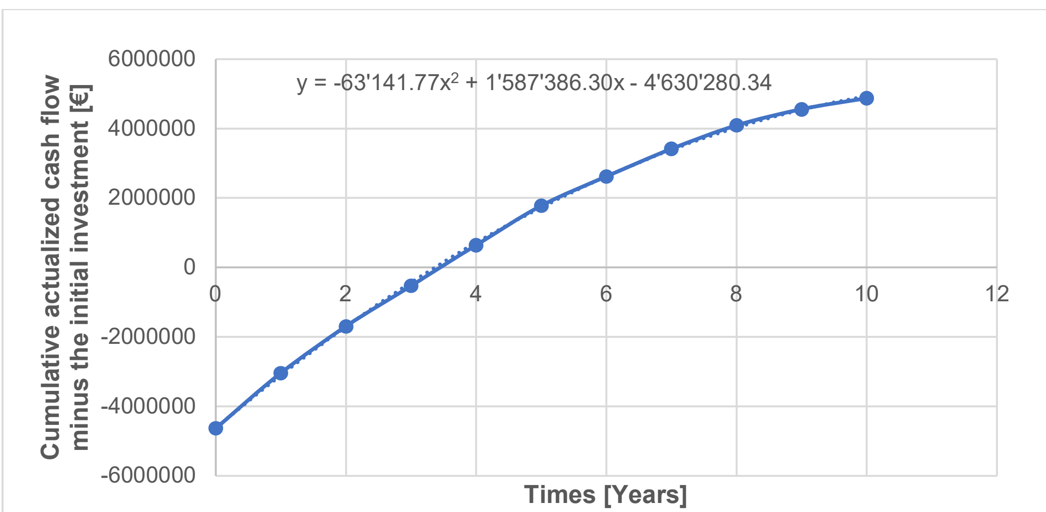


Figure 44:Cumulative actualized cash flow minus initial investment in time with dynamic cost of electric energy, without revenues from WhCs

$$Discounted\ PBP_{dyn} = 3.37\ years$$

The Discounted PBP is a widespread indicator, however, incomplete information is given by it. This investment criterion will not lead to an analysis of the lifetime of the project and no suggestion about the value added by the intervention is considered.

7.5 NET PRESENT VALUE

Once understood that Discounted PBP alone is not sufficient to determine the goodness of the investment, the NPV is calculated.

The NPV represents the algebraic sum of all the actualized cashflow, during the entire life of the project. The NPV takes us information about the long-term gain of the investment, indicating the richness created.

NPV can be calculated as:

Equation 14: Calculation of the Net Present Value

$$NPV = \sum_{t=1}^{lifetime\ project} F_{At} - F_0$$

Also, in this case, the NPV is calculated considering a maximum, average, minimum and with the same dynamic expressed before cost of energy. The results will be respectively:

$$NPV_{max} = 10{,}117{,}662\ €$$

$$NPV_{average} = 3{,}812{,}078\ €$$

$$NPV_{min} = 2{,}168{,}142\ €$$

$$NPV_{dyn} = 3{,}586{,}410\ €$$

The NPV is higher than 0 in all considered cases, even with the minimum revenues from the energy savings. The investment can therefore be considered worthwhile in any case, barring any anomaly in the energy market with an abrupt and constant fall in the cost of electricity over time. Even in this case, the dynamics of the market remain an unknown factor in determining with absolute precision the goodness of the investment.

The SMAT's declared profit, pre-taxation, for 2021 is equal to 48,000,000€ (23). Considering the NPV evenly spreads in the considered years (not a realistic assumption, but in this study, it is considered to have a measure of the enrichment achieved through the intervention), with a maximum cost of energy there will be an increase in the profit of 0.84% in a year, while with the average cost of energy of 0.31%, with the minimum of 0.18% and with the dynamic cost of electricity of 0.30%.

Considering the NPV without access to the incentive the obtained results are:

$$NPV_{max} = 8{,}878{,}311\ €$$

$$NPV_{average} = 2{,}572{,}727\ €$$

$$NPV_{min} = 928{,}791€$$

$$NPV_{dyn} = 2{,}347{,}059\ €$$

The same calculations with respect to the declared profit of SMAT can be done considering the NPV without WhCs revenues. With the maximum assumed cost of electricity, the profit will be increased by 0.74%, with the average by 0.21%, with the minimum by 0.08%, with the dynamic cost by 0.20%.

Summarizing the results obtained for the financial criteria adopted, the following table is produced:

Cost of energy in revenues [€/kWh]	**Discounted PBP [years]**	**Discounted PBP without WhCs [years]**	**NPV [€]**	**NPV without WhCs [€]**
0.249	0.73	1.08	10,117,662	8,878,311
0.185	1.76	2.77	3,812,078	2,572,727
0.156	2.26	3.89	2,168,142	928,791
As in 2008-2022	2.09	3.37	3,586,410	2,347,059

Table 19:Comparison between the financial criteria obtained with and without the revenues from the incentive, considering different costs for electric energy

8 AVOIDED GREENHOUSE GASES EMISSION THROUGH ENERGY EFFICIENCY INTERVENTION IN THE CASE STUDY

In EU policy climate change is, as discussed, a central theme. The main sector that contributes to GHG emissions in Italy, according to European Environmental Agency (EEA), is the energy supply sector with 87788.17 ktCO_2e in 2021.

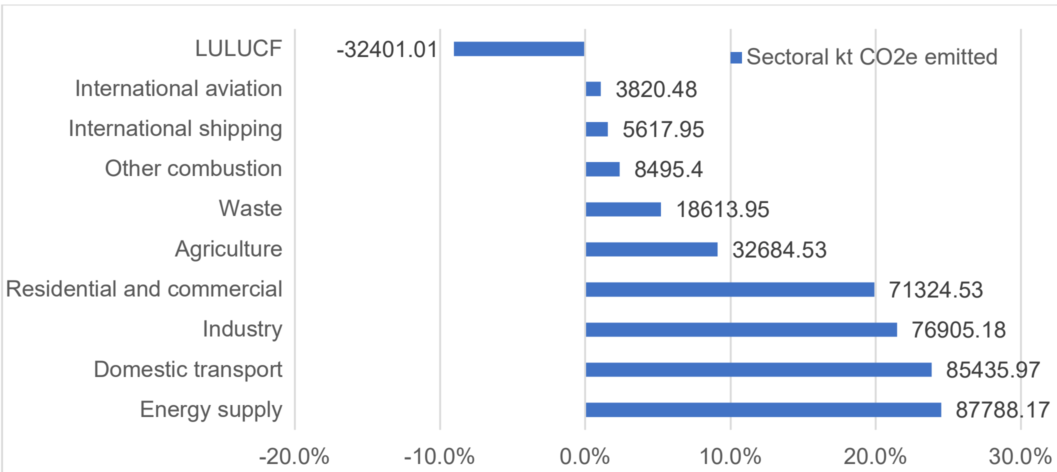


Figure 45: Emitted ktCO2e by sector in 2021, in Italy

Considering the importance of the contribution of this sector in GHGs inventory in Italy, energy efficiency has to be considered also an instrument for the reduction of the impact.

8.1 THE GREENHOUSE GASES PROTOCOL

Starting in 1998, the GHG Protocol provides a globally recognized and standardized method for the calculation and reporting of greenhouse gases emission from different sectors.

According to this Protocol, the emissions created can be categorized into 3 main groups(24):

- Scope 1: Direct GHG Emissions.

These emissions are related to sources that the company directly owns or controls. The main activities that generate these emissions are the transportation of material, workers, waste, and products; physical and chemical processes; combustion of fuels for the production of electricity or steam and heat.

- Scope 2: Electricity Indirect GHG Emissions.
  This GHG release is related to the electricity that company purchases in order to satisfy the power requirements of its owned devices.

- Scope 3: Other Indirect GHG Emissions.
  Are all the emissions, different from Scope 1 and 2, that are not directly related to the company, but are relevant for the business and goals of the company itself. Examples of Scope 3 emissions are derived by outsourced activities, franchises, end-of-life treatments, and purchased materials.

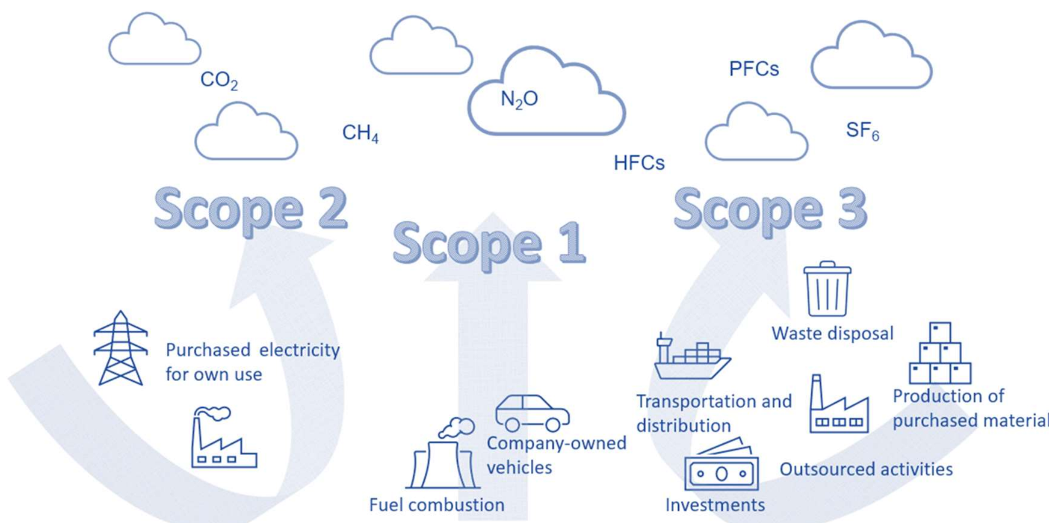


Figure 46: Emissions of GHGs, considering the Scope classification according to GHG Protocol

8.1.1 Scope 2: Electricity Indirect Greenhouse Gases Emissions

In the framework of this work, particular relevance is given to the indirect emissions of GHGs from the use of electricity in the aeration process.

The calculation for the specific purpose is done encompassing the guidelines given for Scope 2 emissions (25). In order to better understand the results of this study a general overview of Scope 2 accounting is given.

For Scope 2, two methods are used to evaluate the emissions from electricity consumption:

- Location-based method;
- Marked-based method.

The location-based approach is based on aggregated and averaged statistics data on electricity production and emissions over a specified time period and geographic region. With this method so, specific emissions factors are obtained by averaging over a specific location.

The marked-based method considers, instead, the contractual information and claims flow, which may be distinct from the underlying energy flow in the grid, in contrast to the location-based technique. The GHG emissions are connected to a consumer's selection of an electrical provider or product in this approach. Agreements between the buyer and the provider specify these options, including selecting a retail power supplier, a particular generator, or a differentiating electrical product. This second method is mostly used by individual corporate procurement actions.

Considering the previous description of the methods, the most suitable approach seems to be the marked-based one, however, being no available information on the specific contractual agreements between SMAT and the electricity provider the calculation is performed using a location-based approach.

According to the calculation algorithm (26):

Equation 15: Calculation of emissions of GHGs according to Scope 2 algorithm

$$Emission_{GHG,fuel} = Fuel\ Consumption\ \cdot Emission\ Factor_{fuel}$$

The emission factor, as discussed, is chosen according to national data (27), related to electricity consumption in Italy:

$$Emission\ Factor = 0.2583 \frac{kgCO_2e}{kWh}$$

Considering all the observations on the decay of the efficiency in air distribution of the section of the plant, the avoided emissions can be calculated considering the ΔkWh for 25 years.

$$Avoided\ Emission_{GHG,i} = Emission\ Factor\ \cdot\ \Delta kWh_i$$

With i= umpteenth year.

Year	Emission factor in kgCO2e/kWh	Delta KWh	kgCO2e/year
0	0.2583	11778635.4	3042421.5
1		11307490.0	2920724.7
2		10836344.6	2799027.8
3		10365199.1	2677330.9
4		9894053.7	2555634.1
5		9422908.3	2433937.2
6		8951762.9	2312240.3
7		8480617.5	2190543.5
8		8009472.0	2068846.6
9		7538326.6	1947149.8
10		7067181.2	1825452.9
11		6596035.8	1703756.0
12		6124890.4	1582059.2
13		5653744.9	1460362.3
14		5182599.5	1338665.5
15		4711454.1	1216968.6
16		4240308.7	1095271.7
17		3769163.3	973574.9
18		3298017.8	851878.0
19		2826872.4	730181.1
20		2355727.0	608484.3
21		1884581.6	486787.4
22		1413436.2	365090.6
23		942290.7	243393.7
24		471145.3	121696.8
25		0.0	0.0

Table 20: calculation of the avoided emissions of GHG related to the substitution of diffusers in Castiglione Torinese WWTP

Summing up all the terms reported in the table, the total amount of avoided emissions for the lifetime of the project, expressed as $kgCO_2e$ and tCO_2e, can be obtained:

$$Avoided\ Emissions_{GHG,tot} = 39{,}551{,}479 kgCO_2e = 39{,}551.5\ \ tCO_2e$$

As can be appreciated not only the intervention leads to an economic advantage but is also important for the reduction of GHG emissions in the plant.

9 CASE STUDY: WHITE CERTIFICATES MATURED FOR THE SUBSTITUTION OF FINE BUBBLE DIFFUSERS IN THE CASTIGLIONE TORINESE WWTP ASSUMING VARYING TEMPERATURES DURING THE YEAR

The calculations performed in the previous chapter are based on the strong assumption that the temperature of the basin and the temperature of the air at the inlet of the turbochargers remain constant during the year. Considering that the power required for the compression of the air is a linear function of the inlet temperature and that the parameters used to calculate the oxygen transferred are a function of the temperature of the basin, a more proper approach needs to vary the output results of this study varying both these temperatures.

In this second part of the study, the variation in temperatures is so considered. This case is analyzed taking into account that the participation in the mechanism is based on monitored data, with daily measurements so a more discrete calculation of the different parameters is more appropriate.

First of all, the temperature in the location of the plant is taken from the climatic data available (28). The temperature taken as reference is the maximum temperature for each month, given by the mean in the period between 1991 and 2021:

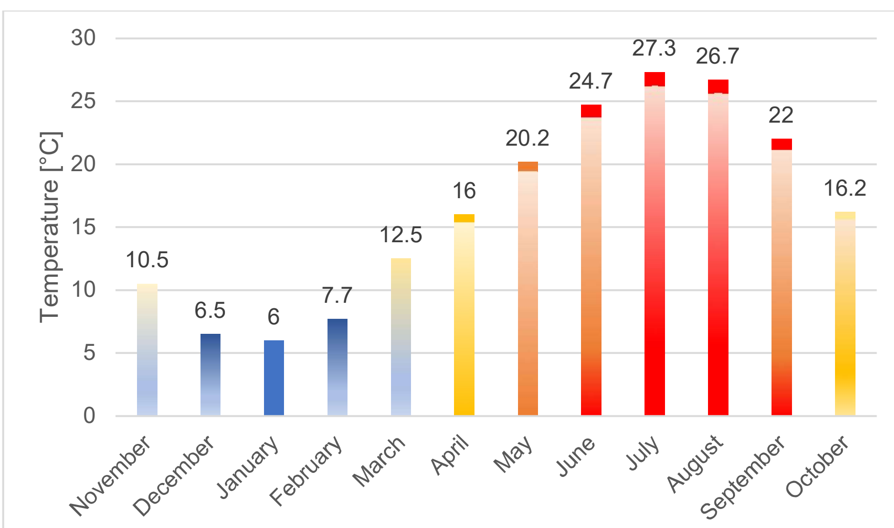


Figure 47: Maximum mean temperature for each month in the location of the plant

For the inlet temperature at the turbocharger for each month is assumed that:

$$T_{inlet} = T_{ext} + 3°C$$

Where T_{ext} in the temperature retrieved by the climatic data, while the increase in 3°C is chosen in order to better consider the operative condition of the turbochargers. It is assumed that in the area where the devices are in winter the temperature will be less cold, while in summer the temperature probably will increase for the heat related to the working machines.

From available information on temperature in the basin of the WWTP in exam, the mean temperature in summer months is 23°C, while in winter months it is 17°C. Starting from this data and considering a distribution of temperatures with the mean values fixed and that follows the external temperature, the temperature in the basin for each month is considered.

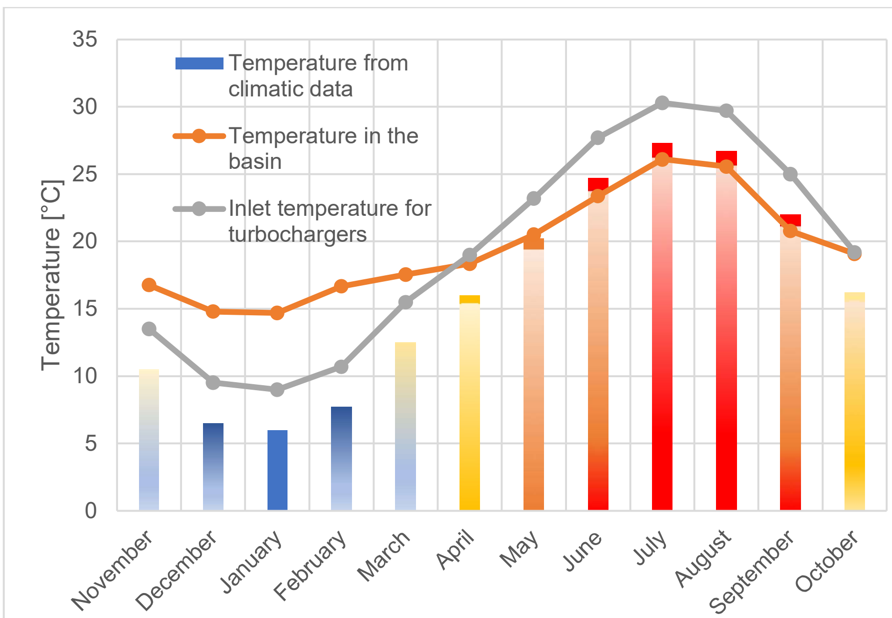


Figure 48: Temperature from climatic data, Temperature assumed to be in the aeration basin and Temperature at the inlet of turbochargers

The other assumptions discussed in the previous chapters still held in this study and the same devices are assumed to be used.

9.1 ESTIMATION OF AIRFLOW FOR EACH DIFFUSER, SOTR, SOTE AND OTR IN BASELINE AND EX-POST CONFIGURATION

The airflow from each diffuser is assumed equal to 6.5 Nm^3/h in baseline configuration.

$$Q_{diff\ baseline} = 6.5\ \frac{Nm^3}{h}$$

This aspect remains constant even with varying temperature, being this airflow rate based on project hypothesis.

Also, SOTE and SOTR, being not dependent on temperatures, remain unvaried:

$$SOTE_{baseline} = 24\%$$

Once all the terms are known the SOTR can be calculated:

$$SOTR_{baseline} = 0.437 \frac{kgO_2}{h \cdot diffuser}$$

Considering the Equation 5: OTR calculation, the Oxygen Transfer Rate can be retrieved in baseline configuration.

$$OTR_f = SOTR \left[\frac{\tau \beta \omega C^*_{\infty 20} - C}{C^*_{\infty 20}} \right] [(\theta)^{t-20}] \alpha F$$

In this case, the OTR_f is a function of the basin temperature, being dependent on:

$\tau = temperature\ correction\ factor = C^*_{st} / C^*_{s20}$

$\omega = pressure\ correction\ factor = \frac{P_b}{P_s} = \exp\left[-\frac{gM(z_b - z_a)}{RT}\right]$

$t = temperature\ of\ the\ basin$

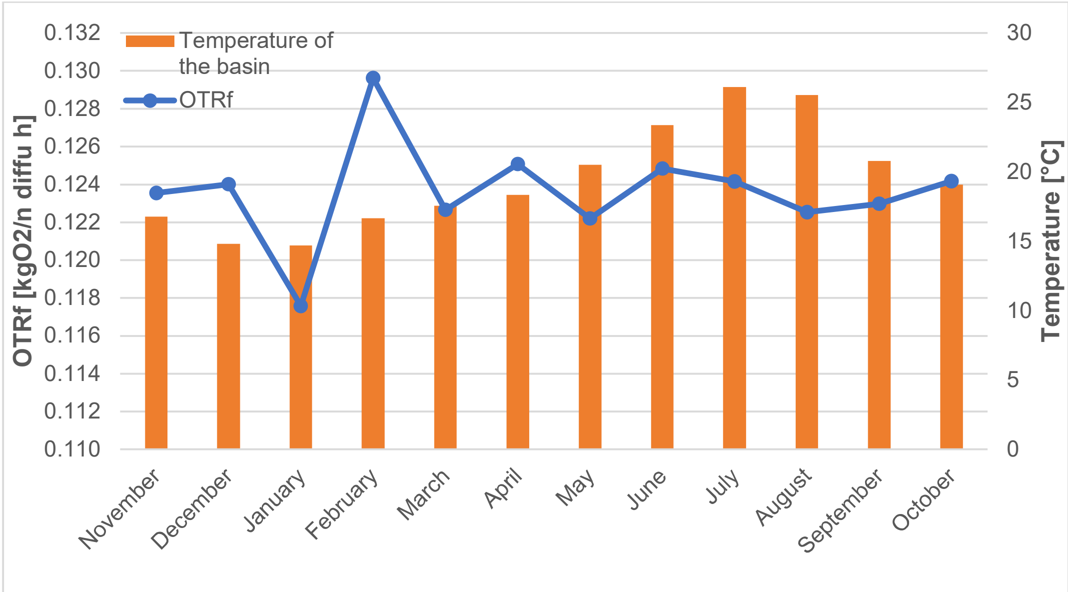


Figure 49: OTRf variation with temperature of the basin

The SOTR and SOTE being not a function of the temperature remain unvaried, together with the Q_{diff}:

$$SOTR_{ex\ post} = 0.297 \frac{kgO_2}{h\ diffuser}$$

$$SOTE_{ex\ post} = 31\ \%$$

$$Q_{diff\ ex\ post} = 3.4\ \frac{Nm^3}{h}$$

9.2 Estimation of transferred oxygen, electric power requirements, Standard Aeration Efficiency and matured white certificates with temperature variation

Also considering a varying temperature the calculations are differentiated as discussed in chapter 7.

9.2.1 Calculation for moduli 1,2 and 3, working with intermittent aeration

The transferred oxygen is a function of the OTR_f, as expressed in Equation 6: Calculation of the transferred oxygen.

The obtained Transferred oxygen in the months in function of temperature of the basin is proposed in the graph:

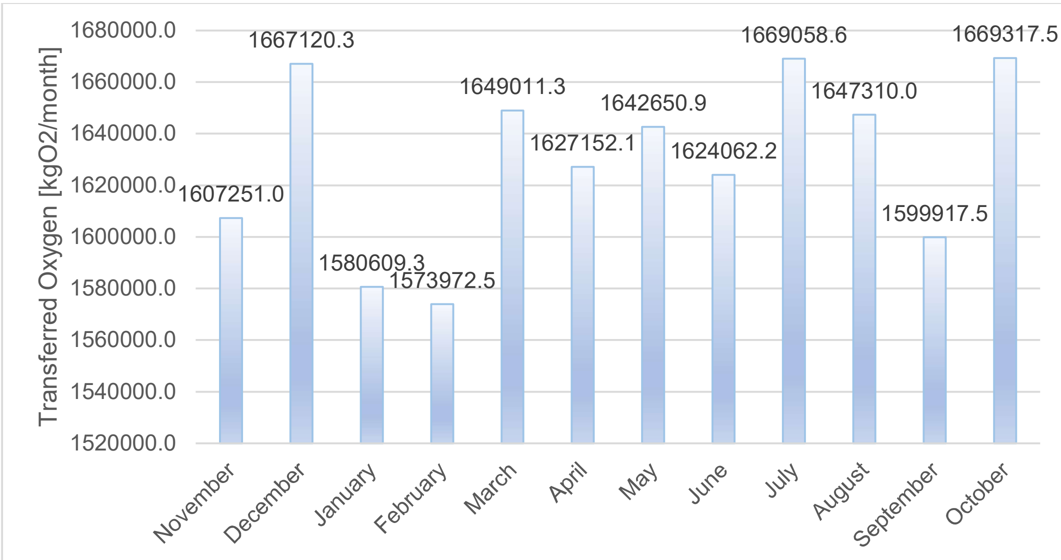


Figure 50: Transferred Oxygen in different months in function of temperature

The transferred oxygen for one year can be obtained by summing up the terms referred to each month:

$$Transferred\ Oxygen_{year} = \sum_{i=0}^{12} Transferred\ Oxygen_{mont} \quad = 19557433.1 \frac{kgO_2}{year}$$

With Transferred $Oxygen_{month}$ = values in Figure 50.

The Dry air flow rate remains equal to the case without a change in temperature:

$$Q_{air\ baseline} = 6.5 \frac{Nm^3}{h\ diffuser} \cdot 9.8 \frac{h}{d} \cdot 44250\ diffusers = 2818725 \frac{Nm^3}{d}$$

$$Q_{air\ ex\ post} = 3.4 \frac{Nm^3}{h\ diffuser} \cdot 9.8 \frac{h}{d} \cdot 44250\ diffusers = 1482275 \frac{Nm^3}{d}$$

Referring to Equation 8: Calculation of the electric power can be understood that the power requirement is a function of the temperature at the inlet and of the other parameters that remain unvaried with respect to chapter 7.

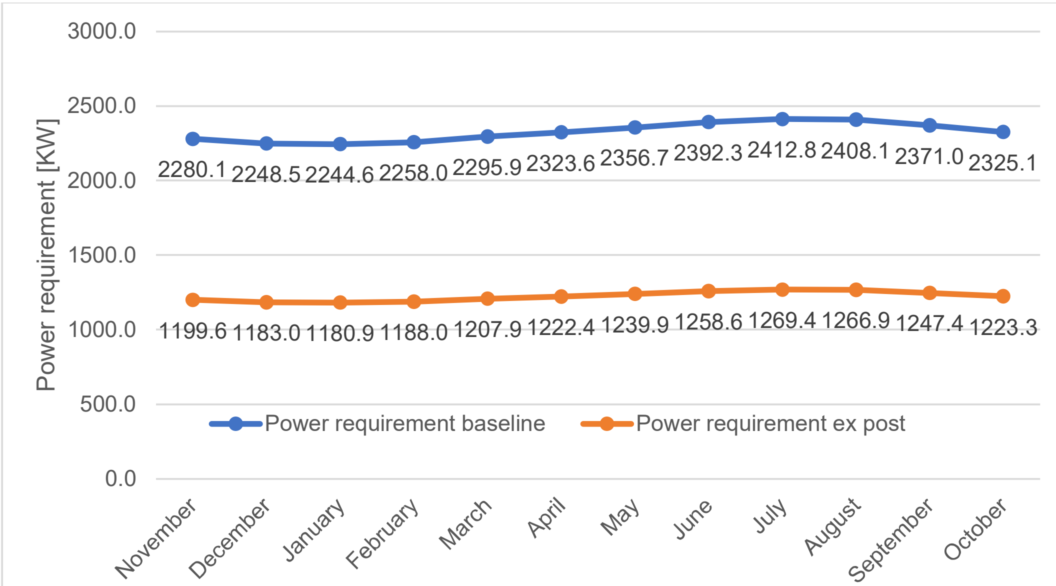


Figure 51: Power requirement in ex post and baseline configuration considering varying temperature

Calculated the power requirement, the electric energy necessary for the aeration can be retrieved for each month in baseline and ex-post situation.

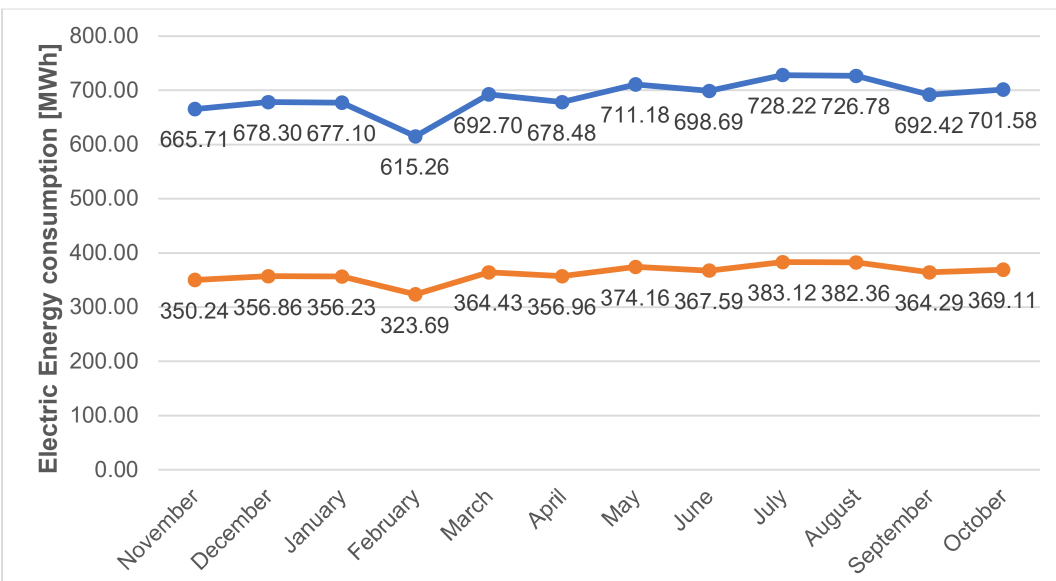


Figure 52: Electric energy consumption in the different months, considering varying temperatures, in baseline and ex-post configuration

Summing up the different terms over one year:

$$Energy_{baseline} = 8322919\ kWh = 8322.9\ MWh$$

$$Energy_{ex\ post} = 4349.0\ MWh = 4349024\ kWh$$

Considering Equation 9: Standard Aeration Efficiency calculation:

$$SAE_{baseline} = \frac{19557433.1 \frac{kgO_2}{year}}{8322919\ kWh} = 2.37 \frac{kgO_2}{kWh}$$

$$SAE_{ex\ post} = \frac{19557433.1 \frac{kgO_2}{year}}{4349024\ kWh} = 4.50 \frac{kgO_2}{kWh}$$

So, the resulting eeo will be:

$$RISP_{varying} = \left(\frac{1}{2.37 \frac{kgO_2}{kWh}} - \frac{1}{4.50 \frac{kg0_2}{kWh}} \right) \times 19557433 \frac{kgO_2}{year} \times 0.000187 \frac{eeo}{kWh}$$
$$= 732.6 \frac{eeo}{year}$$

According to this result, an overestimation of the matured WhCs is done considering the temperature of the basin constant and equal to 17°C and the temperature at the inlet of the turbocharger constant and equal to 20°C. The difference in the calculation is equal to:

$$\Delta eeo_{year} = RISP_{T=con} \quad - RISP_{varying} = (734.4 - 732.6) \frac{eeo}{year} = 1.8 \frac{eeo}{year}$$

The difference is in the order of 0.2% in this section of the plant, not a significative difference.

9.2.2 Calculation for modulus 4 working in step feed configuration

The same estimation can be performed considering the modulus 4.

The obtained results for each month is tabled below:

	Transferred Oxygen [kgO2/month]	Baseline consumption [kWh]	Ex-post consumption [kWh]
November	1312041.6	543436.5	703156.2
December	1360914.5	1356036.7	716228.5
January	1290293.3	1353637.9	714974.4
February	1284875.5	1230007.3	649834.8
March	1346131.7	1384822.2	731758.6
April	1328287.4	1356400.3	716823.4
May	1340939.5	1421763.5	751644.9
June	1325765.0	1396792.9	738776.2
July	1362496.8	1455826.4	770356.4
August	1344742.8	1452947.8	768773.9
September	1306055.1	1384257.3	731844.5
October	1362708.2	1402573.2	741317.1

Table 21: Transferred Oxygen and energy consumption for each month in baseline and ex-post configuration

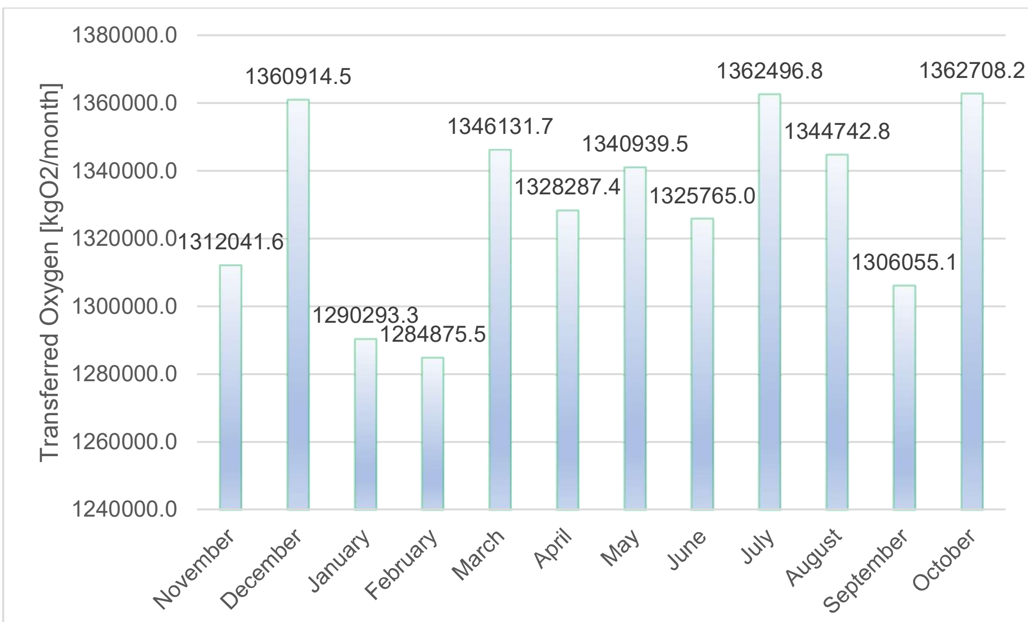


Figure 53: Transferred Oxygen in modulus 4

Summing up the terms for all the year:

$$Transferred\ Oxygen_{year} = 15965251.5 \frac{kgO_2}{year}$$

The power requirements are also obtained in this case as expressed by the following figure:

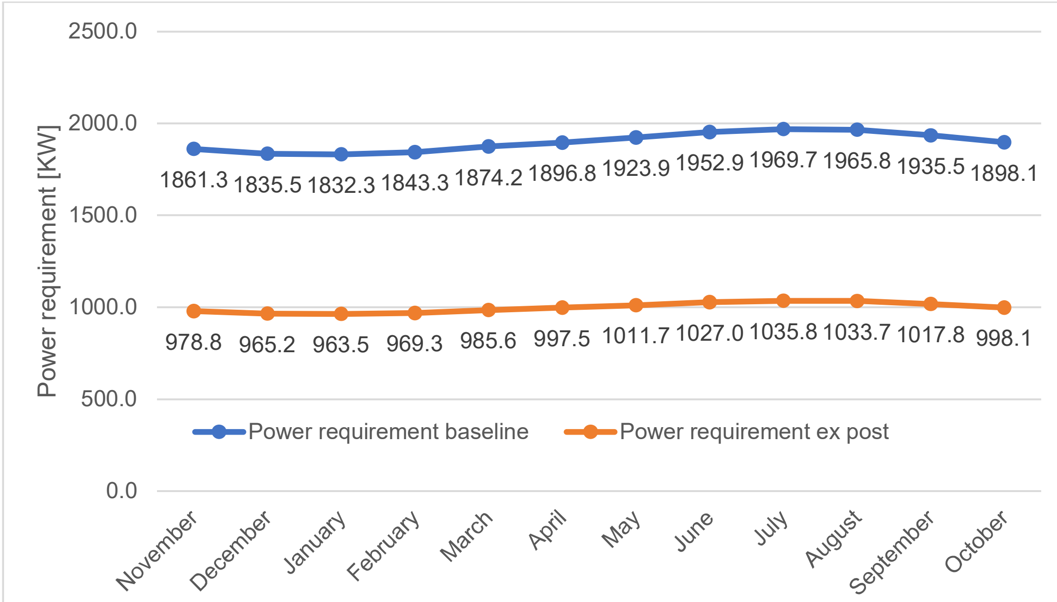


Figure 54: Power requirement for modulus 4 in ex post and baseline configuration

Considering the energy consumption, the results obtained are calculated and reported in the graph:

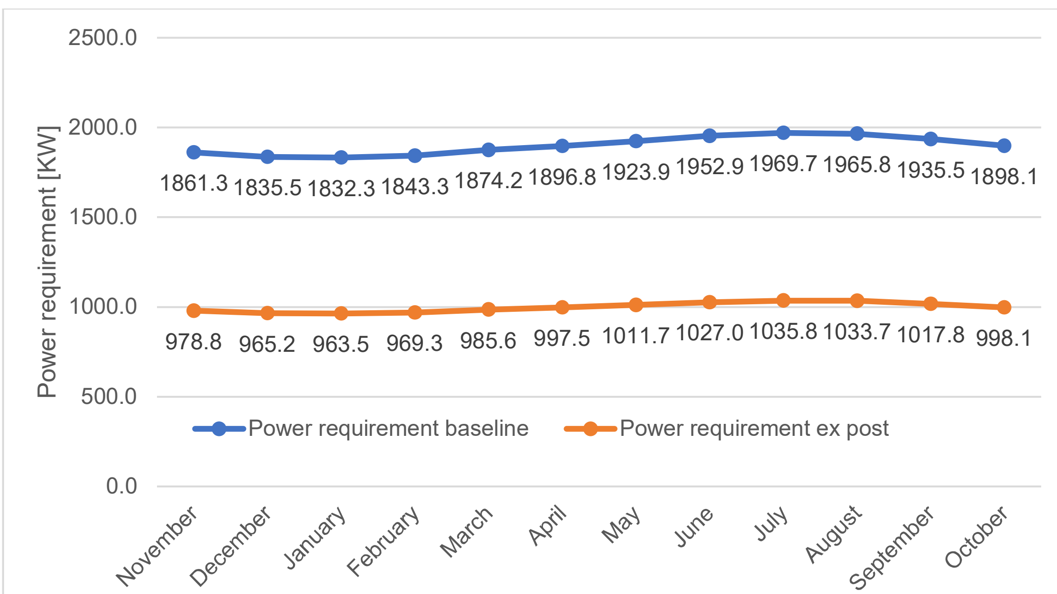


Figure 55: Energy consumption in ex post and baseline configuration for modulus 4

Summing up the terms:

$$Energy_{baseline} = 166380906\ kWh = 16638.9\ MWh$$

$$Energy_{ex\ post} = 8690449\ kWh = 8690.4\ MWh$$

The Standard Aeration Efficiency can be so calculated:

$$SAE_{baseline} = \frac{15965251.5 \frac{kgO_2}{year}}{16525930\ kWh} = 0.96 \frac{kgO_2}{kWh}$$

$$SAE_{ex\ post} = \frac{15965251.5 \frac{kgO_2}{year}}{8690449\ \ kWh} = 1.84 \frac{kgO_2}{kWh}$$

Finally, the RISP in eeo/year can be obtained:

$$RISP_{varying} = \left(\frac{1}{0.97 \frac{kgO_2}{kWh}} - \frac{1}{1.84 \frac{kg0_2}{kWh}} \right) \times 15965251.5 \frac{kgO_2}{year} \times 0.000187 \frac{eeo}{kWh}$$
$$= 1465.24 \frac{eeo}{year}$$

The value obtained without considering the variation of temperatures is of 1468.2 eeo/year. The difference between the 2 terms is:

$$\Delta eeo_{year} = RISP_{T=con} \quad - RISP_{varying} = (1468.2 - 1465.2) \frac{eeo}{year} = 3 \frac{eeo}{year}$$

Be the calculations analogous also in this case the difference is in the order of 0.2%.

In conclusion, it can be stated that temperatures taken to calculate as first approximation the energy consumption and so the RISP well approximate the real situation with varying temperatures during the year.

10 CONCLUSIONS

During this study, the importance of energy efficiency intervention in the plant is understood. The EU policy in the energetic sector considers a pillow “energy efficiency first”. Under this perspective, the studied case represents an investment profitable to meet the European goals in terms of GHG emission reduction and a decrease in energy consumption.

The intervention leads itself to good results in terms of revenues accounted as cost avoided related to the energy savings during the lifespan of the project. The access to WhC mechanism allows a further increase in the value of the project, making the intervention even more profitable. The already installed monitoring devices in the Castiglione Torinese WWTP should make participation to the mechanism easier, being not necessary further works other than that planned for the substitution of the aeration network. This observation implies also avoiding costs for the installation of the monitoring instruments.

10.1 EVALUATION OF SAVED ELECTRIC ENERGY

Considering the total electric energy requirement of the plant, as declared by SMAT (17), the substitution of the aeration network as planned in this case study, will lead in the first year to a decrease in consumption of 21.4%. The energy saved in the biological treatment, corresponding to about one-half of the total electric energy requirement, will be 42.7% in the first year.

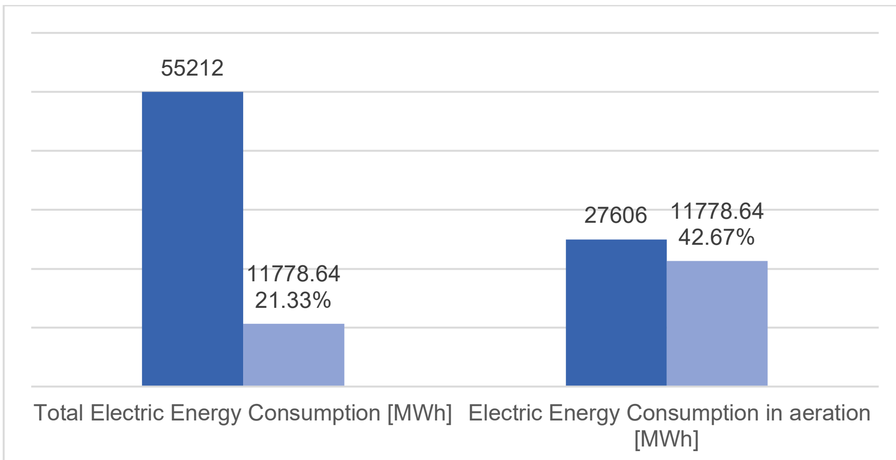


Figure 56: Percentage of saving with respect to baseline consumption on the total consumption and on the consumption in the aeration operation in the first year of implementation

As discussed, the efficiency of the system is expected to decrease. Assuming the lifespan of the project is equal to 25 years, the energy savings on the total, related to the intervention will be equal to 11.1%, while considering the biological treatment only this percentage passes to 22.2%.

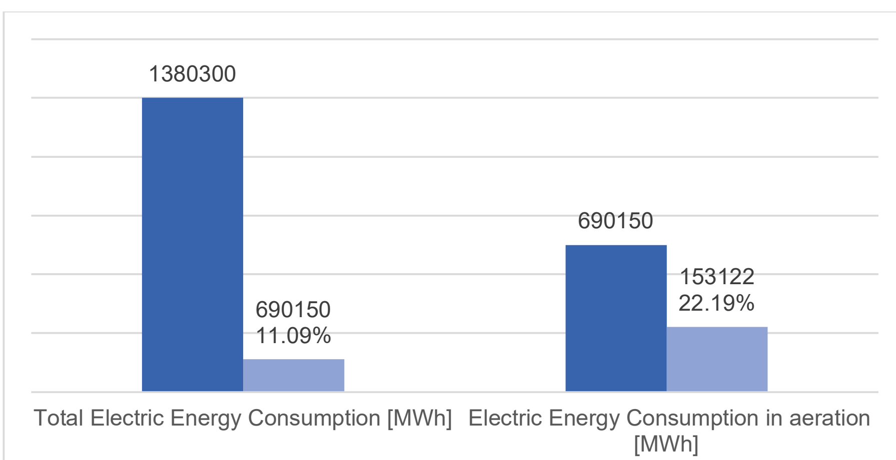


Figure 57: Percentage of saving with respect to baseline consumption on the total consumption and on the consumption in the aeration operation considering all the lifespan

Without any doubt, this is an important result in terms of electric energy conservation in the plant. This consideration assumes particular importance under the current geopolitical assets, contributing to reducing energy in a sector that accounts for more than 1% of the overall electricity consumption in the EU.

10.2 EVALUATION OF INVESTMENT PROFITABILITY

As reported, the electric energy saved through the project leads to avoided costs in the plant. These incremental costs that are not incurred can be considered as a positive cash flow in the plant, which allows understanding the profitability of the implementation.

The revenue coming from the higher energy efficiency can be added to potential revenues coming from the participation in WhCs mechanism, that in the specific case of the considered WWTP, does not require additional investment for the monitoring phase. The white certificates accrued from the replacement of the aeration network provide an additional gain for the first 5 years of the project's life, as prescribed by legislation.

The access to WhCs leads to a non-negligible increase of the current value of the future cash flows of the company, in all considered cases.

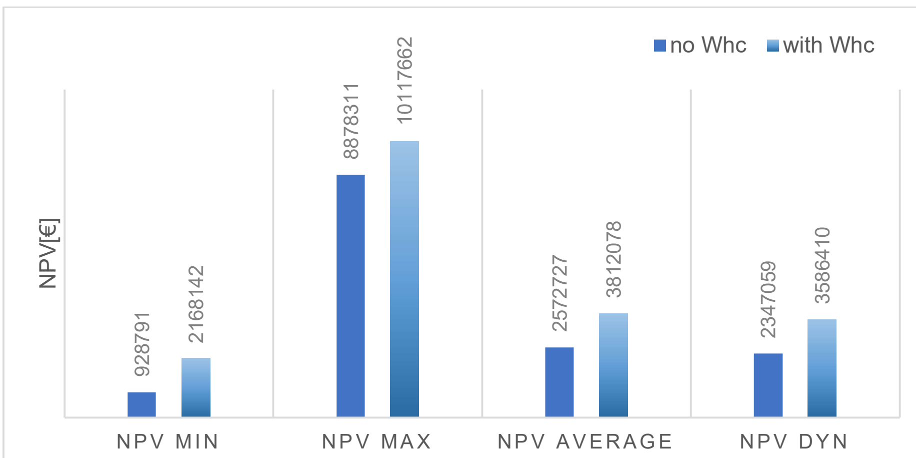


Table 22: NPV comparison with and without the incentive of WhCs

Considering the discounted PayBack Period, the value assumed in years is always below 2.5 years with participation to the mechanism. Taking the same indicator without the revenues coming from WhCs, the discounted PBP assumes higher value, with the time of repayment of the investment that in case of minimum cost of energy is near to 4 years.

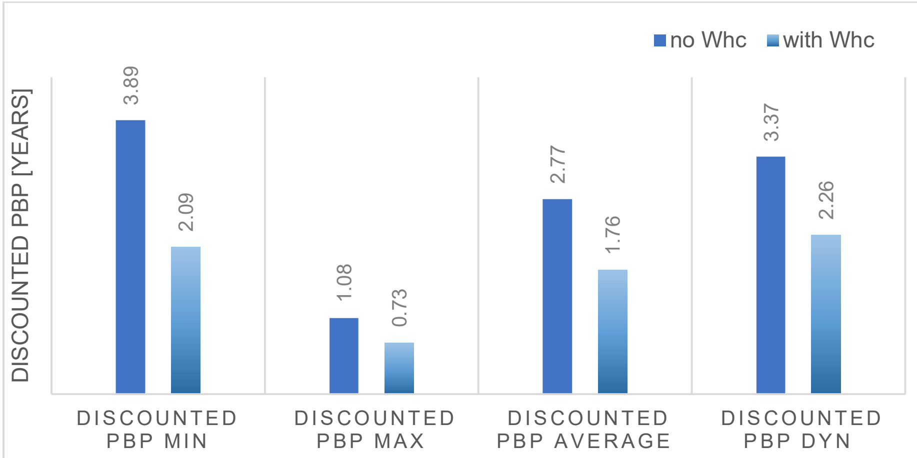


Figure 58: discounted PBP with and without WhCs

10.3 REDUCTION OF THE GHGS EMISSIONS FROM THE PLANT

Energy efficiency is also understood as climate change mitigation action. Reducing electricity consumption within a plant brings with it benefits in terms of GHGs reduction.

To keep the public's trust, the primary goal of the WWT sector has always been to achieve water quality criteria. Therefore, with minimal attention to energy efficiency, WWTPs are often built to meet effluent standards. Because of this, very few, if any, WWTPs were built with energy-efficiency standards in mind. However, this mindset has begun to shift in recent years, mostly due to the broad framework for achieving the 2030–2050 climate and energy goals established by the European Union (29).

Thinking to the Castiglione Torinese in terms of energy efficiency leads also so to environmental benefits in terms of reduced impact dealing with climate change.

In order to better appreciate the contribution of the project to a reduction in climate-altering gases an equivalence with CO_2 absorbed by the trees is calculated. Assuming that a tree, on average, absorbs 25 $kgCO_2$/year (30), considering the mitigation potential of the intervention on WWTP, 60848 trees are needed to offset the same quantity of CO_2. In an area of 1 m^2 can be cultivated, on average, 0.2 trees. Considering this spatial information, the energy efficiency intervention studied corresponds to reforesting an area of 304242 m^2. This areal extension is equivalent to 43 football pitches.

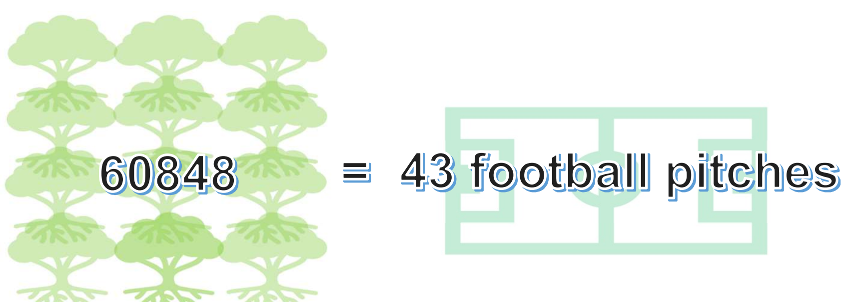


Figure 59: Offset correspondence of the energy efficiency intervention in the WWTP at Castiglione Torinese

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ACKNOWLEDGMENTS

I thank Professor Mariachiara Zanetti for providing me with additional tools for the development of my future and guiding me in the realization of my thesis project. I renew my esteem for the person and professional I have known over the years at the Politecnico di Torino. I thank engineer Giuseppe Campo for supporting me during the development of my thesis with patience, and always making himself available for clarifications and insights.

A kiss sent to heaven to my sister Leda, who was my strength even from up there. You will never cease to be in my every breath.

Thanks to my family, my whole family, for never giving up and for being there, despite the difficulties and pain.

Thank all those who have given me a smile during these years.