C.2.2 Large scale in-field test pilot report

DIADEME LIFE15 CCM/IT/000110
TEST REPORT
RIMINI SITE
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Author	Andrea Mancinelli
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DOCUMENT PURPOSE

This document explains the results of the energy savings lighting test performed in Rimini along Viale Losanna, Via Giuseppe Melucci and Via Giorgio Ambrosoli, from Friday, 8 August 2020 to Sunday, 4 October 2020.

LIFE-DIADEME RIMINI OVERVIEW

LIFE-DIADEME aims at demonstrating a novel and cost-efficient Distributed Adaptive Lighting dimming system. The system will overcome the limitations of the state-of-the-art pre-regulated street lighting solutions and significantly reduce (30% as project target) street lighting energy consumption and CO_2 emissions. Al the activities comply with the UNI 11248 standard on Adaptive Lighting, further enhancing benefits brought by SSL (Solid State Lighting) systems and traditional lighting lamps.
This novel system will integrate state-of-the-art low-cost sensors based on a distributed network, allowing the extension of helpful data detection and monitoring (i.e. noise, traffic and air pollution) to entire cities roads.
Rome (EUR and Pietralata district), Rimini and Piacenza municipalities collaborate with the consortium allowing systems installation along city streets.
Enel X installed the Rimini test site in July 2020.
The consortium switched on the Adaptive lighting method on Saturday, 8 August 2020.
At this time, the adaptive lighting in Rimini it's still working.
About the luminance level road category, the selected road is an M3.
For this kind of street are applied the following nominal parameters.

- Nominal Luminance Level: 1 cd/m^2
- Maximum Road Traffic: 800 vehicles/hour
- UNI11248 Full Adaptive Lighting – Minimum Luminance Level: 0.3 cd/m^2

Figure 1 visually exposes different luminance levels depending on the street lighting strategy for an M3 road. In red, the Full Light strategy where the road traffic doesn't affect the luminance levels.
In blu, the street luminance levels allowed by a pre-programmed statistical system.
In green, the adaptive lighting luminance levels permitted by technical directive UNI11248.
Real-time traffic evaluation enables lower luminance levels and linear regulation between the maximum and minimum level of light.

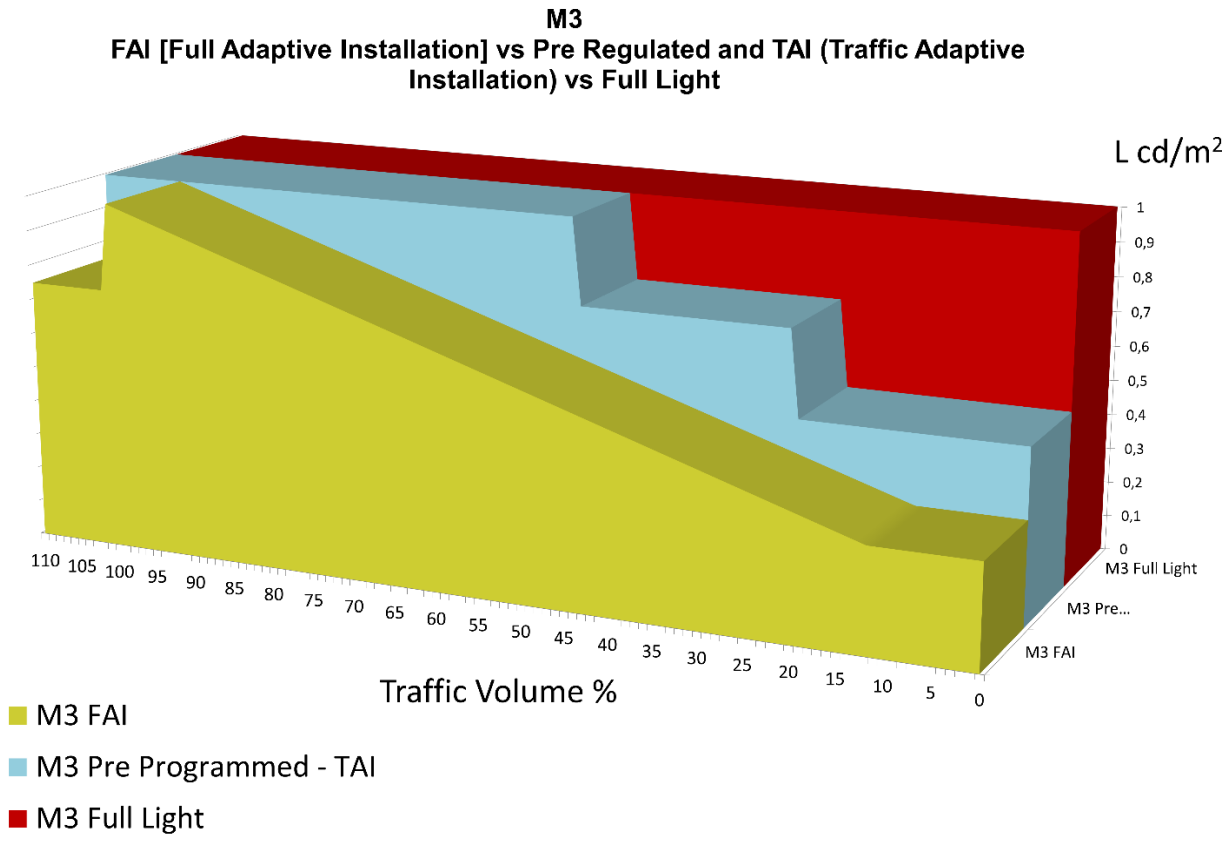


Figure 1 Lighting Strategy - Luminance levels comparison

TESTING SCOPE

LIFE-DIADEME consortium installed the Rimini testing site to evaluate the adaptive lighting system performances in a medium-size urban environment.
Rimini test site, if compared with other test sites, has the particularity of lighting lamps. Rimini lighting plants are all equipped with discharge lights. This technology was state-of-the-art before SSL arise to market.
This test is interesting to evaluate how adaptive technology in an urban environment perform with discharge light technology.
Rimini has a total of lighting points near 30000 units. The LIFE-DIADEME consortium used a small part of this vast luminaries plant to test the discharge lamp's adaptive lighting strategy.
Enel X remotely controls all the Rimini lighting points. A statistical dimming method it's generally applied on all the discharge lamp lighting points. We can consider the Rimini test site as a notable public lighting plant.
Different plants worldwide are currently working with a pre-programmed dimming strategy, as in Rimini.
Testing adaptive lighting technology in Rimini allowed the LIFE-DIADEME consortium to validate the novel system on a discharge lamp plant in a representative mid-sized city of northern Italy.

The consortium validated the system on a total of 76 lighting points equipped with LIFE-DIADEME electronics.
LIFE-DIADEME consortium, thanks to this test site, would demonstrate that:

- an adaptive system can regulate lighting levels thanks to real-time traffic detection and real-time luminance levels.

- Adaptive lighting can perform an energy saving of at least 30% if compared with, as defined by UNI11431, a statistically pre-programmed lighting cycle (state-of-the-art energy-saving method at project start-up time).
- The diffused system can collect valuable traffic volume information.
- Such a system provided with noise measurement capability can significantly support municipalities involved with the Directive 2002/49/EC of the European Parliament about noise detection.
- Low-cost air quality devices can provide diffused data helpful in setting up plans to help local authorities achieve clean air, as requested by the Clean Air Program for Europe.
- LIFE-DIADEME system will provide meaningful information to stakeholders on the Distributed Adaptive Lighting strategy, single roads traffic volume, diffused environmental noise and air quality levels, enabling the Smart City.

TEST SITE OVERVIEW

Rimini is a city in the Emilia-Romagna region of northern Italy and Rimini's Province capital city. It sprawls along the Adriatic Sea, on the coast between the rivers Marecchia and Ausa. It is one of the most notable seaside resorts in Europe, with revenue from internal and international tourism forming a significant portion of its economy. The first bathing establishment opened in 1843. Rimini is an art city with ancient Roman and Renaissance monuments.

As of 31 December 2019, Rimini's urban area was home to 151,200 people, with approximately 325,000 living in the eponymous province, making it the twenty-eighth largest city in Italy.

By the end of 2019, the Municipality of Rimini signed an agreement with the LIFE-DIADEME consortium to provide a small test helpful site to evaluate system performances and smart city data acquisition.
With Enel X support, the consortium designed the test site along Viale Losanna, Via Giuseppe Melucci and Via Giorgio Ambrosoli.
The testing site is a double carriageway, double lane road along with the city.
The consortium designed the test site rapidly, and by the middle of July 2020, documentation was ready for installation and material was supplied to Rimini for placement.
By August 2020, the system was settled up and properly working.
LIFE DIADEME consortium installed along Viale Losanna, Via Giuseppe Melucci and Via Giorgio Ambrosoli in Rimini the following devices:

- 90 LIFE-DIADEME
- 1 LTM device
- 2 Air Quality sensors
- 2 Air Quality sensors above the ARPA cabinet

For an in-depth evaluation of air quality sensors' response, the LIFE-DIADEME consortium organised a collaboration with ARPA Emilia Romagna.
The consortium was able to install, directly above the ARPA cabinet, two air sensors systems. We installed the first system in the centre of Rimini (Via Flaminia) and the second one in a green area of the city (Parco XXV Aprile). In this way, the consortium can explore different gas concentration sensitivity: one set for the traffic zone and the other for the background zone.

Figure 2 Rimini Test Site

Figure 3 LIFE-DIADEME Rimini Test Site Full Installation

Figure 4 Rimini LIFE DIADEME installation

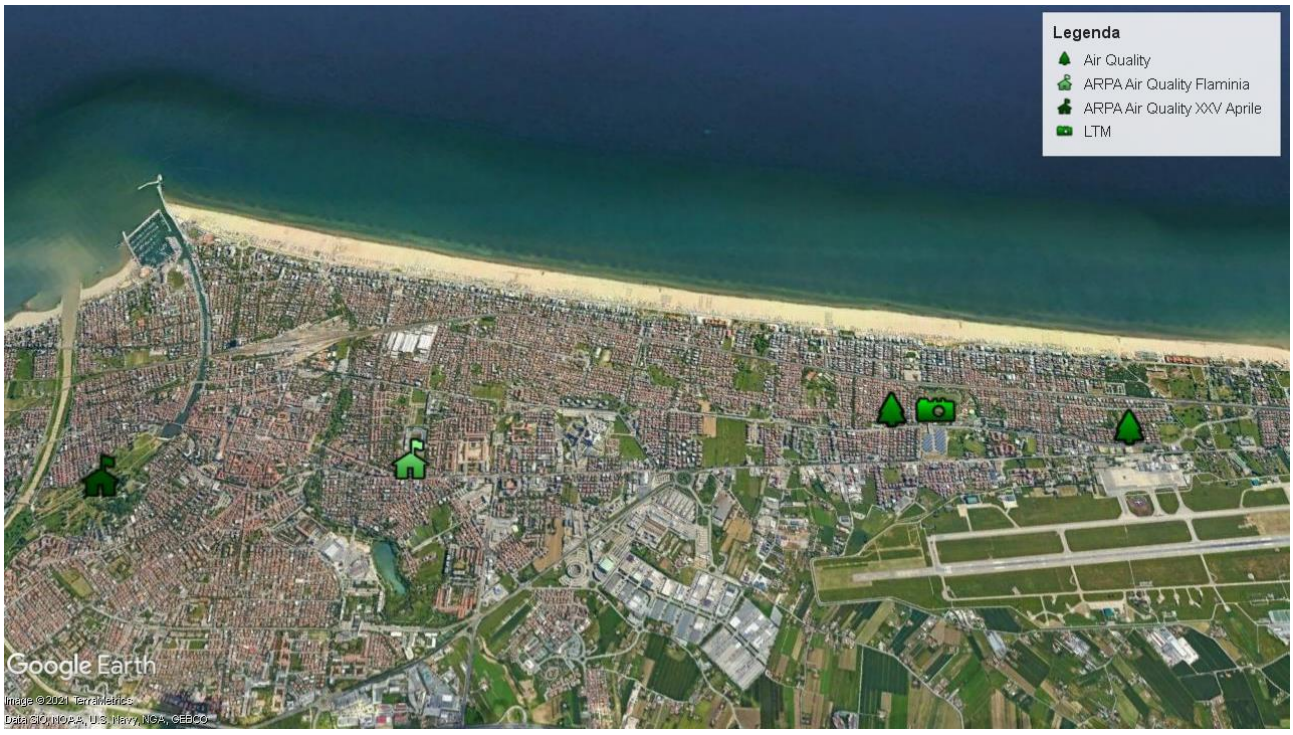


Figure 5 Specialized Devises Rimini installation

Figure 6 Air Quality

Figure 7 LTM

Figure 8 Air Sensor ARPA Via Flaminia

Figure 9 Air Sensor ARPA Parco XXV Aprile

ENERGY SAVING

Enel X installed the LIFE-DIADEME system in Rimini in July 2020.
Setup activities were going on until 25 August 2020.
On the first days of August 2020, the consortium settled in operation mode the LIFE-DIADEME Adaptive lighting system.
Rimini lighting plant it's provided with discharge light lamps, the best available technology before the LED era.
A point-to-point communication system was present on the Rimini lighting plan. The municipality performed street lighting energy saving dimming with a pre-programmed cycle.
LIFE-DIADEME was the opportunity to evaluate adaptive lighting in a different environment compared to more actualised LED lighting plants.
From this perspective, the Rimini test site's energy savings must be considered a complete UNI11248 compliant adaptive lighting application on a discharge lighting plant.
This kind of lighting plant is still popular in Europe, and the test demonstrates that adaptive energy savings can be compatible with this technology.
Figure 10 explains the real scenario applied along with the Rimini test site. The maximum traffic for lanes it's of 800 vehicles/hour. During the example day (15 September 2020), the traffic volume was always lower than the nominal value. In this situation, without considering the first 10 minutes from the plant switch on, the system early starts dimming light to gather target luminance level.
In this way, we can observe that the energy savings directly related to traffic volume and the systems perform energy-wasting reduction as soon as possible.
In the example, the traffic was significantly lower than the nominal values, and the adaptive lighting well works in this condition to maintain low consumption and high street security.
Disclosed data were acquired using the DIADEME LTM system, a computer vision technology able to detect real-time traffic, luminance level and weather conditions.
The green line represents the luminance level driven by the LIFE-DIADEME adaptive system.
The yellow line, referring to UNI1248, indicates the luminance level the system can reach.
In blu, the traffic volume level.
We can observe that the system can firmly drive luminance levels near luminance targets, performing a significant energy saving result even with discharge lamps. The example shows that efficient regulation is possible even with technology different from LED.
From the consortium point of view, the LIFE-DIADEME system well-performed along with the Rimini Test Site during the test period.

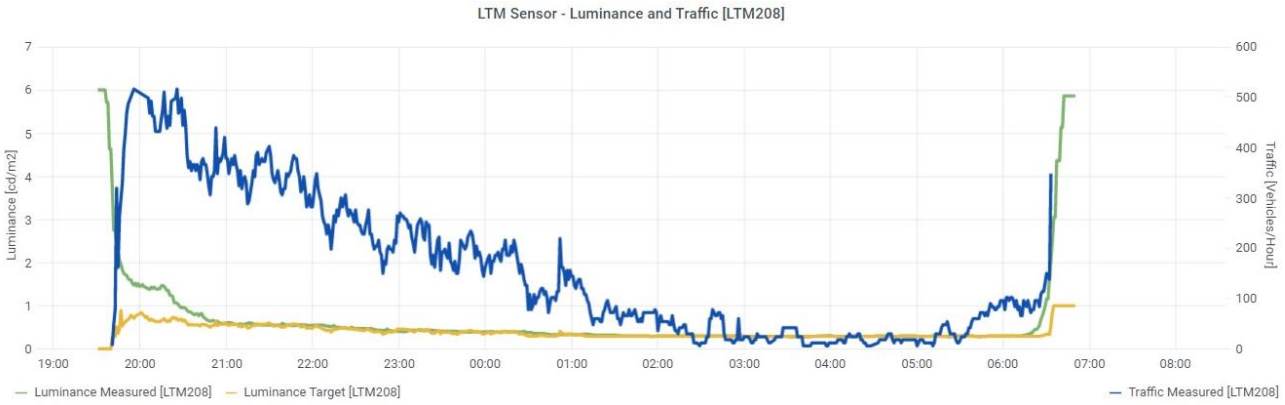


Figure 10 15 September – Adaptive Lighting control

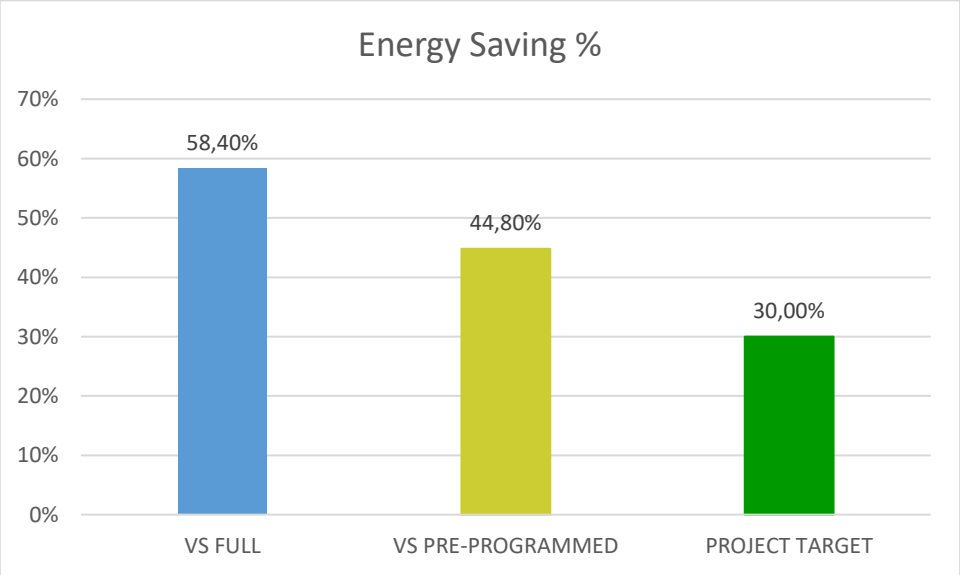
To validate final results in different conditions, a test on Rimini's adaptive street lighting system took place for a long time.
The consortium collected from each single installed lighting fixture the consumed energy.
To evaluate LIFE-DIADEME performances, both the state-of-the-art lighting system (pre-programmed strategy) and the full light system, the LIFE-DIADEME consortium used statistical data directly co-related with in-field installed lighting points.
It's interesting to understand how the adaptive lighting strategy can perform if applied on a similar plant without any energy-saving process. For this reason, in this document, there is the voice "FULL LIGHT" that represents such a lighting plant.

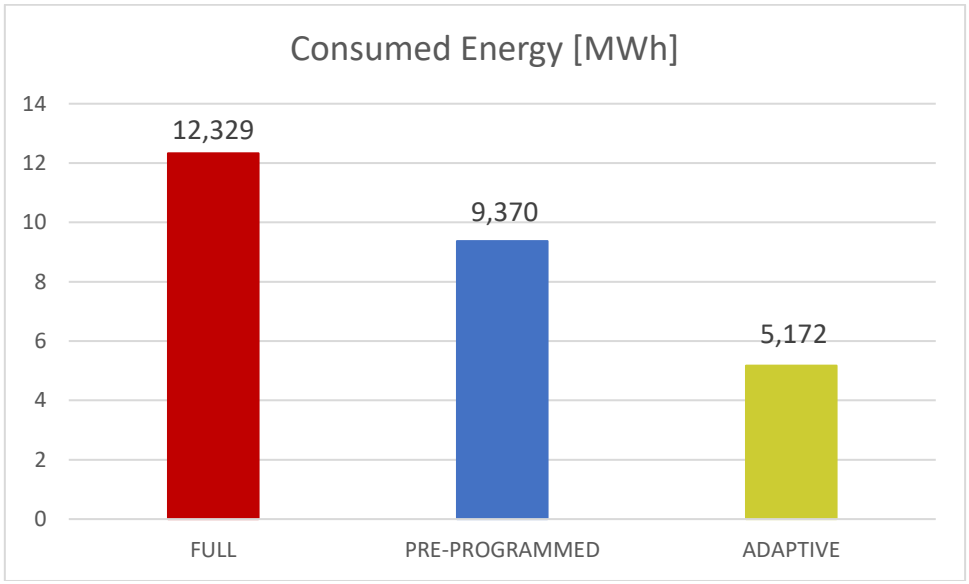
Rimini LIFE-DIADEME site performed better than the 30% energy savings project target.
The LIFE-DIADEME adaptive system, compared with the pre-regulated strategy, provided an energy savings of 44.8% during the test period.
Compared to the full light strategy, results along the same period provided an energy savings of 58.4%.

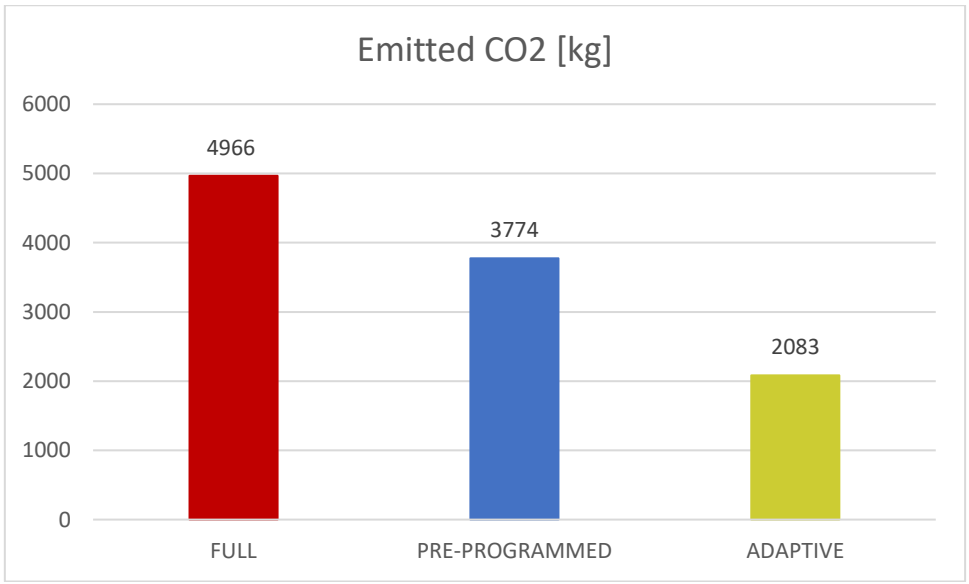
Results confirmed that an adaptive system lighting plant could provide significant energy saving, considerable GHG emission and a lower production cost for street lighting functionality.

	Consumed Energy [MWh]	Emitted CO2 [kg]
FULL LIGHT	12,329	4966
PRE-PROGRAMMED	9,370	3744
ADAPTIVE	5,174	2083

	Energy Saving %	Saved Energy [MWh]	Saved CO2 [kg]	Saved Costs [€]
VS FULL	58,40%	7,2	2900	€ 1300
VS PRE-PROGRAMMED	44,80%	4,1	1700	€ 751
PROJECT TARGET	30,00%	2,8	1130	€ 515




Consumed Energy [MWh]
14
12
10
8
6
4
2
0
12,329
9,370
5,172
FULL
PRE-PROGRAMMED
ADAPTIVE


Emitted CO2 [kg]
6000
5000
4000
3000
2000
1000
0
4966
3774
2083
FULL
PRE-PROGRAMMED
ADAPTIVE

TRAFFIC MONITORING

The system performs a 24/24h traffic level detection under each single lighting point equipped with a LIFE-DIADEME device. This full-time acquisition capability it's provided thanks to a battery installed inside each LIFE-DIADEME device.
The battery enables continuous monitoring and communication, and it's recharged overnight once lamps are on. In the early morning, when the lighting plant it's powered off, the smart city system starts working thanks to the stored energy.
By night, once the lighting plant is working, the LTM camera provides the LIFE-DIADEME system to perform traffic count using computer vision algorithms. Computer vision enhances precision about traffic volume data collected. A sophisticated device as LTM can perform processes to identify traffic, weather and luminance in real-time conditions. The system used data acquired both by LIFE-DIADEME devices and LTM cameras to drive street lighting levels according to UNI11248 Technical standards.
In Figure 11 can be observed a picture where's reported the traffic volume along the entire considered period. Data exposed in the graph were collected using diffused traffic sensors of LIFE-DIADEME devices.
The peaks value refers to daytime traffic.
The peak traffic level seems to be near 800 vehicles/hour.

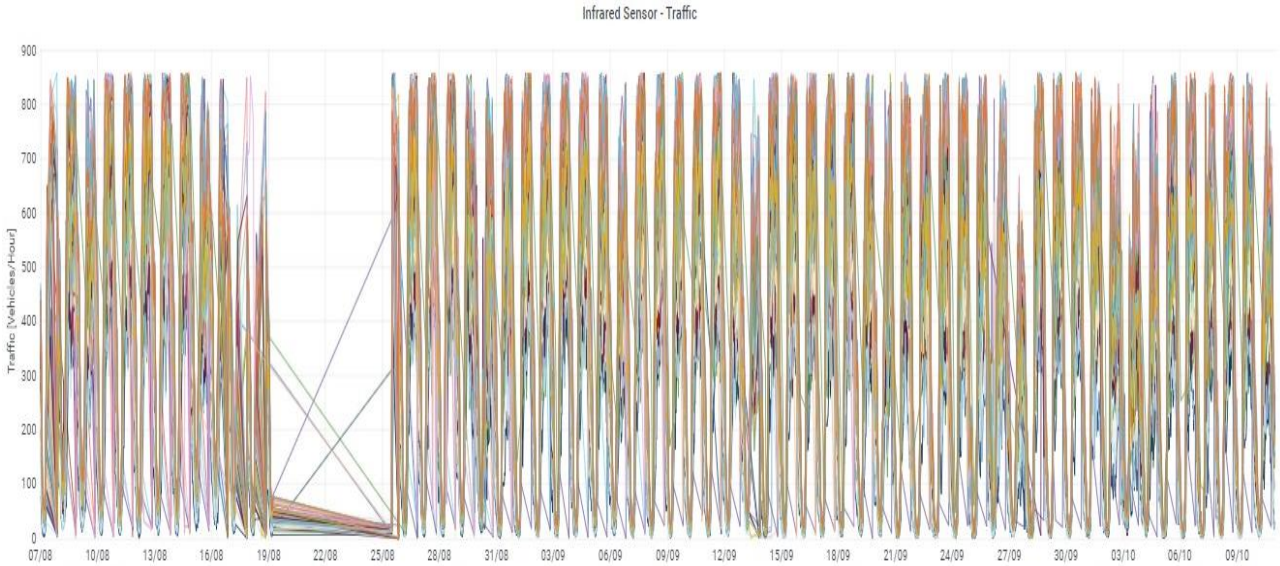


Figure 11 Traffic Volume 07/08/2020 to 04/10/2020

ENVIRONMENTAL NOISE

The consortium equips the LIFE-DIADEME systems with a low-cost sensor to collect environmental noise around the lighting point. Each electronics board can perform a dedicated evaluation of background noise and peak noise, using a correction curve to model human audio behaviour.
System providers can use diffuse noise detection to support municipalities in the direction of directive 2002/49/EC of the European Parliament and the Council of 25 June 2002 relating to environmental noise assessment and management.
This Directive shall aim to define a common approach intended to avoid, prevent or reduce on a prioritised basis the harmful effects, including annoyance, due to exposure to environmental noise. A municipality, to reach the Directive targets, should implement progressively:
(a) the determination of exposure to environmental noise, through noise mapping, by methods of assessment common to the Member States;
(b) ensuring that information on environmental noise and its effects is made available to the public;
(c) adoption of action plans by the Member States, based upon noise-mapping results, to prevent and reduce environmental noise where necessary and significantly where exposure levels can induce harmful effects on human health and to preserving environmental noise quality where it is good.

The consortium doesn't design the LIFE-DIADEME noise acquisition system as a replacement for calibrated instrumental measurements requested by the Directive. The target of a diffused environmental noise acquisition, working 24/24h, is to provide the municipality with helpful information about ecological noise in different zones and district. The system, continuously monitoring space around the lighting plants, provide supervision for human safety and environmental conditions.

Every single device provides for a continuous noise sampling audio parameters.
Harmonica Index t's the final result of the LIFE-HARMONICA project.
The HARMONICA project (Harmonised Noise Information for Citizens and Authorities) had several objectives:

- make information on noise more accessible and closer to people's perceptions by eliminating the technical terms that are difficult for laymen to understand.
- Assess noise abatement actions harmonised and promote practical steps to help the authorities draw up their action plans to implement the 2002/49/EC Directive.
- Facilitate the transfer of this approach to European cities to support the policies in place better to reduce environmental noise and improve access to information for the general public.
- Contribute to developing a common and shared culture allowing everyone to understand the noise better.

The development of a simple index for presenting environmental noise levels should meet particular concerns:

- Ease of understanding by the general public as operating on a scale from 0 to 10, rather than decibels.
- A simple calculation of environmental noise from in-field measured data.
- Calculate for one-hour time slots represent the index changes over a day, and derive average results over any type of period (day, night, 24 hours, week, month, year).

- Considering two significant components that affect the noise environment: background noise and noise events that exceed this background noise (noise peaks).
- A concrete representation of people's perceptions of their noise environment more than do the indicators currently used in the European regulations.

LIFE-DIADEME system, using the output of LIFE-HARMONICA, provides noise level on a scale from 0 to 10, where 0 it's the silence, and 10 represents an intense noise.

Acquired data shows a low noise activity in the monitored area. Values below 4 represent a tranquil environment. From Figure 12, we can observe that daily noise is higher than night noise, as expected if compared with road traffic and human statistical activities.

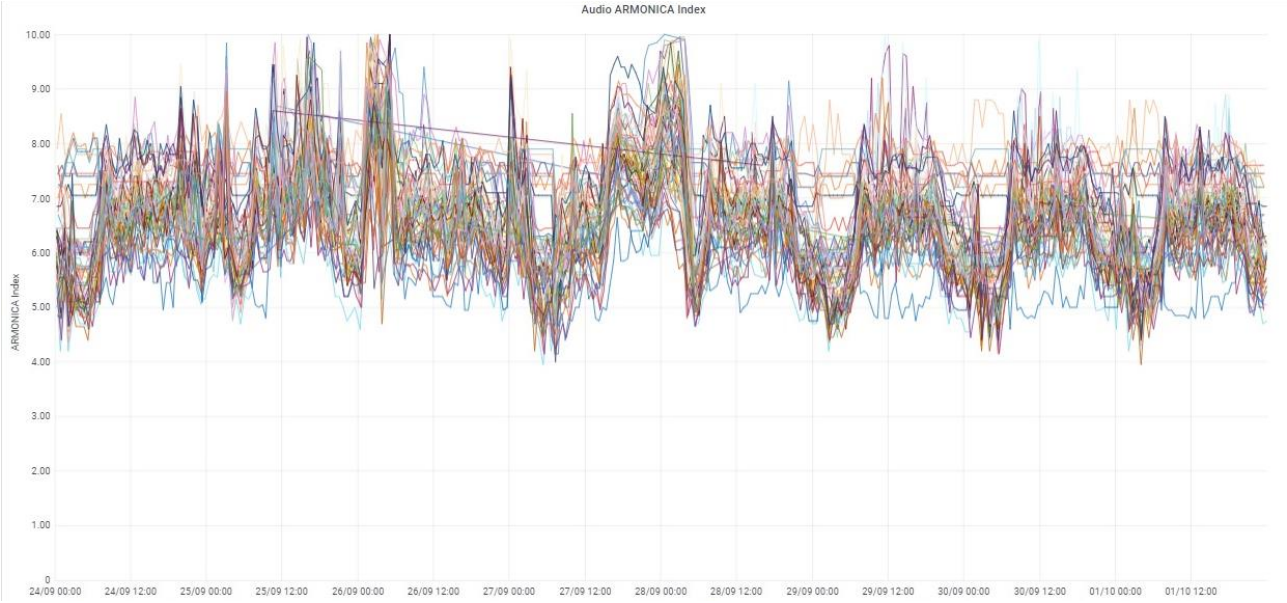


Figure 12 Harmonica index 24/09/2020 to 01/10/2020

Environmental Noise – In Field measurement

On 3 December 2020, the LIFE-DIADEME consortium organised a noise measurement campaign on the Rimini test site.
The measurement of acoustic noise level it's a time-consuming activity. As prescribed by technical standard, a sample it's acquired every 15 minutes. The tester, to obtain significant noise level measurement, should get different audio samples.
The consortium has bought a portable audiometer to realise in-field noise measurement acquisition.
Measurements took place along Via Giorgio Ambrosoli, in a zone between two different french roundabouts.
We settled up the audiometer station following the technical directive requirements: 1,5m from ground level, targeting the street direction.
To evaluate LIFE-DIADEME system performances, we have compared acquired data from the lighting point devices with the data obtained by the certified audiometer.

Figure 13 Audiometric Test Setup

Data comparison between the certified audiometers and the LIFE-DIADEME noise acquisition system needs a more accurate evaluation.

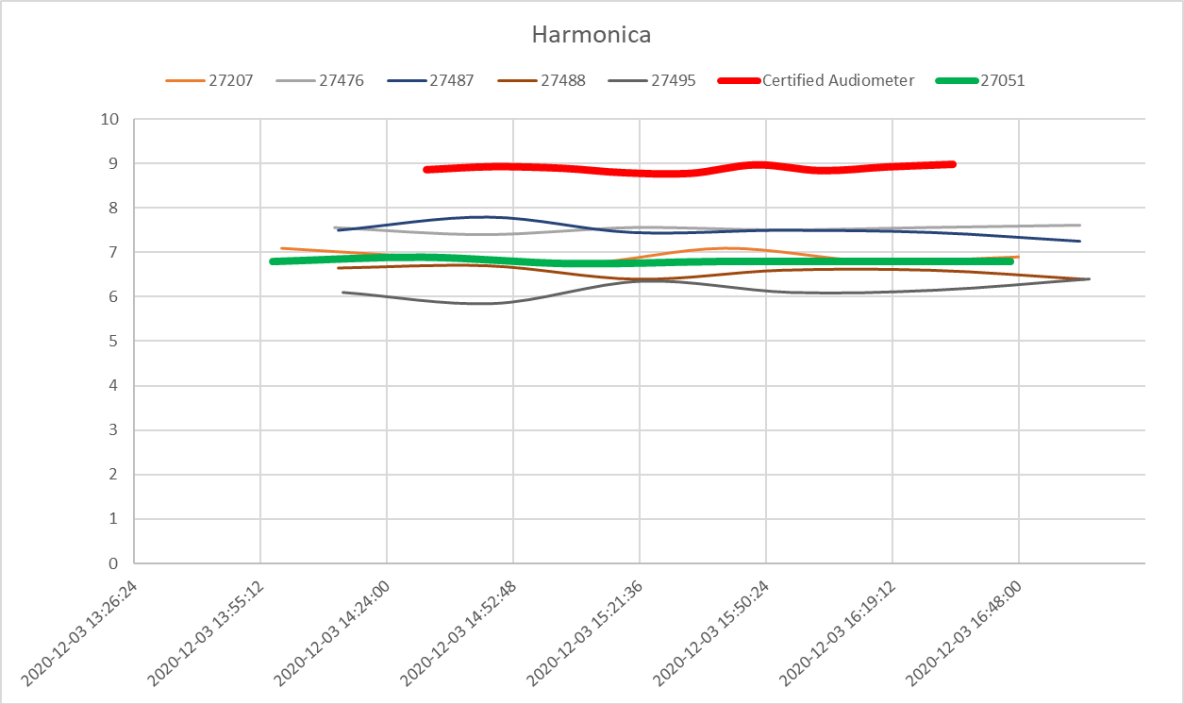


Figure 14 Harmonica Index Evaluation

Analysing previous figures Figure 14, it's easy to observe that the LIFE-DIADEME noise detector's shape is similar to the reference (in red).
The measurement of LIFE-DIADEME systems seems affected by some physical behaviour Applying this easy correction, we obtained the following results Figure 15.
These results are significantly impressive and aligned with what we detected along with the Piacenza Test site.

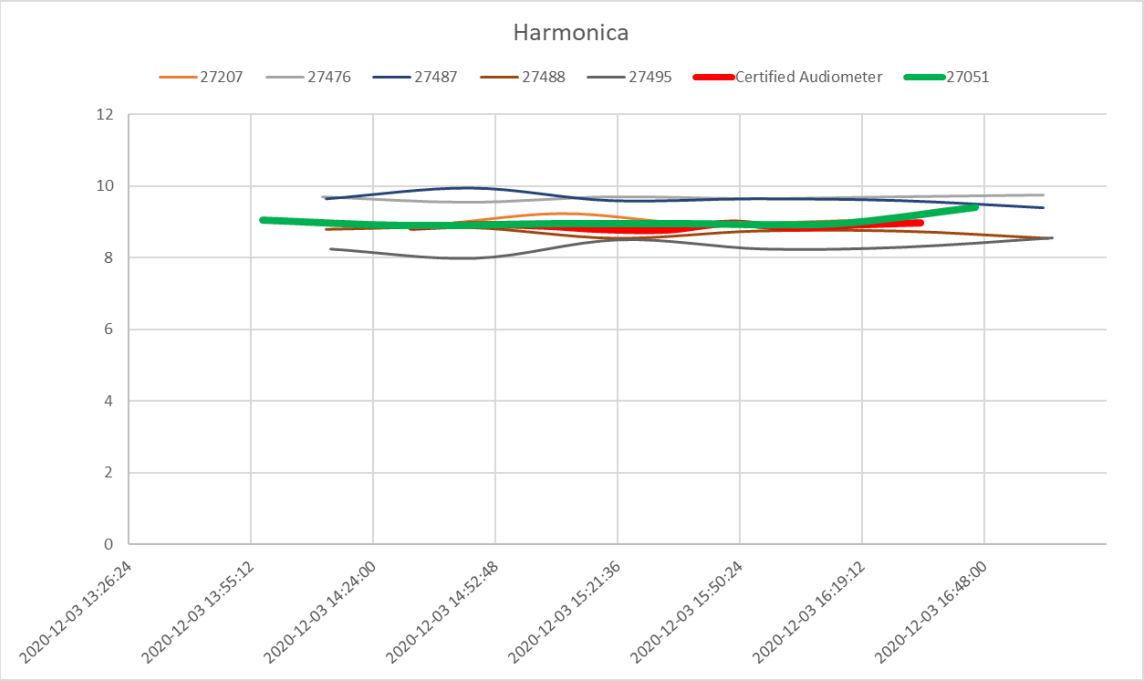


Figure 15 Harmonica Index Evaluation Offset Correction

Results from the other LIFE-DIADEME are of absolute importance. The shape of the curves is similar. The observation zone it's limited, and the detected noise seems quite the same for each lighting point.
The easy correction of the offset represents a simple and appliable solution for data calibration.

Data collected by different lighting points all around the Rimini test site, as previously shown, indicates that we can consider the information collected by the system of great value.
To provide a heatmap representation of the noise level captured under each lighting point, using the LIFE-DIADEME system can be considered a unique solution for the municipalities.

Figure 16 Noise Measurement With Certified Audiometer

AIR QUALITY DETECTION

Air Quality Installation

For the LIFE-DIADEME Rimini site, the consortium installed a total of 4 quality air detection unit.
Enel X installed 2 Air Quality system along via Ambrosoli and Viale Losanna, the street involved in the LIFE-DIADEME test.
Thanks to the collaboration with ARPA Emilia Romagna, The consortium had the opportunity to install two detection unit directly above different ARPA cabinet: one in the centre of Rimini (Flaminia – Traffic station) and the other one, inside a park near the city port (Parco Parco XXV Aprile – background station).

Figure 17 Air Quality Systems Rimini Site

All the Air quality Systems mounts low-cost sensors to acquire concentration of CO, NO, NO2, O3, atmospherical pressure, relative humidity and temperature.
Thanks to the experience acquired by Roma air quality devices, the setup of Rimini air quality devices, if compared to what the consortium made for Rome test site devices, was slightly different.
Before the delivery to Rimini, Reverberi changed some electronics settings and performed a single system calibration. The LIFE-DIADEME consortium used data supplied by an providerto

adjust every sensor installed inside the air quality electronic system in a different and specific way.
In Rimini, the consortium installed a total of four calibrated air quality systems in July 2020.

Air Quality Detection Results

Compared with ARPA Emilia Romagna's reference values, low-cost data gave outstanding relative error results.
The project target was to provide the municipality with a low-cost instrument to monitor and inform the decision-maker about air quality levels in different city zones.
Such affordable and reliable technology enables the municipality to project an air quality detection network.
A so designed diffused air monitoring system can return feedback on developed actions to mitigate pollution emission in well-defined zones.
We can consider a system with less than 30% of error helpful support to monitor and plan urban pollution strategies. It's the preferred choice to support mitigation strategies and evaluate the results of different developed pollution activities using diffused and low-cost air quality systems.

The LIFE-DIADEM low-cost sensors, if compared with ARPA data, exposed impressive results.
Along the testing periods, measurement errors on different gases concentrations were always less than 10%. If we focus on the lower temperature period, acquired data provided exciting results, reducing the error and increasing the accuracy.
About the project target, the unit tested in Rimini fulfil the project targets.

CONCLUSIONS

LIFE-DIADEME system tested in Rimini provided better energy and GHG savings results if compared with the project targets.
Even with discharge lamps technology, the adaptive system performed a 44.8% energy saving in the monitored period, going beyond the 30% fixed as project target.
This way, such a system can push, in street lighting application, energy savings and security well beyond current state-of-the-art limits.
A system like LIFE-DIADEME can be considered an exciting opportunity to reduce energy consumption and GHG emission in all street lighting applications.
Even more, the system data acquisition capabilities of the Rimini test site was able to exploit real-time traffic condition, collecting valuable information about traffic volume along Viale Losanna, Via Giuseppe Melucci and Giorgio Ambrosoli. The municipality can use data to project the urban viability with a different perspective and supported by in-field records.
The municipality can mix environmental noise and air quality levels to organise the city in a more eco-friendly way.
Acquired data on a single road can provide disruptive innovation. It's awe-inspiring that sensation about noise, traffic and air quality are finally measured. Real numbers provide the metric to measure the results from performed actions.
From consortium evaluation, LIFE-DIADEME in Rimini fully achieved all the project targets.