LIFE-TRIALKYL

LIFE14/ENV/IT/000346

An innovative
and
sustainable
continuous process for the development of high quality trimethyl phosphite

EXECUTIVE SUMMARY

LIFE14/ENV/IT/000346 is produced with the financial contribution of the LIFE programme of the European Union

With the contribution of the LIFE Programme of the European Union under grant agreement LIFE14/ENV/IT/000346

Italmatch Chemicals

RISE

THE PROJECT TEAM

Italmatch Chemicals is a Global Specialty Chemical Group, with leadership in Phosphorus Derivatives (both Organic and Inorganic), Flame Retardants, Plastics Additives, Lubricant, Water & Oil, Wastes management and Recovery, Detergents, from synthetic to fully natural products. Italmatch is coordinator of LIFE TRIALKYL project and was responsible for the design, set up, testing and validation of a novel more sustainable continuous process to produce phosphorus based additives in the range of trialkyl phosphites.

RISE is a leading international research institute located in Sweden working in strict synergy with public and private entities by offering its services towards a more sustainable chemistry. RISE, associated beneficiary of LIFE TRIALKYL, was responsible for measuring, analyzing and defining the environmental indicators to be monitored for the LCA and SEA assessment as well as supporting in the industrial validation and processing indicators to provide insights on the lowered environmental impacts of the novel TRIALKYL technologies.

The Associated Beneficiary "**SC SVILUPPO CHIMICA SPA***",* has strong experience in supporting, on commercial basis, the competitiveness of the whole Chemical Industry. SC was responsible of Dissemination and Communication actions in the project under the supervision and fully supported by Italmatch Chemicals Spa, especially regarding the type of results to be disseminate to the specific audience, including stakeholders. **SCSC** was responsible as well of the LIFE Trialkyl Web site development and realization, coordinated by ITC and supported by the other parties

www.life-trialkyl.eu

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List of key words and abbreviations

Keywords:

Innovative Continuous Industrial Chemical Process
Phosphorus Chemistry
Trialkyl phosphite
Phenol free
Solid phase reaction by-product
LCA (Life Cycle Assessment)
Circular economy
Social care chemical product
Sustainable Chemistry (SusChem)
Waste prevention
Water management
Energy saving
Europe, Italy, Sweden, Global
Market survey

Abbreviations:

ITC: Italmatch Chemicals SpA
SC: SC Sviluppo Chimica SpA
SP: SP Sveriges tekniska forskningsinstitut AB now RISE
RI: RISE Research institutes of Sweden, ex SP
TMPi: trimethylphosphite
TRIALKYL: trialkylphosphite
LIFE TRIALKYL: the project LIFE14/ENV/IT/000346
WIE: Water Innovation Europe
WE: Wayer European Platform
ESPP: European Sustainable Phosphorus Platform
PPs: Partners
E.R.E: Environment & Resource Efficiency
LCA: Life Cycle Assessment
SEA: Socio-Economical Analysis
PPI: Project Progress Indicators
SPI: Specific Project Indicators
KPI: Key Performance Indicators
VOC: Volatile Organic Compounds
TAP: Tri Alkyl Phosphites
CTR: Comitato Tecnico Regionale- Authorization Institution
CB: Coordinating Beneficiary
AB: Associated Beneficiary

The Objectives

LIFE TRIALKYL project aims to demonstrate a highly sustainable novel and efficient continuous process for the production of trialkyl phosphites with a specific focus on trimethyl phosphites. The task is to contribute in a significant way to the European shift towards a resource-efficient, low carbon and human health oriented economy within the chemical sector, by providing to the market a new industrial process, better than the *state of the art,* which is now based on more toxic and dangerous chemicals and provides a lower quality product. The major result of the LIFE TRIALKYL project is a social care range of trialkyl phosphites, phenol free, highly pure, out of a process that does not involve water either in the reaction nor in the waste management and that provides the product in a high yield. From a more general climate and environmentally linked perspective, the LIFE TRIALKYL process was expected to consume 30% less of energy consumption than the state of the art technology and to cause a VOCs emission significantly reduced either in the process chamber and /or in the outside air environment because of the innovative applied engineering technology.
In a glance the expected most tangible result is to design, develop and validate a novel trialkyl phosphites process technology, which offers:

1. a phenol free range of trialkyl phosphites
2. a highly pure range of trialkyl phosphites with a pureness higher than 90%
3. a high yield, 30% less energy consuming process versus the state of the art technologies
4. a more controllable lower VOC emission process versus the state of the art technologies
5. a circular model with respect to the generated reaction by products
6. the absence of any waste water and waste water treatment need
7. a consistent level of replicability for any FID (First Industrial Deployment) and mass production foreseen implementation step

by a properly installed pilot plant including

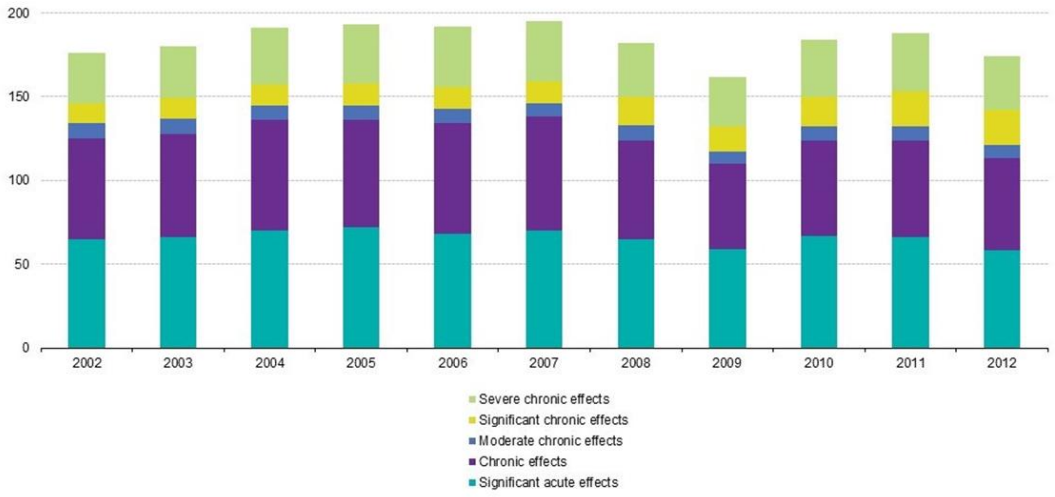
8. control and usage protocols (manuals)
9. LCA

and meeting the market needs according to the developed

10. Trialkyl Phosphites market scenarios investigation
11. Socio Economic Assessment aimed at identifying the gained level and the potential spaces for further improvement
12. Dissemination and Communication actions aimed at emphasizing the comparison with the consolidated state of the art technologies (phenol and tertiary amines based) and in response to the European environmental and sustainability agenda.

Premises: The state of the art and the ambitions

Chemicals are an essential component of the EU citizens' daily lives. The EU chemical sector is also a major strategic sector for the EU area, accounting for nearly 38.1% of the global trade, and 1.1% of the EU GDP as of 2010 [2014, CEFIC]. However chemicals might pose a severe threat for the environment and health, as the share of total toxic chemicals produced in the EU with respect the total chemicals produced is approximately 62% as of 2009 [2013, EUROSTAT].



(1) The different classes of chemicals are ranked according to their environmental impact from the most harmful (bottom class) up to the least harmful (top class).
Source: Eurostat (online data code: ten00011)

Fig. 6.Production of harmful chemicals (Mio tons), by toxicity class in the EU-27 (Mio tons) [data from EEA]

Trimethylphosphite (TMPi) is an organophosphorus trialkyl compound used in a large variety of applications, including crop protection, flame-retardants and plastics production. However, in current state of the art technologies, the TAPi production involves chemical intermediaries such as tertiary ammines that need to be treated and recovered in sodium hydroxide (NaOH), solutions and chlorinated solvents in the standard synthesis process, or phenols during the transesterification process. In these processes, highly toxic substances are used (tertiary amines, chlorinated solvents, NaOH and phenols derivatives) [2014, ECHA database]), whilst wastewater needs to be chemically treated and neutralized, with the consequent relatively high energetic costs and related GHG emissions.

The LIFE TRIALKYL aimed at demonstrating a highly sustainable novel and efficient continuous process for the production of TAPi that will benefit the environment and humans' health.

In fact, the new process rethinks the TAPi production by avoiding the aforementioned toxic chemicals and use instead PCl_3, methanol and anhydrous ammonia as precursors.

The state of the art technologies are not responding to the European Environmental policy causing the transfer of this production out of the European borders in spite of being Europe one of the major consumers of the deriving products.

The LIFE TRIALKYL process allows to

- completely avoid the production of contaminated wastewater, the use of phenols or tertiary amines,
- greatly reduce the water used and wasted (100%) and energy consumption (20-30%),
- providing NH_4Cl by-products useful for other sectors (e.g. agriculture), (today the 90% of the global NH_4Cl production is used as a nitrogen source in fertilizers. Moreover, in the recent years we have seen a strong interest in ammonium chlorides as, non-bio-degradable quaternary ammonium salts are prohibited by the European Commission in relation to biological fruit and vegetable products treatments in disinfection or growth adjuvants (2011/383/EU) [2010, M. X. Vieira et al., Rev. Bras. Ciênc. 34 (4)]).

For such a reason the present innovation, whilst avoiding the use of toxic chemicals and the treatment and disposal of wastewater, it will bring by-product useful in other sectors, thus minimizing the environmental impact of the chemical industry in terms of waste, disposal and safety and enhancing the circular economy (COM -2014- 398 final).

Hence, the innovation introduced by the LIFE TRIALKYL project will have tremendous environmental and socio-economic impacts at the EU and global levels.

In addition:

LIFE TRIALKYL constitutes a positive example of eco-sustainable chemistry by demonstrating

- To be in line with Proposal for a Directive of the European parliament and of the council on energy efficiency and repealing (2004/8/EC and 2006/32/EC) regarding the Energy Efficiency.

LIFE TRIALKYL offers an innovative process characterized by a consistent reduction of energy consumption

- To be in line with REACH directives and the European Chemicals Agency (ECHA), the EU Regulation on chemicals and their safe use (EC 1907/2006).

LIFE TRIALKYL technology will ensure a safer and more sustainable or economical use of chemicals, avoidance of utilization and production of hazardous chemicals like chlorinated solvents (e.g. dichloromethane), phenols derivatives and tertiary ammines showing

- To be in compliance with the following Directives on Water:
    - SEC(2007) 993 proposed seven policies option to increase water efficiency and water savings, in particular: i) fostering water efficient technologies and practices and improving knowledge.
    - Directive 2000/60/EC, integrated approaches for the implementation of the EU Water Framework Directive, regarding, in particular, the ensuring of at least a minimum chemical quality (particularly in relation to very toxic substances), everywhere in the Community.
- To be in line with the COM/2007/0062 strategy, which aims at achieving a sustained reduction of occupational accidents and diseases in the EU through various EU and national actions.
- To be in line with Directive 80/1107/EEC and Directive 2009/161/EU on the protection of workers from the risks related to exposure to chemical, physical and biological agents at work.

The LIFE TRIALKYL limits the use of hazardous chemicals substances to be released into the working environment, by the integration of sealing solutions.

- To be in compliance with Europe 2020 Strategy and Resource Efficiency, regarding Greenhouse Gases (GHG) emissions (20% saving) and increase in energy efficiency (20%).

The above reported objectives linked to chemical and environmental sustainability and implementing the human health conditions in a modern industrialized society are shown in Fig.2, where the expected results versus the state of the art processes are shown in a clear schematic way.

The two *state of the art* processes are respectively:

1) PCl_3 + methanol + tertiary amines process (presumably 75% of the global production share)

2) Trans-esterification process.

The Achievements

The LIFE TRIALKYL project during its four years working time has succeeded in

- developing and validating a disruptively novel process which moves away from the state of the art technologies according to the objectives
- offering a more sustainable range of trialkyl phosphites impacting on a wide range of market segments such as advanced plastic materials, agrochemicals and pharmaceuticals
- successfully testing both the process and the quality of the produced tributyl and trimethyl phosphites
- developing a complete LCA and SEA for the LIFE TRIALKYL process
- contributing to the environment and sustainability European program by offering a novel technology which could implement the BAT system, meeting the social innovation

requirements as well as the technical ones according to the defined quantitative objectives

As a fact, LIFE TRIALKYL project proved that Trialkyl Phosphites can be effectively synthesized starting from PCl_3, NH_3 and alcohols, in a continuous process.

- measuring and comparing specific environmental, social and economic KPIs in a strictly quantitative way, therefore offering a solution in line with the sustainability criteria.
- estimating the potential reduction of the energy consumption at local, regional and global level, applying the parameters identified in the testing and industrial validation phase.
- The LCA and SEA evaluations, including environmental achievements and energy consumption reductions were relevant parts of the whole project.

The above described main chemical targets and achievements as well as the environmental goals regarding:

1. **Reaction** (High reaction yield beside a reaction kinetic highly towards the Trialkylphosphite production, supported by a fast formation of NH_4Cl in solid phase continuously separate)
2. **Energy** (Lower energy consumption vs the state of the art technologies)
3. **Emissions** (Controlled /lower VOCs emissions and PM10 Particulate Matter formation) can be summarized in a quantitative way in the following schemes (fig.1)

SPECIFICATION PARAMETERS	TRIALKYL PHOSPHITES RANGE			
	Trimethyl phosphite TARGET	TMPi Lot.08072019	Tributyl phosphite TARGET	TBPi Lot.1906990013
APPEARANCE	Clear liquid	Clear liquid	Clear liquid	Clear liquid
COLOUR (APHA)	Max 50 apha	10 Apha	Max 50 apha	10 Apha
TAN EXPECTED TYPICAL VALUE TARGET	<1 target 0.5 max	0,25	<2 target 0.5 max	0,1
GC PURITY LEVEL	>95%	95,6%	>90%	91,5%

Fig. 1

SPECIFICATION PARAMETERS	TRIALKYL PROCESS' ENERGY CONSUMPTION	
	Trialkyl process	**TEA (state of the art) process**
KWh/Kg	3	5

Fig. 2.Energy consumption comparison: Life trialkyl vs TEA conventional process

	EMISSIONS		
	Trialkyl process		**TEA (state of the art) process**
PM10 eq	0,009 kg		0,12 kg
Social cost PM10 (methodology Hendriks et al 2011)	€19926 per year		€265680 per year
VOC	NH3	MTBE	Theoretical calculation
ppm (NO RECYCLE)	40	4700	150 ppm

Fig. 3. .Emission comparative analysis LIFE Trialkyl vs conventional TEA

Therefore:

The LIFE TRIALKYL process is validated and fine-tuned for both the TBPi and TMPi and validates the targets and objectives of synthetic route feasibility, energy efficiency, wastes reduction, emission reduction, enhanced circularity of the novel process. Moreover, the LIFE TRIALKYL process provides good quality sustainable products, with the desired purity.

The Expected longer terms results

EU Environmental policy and integration with relevant sectorial specific policies

The environmental, chemical and social benefits deriving from the successful set up and operability will contribute to the long-term implementation, updating and development of the EU environmental policy and legislation with a specific focus on the Phosphorus chemistry, the Water Resource Environmental Policy and the agro chemistry. Thereby contributing to sustainable development ("Roadmap to a Resource Efficient Europe") of the chemical processes in compliance with the priorities underlined under the LIFE 2014-2020 Program, that is the:

-Implementation of SEC (2007) 993: to increase water efficiency and water savings, in particular by fostering water efficient technologies and practices

-Implementation of the COM (2005) 666: Thematic Strategy on the Prevention and Recycling of Waste

- Implementation of the Environment Action Programme to 2020 of the 7th EAP (DECISION No 1386/2013/EU) and of the EU2020 Flagship initiative Sustainable Growth in turning the Union into a resource-efficient, green and competitive low-carbon economy

-Implementation of the REACH EC Regulation on chemicals and their safe use (EC 1907/2006) to improve human safety and mitigate the effect of chemicals on the environment, whilst ensuring a high level of innovation and enhancing competitiveness of the EU chemical industry, even through the limitation of the VOCs emissions (Directive 1999/13/EC).

-Implementation of "Sustainability policy within the Phosphorus value chain" (www.susphos.eu; II° International Conference on Sustainable Phosphorus Chemistry, 9-10 March 2016, Berlin) and pursues its industrial application, as reported by Tomáš Turecki (European Commission, DG Research and Innovation- *Unit I.2 – Eco-innovation*) in the Relation to the Audience of the ESPP, titled "Phosphorus stewardship in industrial applications" Brussels, 1 December 2016**.** This means, in a glance, to reduce the N and P problem by adopting a sustainable, green and circular chemistry (J.C. Slootweg, SUSPHOS/EU, and ESPP-1-12-2016).

Moreover, LIFE TRIALKYL complies with the Commission Decision 2011/383/EU regarding the ban of not readily biodegradable quaternary ammonium salts, since the LIFE TRIALKYL reaction provides NH_4Cl by-product that will be used as fertilizer in the agrochemical sector

Indicators	PCl_3+methanol+ tertiary amines	Transesterification	LIFE TRIALKYL	% saving	Saving estimates on a 3,000 t/year TMPi production in the EU
Energy Consumption (kWh/kg TMPi)	5 kWh/kg	5-6 kWh/kg	3.5-4 kWh/kg	20-30%	>3,000 MWh/year
Continuous processing	No	No	Yes		
Toxic chemicals and intermediaries	**PCl_3, NaOH, Chlorinated solvents** (e.g. dichloromethane), aromatic solvents, **tertiary amines** (e.g. trimethylamine, ethanamine, tributhylamine, DMCHA), **methanol**	**Phenols derivatives** (e.g. phenol, dialkyl phenyl, diphenyl alkyl phosphite, bisphenol-A [Restricted by 2011/8/EU Directive - EU Food Safety Authority]), **methanol**	**PCl_3, NH_3 anhydrous, methanol**	Avoidance of NaOH, Chlorinated solvents), aromatic solvents, tertiary amines, Phenols derivatives.	> 11,000 t/year (against 1,023 t/year NH_3 substitution)
Water consumption (l/kg TMPi)	8 l/kg	~ 0 l/kg	0 l/kg	Up to 100%	> 24 M l/year
Wastewater (l/kg TMPi)	4.124 l/kg (neutralisation step)	n/a	0 l/kg	Up to 100%	> 9 M l/year
Logistics (supply/disposa) (km-average)	China: ca. 14,000 km (ca. 50% share) India: ca. 9,000 km (ca. 50% share)	China: ca. 14,000 km (ca. 50%) India: ca. 9,000 km (ca. 50%)	0 (theoretical)	100% (theoretical) 15% expected after 3 years from the demonstration	380 t CO2/year
Air quality (VOCs emissions) (ppm)	<150ppm	<150 ppm	<5 ppm	97%	<5ppm
By-products useful for other sectors (circular economy)	none	none	NH_4Cl (>40% yield): 1.3 kg/kg TMPi		3,900 t/year availability for other sectors

Fig. 7. Expected results and environmental benefits

Impact of the expected results on the marketing policies

In order to comply with the defined Environmental policy, EU is investing to develop a more and more green and sustainable chemistry and to develop innovative and high performing solutions for the market.

A clear scheme of the impact of such policies on the market scenarios of TMPi and on the consumers demand is schematically reported in Fig.8 with the specific reference to TMPi and, more generally, to trialkyl phosphites in the Plastic industry and in Agrochemistry. Regarding agro sector and considering the circular feature of the LIFE TRIALKYL, NH_4Cl represents an interesting solution as well to a more sustainable agrochemical industry by providing the right substrate for a series of Innovative Research projects already in progress and that will integrate these results into them.

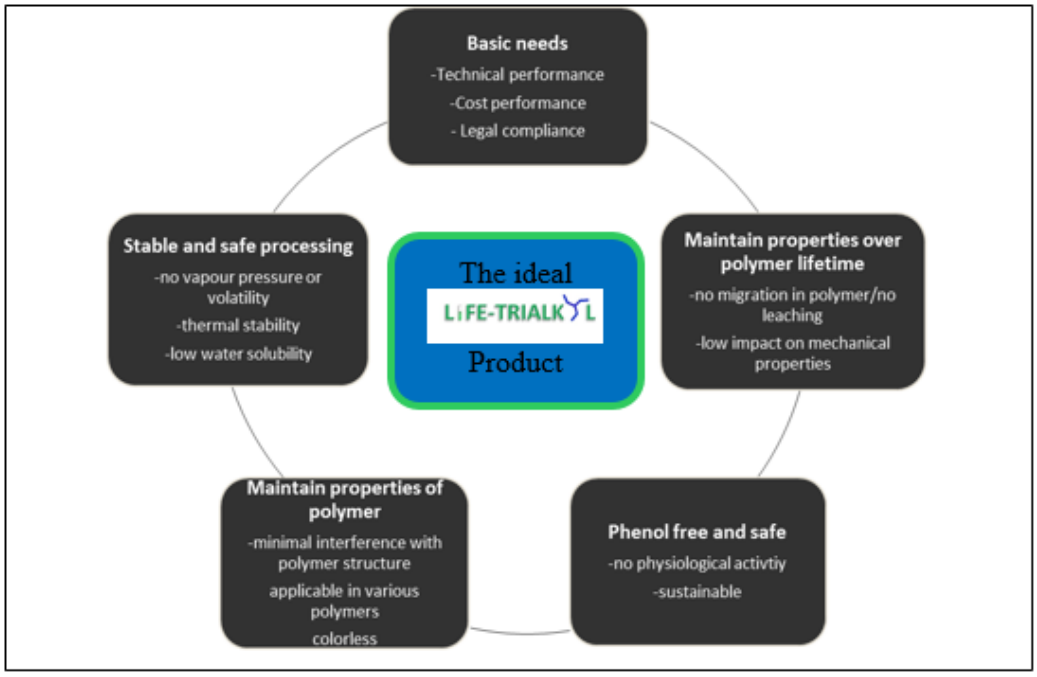


Fig.8- Impact on the market demands' scenario

.As a result of these short and long-term expectations, the LIFE TRIALKYL market scenarios appear of great interest for the EU and the global context, especially within the Plastic Industry and downstream sectors. A detailed market scenarios report is an outcome of this project, showing the profitable integration of the environmental issues into the other policies, the repeatability and transferability of the demonstrated technology, including the marketing strategy and the economic feasibility.

The LIFE TRIALKYL impacts in details

1. The market background and environmental benefits scenario

The market background study confirmed that trialkyl phosphites are important key intermediates in the chemical industry in a large variety of applications such as Flame retardants, Stabilizers (focus on PVC), Organophosphorus herbicides and pesticides, Catalysis promoters, Plasticizers. In addition, they are demonstrating specific properties in the APIs synthesis, reasons why, the Pharmaceutical segment is considered.

This study indicates that there is a real need for more eco sustainable and Life Cycle Assessed agrochemical solutions, like NH_4Cl, in the disinfection, fertilization and plants nutrition's segments within agricultural sectors in Europe as well as out of Europe.The development of the market scenarios considers to maintain or develop the best as possible performance of this category of additives and chemical intermediates in compliance with both the "Environment Action Program to 2020" of the 7th EAP (1386/2013/EU) and the EU policy pillars for Research and Innovation. Therefore, one of the pillars of the market strategy is the compliance with the green and sustainable innovative chemistry program, in the area of the Phosphorus Chemistry, the Water Challenge and the agricultural EU economic strategy. The below reported table clearly explains the most relevant differences among the global adopted production processes and the novel LIFE TRIALKYL which will open new market scenarios.

TRANSESTERIFICATION	**Process for the production of symmetrical trialkyl phosphites, which are also known as phosphorus acid trialkyl esters, from phosphorus trichloride and alcohol in the presence of an auxiliary base as an acid-binding agent and a solvent.US 5710307 A- BAYER / Lanxess method**	**PCl3 and MeOH in the presence of an auxiliary base, NH3 anhydrous- LIFE TRIALKYL PROJECT** 
1. Batch wise process in multiple phases	1. Batch wise and/or continuous single phase process	1. Continuous single phase process
2. High production of significant quantities of Phenols. The major responsible for overlimit VOC content in all the final derivative TMPi stabilizers and co-stabilizers.	**2. Solvents implications: aromatic and chlorine based solvents in the process** "*The present invention provides a process for the production of trialkyl phosphites by reacting phosphorus trichloride with the corresponding alcohols in an inert solvent in the presence of an auxiliary base, which process is characterized in that alkyl aromatics having more than 50 wt. % of aromatic carbon atoms". The mostly used aromatic solvents can be trimethyl benzene, isopropyl benzene, butyl benzene, and, mainly tetrahydronaphtalene".* In addition this method could imply the usage of chlorinated solvent such as CH2Cl2 to recover the chlorinated amines	**2. Phenol free process** "*The importance of a phenol free process: Plastemart 2013* *In recent years there has been much concern with exposure to volatiles from the processing of PVC resin, and the exposure to volatiles from articles shaped from stabilized PVC resin exposed to elevated use temperatures. The volatilization of one or more components or of the decomposition products therefrom, cause the condensation of these volatile components as "fog" on surfaces adjacent to the PVC articles. It has been found that one of the volatiles from the processing of PVC containing certain stabilizers is phenol. T* ***he phenol comes from the phosphite used in combination with the mixed metal stabilizer. There is a great need to eliminate or at least minimize the phenol content of phosphite stabilizers and still have a stabilizer that gives good color and processing stability.*** *One important objection to the contamination of PVC resins with phenol is based on the use of vinyl chloride polymers in food applications, e.g. in the manufacture of food containers.* ***The use of phenol-free stabilizers prevents the transfer of objectionable odors or materials to food. Therefore the possibility to avoid phenol residues in phosphites could open or enlarge even additional market segments plus improving the sustainability level of the present ones"****.* **2.a. no need for any phenol removal distillation process**
3. Although the phenol formed in the transesterification reaction is removed by distillation , the products still contains quantities of free phenol and phenol bound as a phosphite ester **may be liberated only during compounding and mixing with increasing costs in the compounding processes**	**3. a. Usage of tertiary amines , Tributylamine**, not to have a solid second phase, generates the formation of liquid chloridrated amines that need to be separated via liq/liq separation process with the necessary consequent recycling process to recover the utilized solvents with an additional extra cost. **3. b. Usage of diverse amines would generate**, by adopting this process, solid amine hydrochlorides, which need to be initially separated and then washed with additional costs and with the major disadvantage of partially hydrolise the triakylphosphites to dialkyl phospites, unless they are removed by water .In this case the process requires the resultaing water treatment process to properly recover the washing waters. **3.c. the forming HCl react with TMPi to give methanchlorine, CH3Cl**, formation to be blocked by CH3ONa , with a non-sustainable cost.	**3. In this process** **3.a. no washing processes needed** **3.b. feasible reintroduction of the formed by product NH4Cl in the circular economy** for agrotech usage **3.c. no water recycling need**

Fig.14- LIFE TRIALKYL in the actual global scenario

2. Impact on the market potential: actual value and forecast

The quantitative analysis of values and forecasts met the expected outcomes as from the project proposal. As a fact, organic phosphites based stabilizers are about the 10% of the total heat stabilizers for PVC, that means about 200.000 tons consumption worldwide only for PVC application (175.500 tons). Major problems in this phase were related to the difficulty in quantifying exactly this global consumption of organic phosphites (both alkylic and aromatic) and in comparing it to the actual and potential demand worldwide with a splitting by product type, by production technology adopted, by price, by market share and growth rate per geographical region and application segment.

Based on focused investigations of the major global chemical industry marketing reports through the EU platforms and private providers and by using globally recognized Big Data free web solutions, the following estimations in graphs were developed:

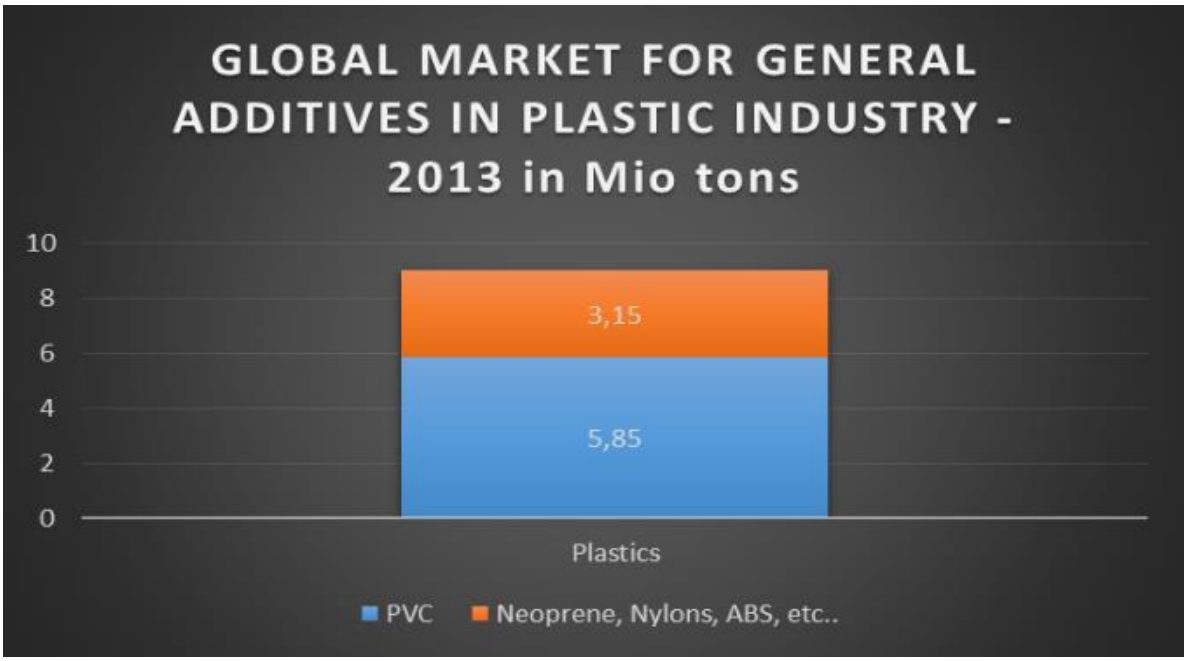
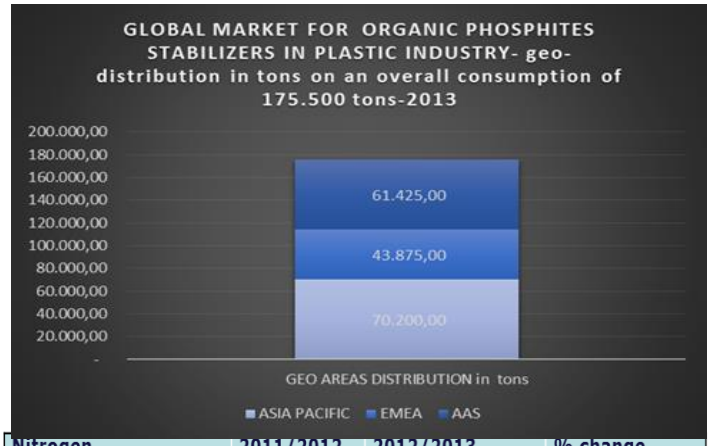


Fig.18- The downstream market value of Life trialkyl

Fig.15- The downstream market value of Life trialkyl FOCUS PVC



From a geo distribution point of view, on 175.500 tons of organic phosphites, an average consumption of 70.200 tons in AP, 43.875 tons in EMEA and 61.425 tons in Americas, as from the outcome geo distribution for this intermediates

Nitrogen fertilizerTrade balance (million tons of N)	2011/2012	2012/2013	% change
Import to EU-28	2.3	2.7	+17%
Export from EU-28	2.0	1.9	-7%
Nitrogen fertilizer consumption in EU-28 (million tons of N)	2011/2012	2012/2013	% change
Agricultural use	10.5	11.0	+5%
Technical use	1.7	1.8	2%

With regard to NH_4Cl, the study demonstrated that the circular economy model is fitting with LIFE TRIAKYL scope in this implementation phase. As a fact, the ammonium chloride's potential introduction in the existing market is confirmed by its consumption values over all Europe and, more generally at global level. Beside a stable consumption and production volumes, an even increasing trend is confirmed due to its higher sustainability versus the quaternary ammonium salts from either a healthiness or an environmental point of view.

3. The LIFE TRIALKYL impact on the European sustainable chemistry program

A Socio-Economical Analysis (SEA) based on the European Chemical Agency (ECHA) guidelines for SEA was performed by RISE to compare the impact on society of both the LIFE TRIALKYL process and the TEA process.

In this SEA study, the existing TEA production process is compared with the new TRIALKYL process to produce TMP. The evaluation is based both on laboratory data and design of the pilot line, and on the measured final industrial data. The results of the SEA analysis are economic benefits and risk presented as "scenarios", such as the "non-use scenario" for the Trialkyl production process and the "applied for use scenario" for the TEA production process.

Similar to the LCA, the original plan was to use as much experimental/pilot data in the SEA as possible. The final results are based on the industrial validation on the pilot line.

ACHIEVEMENTS:

- The comparison, in terms of cost and benefits to society of shifting TMPi production to the LIFE TRIALKYL process, was performed on a Cost Benefit Analysis and ECHA guidelines and shows that shifting to the LIFE TRIALKYL process is beneficial to society (see Fig. 16a and 16b)
- Preliminary SEA results: outcomes show promising improvement compared to the conventional TEA process (see Fig. 16a and 16b)
- The updated preliminary SEA results (Fig.16b) have shown that despite the cost of a new production plant (for example capital cost of € 1.5 Mill), the EU society benefits significantly from the shift to the Trialkyl process. This due to the improved benefits within human health (for example reduced costs for chemicals from TEA €261.734/yr to Trialkyl €24.921/yr) and the

benefit for the environment (for example reduced costs for climate impacts from TEA €321.848/yr to €19.103/yr). By comparing the overall costs of the Trialkyl production process (€7 Mill) against the cost of the TEA production process (€20 Mill) it is evident that EU society benefits significantly from the shift to the Trialkyl process over the period considered.

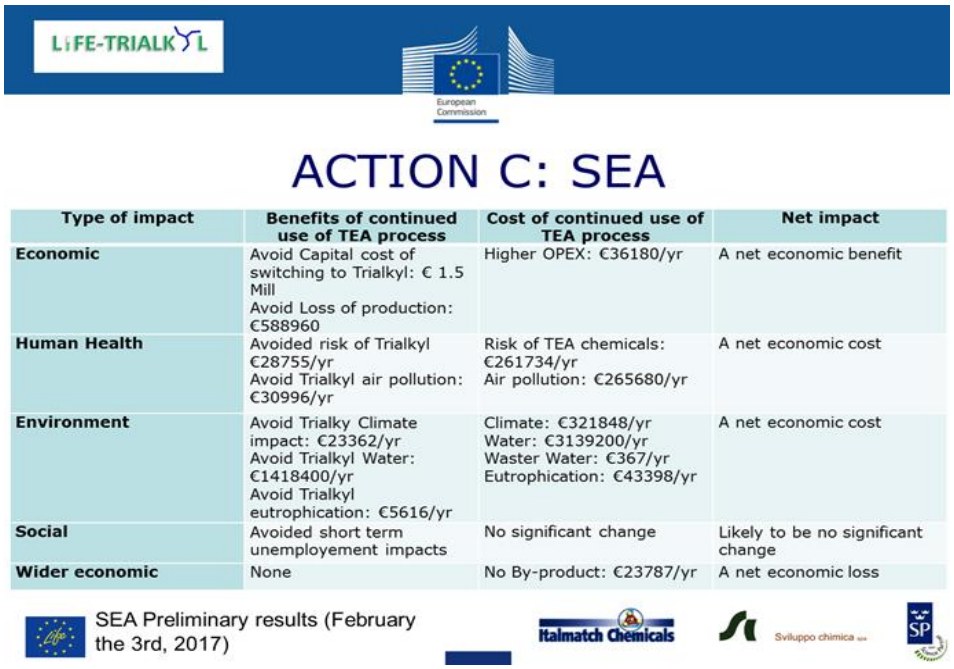


Fig.16a- Preliminary SEA results based on process flow diagram (February the 3rth, 2017

Fig.16b-Updated SEA results based on laboratory analysis (June, 2017)

- The final results, based on the running pilot plant, show even better results: the updated capital cost for the pilot plant was 1.154 Mill (23% lower than the original from 2017). The updated operational cost were based on 3 workers in 2019 instead of 6 workers in 2017 (33% lower than the original from 2017) (Fig. 16c)

- The overall SEA results show similar or better results (around 10% better results for better CAPEX).

Type of impact	Benefits of continued use	Cost of continued use	Net impact of continued use
Economic	Avoid Capital cost of Trialkyl: € 1.5 Mill (2017) CAPEX: € 1.154 Mill (2019) (23% better, Pilot 2019) Avoid Loss of production: €588960	Higher operational costs OPEX: €36180/yr (2017) OPEX: €108 000/yr (2019) (3 times higher, Pilot 2019)	A net economic benefit *23% better CAPEX* *3 times better OPEX* *(for Pilot Plant 2019)*
Human Health	Avoided risk of Trialkyl chemicals €24921/yr Avoid Trialkyl air pollution: €19926/yr	Risk of TEA chemicals: €261734/yr Air pollution: €265680/yr	A net economic cost
Environment	Avoid Trialkyl Climate impact: €19103/yr Avoid Trialkyl Water: €1179360/yr Avoid Trialkyl eutrophication: €5054/yr Avoid Trialkyl aquatic toxicity: €44.16/yr	Climate: €321848/yr Water: €3139200/yr Waste Water: €367/yr Eutrophication: €43398/yr	A net economic cost
Social	Avoided short term unemployement impacts	No significant change	Likely to be no significant change
Wider economic	None	No By-product: €23787/yr	A net economic loss

Fig 16c - Final SEA results based on Pilot plant (June 2019)

4. Policy impact: achievements which supported legislation (regional, national, EU)

An overall synthetic idea of the LIFE TRIALKYL impact on policy as a whole is clearly exposed by the following "GENERAL IMPLICATIONS & IMPACTS" picture (fig.24), which clearly show the variety of policy implications that crosses the LIFE TRIALKYL process. The **LIFE TRIALKYL** project addressed relevant environmental and socio-economic factors. In fact, the proposed innovation greatly reduces the water and energy footprint in the production of TMPi (incl. GHG emissions), the production of wastewater and the use of toxic chemicals for humans. These factors will consequently benefit the EU citizens in terms of EU competitiveness (industry growth, youth employment), the reduction of chemical-industry related diseases (inflammation and cancer), and contamination of water resources.

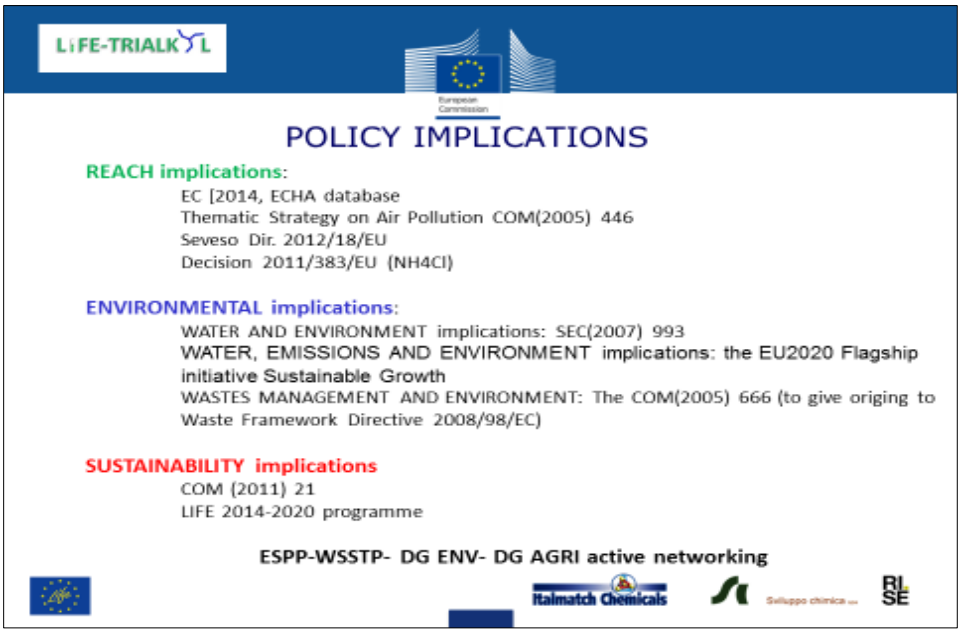


Fig.24- life trialkyl global policy implications

In particular, the LIFE TRIALKYL innovation reduces energy consumption by 40%, water consumption by up to 40% and wastewater generation by up to 100%. Thus, the project contributes to the following EU policies and strategies:

1) The Environment Action Pr. to 2020 of the 7th EAP (DEC1386/2013/EU) which aims at
   - turning the Union into a resource-efficient, green and competitive low-carbon economy;
   - reducing GHG emissions and enhancing energy and resource-efficiency in the Union;
   - the objective that, by 2020, chemicals shall be produced and used in ways that lead to the minimization of significant adverse effects on human health and the environment.

The **LIFE TRIALKYL** project represents indeed an important innovation in this sense by greatly reducing the energy and water consumption, and use of toxic chemicals with respect to the state-of-the-art processes, by using simpler precursors and reducing waste up to 100%.

2) The **REACH EC Reg.** on chemicals and their safe use (EC 1907/2006) aims at improving human safety and mitigating the effect of chemicals on the environment, whilst ensuring a high level of innovation and enhancing competitiveness of the EU chemical industry. Additionally, **Seveso Dir.** 2012/18/EU obliges Member States to ensure that operators have a policy in place to prevent major accidents. Operators handling dangerous substances above certain thresholds must regularly inform the public likely to be affected by an accident, providing safety reports, a safety management system and an internal emergency plan. Also, **Directive 80/1107/EEC and 2009/161/EU** address the protection of workers from risks related to the exposure of chemicals, physical and biological agents. The **LIFE TRIALKYL** innovation complies with the aforementioned Directives and Regulations thanks to the reduction of toxic chemicals, the use of simple precursors (avoidance of phenol based toxic chemicals as raw materials for the synthesis of derivatives), and the integration of sealing solutions to minimize VOCs emissions. Moreover, the LIFE TRIALKYL consortium took all the necessary actions to minimize the risks for workers by carefully engineering the demonstrator (incl. manual, risk contingencies, emergency plan, and quality control procedures) by developing an integrated risk assessment under SEVESO directive.

3) Moreover, the project complies with the **Decision 2011/383/EU** regarding the ban of not readily biodegradable quaternary ammonium salts, since the TRIALKYL reaction provides NH4Cl by-product in 95% yield that can be used both in agrochemistry as well as in chemical industry.

The **LIFE TRIALKYL** preliminary toxicological evaluation as well as the developed SEA confirm this assumption.

4) The **EU2020 Flagship initiative Sustainable Growth** aims at achieving resource efficiency, green and competitive economy. The initiative aims at least 20% GHG emissions reduction by 2020 (1990 as benchmark) and at least 30% reduction by 2050. The EU climate and energy package is committed to the so-called 20-20-20 targets, i.e. a 20% reduction in EU GHG emissions from 1990 levels, raising the share of EU energy consumption produced from renewable resources to 20% and a 20% improvement in the EU's energy efficiency. Such actions are in-line with post-Kyoto protocol, which aims at 10-40% GHG emissions reduction by 2020 compared to 2005 levels. Also, the resource efficient Europe COM (2011) 571 Communication aims at decoupling the economic growth from the overuse of resources (e.g. materials and water) and at making the EU-area a competitive and sustainable economy by 2050.
LIFE TRIALKYL is fully in line with the aforementioned strategies by addressing energy consumption and by reducing the TMPi production energy by 40%. The development of alternative TMPi production routes further stimulates the chemical industry towards sustainable routes at the EU and global scales.

5) **SEC (2007) 993**. Water scarcity has emerged as a major challenge – and climate change is expected to make matters worse. Regarding the industry about 40% of the total water is used as of 2008 (2008, EEA, Water use by sectors). The most intensive water consuming sectors are metallurgy, chemicals and chemical products, paper, mining and food products and beverages. SEC(2007) 993 proposed seven policies option to increase water efficiency and water savings, in particular fostering water efficient technologies and practices and improving knowledge. In addition, the EU's ambitious Marine Strategy Framework Directive (2008/56/EC) aims at protecting more effectively the marine environment across Europe, and achieving Good Environmental Status (GES) of the EU's marine waters by 2020.
The **LIFE TRIALKYL** innovation complies with the aforementioned directives by reducing the water required in the production process by up to 40% for the foreseen TMPi production in EU and wastewater production by 100%. Moreover, the present innovation will foster the use of more efficient technologies or raw materials towards a lower water use in the industrial sector.

6) The COM(2005) 666 **Thematic Strategy on the Prevention and Recycling of Waste** sets as long-term EU goal to become a recycling society that seeks to avoid waste and uses waste as a resource. The Waste Framework Directive 2008/98/EC sets the basic concepts and definitions related to waste management and lays down waste management principles such as the "polluter pays principle" or the "waste hierarchy". The revised **Waste Framework Dir.** requires that Member States established, from 12/12/2013, set national waste prevention programs. The aim of such measures is to break the link between economic growth and the environmental impacts associated with the generation of waste. The **LIFE TRIALKYL** project complies with such Directives thanks to the 100% saving of wastewater and the production of **only TMPi and NH4Cl by-product, which can be reused towards a circular economy**.

7) The **Life Cycle Assessment** (LCA) analysis consists of a series of activities aimed at assessing the environmental impact of a chosen process and product from the procurement of raw materials to the final disposal. LCA procedures and definitions are regulated by international ISO 14040:2006 standards. The assessment of the environmental impact considers important indicators (i.e. GHG emissions, energy and water consumption, emissions, waste). The monitoring procedures was conducted in loco and by using literature data from international databases. Finally, the results of the assessment will be disseminated to the widest possible audience.

8) **COM (2011) 21** encourages EU companies to undergo continuous innovation and technology transfer processes and at the spreading out of knowledge towards the industrial community, academia, the wide public and policy makers.
LIFE TRIALKYL innovation stems from the need to elaborate sustainable solutions in the chemical sector. For such a reason the project partners conducted extensive research on sustainable alternatives in terms of chemical reactions pathways and industrial processing, resulting in the introduction of a new chemical formulation and industrial process. The partners are fully committed in spreading out its achievements and impacts towards the industrial and academic community in order to obtain relevant feedback and possibly start future collaborations.

Last, but not least, the LIFE TRIALKYL project complies with all the requirements of the LIFE 2014-2020 programme, and the "Environment Action Programme to 2020" of the 7th EAP, in terms of environmental and socioeconomic impact at the EU level. Therefore, the present innovation constitutes an important demonstration of the feasibility of highly sustainable and eco-friendly solutions in the chemical sector, especially considering the substantial cut of GHG, water consumption and wastewater, emitted pollutants and limiting toxic chemicals.
The project can also contribute to the above policies update and development by:

- furtherly push the EU chemical industry towards new sustainable and safer approaches with specific reference to GHG emissions and minimization of effects on humans health and environment (7th EAP DECISION 1386/2013/EU)
- demonstrating to greatly reduce PM10 emissions , especially in working environments (clear air package 18/12/2013)
- providing NH4Cl by product to agrisector in view of future greener and more circular economy (Decision 2011/383/EU)
- Contributing to the updating of COM (2005) 666 on wastes prevention and recycling.

5. Environmental impact and resource efficiency

The present innovation constitutes an important demonstration of the feasibility of highly sustainable and eco-friendly solutions in the chemical sector, especially considering the substantial cut of GHG, water consumption and wastewater, level of emissions and avoidance of toxic chemicals. We thus expect the present innovation, given the important advantages, will enhance the EU chemical industry share on the global market and embrace the Circular economy concept by re-cycling in the economy the generated by products.
The main environmental project's focus are therefore:
1. Resource efficiency in terms of energy and circular economy
2. Resource efficiency in terms of raw materials and water consumption
3. Chemicals substitution and chemicals released vs the state of the art
4. Air emission-air quality

The innovative environmental aspects of the project come out of the direct comparison of the various existent processes.
Presently, two state of the art technologies are implemented worldwide:

1) PCl_3 + methanol + tertiary amines process (presumably 75% share)
2) Trans-esterification process.

which show different sustainability levels of the respective synthetic processes. The environmental impact of the Trialkyl process is assessed in the LCA report, based on laboratory data and scaled for the pilot plant. It is clear, from the developed LCA and SEA, that the state-of-the-art processes are much less sustainable in terms of energy consumption, water consumption, waste generation and use of toxic substances (namely NaOH, chlorinated solvents, tertiary amines and phenols derivatives). Moreover, the additional steps required to neutralize byproducts make the industrial production not sustainable nor cost-efficient and energy consuming (GHG emissions). On the contrary, the innovative

TRIALKYL synthetic route tackles such environmental and hazardous aspect of the state-of-the-art technologies.

Resource efficiency in terms of energy - circular economy and climate change

From a state of the art energy consumption value, related to the current standard tertiary amines process, of 5kWh/Kg, the innovative process works with an energy consumption of 3.0 kWh/Kg. The energy consumption decrease will affect not only the economic aspect of the Trialkyl phosphites manufacturing, but also the environmental aspect linked to a more sustainable C footprint.

The preliminary LCA results give emission of 3.14 kg CO_2eq for the Trialkyl process vs 52.9 kg CO_2eq for the TEA process per kg of TMPi produced. Using a social cost of carbon of €33.8/ton (EPA 2017) and for a 180 ton/year plant size this gives a respective climate change cost are calculated according to the following calculation:

3.14*180000kg *€33.8E-3/kg/kg = €19104 per year for the Trialkyl process

52.9*180000kg *€33.8E-3 = €321848 per year for the TEA process

In addition, the novelty of the technology process makes it possible the 100% reuse of the generated by product NH_4Cl, recovered, and purified, in solid phase ammonium chloride.

Resource efficiency in terms of water consumption, raw materials and wastes management

LIFE TRIALKYL clearly demonstrates a novel continuous process characterized by a much lower water consumption and wastewater as compared to state-of-the-art technologies.

Water depletion

The preliminary LCA results give water depletion numbers of 16.38 m^3 for the Trialkyl process vs 43.6 m^3 for the TEA based process for each kg of TMPi produced. This is water depleted all along the value chain from the upstream chemicals used in the process and their manufacturing, to the energy used. Using the water price (Public Policy 2017) of €0.4/m^3 found in Milan (Italy), the total water costs are calculated according the following calculation:

€0.4/m^3 *16.38m^3/kg *180000kg = €1 179 360 per year for the Trialkyl process

€0.4/m^3 *43.6m^3 /kg *180000kg = €3 139 200 per year for the TEA based process.

This is not the price the Trialkyl plant owner would have to pay for water consumption but the total cost of water depletion which occur all along the two different value chains of TMPi production

Waste water:

A state-of-the-art TEA based process of 180 ton/year TMPi production has to treat 320 000 l/year of wastewater (Italmatch, Carlini 2017). Assuming a proportionality factor, a 180 ton/year TEA based plant would produce 720 000 l/year. In the Trialkyl based process, the process water is reused and recovered in the pilot plant.

The process water production of TBPi, which is about about 30m3/h (Italmatch, 2019), not saturated by NaCl can be 100% recovered.

Waste (other solvents):

The solvents used in the TEA based process, are also chlorinated solvents (e.g dicloromethane, CH_2Cl_2).

Therefore, we can confirm that the innovative LIFE TRIALKYL process does not produce any not reusable waste and will produce reusable waste NH_4Cl in a quantity equal to 120, 5 tons per 180 tons of TBPi produced per year at the end of the project and 2678, 5 tons per year of reusable NH4Cl per 4000 tons per year of TBPi, 5 years beyond the end of the project

Eutrophication:

The LCA preliminary results give numbers of 0.0072 kg PO_4eq for the Trialkyl process and 0.049 kg PO_4eq for the TEA process per kg of TMPi produced.

The cost of 1 kg PO_4eq emission being €3.9 (Ecocost value 2017) this results in 3.9*180 000*0.0072 = €5054 per year and 3.9*180 000*0.049 = €43398 per year of eutrophication costs for the Trialkyl process and TEA process respectively.

The following table can summarize the whole environmental benefits generated by life trialkyl vs the state of the art technologies. By comparing the TEA with the Trialkyl process demonstrates that the environmental impacts are much better for the Trialkyl process compared to the TEA process (between 60 and 90%).

Type of impact	Trialkyl process	TEA process	Difference
Acidification Potential AP [kg SO2 eq per kg TMPi]	0,017	0,21	-92%
Eutrophication potential [kg PO4 eq per kg TMPi]	0,007	0,049	-85%
Global warming potential [kg CO2 eq per kg TMPi]	3,14	52,9	-94%
Ozone depletion potential [kg CFC 11 eq per kg TMPi]	7,6 E-7	3,86 E-5	-98%
Photochemical oxidant potential [kg NMVOC per kg TMPi]	0,01	0,29	-96%
Energy demand [MJ per kg TMPi]	64,6	901,6	-93%
Water depletion potential [m3 per kg TMPi]	16,4	43,6	-62%

Fig.25- Environmental impacts from the Trialkyl and TEA process, LCA statement-RISE

Chemicals substitution and chemicals released vs the state of the art

Considering an estimated total consumption in the world of 20.000 tons per year of TMPi intermediate based additives in the plastic industry, the substitution value of the actual standard TMPi by the new LIFE TRIALKYL TMPi phenol free cannot be correctly calculated at this moment.
The 180 tons/year produced by the pilot can partially substitute some of this consumption at global level. These quantities could raise up to 4.000 tons 5 years beyond within Europe.
Now the following projection, developed along the project, and to be adjusted according to the feedback by the contacted potential stakeholders shows that:

a) Considering the Transesterification actual state of the art process, the production of 180 tons/year of TMPi requires 261 tons /year of triphenylphosphites and generates the subsequent amounts of phenol derivatives with all the related environmental issues.
Thanks to the LIFE TRIALKYL innovative process, in order to produce 180 tons/year, we avoid the usage of 261 tons/year of triphenyl phosphites, which will be 5.800,00 tons per year if referred to the expected EU demand of 4.000,00 tons per year.
b) Considering the standard ion exchange production process based on the tertiary amines, the production of 180 tons/year achievable by the pilot will avoid the usage of 461.5 tons/year of tertiary

amines and 720 tons/year of Dichloromethane and 540 tons/year of Sodium Hydroxide for a total amount of 1.721,5 tons per year.
If we consider the whole production of the expected demand by the European Union equal to 4.000,00 tons of phenol free TMPi per year, then the ammonium chloride production as reusable by product will raise up to 2.678,00 tons per year.
On the other side, the marketable product TMPi (for intermediate use only, registration nr. EC 204-471-5 CAS 121-45-9) is phenol free. Therefore, no release at all would be present with the dissemination of this technology.

Air emission and air quality including GHG

VOC emissions at the moment are not in line with the expected results, therefore the analysis is referred to GHG emissions and PM10eq.
The PM10eq related to the LIFE TRIALKYL process are equal to 0,009 Kg vs 0.12 Kg for TEA process.
Regarding the Greenhouse Gas emissions-CO2: for a proper comparison in CO2 emission related to the state of the art and the expected improvements we must consider the two cases:
a) Standard production process from India and China exclusively by shipping:
-beginning (80 tons/year consumption in Milano): 0,88 kg CO2/year/km
-end (180 tons/year capacity of the pilot plant): 1,98 kg CO2/year/Km
-5 years beyond (European expected consumption of 4.000,00 tons): 33 Kg CO2/year/km

b) Same quantities along the years but produced in Europe by adopting the innovative LIFE TRIALKYL chemical process: the gain will be in the distance reduction and in the related shipping CO2 consumption that will lead to roughly a saving of CO2of about 500 tons per year considering a European consumption of 4.000,00 tons/year of Phenol Free TMPi.

Analysis of benefits - Economic and Social

Economic benefits

Chemicals are an integral part of modern life and in our EU industrial society, with over 100 000 different substances in use, the chemical industry is one of the biggest industrial sectors. It generated around 111 M EUR of the value added of the EU‑27 manufacturing industry in 2010 [data from 2010, EUROSTAT]. It is also an important source of employment in many regions of the EU. In the EU‑27, some 28.600 chemical companies employ a total staff of about 1.16 M people, equivalent to 3.9% of the EU manufacturing industry's overall workforce [data from 2010, Eurostat].
The EU area is the world top importer and exporter of chemical substances as of 2012 [CEFIC], accounting for nearly 38.1 % of the global trade, and 673B EUR total sales, and it accounts for about 1.1% of the EU GDP as of 2010 (CEFIC). However, the EU currently faces strong competition from Asian countries, especially China, which reached about 30.5% of the world chemicals sales in 2012. Europe's producers are focused on reducing fuel and power consumption per unit of production to ensure they remain competitive on world markets. In fact, between 1990 and 2009, annual chemicals production climbed an average 2.5% while energy consumption fell by 1.7%.
In this context, the EU trialkyl phosphites production does not exists at all, due to the unsustainable state-of-the-art processes from economic and energetic point of view (supplies mainly located in India and China).
When it comes to the production of chemicals, the share of environmentally harmful chemicals in totalEU-27 chemical production has not changed significantly over the last 10 years and production of environmentally harmful chemicals fell by 31 million tons (or 16.0 %) to a lower 163 million tons in 2009. As for the overall production of chemicals, there was a strong rebound in 2010, followed by a modest increase in output in 2011, and a further fall in 2012. This resulted in 174 million tons of environmentally harmful chemicals being produced in the EU-27 in 2012, roughly the same as had been produced in 2002 and lower than in all intervening years except for 2009.

In addition, there is a direct effect of the harmful chemicals produced on the environment, either in terms of wastes management or in terms of water consumption and pollution in an ecosystem where water is a critical element for both our society and economy. As a fact , the usage of water in Europe accounts for an overall $2.27x10^{+15}$ l/year as of 2009 [2009, EEA, Water resources across Europe]. Water is used intensively by the industry (57%, 45% for energy generation only), public (21%) and agriculture (22%) [Data from CEFIC]. During recent years, the water quality in the chemical industry has not shown significant improvements and it appears to reflect the total EU production itself [data from 2009, CEFIC and E-PRTR].
In comparison, the EU chemical industry waste (incl. wastewater), as 2009, recorded an increase in the waste production and disposal, and a decrease in the recovery of waste.
It is thus evident that considerable efforts need to be done by the chemical industry in terms of energy and water consumption, and, in particular, waste production mitigation. Innovative plants and processes, new technologies, and skilled operators are recognized as essential elements towards a higher level of sustainability [CEFIC], for Environment, economy and Society.

The jobs impact evaluation is calculated for the project staff at the beginning, at the end and 5 years beyond to be dedicated to the unique pilot plant.

- The estimated average cumulative operating expenses per year, including FTE, S&M expenses, Raw materials and maintenance of the plant is, now equal to 350.000 euro.
  Regarding the estimated cumulative revenues are based on the predicted demand by the European market of 4000 tons/year.
- The estimated TMP average market price, based on the available data on the market, is the following:

Average purchase cost of TMP	2671 eur/ton
Average market price	3468 eur/ton
LIFE TRIALKYL estimated cost (PILOT at 100% capacity)	1899 eur/ton

- A prior estimation of the volume potential regarding both the trialkyl phosphites and the NH_4Cl byproduct in solid form in tons volumes leads to an overall maximum potential for generic Trialkyl phosphites of about 200.000 tons consumption worldwide only for PVC application (175.500 tons) of which TMPi represents roughly 10% of it (20.000 tons)
- Regarding NH_4Cl, assuming that it would partially substitute NH_4NO_3 in the transforming industry, which values 2.131 Ktons, at least 10% of it can be at the moment a consistent prediction.

Social benefits
The social benefits of LIFE TRIALKYL are deriving from the successful feasibility of the LIFE TRIALKYL Novel process, which will contribute to improve the Health status of both consumers and chemical industry's operators by proving all the above-described specific benefits. In addition to this, Citizens' health is a very important point on the EU agenda [COM(2007) 630 final] so that the EU strategy "Together for health" aims at improving public health, prevent human illness and diseases, and identify sources of danger to human health. Chemicals are present in virtually everything that society uses on a daily basis. Chemicals have a number of benefits for human health and contribute to the overall quality of life, but may also present risks. The chemical industry in Europe is highly regulated in terms of both its products and its operations, and it is around twice as safe as overall European manufacturing.
According to recent research, 19 % of EU Workers Report are exposed to toxic vapors for a quarter or more of their working time, while 15 % of workers have to handle dangerous substances as part of their daily work [data from the European Agency for safety at Work]. Moreover, less than 10% of the working population has access to occupational health services in many European countries [data from

WHO-Europe]. Poor working conditions result in 300.000 work-related deaths and economic losses of 4% of the gross domestic product of the European Region every year [data from WHOEurope].
The LIFE TRIALKYL project aims at contributing to a lower incident of occupational related diseases and risks by:

1) Avoiding harmful and toxic chemicals like tertiary amines and phenols derivatives and chlorinated solvents. The TMPi synthesis reaction will consist of the simplest possible chemical reagents (i.e. PCl3, anhydrous ammonia and methanol), and will have as output TMPi and ammonium chloride, which can be used as a fertilizer.
2) Eliminating wastewater. Thus, no additional corrosive substances like NaOH and chlorinated solvents will be used for neutralization purposes, and the potential release of VOCs. Additionally high salinity water release in the environment will be avoided.
3) Protect the workers and the environment sealing the pilot line with most secure and safe technology present in the market, which will avoid potential leakages and release of chemicals.

The LIFE TRIALKYL estimates to reduce the incidence of accidents and diseases by at least 2%. This will in turn reflect on the national health expenditure, which is about 6-11% of the GDP [2012, EUROSTAT, Healthcare statistics], in line with the EC "Improving quality and productivity at work: the Community strategy 2007-2012 on health and safety at work" strategy. The project complies with the Seveso Directive (2012/18/EU) on the prevention of occupational risks too.
Moreover, a well-targeted dissemination campaign will raise the awareness of citizens on worrying and important aspects, i.e. the pollutants emissions and toxic chemicals, GHG emissions, water consumption and climate change.
LIFE TRIALKYL contributes as well to disseminate the culture of the Social Care chemical products, offering a highly sustainable C Footprint, reduced by 94% if compared to the state of the art technology. The LIFE TRIALKYL project aims at innovating TMPi production technology by replacing state-of-the-art methodologies (i.e. PCl3+tertiary amines and methanol, and transesterification reactions) with a continuous industrial process based on a different reaction. This, as explained in earlier sections, will bring to a consistent energy saving (20-30%) and water saving (up to 100%) in the manufacturing process, whilst it will completely avoid the production of wastewater (100% saving), and the use of toxic chemicals like NaOH, chlorinated solvents and phenols derivatives, whilst minimizing emissions.
Through the entire duration of the project, the LIFE TRIALKYL team minimized the use of unnecessary means of transports for travel and meeting, and they will use the most sustainable solutions (e.g. train transport and digital communications).

Conclusions:

By comparing the economic benefits of continued use of the “TEA” process (for the timeframe of five years) with the scenario where the TEA plant has to shut down (wait for one year for the Trialkyl plant to be built and then have a 4 years production), it is clear that the society benefits significantly from the shift to the Trialkyl process. This demonstrates that the costs of continued use of the TEA process outweigh the benefits by several orders of magnitude, and that a shift to the Trialkyl process is clearly justified from a societal perspective**.**

Type of impact	Benefits of continued use	Cost of continued use	Net impact of continued use
Economic	Avoid Capital cost of Trialkyl: € 1.5 Mill (2017) CAPEX: € 1.154 Mill (2019) (23% better, Pilot 2019) Avoid Loss of production:	Higher operational costs OPEX: €36180/yr (2017) OPEX: €108 000/yr (2019) (3 times higher, Pilot 2019)	A net economic benefit *23% better CAPEX* *3 times better OPEX* *(for Pilot Plant 2019)*

	€588960		
Human Health	Avoided risk of Trialkyl chemicals €24921/yr Avoid Trialkyl air pollution: €19926/yr	Risk of TEA chemicals: €261734/yr Air pollution: €265680/yr	A net economic cost
Environment	Avoid Trialkyl Climate impact: €19103/yr Avoid Trialkyl Water: €1179360/yr Avoid Trialkyl eutrophication: €5054/yr Avoid Trialkyl aquatic toxicity: €44.16/yr	Climate: €321848/yr Water: €3139200/yr Waste Water: €367/yr Eutrophication: €43398/yr	A net economic cost
Social	Avoided short term unemployement impacts	No significant change	Likely to be no significant change
Wider economic	None	No By-product: €23787/yr	A net economic loss

Fig.26 Benefits and risks associated with continued use of the TEA process refreed to life trialkyl.

Policy implications

Policy implications are mainly of environmental nature; as a fact LIFE program is strongly focus on supporting and realizing, by funding, ecosustainable solutions in all the sectors in order to meet the society development and progress needs by pushing for the Research and Innovation actions towards a sustainable universal model, in this case within Green Chemistry. The EU environmental policy aims at maintaining or developing the best as possible performance of this category of additives and chemical intermediates, in compliance with the "Environment Action programme to 2020" of the 7th EAP (1386/2013/EU). More specifically for this Phosphorus chemistry case, the market recognizes and defends the principles declared in the "Sustainability policy within the Phosphorus value chain" (www.susphos.eu; -II° International Conference on Sustainable Phosphorus Chemistry, 9-10 March 2016, Berlin). For this reason, the industrial world is requested to pursue its industrial application, as reported by Tomáš Turecki (European Commission, DG Research and Innovation- *Unit I.2 – Eco-innovation*) in the Relation to the Audience of the ESPP, titled "Phosphorus stewardship in industrial applications" Brussels, 1 December 2016.

This means, in a glance,

- to reduce the N and P problem by adopting a sustainable, green and circular chemistry (J.C. Slootweg, SUSPHOS/EU, ESPP-1-12-2016)
- to reduce GHG emission in compliance with the EU2020 strategy by 20%
- to reduce hazardous chemical wastes (2000/532/EC Comm.)
- to reduce VOC emissions (1999/13/EC)
- to protect workers form the risk of exposure to chemical, physical and biological agents (Directive 80/1107/EEC. 2009/161/EU, 2012/18/EU)
- to reduce water consumption in compliance with the Water framework Directive (2000/60/EC) and the White paper COM (2009)147.
- to substitute the non-bio degradable quaternary ammonium salts, prohibited by the European Commission in relation to biological fruit and vegetable products treatments in disinfection or

growth adjuvants (2011/383/EU) [2010, M. X. Vieira et al., Rev. Bras. Ciênc. 34 (4)], by the NH4Cl, responsible for a much lower VOC & higher efficacy

Moreover, life trialkyl can contribute to the implementation and design of all those regional, national and European legislation

Innovation and demonstration value

The level of innovation and demonstration value added by the EU funding program stays in:

I. creating an operational model which facilitate the technology transfer of innovative ideas from the Lab to the industry and to the market generating profit and societal development
II. generating progress towards a profitable Eco sustainable economy
III. stimulating the cross fertilization among different sectors
IV. providing proper real instruments to support the enterprises in their development in the interest of the European and global societal healthiness and welfare.
V. Supporting the fulfillment of the European policies regarding Environment, Health, Societal more sustainable systems by funding projects with specific focus on the directives and Regulations

Best Practice lessons

The project is developed according to the Project Management Rules and a specific competence was included in the Project team from the beginning in order to best comply with the requested activities and to organize the actions in a way to continuously involve all the partners above the single entities. This provided to the team members the right implementation of their management skills as a value to be replicated on other projects. The high level of the technical content challenged the LIFE TRIALKYL team to apply all the Project Management tools to avoid or at least reduce failure risks such as:

- Regular operational meetings
- Mind mapping-brain storming and actions plan revisions
- Risk and Mitigation plan with updates and application of the defined corrective actions
- Costs monitoring and budget revision sessions to orient the investments towards the successful realization of the project's objectives
- Multicultural management approach to develop and successfully apply the proper communication instruments in order to meet the diverse sectorial models (from science to operations to finance, to marketing).

In practice, the general governance of the project was guaranteed by adopting specific practices such as:

I. Compliance by Application of risk criteria to assess, evaluate and mitigate serious types of non-compliance:
   - Directive 2010/75/EU of the European parliament and of the council of 24 November 2010 on industrial emissions (integrated pollution prevention and control)
   - Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012 an the control of major –accident hazards involving dangerous substances, amending and subsequently repealing Council

   In addition, expert duty holder performed the technical consultancy to LIFE TRIALKYL regarding the regional and domestic permits and authorization dealing with the preliminary risk assessment Law 81/2008. In addition, the "Engineering and Services" consultancy office plus other control local authorities will provide the conformity of the machinery design according to the Directive 2006/42/CE.
II. Two enforcement bodies, including an external consultant, were involved in this process for Managing monitoring programs or schedules; ensuring that the monitoring required in the

permit has been done, at the correct locations, for the correct parameters, and at the correct frequency; Pre-processing, performing calculations and validating the data for compliance with any alert or reporting levels; generating routine compliance reports for authorities.

III. Risk management: At the beginning compliance with chemical risk assessment plan and risk and contingency plan related to the overall project have been performed. Then monitoring the compliance of the identified activities to prevent and manage the risks plus the update of the risk is held at standard frequency.

Project management highlights

Data Project

The project was funded by the LIFE Programme of the European Union, under the code LIFE14/ENV/IT/000346.

Project location:	Italy
Project start date:	16/07/2015
Project end date:	16/07/2019
Total budget:	€ 2.243.969
EU contribution:	€ 1.346.381
(%) of eligible costs:	60%

The project Gantt Chart

The project underwent several major changes in the duration time frame and the length of the various actions changed in consequence of external factors (authorizations) as well as internal ones (Team's changes along the years). Beside the extension time of the project which meant the generation of a new project Gantt chart and related effects, the Audit of costs and incomes previously set with the external public auditors Deloitte-STS) was reset by appointment of Baker Tilly, that postponed the closure of the final reporting to the 31st October 2019. The resulting Gantt Chart is below reported and shows the prolongation of the project of one year in total.

Action		2015				2016				2017				2018				2019				2020			
Action number	Name of the action	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
A.Preparatory action (if needed)																									
A.1	Preparatory action			X	X	X																			
A.2	Design of the pilot line			X	X	X																			
B. Implementation action (obligatory)																									
B.1	Realization of the pilot line					X	X	X	X	X	X	X	X	X	X										
B.2	Prototype, testing and validation							X	X	X	X	X	X	X	X	X	X	X	X						
B.3	Industrial validation and fine tuning														X	X	X	X	X						
C. Monitoring of the impact of the project actions (obligatory)																									
C.1	Health assessment for hazardeous materials and Environmental Impact Assessment			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
C.2	Socio-economic impact evaluation							X	X	X	X	X	X	X	X	X	X	X	X						
D. Public awareness and dissemination of results (obligatory)																									
D.1	Disseminationa and Communication			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
E. project management and monitoring of the project progress (obligatory)																									
E.1	Project management			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				
E.2	Networking activities with other EU projects			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				
E.3	Indicators of progress			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				
E.4	After-LIFE Communication Plan									X	X	X	X	X	X	X	X	X	X	X	X				

Fig 9

The Project Management organizational structure

It is composed by transversal functions (Project Coordinator, Project Direction and Financial Assistance) and dedicated Project Teams at individual partners level (Action leaders), as shown in the project organizational chart below.

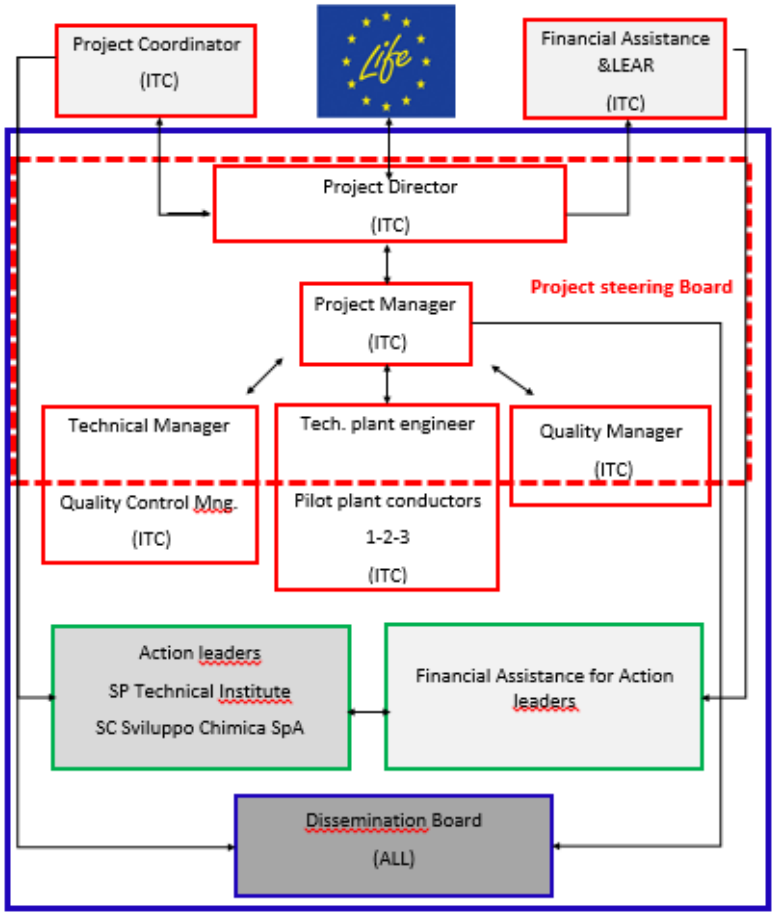


Fig.10: Project organizational structure

The Coordinating beneficiary (ITC) with the collaboration of several management bodies carries out the project management in order to facilitate the cooperation, to drive the synergic actions and develop the project plan in collaboration with the action leaders and their related project teams. The organization covered all the strategic, technical, financial, communication and dissemination actions under the transversal coordination of a Project Coordinator encharged with the approval of the project.
In addition, the high level of novelty of the proposed process technology required a plant engineering team fully dedicated to the pilot line set up, monitoring, adjustments, process control, process parameters verification and standardization. Therefore, a special team composed by a plant engineer and three pilot operators was dedicated to the pilot installation and testing down to the industrial validation.
The project management activities ran accordingly to the work plan; beside the cited major changes. Role assignments' communication, specific contracts and changes were duly reported and sent on request to the EASME appointed monitors. A IInd Progress report was developed and submitted to EASME in 09/2018 in addition to the standard ones.
Reports about the project activities were developed in line with the GA guidelines on monthly and/or quarterly basis according to the actions performed as well as the project monitoring actions by using the Risk & Contingency plan, including its monitoring updates and the Project Progress Indicators.

The Indicators of Progress: PPI (Project Performance Indicators)

The LIFE TRIALKYL PPIs reported in the Project Proposal and approved by all the partners in the kick off meeting held in September 2015, were quite confirmed all along the project's activities. In the final phase, in spite of the slight deviations, they still constitute the reference to monitor the progress of the project in line with the expected targets and comply with the Key Performance indicators loaded in the adopted EASME KPI database on EU KPI webgate. The PPIs were monitored during the project, action-by-action, reporting deviations and/or coherence to the expected results in the Project Progress Indicators Table. The PPIs table, refers to the final quantitative outcomes of the project in details and is coherent with the final KPIs registered in EASME KPIs database whose initial values were annexed to the submitted Mid Term report.
Apart from small deviations, related to the niche character of the project the expected results were fully met as shown in the table below which reports in a synthetic way the fitting between the expected results and the achievements of the project monitoring activity per each action, as from the internal reporting and progress reporting actions.

ACTION	MONITORING DESCRIPTION AND OUTCOME
A - Preparatory actions	The preparatory lab indicators and the pilot indicators were fully met as well as the process parameters, which were fully met in the simulation of the pilot line. See detailed deliverable A1.1. and A1.2
B - realization of the pilot line; Prototype, testing and validation; industrial validation and fine tuning	The pilot set up, blue prints; pilot manual, performed tests and related yield results were in line with the expected results. The industrial validation was successful for both TBPi and TMPi Phosphites range The start-up of the pilot, the testing phase and the industrial validation was performed strictly monitored by the dedicated technical meetings
C 1 - Environmental performance	The environmental and toxicology measurements as well as the LCA of this chemical novel process were completed according to the work plan and provided good results in line with the expected outcomes, except for specific values which were towards a much better sustainability, even if below the expected values.
C 2 - Socio economic impact evaluation	The market scenarios report as well as the SEA were completed according to the work plan and the related quantitative outcomes confirm the sustainability of the process, except for a specific VOCs emission-MTBE that requires an additional adaptation of the pilot plant.
D 1- Dissemination & Communication	The dissemination activities followed the strategy and actions were duly reported and completed by all the partners involved. LIFE TRIALKYL took part into 4 major international events (P Platform general assembly, WSSTP annual conference with projects presentations, SUSCHEM Italy conference and SETAC conference in Barcelona). Potential stakeholders and end users were selected and listed as well

	as participants to the events. Additional interests from the market will come after the conclusion of the project and the final conference. In addition, website visits are still being monitored. Quantitative analysis is included in the quantitative KPI webgate database
E 1- Project monitoring	Reporting activities and project management developed according to the set activities and objectives. A time extension request with its additional Grant agreement amendment was done in order to cover the delay generated by the authorization route.
E 2- EU Networking	EU networking was completed in line with the work plan and the deliverable is properly updated and closed.

The Dissemination and Communication achievements

The Dissemination and Communication scope is fundamental for disseminating the environmental and health benefits of the project to the widest possible audience. For this reason, it was considered pivotal to the validation of the project objectives and to raise the awareness of the wider public regarding environmental and health topics, which are at the core of dedicated EU regulations and directives.
All the performed actions were originated by the Dissemination and Communication strategy defined by the partners and in line with the project proposal where the expected results of this action are exposed as follows
The achieved results, organized in deliverables, submitted to EASME along the project up to the final versions, are briefly described below and can be explored in details through the dedicated Deliverables attached to this Final report.

1. **The Dissemination Plan**, developed with the aim to meet the LIFE TRIALKYL objectives defined in the proposal through the development of the Communication Strategy, included the realization of the **LIFE TRIALKYL logo** below reported in the two available formats and colour and the **PROJECT signatures**

LIFE-TRIALKYL LIFE-TRIALKYL

LIFE-TRIALKYL Italmatch embraces LIFE programme: discover more on www.life-trialkyl.eu

LIFE-TRIALKYL SC embraces LIFE programme: discover more on www.life-trialkyl.eu

LIFE-TRIALKYL SP embraces LIFE programme: discover more on www.life-trialkyl.eu

2. The mid-term workshop
The Mid-Term Conference (1-day workshop organized in Arese, Italy, on 27 June 2017) was the occasion to present the first results of the LIFE-TRIALKYL Project to Competent Authorities, to the identified potential stakeholders and to other LIFE Projects, involved in similar themes. And, for the participants, it was the opportunity to visit the Pilot Plant.
The Mid-term conference was the launch of a series of additional networking opportunities as well

3. Development of the project website www.life-trialkyl .eu

The LIFE TRIALKYL website was published on line in January 2016, and it is constantly updated, lasting 5 years after the closure of the project in order to include all the after LIFE actions.

From April 2016 (starting of the monitoring activity) to July 2019 the website was visited **94.047** times (the graphic is reported in the specific deliverable).

4. Development of a dedicated notice board

The notice board, to be exhibited at the various events, was developed in line with the second key element of the communication strategy in order to enhance the meaning of the project brand.

5. Preparation of brochures, fliers, dissemination material

- **Flyer**
  The flyer, printed in 1,000 copies, was sent to all the Partners (300 copies to RISE and 400 copies to ITAL). An electronic format was loaded in the project website as well and almost all copies were distributed during events and exhibitions.
- **Brochure**
  The brochure, developed in its final version between January and April 2019, is the marketing vehicle for the LIFE TRIALKYL process. It contains information about the development of the pilot plant, as well as about the timeline, the difficulties Partners dealt with, the innovative aspects of the pilot plant, the first results obtained and the benefits for the different market sectors. 200 copies of the brochure were printed and distributed during the final conference and it will be a useful tool during the after-LIFE phase.
- **Newsletter**
  Despite of what was foreseen in the project proposal, Partners decided to not publish a specific newsletter of the LIFE-Trialkyl Project, but preferred a flyer type. Considering the very technical and sectorial aspects of the project, according to the partners the lack of a newsletter did not represent a limit in the spread of project activities and results. The newsletter would have been too general and for this reason, it would not be a very functional and effective tool to the achievement of the communicative aims.
- **Final Poster**
  The poster was prepared based on use of the evaluation of environmental and socio-economics affects with the main aim to present the project as a perfect example of successful synergy among R&D, process technology and environmental issues. The idea behind the poster is to illustrate the connection between the new process and the circular economy and in particular, the strong link between the assessment of environmental impact and socio-economic impact, both fundamental for moving towards sustainable choices. The final poster, in English, was exhibited during the final conference

6. Realization of the LIFE TRIALKYL Layman report

The Layman's report summarizes the project work for a general audience.
The report contains a description of the project, its main objectives, the actions carried out and the results obtained.
Due to the consolidated appreciation for the graphic design of the other developed dissemination tools, by stakeholders, PPs decided to maintain the same elements already used in flyer, posters and brochure. The enhancement of the brand recognition was immediate, thanks to its clear graphic identity...
PPS decided to print 150 copies of the Layman's report in order to use it to present the project in the after LIFE period. The paper copies was distributed among Partners.
PPs decided to choose English and Italian as official languages of Layman's report. Swedish was not included based on RISE's suggestion. The accuracy of texts was verified by a specialized translator.
The Layman's report was distributed during the Final conference and it will be used as one of the main tool to communicate and disseminate the projects among stakeholders, client and other EU projects in in the after-LIFE phase

Fig.17-The principal flyer

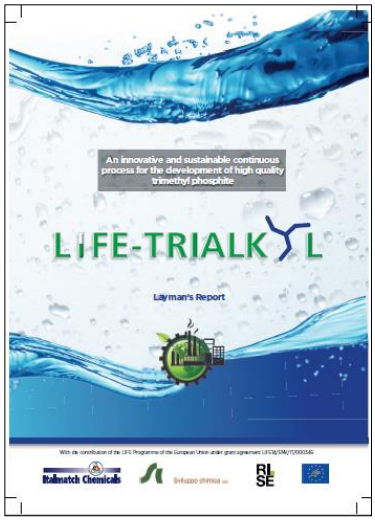


Fig.18- Layman's report

7. Preparation of scientific/technical articles for publication on international journals and professional magazines

Preparation of meaningful publication was very difficult for the PPs since the testing phase of the project was achieved.
Nevertheless RISE, based on an official presentation of LIFE TRIALKYL preliminary results during the SETAC conference (27-28 November 2017), which included two published publications, prepared and published a scientific poster.
The delay in the pilot plant and the consequently delay of the testing phase' results forced partners to carry on activities differently from the previous set up activities.
Indeed, it was very difficult to publish scientific articles on international journals. Usually scientific publications are subjected to an evaluation by a commission of experts. A positive evaluation of an article without reliable and finalized data would have been very difficult to be obtained.
Along 2019, during the last phase of the project, when the technological innovation could be promoted, Partners decided to contact Italian specialized magazines, in order to promote environmental and socio-economic impacts.
SCSC and ITAL cooperated in order to maximize the diffusion of the knowledge of the project through the media and completed the publication plan with a specific information articles campaign.
All the articles were also published in a pdf version on the project website.

8. The final conference

The event, held on 25th June 2019 in Milan at Federchimica's premises, was the occasion to present the final results of the project to selected end users, to policy makers, sectorial experts and national authorities, in order to maximise sinergies with them. The Final Conference was also an opportunity to present the environmental benefits, the new market scenarios and the socio-economic impact coming from the LIFE-Trialkyl Project. Speakers covering all the main aspects of the Project together with speakers coming from Italian Institutions and European Platforms, actively partecipated to the closing Q&A session enphasizing aspects such as

- the benefits and results obtained
- the activities to be done after the end of the project
- the difficulties tackled
- the strong potential of the project, in particular for its deep link with sustainability and circular economy.

The participants were directly invited by the project team, selected on the basis of potential future cooperation (e.g. other LIFE project, universities, institutions), of relation with the themes dealt (e.g. National and European Authorities and Institutions, Research Centers and Universities), of potential interest in the final product (end users), of interest to disseminate the results (specialized magazines or media).

Fig.20-The final conference

9. Generation of Networking opportunities-presentation of project's results to international conferences/fairs

The initial Midterm conference was the launch of a series of additional networking opportunities, among which the following were adopted in order to disseminate results and open issues to the "Expertize society as well as to the social community.

The networking in details

Along the project many networking occasions were outlined and developed with the purpose to establish links with similar LIFE and/or other European and national initiatives to increase consistently the project's expected results and impact on the society of the European citizens. Furthermore, during these years, LIFE TRIALKYL representatives participated in several events organized by specific European financed projects, sectorial-based European platforms, European and national relevant Institutions. The expected results were to develop cross fertilization actions, communication actions, and stewardship actions and to generate partnerships and collaborations with specific stakeholders.

We defined a clear plan with a special focus on the Phosphorus Chemistry, the Water management (Industry-Urban-Agri) and the Health and Safety regulatory issues.

In addition, the networking activities, shall meet four major project's scopes:

1) the reduction of the environmental impact

2) the improvement of the circular economy concept
3) the innovation in Chemistry as a leverage to increase the European citizens welfare
4) the sustainability evaluation of any process involved

All the partners participated directly to the networking actions in line with their company features and SC Sviluppo Chimica acted as a generator of opportunities to facilitate the networking process.

The major achievements can be here listed in a glance:

- **E4WATER:** this project closed at the end of 2016, addresses crucial process industry needs, to overcome bottlenecks and barriers for an integrated and energy efficient water management. E4water unites in its consortium large chemical industries, leading European water sector companies and innovative RTD centers and universities, active in the area of water management and involved in WssTP and SusChem European Technology Platforms. LIFE TRIALKYL benefit from the FP7-E4 Water findings, guidelines and strategies on water management, and the project network of stakeholders by getting **introduction to the WssTP platform as a hub to meet industrial stakeholders.**
- **4CITIES:** the 4CITIES global initiative involves all the major projects to meet the ambitious energy and climate targets for 2030, minimizing environmental impacts and risks of a synergic circular usage of water transversal to agri-urban and industrial segments. LIFE TRIALKYL participated to the related **Water Watch Summit** held in Milano 31/10/2018 taking part in two round tables about sustainable industry and regulatory issues, that gave origin to the quarterly participation to the **quarterly meetings of the Cluster LE2C- Lombardy Energy Cleantech** to watch the emerging compounds of concern in relation to life trialkyl process and to synergize with new coming funded projects within the Innovative pilot actions
- **LIFE+ WEEELABEX**: this project project aimed to protect the environment by improving WEEE collection and recycling practices in Europe. Representatives of the project were met at K Dusseldorf fair in 2016. The synergy aims to support the lay down a common and harmonized set of European standards with respect to collection, handling, storage, recycling, preparation for re-use and disposal of WEEE. These standards would demonstrate compliance with EU health, safety and environmental legislation. LIFE TRIALKYL will benefit from the LIFE+ WEEELABEX project in terms of standards, recovery and disposal when considering trimethyl phosphite applications as flame-retardants in WEEE.
- **FP7- RecoPhos:** this project, now closed, is about an innovative system to recycle phosphorus derivatives in a pure state form the sludge and in a form suitable for generating a secondary raw Material. The RecoPhos project is a EU FP7 funded project to develop a new process to generate white/ yellow Phosphorus from wastes, such as sludge or ash, from which it is possible to produce the PCl_3, primary source of Life Trialkyl. Recophos consortium has been met during the mid-term conference (Wilhem Skipper) in June 2017 and now the project is developing under the innovation umbrella of BEYOND INNOVATION Dept in Italmatch chemicals to enhance the Footprint of LIFE TRIALKYL

The After- LIFE plan

The goal of this action is the drafting of an after LIFE Communication plan aiming at identifying a communication strategy to continue the project dissemination after the project ending and to outline the future activities. The document was drafted during the last months of the project by the coordinating partner in collaboration with the project team and describes the future actions that are going to be carried out in order to guarantee the continuation of the dissemination activity, once the funded phase is completed including:

- LIFE TRIALKYL promotion at conferences and fairs
- Dissemination of the informational materials
- LIFE TRIALKYL website update
- Direct communications
- LIFE TRIALKYL video

For such action was done a preliminary outline of the leading partner, the partners involved and the expected deadlines. Furthermore an evaluation of the budgeted costs was done.

Evaluation of project implementation

At the beginning of the project activities, the project implementation methodology has been defined by the Coordinating Beneficiary and discussed within the partnership. In order to ensure the effectiveness of project's implementation a complete Project's Risk analysis and a Project's Risk &Contingency plan was developed and updated.

This Risk Management Plan has the purpose to identify, assess, respond to, monitor, and report risks associated with the LIFE-TRIALKYL project overall, covering the governance, the financial, the operational, the business and the management sessions, including the Chemical and Environmental risks that were deeply analyzed and reported in the preparatory actions phase of the Project. It outlines what and how things can or might go wrong, their potential effect, how risk management activities are performed, recorded, and monitored throughout the lifecycle of the project and provides templates and practices for recording and prioritizing risks. This risk management plan includes as well the identification of the corrective actions and their cost evaluation in order to efficiently respond to the project risk. This plan includes also the action plan for unforeseen events (Contingency plan) and how to face the emergencies that might occur.

The updated monitoring reports were developed on semestral basis along the project and took advantage of the Project Activity Reports developed by and shared with the project team. This reporting activity were very helpful for the Coordinating Beneficiary to become aware of the development of each project action, to track project progress and identify problems and risks in order to enforce proactive management. It was also decisive to encourage the team to the achievement of the expected requirement within the reporting period and to schedule the future activities and define new short deadlines.

This monitoring activity was very intense, request much more resources then estimated in terms of persons/months, especially as of the coordinating beneficiary. Nevertheless we are convinced that this activity has been essential for the management of the problems encountered, permitting us to overcome the criticalities, to achieve the project goals and to avoid possible wasting of money and time.

Spillover potential effects

1. Entry into new entities and projects- continuation phase

a) Future funding possibilities have been evaluated in general terms and considering the type of scope of the project we foreseen the potential involvement of other Private investors- equity for an initial investment of 3.000.000 euro, 5 years beyond the end of project for replication or implementation of the pilot plant and capacity plus the setting up of a Business strategic plan including additional FTEs and market developments

b) Replication of the pilot plant: further use of the pilot to produce for the market needs and development of new plant or implementation of the pilot to satisfy the expected 3000 tons/year plus an additional quote of the existing 20000 tons/year of the global consumption (TMPi, not generic trialkyl phosphites derivatives).

2. Entry into new sectors- continuation phase

The new sectors that will be entered are

a) Agriculture

b) Manufacturing of TMPi

Synergic actions are foreseen in the continuation phase with downstream stakeholders and opinion leaders of utilizers of trialkyl phosphites in order to explore the results application in new sectors such as:

- plastic automotive segment
- food packaging segment
- masterbatch producers
- plastic compounding
- agro-technology

In addition, dissemination actions will be maintained with the institutional and policy makers, such as WSSTP platform members, ESSP platform members, SUSCHEM for further relevant development.

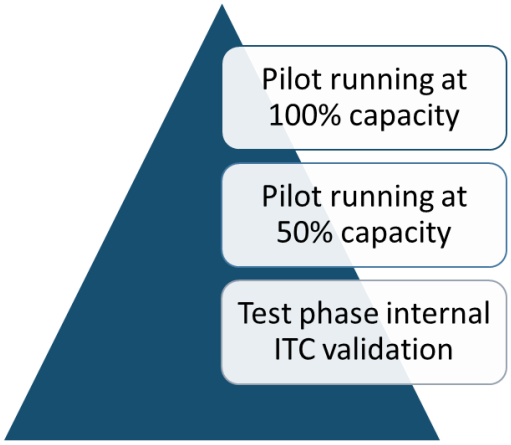
3. Entry into new geographic areas

The geographic distribution, still in the draft level, takes into account both the lowest CO2 equivalent emission consumption and the targeted stakeholders feedbacks in line with the replication models. The various possibilities have been already defined and replicability will be possible either in Europe or in USA and China, according to the market scenarios study. Starting from a NUTs2 territorial extent (ITALY- NORTH WEST-WEST- LOMBARDYA-MILAN) it could progress up to NUTs1 in the after LIFE timeframe (ITALY-EUROPE – GLOBAL) with a consequent cascade effect on the Environmental, Economic and Social impact at EU and global level.

4. Replicability, transferability, cooperation

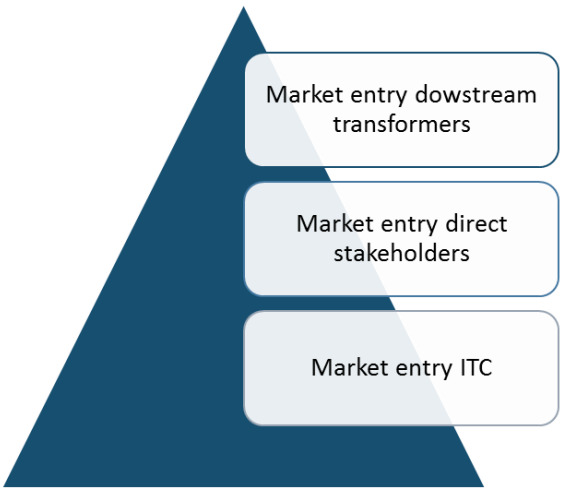
A theoretical study about the replicability and transferability potential was developed and several outcomes contributed to set the market entry scenarios. Three different implementation models have been developed:

Target I: short term: realization of the pilot line with no replicability or transferability, but exploitation of the deriving IP. The model refers to the successful completion of the LIFE TRIALKYL process technology and aims at 500Kg/d production

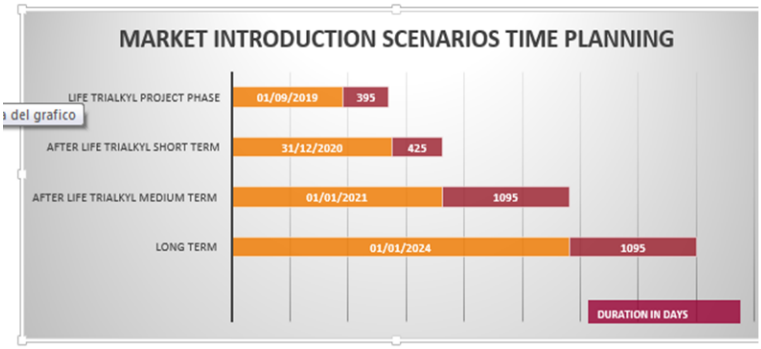


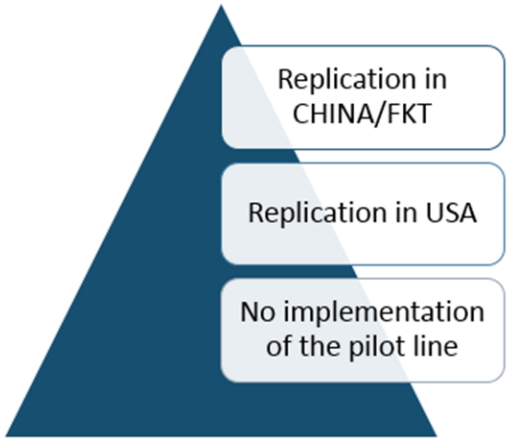
Target II: short to medium term: market entry to the direct stakeholders and downstream transformers: in this case replicability is limited to the model pilot “as is” even in cooperation of selected stakeholders.

The plan strongly depends on the stakeholders feedback out of the Dissemination activity performed along the project’s life and will be characterized by a significant marketing investment by the coordinating beneficiary. The volumes will be produced by the Pilot line as it is or by a revised model based on the stakeholders feedback about performances of the TMPi produced.



Target III: long term: market entry at all levels and global extension of the benefits, including economic growth. In this case replicability is not limited to the “Pilot as is”, but further plants designs and set up according to different dimensions ‘needs will have to be performed.





This third model, in which replication takes into account the gained Carbon footprint value, requires the completion of the market analysis with the stakeholders feedbacks on the validated TMPi and TBPi samples received and under evaluation.
On this basis, the potential for replication in other markets is elaborated together with a related industrial strategic plan and consequent investments and considers the actual presence of ITAL in Germany and in China were the “0Km” concept could be applied to the LIFE TRIALKYL process
The entry into new sectors- continuation phase was considered as well in the replication analysis. According to the developed action plan the new sectors to be entered are
a) Agriculture
b) Manufacturing of TMPi
as well as downstream, sectors in which strict **s**ynergic actions are foreseen with stakeholders and opinion leaders of utilizers of trialkyl phosphites in order to explore the results application in:

- plastic automotive segment
- food packaging segment
- masterbatch producers
- plastic compounding
- agro-technology

In addition, dissemination actions will be maintained with the institutional and policy makers, such as WSSTP platform members, ESSP platform members, SUSCHEM for further relevant development

Key Project level Indicators – KPIs

All the defined Project Specific indicators, were monitored along the project and met the expected results both for quality and for quantity. The SEA and LCA development as well as the completion of the testing phase, the Market scenarios completion and the closure of the defined dissemination activities made it possible to update the KPI monitoring system of the LIFE program by compiling the KPI 2.0 version of the informatics database on the webgate. Wherever the related actions have been performed, the results are in line with the predicted indications. Almost all the quantitative values predicted at the beginning of the project were confirmed with the exception of the quantitative VOC (NH3) that needs to be more lowered in order to fulfill the target of < 5 ppm vs the higher than 150 ppm of the state of the art TEA process. The complete file compiled in the LIFE webgate is not yet reported in Annex 6 together with the initial file, as it is not yet validated. Nevertheless, the quantitative achievements vs the expected results are duly reported in Annex 5 as the PPI are perfectly aligned with the KPIs of the project.
The comments are directly readable on the webgate, being not extractable neither in pdf nor in excel, and demonstrate clearly the achievements of all the goals of the project LIFE TRIALKYL:
The main descriptors, which were monitored, are the following:

- **Humans (to be) influenced by the project:** in strict relation with the dissemination and networking activities carried on along the project, this indicator is highly positive thanks to the increased awareness of the initiative and the quality of the LIFE TRIALKYL product

- **Water consumption for production and process water depletion:** both data show the higher level of sustainability of the LIFE TRIALKYL process versus the state of the art TEA and phenol based technologies.
  Additionally for water depletion: The preliminary LCA results give water depletion numbers of 16.38 m3 for the Trialkyl process vs 43.6 m3 for the TEA based process for each kg of TMPi produced. This is water depleted all along the value chain from the upstream chemicals used in the process and their manufacturing, to the energy used. Using the water price (Public Policy 2017) of €0.4/m3 found in Milan (Italy), the total water costs are calculated according the following calculation:
  €0.4/m3 *16.38m3/kg *180000kg = €1 179 360 per year for the Trialkyl process
  €0.4/m3 *43.6m3 /kg *180000kg = €3 139 200 per year for the TEA based process.
  This is not the price the Trialkyl plant owner would have to pay for water consumption but the total cost of water depletion which occur all along the two different value chains of TMPi production

- **Wastes management:** the LIFE TRIALKYL process contributes to decrease drastically the by product and process wastes, avoiding the water desalination (TEA process) process and allowing the circular management of the NH4Cl by product which is formed in the LIFE TRIALKYL process. Also PO_4^{3-} are drastically reduced , leading to a more sustainable eutrophication

- **Resource efficiency - circular economy:** The NH4Cl in solid form will be 100% reused in the agrochemical applications. Stakeholders are being collected through the held dissemination activities and through the networking across various downstream sectors

- **Chemicals released and substitution:** mainly this is Phenol and its derivatives which is neither released nor contained in the plastics derivatives, as well as Trietanolammine and related ammonium salt. In general, ss fully confirmed above this novel process confirms the possibility to abandon the existent technologies which are responsible for releasing dangerous chemicals in our environment. In addition, these chemicals will be substituted with chemicals that can be recycled circularly in our economy. A social deriving benefit is even of impact, as no Phenols will be anymore released directly during the production and indirectly from the manufactured deriving plastic materials

- **Air – emissions and Air – quality:** The drastically lowered emissions of PM10 are confirmed by the LCA study (Deliverable C1.3) and by the SEA based on the industrial validation of the process; VOC emissions (NH3), even if lower than the theoretical 150 ppm of the TEA process are not less than the predicted 5 ppm. (NH3: 40 ppm). In addition we measured high levels of MTBE (reactions solvent's emission: as a fact, the VOC emissions from the process (last sampling, trimethyl phosphite) were > 0.6 % (> 6000 ppm, average value of 4700 and 8500 ppm see Report). The main VOC was MTBE but there were several additional VOCs present with emissions far above 5 ppm. With an enhanced cooling system and a successful closed system, the VOCs might be reduced to a much lower level.

- **CO2:** also the CO2 equivalent related to the LIFE TRIALKYL process (0.009 vs 0, 12 kg per 1 kg of product respectively for life trialkyl process and TEA state of the art process) are of real impact**.**

- **Energy saving:** the LIFE trialkyl process requires 3.05 KWh vs 5.4 KWh per kg of TMPi produced respectively by Trialkyl and TEA process

- **Website:** the expected return by these disseminating tools were achieved , showing 94000 individual visits vs predicted 80000

- **Other tools for reaching/raising awareness of the general public:** the other set tools such as LinkedIn , twitter and web magazines , duly registered were in line with the expectations

- **Networking:** Confirmed interest received by stakeholders in the activities (even if lower than the originally predicted) as well as the synergies among the funded projects and private additional stakeholders belonging to new sectors such as EV batteries (recycle of NH4CL in the electrolytes recovery)

- **Jobs:** we have only considered people involved directly in the Project, whole team; an exact calculation of the new jobs creation related to the replicability model adopted was performed after the testing phase of the pilot in order to have experimental data on capacity and market development approach, but no specific projections are now available

- **Running cost/operating costs during the project and expected in case of continuation/replication/transfer after the project period:** the initial costs have been confirmed, a s in line with the replication models under investigation

Specific Context	At the beginning	At the end	5 Years	Units	Comments
N/A	0	2700000	1000000	€	We consider the costs of the whole project including partners that are not based in Italy (choice N/A). The "at the end" value includes the additional costs of the pilot plant construction and the not eligible costs. In the five years beyond value we only consider the Italmatch SpA costs.

- **Capital expenditure expected in case of continuation/replication/transfer after the project period:** these values have been confirmed in the final KPIs evaluation

Specific Context	5 Years beyond	Units	Comments
Milano	150000	€	Cost per year. This value to be revised in the second phase of the project after the strategic business plan preparation and having the results of the pilot production. In case of unique production by the pilot no additional capital expenditure are requested. If we consider a market need of 3000 tons/year then we need to replicate the pilot line to cover such demand with an additional investment of at least 3 millions euros.

- **Operating expenses expected in case of continuation/replication/transfer after the project period:** Costs are confirmed, limited to the pilot plant

Specific Context	5 Years beyond	Units	Comments
Milano	350000	€	Expected costs per year. Including FTE, sales & marketing expenses, raw materials and maintenance of the plant.

- **Revenue expected in case of continuation/ replication/transfer after the project end:** Same level of assessment as the one included in the comments, at the moment and confirmed. A deeper analysis is in progress depending on the adopted model

Specific Context	5 Years beyond	Units	Comments
Milano	0	€	What we can predict now is 180 tons/year with the actual pilot, without any replication of the plant. Price and related revenues not available now. If we consider the predicted demand by the market of 3000 tons/year than we must replicate the pilot with an additional capex. Again price per unit not yet available, only volumes in tons.

- **Future funding:** Future funding could be by the private equity and by other chemical partners such as BASF that is evaluating the samples...The expected budget is here confirmed at this stage of the project

Specific Context	Choose the Type of funding.	5 Years beyond	Units	Comments
Milano	Private investors – equity	3000000	€	For replication or implementation of the pilot and business plan development/realization.

- **Entry into new entities/projects**: This point developed in the report is linked to the replicability models and market approaches that are the driving leverages for the future of LIFE TRIALKYL. Replications and continuation were deeply discussed and analysed and 3 different strategies can be recognized and are reported in the market scenarios report. Therefore initial figures here reported should be:
1. continuation of the pilot up to 100% capacity running to satisfy the identified market needs; therefore no implementation of the pilot
2. replication in USA and or
3. replication in FKT/CHINA to get the additional quotes

Specific Context	Choose whether the project actions and/or results are to be replicated or transferred.	Comments
Milano	Continuation	Further use of the pilot to produce the TMPi for the market needs.
Milano	Replication	Development of new plant or implementation of the pilot to satisfy the expected 3000 tons/year plus an additional quote of the existing 20000 tons/year of the global consumption.

- **Entry into new sectors:** The two predicted sectors, agriculture and Manufacturing are confirmed.

- **Entry into new geographic areas:** The new areas have been object of study, see action C2.1 development can be confirmed in Europe beyond the 5 years and around.

Comments on the financial report

Summary of costs incurred

-Costs incurred from start date to final date split per partner are as follows:

Budget breakdown per partner	Budgeted costs in €	Cost incurred from the start date to end date	% of Budget spent
Italmatch Chemicals SpA	1.869.290	1.867.432	100%
Sviluppo Chimica SpA	105.084	93.276	89%
RISE Research Insitutes of Sweden AB	269.595	258.103	96%
totale	**2.243.969**	**2.218.812**	

The Final Consolidation Financial Report and the Final Financial Reports of each partners have been properly released in attachment to the confidential complete final report to EASME.

Final Financial Report ITALM

Final Financial Statement RISE

Final Financial Report SCSC

Consolidated Financial Statement

As a general comment , it can be declared that actual costs reported are slightly lower than the costs budgeted in the project proposal. This difference is the result of a different mix between the various cost categories.
A considerable saving in Consumable and other small saving in all other categories, allowed compensating the extra costs that the construction of Prototype needed.
Nevertheless, the budget shift among the various categories do not exceed the limit of 20%.
Making reference to each action in the project, the table here following compare budget to actual costs per action:

Accounting system
Each partners have implemented a dedicated cost center to Life project, in order to track costs.
ITAL has implemented both a cost center and a capex line.
Cost of prototype, as per Italian gap must be capitalized, so the capex line collects costs for prototype, while the cost center collects all the other costs, except personnel costs.
SC dedicated a specific cost code for the LIFE- Trialkyl Project: 15H000002, as well. Therefore, all the expenditures occurred for the Project are registered under this code.