Attachment 6

Cement kiln process and their emission impacts

The use of alternative fuels in the cement industry and their emission impacts

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Alternative fuels are a well-established aspect of cement kiln operation worldwide. On the available figures, the replacement of traditional fossil fuels with alternative fuels has reached on average 14% fuel replacement. This outcome has been achieved with no adverse impacts upon the cement kiln emissions and is a consequence of the unique characteristics of the cement manufacturing process.

Concrete is cited as the most consumed product on earth after water. Concrete comprises around 15% by weight of cement. Cement is the vital ingredient. It is the glue that holds together the sand and aggregate that forms concrete.

Cement production consumes large quantities of raw materials and fuels and produces significant quantities of carbon dioxide. The production of 1 tonne of cement consumes around 1.6 tonnes of raw materials and 0.1 tonne of coal and produces 0.8 tonne of carbon dioxide. As a consequence carbon dioxide emissions from cement kilns comprise approximately 5% of global emissions. Under the auspices of the World Business Council the Cement Sustainability Initiative (CSI) was developed which is a global effort by 25 major cement producers with operations in more than 100 countries who believe there is a strong business case for the pursuit of sustainable development in the cement sector. Collectively these companies account for around 30% of the world's cement production and 60% of cement production outside China. The cornerstones of this initiative is the development and promotion of the use of Alternative Raw Materials and Fuels derived from waste. The expressed aim is to convert waste that has significant calorific value into a cement kiln fuel or reuse waste streams that have a suitable chemistry as raw material replacements.

Data available from the CSI for 2012 shows the replacement of traditional fossil fuels with alternative fuels had reached around 14% amongst the member companies. This outcome represents around 14 million tonnes per annum of waste. The principal components of the alternative fuel stream were biomass and solid shredded waste each comprising around 25% of the alternative fuel consumption. The biomass comprises timber waste, rice husk and a range of other materials such as grape marc, olive pips etc. The solid shredded waste also known as RDF/SRF/PEF is largely derived from Commercial and Industrial waste, Municipal Solid waste and Construction and Demolition waste.

The use of solid shredded waste has grown to the point that the classification, sampling and testing of the material in Europe is now the subject of a European Standard EN 15359 2011 and is freely traded within the European Union. The export of solid shredded waste from the UK has grown from nothing in 2010 to over 2 million tonnes in 2014. This growth in trade has been driven by changes in the UK regulatory environment a lack of capacity to absorb additional volumes within the UK and the capacity of cement kilns and waste to energy plants in mainly northern Europe to accept additional material.

In Australia, ResourceCo supplies a proportion of the fuel requirements of Adelaide Brighton Cement at Birkenhead in South Australia with solid shredded waste derived from Commercial and Industrial Waste and Construction and Demolition waste. ResourceCo also has a processing operation in Malaysia that supplies a proportion of the fuel requirements of a large multi-national owned cement kiln. The feed material to this kiln is solid shredded waste derived from Municipal Solid waste and

Commercial and Industrial waste. Approximately 80% of the fuel is sourced from Australia and 20% is sourced locally.

It has been a feature of the Adelaide Brighton operation and the Malaysian operation that the change in fuel has had no adverse impacts upon the emissions to the environment and this finding is consistent with cement kilns around the world using alternative fuels. In the case of the Malaysian cement kiln the use of solid shredded waste also known as PEF has resulted in a reduction in Nitrous Oxide emissions of around 20% and a reduction in Carbon Dioxide emissions of approximately 20, 000 tpa.

This outcome is not surprising given the inherent nature of the cement manufacturing process. The species that are emitted from a cement kiln and that are of interest to a regulator can be broadly divided into the classifications of Dust, Nitrous oxides, Organics, Acid gases and Metals.

Dust: The particulate emissions from a cement kiln bear no relationship to the fuel being used but are purely a consequence of the type of dust collector that is used and the standard to which it is maintained and operated. Given the fact the process is counter current ie the gas flow is the opposite to the material flow the dust that leaves in the cement kiln stack is the fine component of the raw material input comprising typically limestone and clay.

Nitrous oxides: While NOx can be formed in a cement kiln from atmospheric nitrogen and the nitrogen in the fuel, it can also be destroyed depending upon the combustion conditions. The formation of NOx in a cement kiln is largely driven by the peak flame temperature in the main burner. The production of NOx by this mechanism can be offset by a phenomenon known as reburn in the kiln calciner where combustion of the fuel can produce conditions that destroy a portion of the NOx. It has been found in many kilns that the burning of a secondary alternative fuel can produce these conditions and this phenomenon has been observed with the burning of PEF in the Malaysian kiln.

Organics: The major concern with organic emissions is typically dioxins and furans (PCCD, PCCF) and Volatile Organic Compounds (VOC, TOC). The presence of additional chlorine in the system in the plastics component of PEF raises the question of whether there will be an increased risk of emissions of dioxins and furans. In the cement kiln system the principal determinant of the dioxin and furan emission is the cooling rate of the gas from the preheater exhaust temperature of 360 degrees C to under 200 degrees C and not the chlorine concentration in the gas stream. It is the time the gas spends in this temperature window that determines the dioxin and furan emission. The cement process raw milling system provides the ideal quenching system to avoid dioxin and furan formation, with limestone at ambient temperature being contacted with the hot preheater gases. Volatile Organic Compounds present in the kiln stack emissions are exclusively a consequence of the incomplete combustion of the organic components in the raw materials burning at relatively low temperatures (350-450 degC) and, as a consequence, forming a range of organic compounds. The fuels burn at such high temperatures with enough oxygen and for sufficient time that combustion is complete.

Acid gases: The components that can potentially form acid gases are chlorine, sulpher and fluorine. Although there is additional chlorine entering the system with PEF and there is the potential to form HCl from hydrogen radicals from the fuel combustion, the chlorine has a greater affinity to form compounds with potassium and sodium which remain trapped in the system until they reach an equilibrium and exit with the cement clinker. Similarly, any sulpher in the system preferentially reacts with potassium and sodium and then calcium and exits the system with the clinker. Fluorine behaves in a similar fashion. These effects can be likened to the process that takes place in a lime scrubber

Metals: The major impact on metals emissions from a cement kiln is the dust release from the emission control device. This dust comprises the raw material and the metal component of the raw material is essentially what comprises the metal emissions. The research arm of VDZ, the German Cement Industry Association has estimated the contribution the metals in fuels make to the stack emissions. For the eight refractory or non-volatile metals (Sb to V) the contribution is 0.0005%. For the semi-volatile metals (Cd and Pb) the contribution is 0.002%. For the volatile metals mercury and thallium the outcome can be unpredictable but is estimated at 0.02% for thallium and up to 100% for mercury. Thallium is an extremely rare metal. Mercury must be managed to low levels but for all the other metals present in fuels the impact upon emissions is so low as to be immaterial

While the preceding discussion deconstructs the emissions profile of a cement kiln and examines the conditions within the process that reinforce the observation that changes in fuel type have no adverse impact upon emissions there are also references available in the scientific literature that support this conclusion.

One of the best documented studies was conducted by the University of Lisbon on the cement kilns operated by Secil a Portuguese cement company [1a,b]. The work noted that *"One important conclusion is that the use of different alternative fuels has no impact upon the level of emissions and as the whole process was carried out within the control of the community, it was a consensual deduction."*

The use of alternative fuels by the cement industry is a means of improving the sustainability of that industry by reducing its impact upon virgin resources in the form of fuels and raw materials, reducing carbon dioxide emissions as well as providing a better solution for waste management. The overwhelming evidence is that these outcomes can be achieved without any additional adverse impact upon environmental emissions.

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More than meets the eye: emissions (bio-)monitoring, dispersion and risk analysis as innovative tools

by Maria João Botelho, Secil, and José Manuel Palma-Oliveira, University of Lisbon/Secil, Portugal

The conspicuous nature of the cement industry, the need for the use of alternative fuels and a strict regulatory context usually drives definite attitudes from the community and from society at large. The integration of all these aspects is undoubtedly the major challenge to the cement industry worldwide. Secil's emissions control and innovative monitoring methods have become a tool to sustain fuel diversification and community goodwill, besides providing in-depth knowledge about every impact.

The relationship between industry and local communities has been marked in recent decades by an accentuation of perceived risk, despite the absence of significant emergencies or disasters. This is a direct consequence of a diverse set of factors, including the rundown of industrial activity and a greater social concern about pollution. There are some regional factors that can exacerbate this issue as a result of specific environmental and social contexts (eg, a facility situated in a natural park).

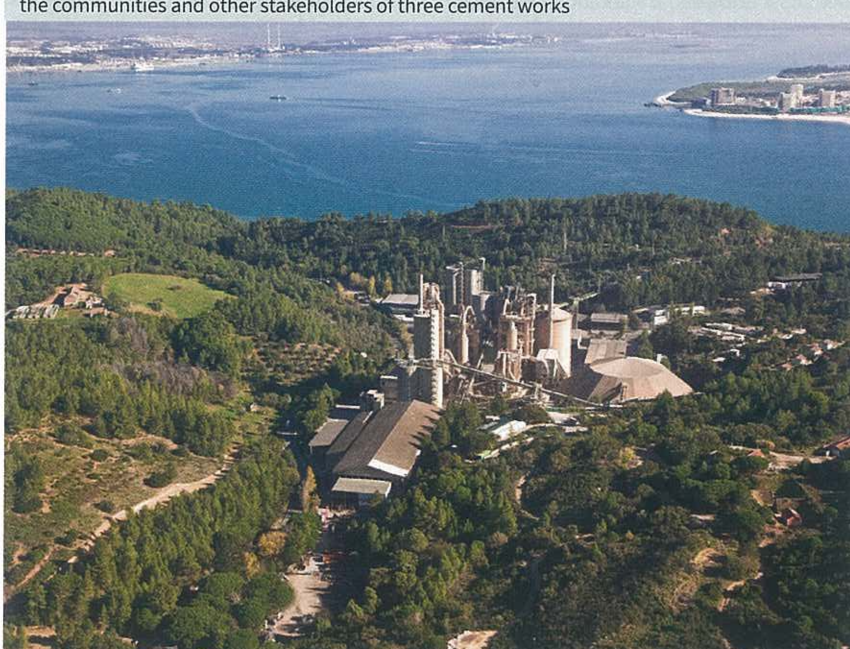
Due to current risk perception and control it is easily understood that the community (and sometimes even the authorities) will point to the destruction caused by quarries, while the company will stress the recovery undertaken .[1,2] Similarly, society views industrial processes as high risk, while companies 'know' that their operations are low risk. More importantly, society 'evaluates' pollutants as highly damaging, while companies recognise that they can be controlled, as evidenced by the fact that levels are consistently lower than the legal limits.

Information provided to stakeholders when engaging with them in consultations does not usually take into account these fundamentally-different perspectives. Even when grounded in solid risk communication principles, these consultations employ top-down approaches based on international data (eg, current dioxin data from international sources), that are limited in scope (ie, responding only to what is considered important), defensive rather than proactive, and largely unable to adapt to new, unexpected problems and crises. Given these factors, an industrial facility such as a cement plant may not appreciate the nature of its impact and is therefore vulnerable to false or misguided attacks.

Programmes like the Cement Sustainability Initiative and organisations like CEMBUREAU, the European cement association, are incredibly good sources of global information, but local communities find it hard to accept this, and always stress the specific context involved. Well, they are right, since the differences between facilities, contexts and so on, need to be included in the analysis when the 'here and now' is what really matters to our communities. To obtain good-quality data about the specific context, why not integrate the community in that endeavour and jointly decide what to do, and thereby address issues that are considered important?

The need to use alternative fuels for cement production has raised this set of issues to a new level. While coal is a 'known and old risk', alternative fuels and hazardous waste are perceived as new. That has huge psychological and social consequences that can be disastrous to the strategy of the industry.[3]

Secil's research programme investigated the environmental impacts of alternative fuel use on the communities and other stakeholders of three cement works



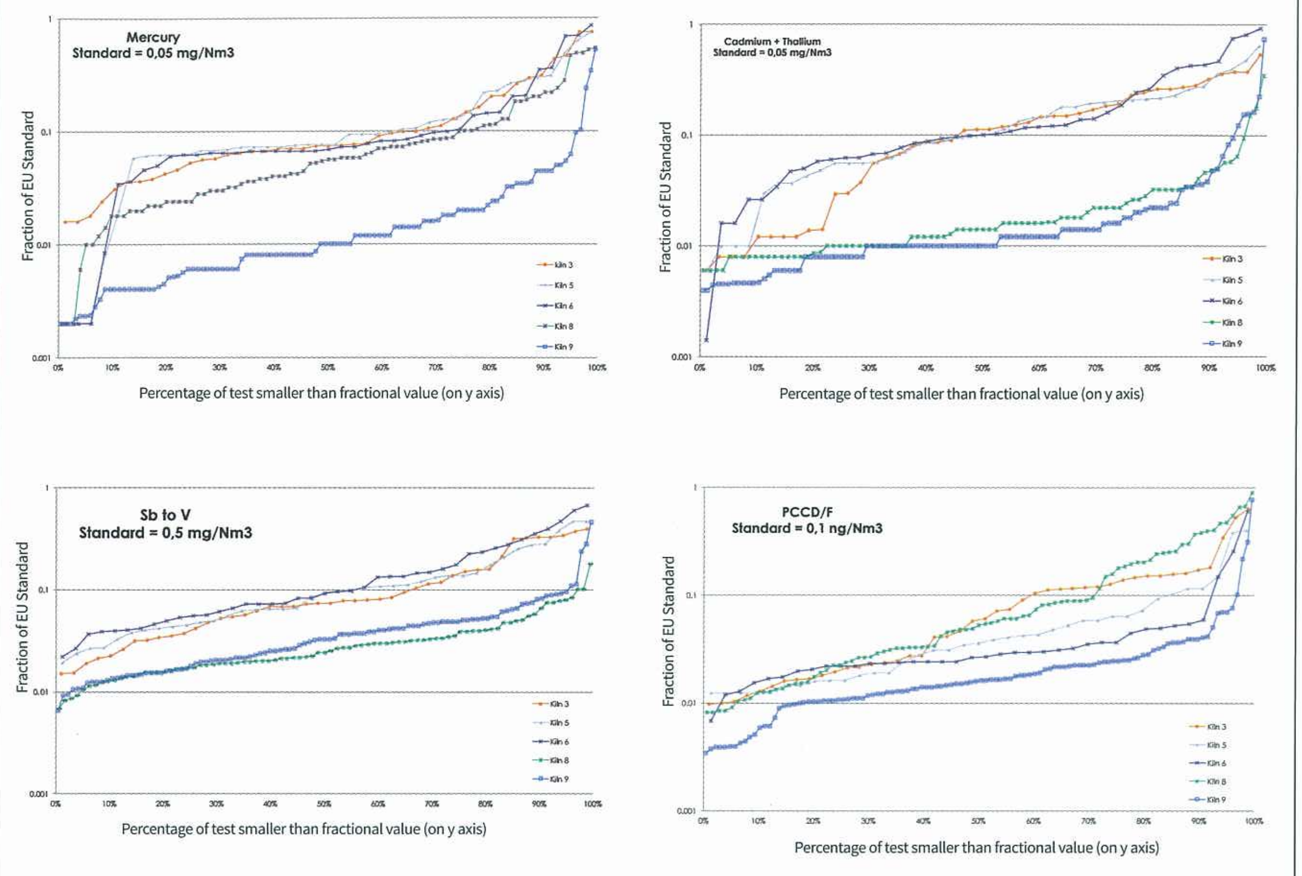
Environmental Stakeholders Committee (ESC)

Since 2003 Secil has maintained a series of environmental stakeholder committees to serve three different facilities in Portugal. The committees bring together environmental NGOs, health authorities (environmental medicine and sanitary experts), universities, the Association of Environmental Engineers, nature management areas, neighbours (such as the hospital) and a tourist operator (for the beaches in front of the facilities).

Trust is always considered essential, but how to achieve it is less clear. Based on the science of risk communication and control, we have to work on the trust dimension, ie:

- the company's willingness to change
- safety and consistency
- the company's honesty in reporting its actions
- credibility and equitability
- concern for the environment and competence in handling the environmental aspect of any operations.

Figure 1: ratios of measured stack-gas concentrations to EU Directive 2010/75/EU limits. Distributions of test results for all five kilns. Non-detects plotted at detection limits



Some basic rules have to be in place to obtain this trust, such as giving full access to all relevant environmental reports and allowing all committee members to have full access to the facilities, as well as the possibility of hiring experts to help the committee to have an independent view of the plant proposals and reports.[4] With all that in place, Secil has started a process of scientific research that the community has defined, checked and confirmed in its conclusions.

The action research programme

One can summarise the key questions facing the industry with respect to emissions and pollutants as: what are the emissions, from which fuels, what are the environmental and health impacts? Despite the amount of global information about these different issues, there is still a need for tailored, specific and integrated knowledge that can address these questions with a research methodology that can – and this is the crux of the matter – bring the community on board by jointly defining the research programme.

What are the emissions? From which fuels?

Secil, like the huge majority of players in the industry, follows Best Available Techniques (BAT) from the EU Cement and Lime BAT Reference Document (BREF-CLM) and thus monitors online 'criteria pollutants' (ie, the US class comprising those that cause smog, acid rain and other health hazards) as well as heavy metals and PCDD/Fs. But these activities are not sufficient to address the concerns of either the regulatory system and of the community with regard to the impact of emissions on population health and the environment. Addressing this question adequately is vital for the future of the industry.

Secil, therefore, set out to carry out a comprehensive study to address all of these issues. To obtain comparable data, Secil controlled the type of fuel mixture, and more importantly, agreed with the environmental committees of various facilities that the new fuels should be systematically tested before being put into regular use. As a result, the company shifted the discussion from an exclusive focus on emissions per se (ie, "RDF produces dioxins") to the existence of significant differences between the 'business as usual' fuel mix – coal and petcoke – and the new profile of fuels (including hazardous waste).

The results provided the company with the most complete set of data known to a cement company worldwide. As a result, Secil could inspect the data by kiln or by facilities, making it possible to draw specific and general conclusions with a high degree of certainty.

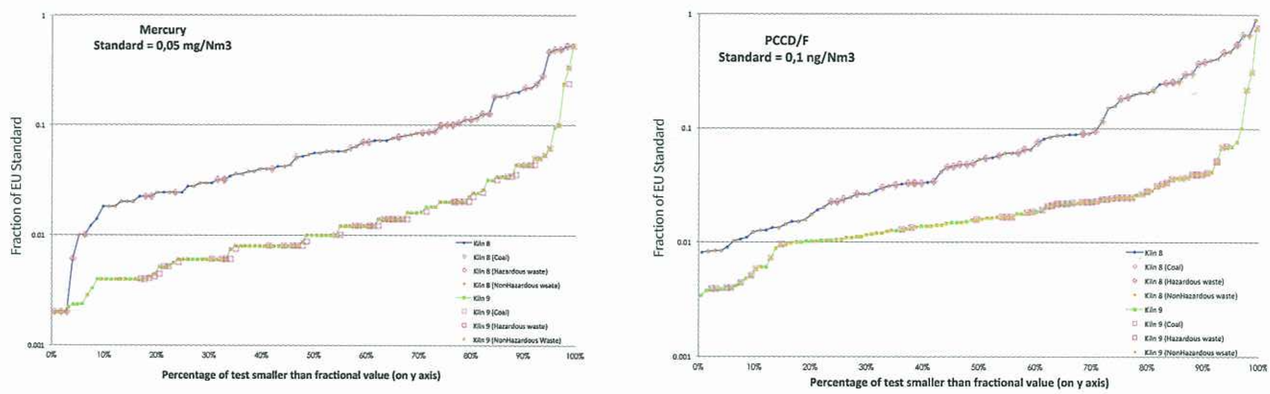
Elsewhere the results comparing two kilns using hazardous waste and other fuels were analysed.[5,6] In this text the authors extended that analysis to the five kilns in Secil's three facilities in Portugal. The EU Industrial Emissions Directive (2010/75/EU) sets limits on the exhaust gas concentrations of:

- mercury (Hg, 0.05mg/Nm^3)
- cadmium and thallium (Cd+Tl, 0.05mg/Nm^3 combined)
- antimony, arsenic, lead, chromium, cobalt, copper, manganese, nickel and vanadium (Sb-to-V, 0.5mg/Nm^3 combined)
- PCDD/Fs (0.1ng/Nm^3 combined toxic equivalents to 2,3,7,8-tetrachlorodibenzo(p)dioxin) at standard temperature (273K) and pressure (101.3kPa) and 10 per cent oxygen (dry gas basis).

Figure 1 shows the overall results of the stack-gas sampling programme (more than 300 measurements), normalised by the applicable EU limits. The limits were not exceeded in any of the tests. Moreover, the bulk of the test results were far below the limits. Many of the pollutants have low detection frequencies.

About 83 per cent of PCDD/F, 80 per cent of Hg, 77 per cent of Cd+Tl and 82 per cent of Sb-to-V stack test results are lower than their respective limits by a factor of more than 10 when all five kilns are considered. From Figure 1 one

Figure 2: ratios of measured stack-gas concentrations to EU Directive 2010/75/EU limits. Distributions of test results for two kilns using a more complete set of alternative fuels including hazardous waste. Non-detects plotted at detection limits



can conclude that the bulk of the test results are way below the emission limits in all the kilns. Furthermore, the differences between kilns are more marked than the differences between fuels.

This point is clearer in a more profound analysis using kilns 8 and 9, where hazardous waste was used in combination with a complete array of different fuels like tyres, meat and bone meal, fluff and normal RDF. All conditions were compared between the test units and the control situations, ie only coke or coal.[6] It was difficult to detect the influence of the fuel feedstock, with the exception of coal, since the differences in the emissions from the two kilns are clear, despite the fact that they are well below the limits. Figure 2 presents the data from those kilns using dioxins/furans and mercury emissions. One important conclusion is that the use of different alternative fuels has no impact on the level of emissions and as the whole process was carried within the control of the community, it was a consensual deduction.

Environmental and health impact

However, the impact of emissions is not completely dependent on their concentration and legal limits but also on contextual factors, including the sheer quantity of exhaust gas, the surrounding landscape and land use, and the density of human population. To fully understand this impact, Secil carried out several pollution dispersion studies based on various climatological years (eg wetter and drier) and based either on the actual data or on estimates based on the EU limits. The results showed a lower impact in every case, and were used to fine-tune the location of air quality monitoring stations.

But that was not enough. Dispersion studies are based on hourly or annual concentrations. A cement facility normally works 24 hours a day, for years (Secil's oldest facility in Portugal started in 1904 and the newest in 1946). The cumulative impact can only be determined through an environmental and health risk analysis carried out using the most conservative scenarios defined with the community.[7] The conclusions were straightforward and the risk was considered minimal. Again, all these processes were jointly developed with the community committees and supported by independent bodies.

Environmental biomonitoring

Besides the air quality monitoring stations that only track the so-called criteria pollutants, all of this depends very much on scientific and technical reasoning, heavily based on mathematical models that, despite being validated and conservative cannot disguise their characteristics. Therefore, it was essential to find a way to analyse the real concentration of pollutants in the environment. Since 2000, and more systematically since 2008, Secil has been using biomonitors, ie, using living organisms to monitor pollutant levels in the environment. In this case, the company used lichens, the most studied biomonitors of air pollution, to analyse heavy metals and PCDD/F concentrations. The concentrations of given pollutants, measured within the organism, are used to reconstruct the spatial and temporal deposition patterns of the pollutants at a given location.

Some of the results are presented in Figure 3. It is clear that not only has the concentration been diminishing, by approximately 30 per cent in the last 10 years, but also that the concentrations of those pollutants are very low and the facilities' contribution is around two per cent of the baseline levels.[5,8]

Conclusion

This very technical and integrative procedure was able to provide the company with the following conclusions:

Figure 3: temporal variations of mean concentrations in PCDD/F measured in the two chosen lichen species between 2000 and 2011

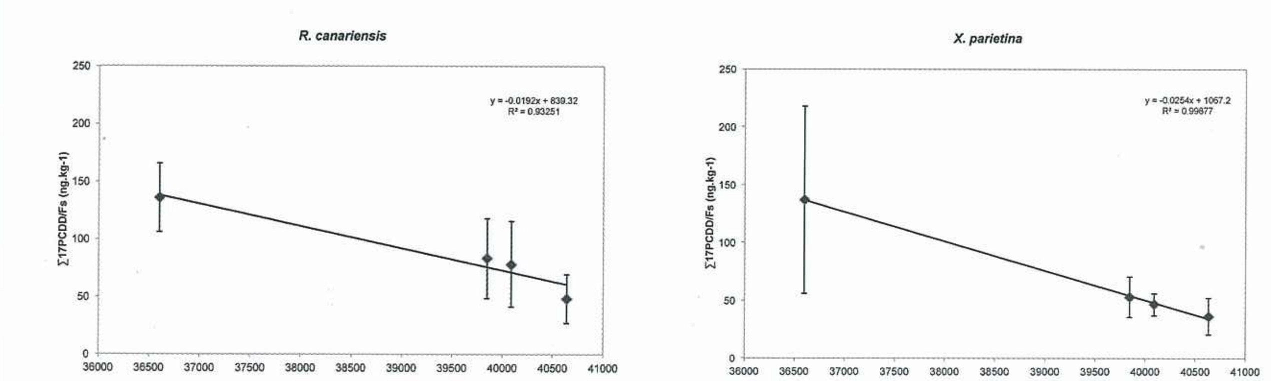
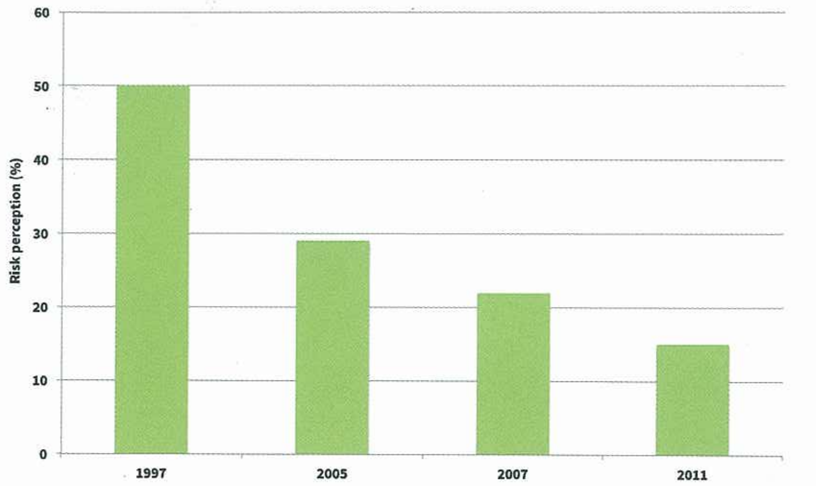


Figure 4: communities' risk perception, 1997-2011



- The concentration levels of pollutants from Secil's facilities in the environment are currently below the background levels.
- The health and ecological risks are minimal.
- The concentration of pollutants in the environment is now significantly lower when compared with the recent past, thus obtaining a clear measurement of the impact of technical improvements in abatement techniques.
- The use of different alternative fuels has no impact on emission levels.

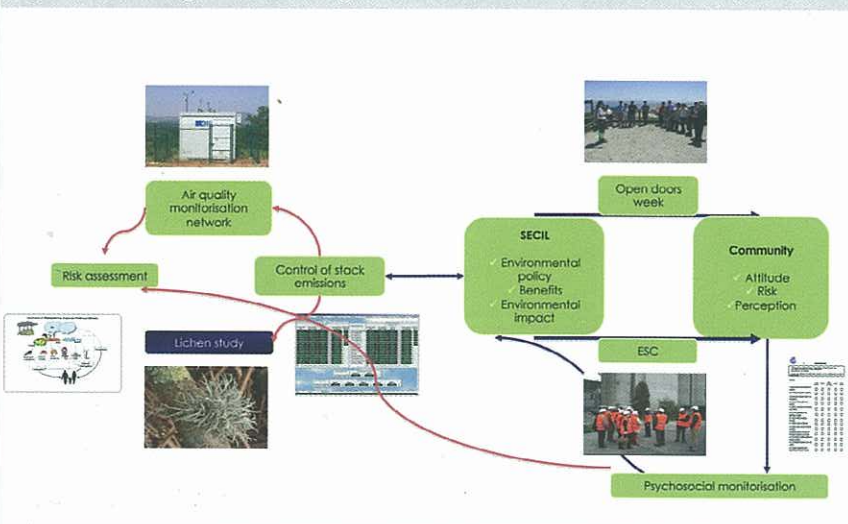
This whole process has been defined in partnership with the community, providing a considerable amount of goodwill. This can be measured in a series of psychosocial studies (1997, 2005, 2007 and 2011) to access the attitudes and risk perception. The percentage of people assessing the operation as risky has decreased by 36 per cent (see Figure 4) and in 2011 more than 70 per cent of the people in the nearby communities recognised the degree of positive change in Secil's activity.[9]

The company's partnership with universities and researchers has produced a diverse set of papers that have been published in peer-reviewed scientific journals.

The main tenet of this perspective is to reject 'common sense' approaches, while assuming that, despite the fact that communities are wary of technical conclusions, they are able to understand the scientific reasoning or the importance of measurements and experimental comparisons. Secil always focusses more on the process of obtaining data rather than providing the conclusions up-front.

This whole process follows a theoretical and practical framework that is summarised in Figure 5 on the basis of the most modern theories of risk assessment and management, which try to deal objectively with the perceptions of risk and integrate them into a risk management process that is able to add goodwill and contributes to value creation. ■

Figure 5: Secil's integrative risk management framework



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