Emissions from diesel generation in Small Island Power Systems - Recommendations for the revision of the Gothenburg protocol

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Emissions from diesel generation in Small Island Power Systems - Recommendations for the revision of the Gothenburg protocol

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AIMS OF THIS PAPER

The key aim of this paper is to inform national governments in the ongoing negotiations on the update of Gothenburg protocol negotiation, in particular in sending amendments in advance of the next meeting in September. The paper represents the special concerns of operators of diesel generation plant in small island electricity systems, who are concerned that inappropriate legislation may threaten the security and economics of power supply on small islands. The key issue in the current proposals for the protocol update concern emissions

KEY MESSAGES:

- **It is important that small island communities play their part in improving the environment. It is equally important to recognise the difficulties of enforcing low emission levels of atmospheric pollutants based on the mainland operation of diesel engine generators; which does not accurately reflect the operating conditions faced by island communities.**

- **For the purposes of diesel power generation on islands, EURELECTRIC recommends the adoption of emission limit value 3 (ELV 3 upper level) included in the proposed update to Annex V of the UNECE Gothenburg Protocol.**

- **More stringent emissions regulation than that in ELV 3 is not practical for island generation due to the highly variable operating cycle of island diesel generation plants.**

- **With the increasing input of intermittent renewable energy, the operating cycle of diesel plant may actually become even more variable.**

- **A 'period of grace' of (say) ten years to allow island to move to the more stringent ELV2 or ELV1 is unlikely to be successful, as the duty cycle for diesel plant in island communities will not have altered by the end of this period of grace.**

- **No new emission regulations should be applied to existing plant.**

1. FEATURES OF SMALL ISLAND POWER GENERATION

The geographical isolation of small islands from the extensive infrastructure present in continental European areas places particularly difficult challenges on the operators of island electricity supply networks to provide sustainable and reliable supplies of electricity at an affordable cost. In particular they are required to operate an electricity supply system which is subject to extreme variations of electricity demand, on both daily and seasonal bases.

Island generators face specific challenges that may not be immediately obvious to observers more used to continental (mainland) electricity generators. For example the lack of economies of scale, the restricted fuel choice for island generators, the geographic remoteness from continental infrastructure, the need for flexibility of generating plant to operate with high variations of duty cycle resulting from daily and seasonal variations in the island's electricity demand, and increasingly, fluctuating input from renewable power sources.

The use of land based (stationary) diesel generators is commonplace in island communities, since they often represent the best choice of generation plant to meet the issues identified above. Diesel generators offer good operational flexibility, reasonable cost and are quick to start-up and efficient to operate across a range of power demands. However, island diesel generation systems do have significantly higher operating costs than mainland power systems as a result of the small scale and high cost of the fuel, which can be further increased by the need to import to remote locations. Therefore, electricity tariff costs can be significantly higher on islands and a higher proportion of household incomes; therefore further increases in tariffs could result in significant hardships for island residents.

The size of generators installed on islands is a compromise between the use of the larger power units for enhanced efficiency, whilst maintaining an adequate level of redundancy in case the failure of units (it is important to remember that one unit may be on maintenance; in order to prepare for sudden failure of another unit implies that two reserve units may be needed). Therefore, island power generation typically consists of a number of units, each in the typical range of 1MW - 20MW. The needed level of reserve margin is further increased by the lack of electricity storage on islands, meaning that the plant must be able to support the maximum possible peak load of the island, even whilst having one unit out of commission.

Figure 1: Typical diesel generation plant

As explained above, diesel plant on islands typically operate at highly variable load, resulting from the high variations in demand and the relatively large size of individual generators as compared to total demand. Islands typically have more fluctuating power demand over both periods than mainland location. On a 24 hour basis, the lack of industrial plants means that overnight power consumption tends to be rather low. Over a yearly period, island generation can fluctuate highly due to seasonal variation in tourism – many islands have a high dependence on the tourist economy. The variability of the load on island diesel plants is likely to increase further in future with an increased share of intermittent renewables in their power systems / the diesel generation will have to rapidly cycled to fill in the gaps in renewable power generation

The emissions from the diesel generators used on islands have been significantly reduced in the last years through the use of low sulphur fuels and the incorporation of modern combustion technologies produces. For example, the emissions of nitrous oxides (NO_x) from the larger engines used for diesel generation has already been reduced by up to 40% since the beginning of the 1990s while maintaining the same (high) efficiency, as a result of extensive R&D on the engine design itself.

Further reducing these emissions will be challenging, particularly because the highly fluctuating operating cycle of island power plants has important implications for the functioning of emissions regulation equipment on plants.

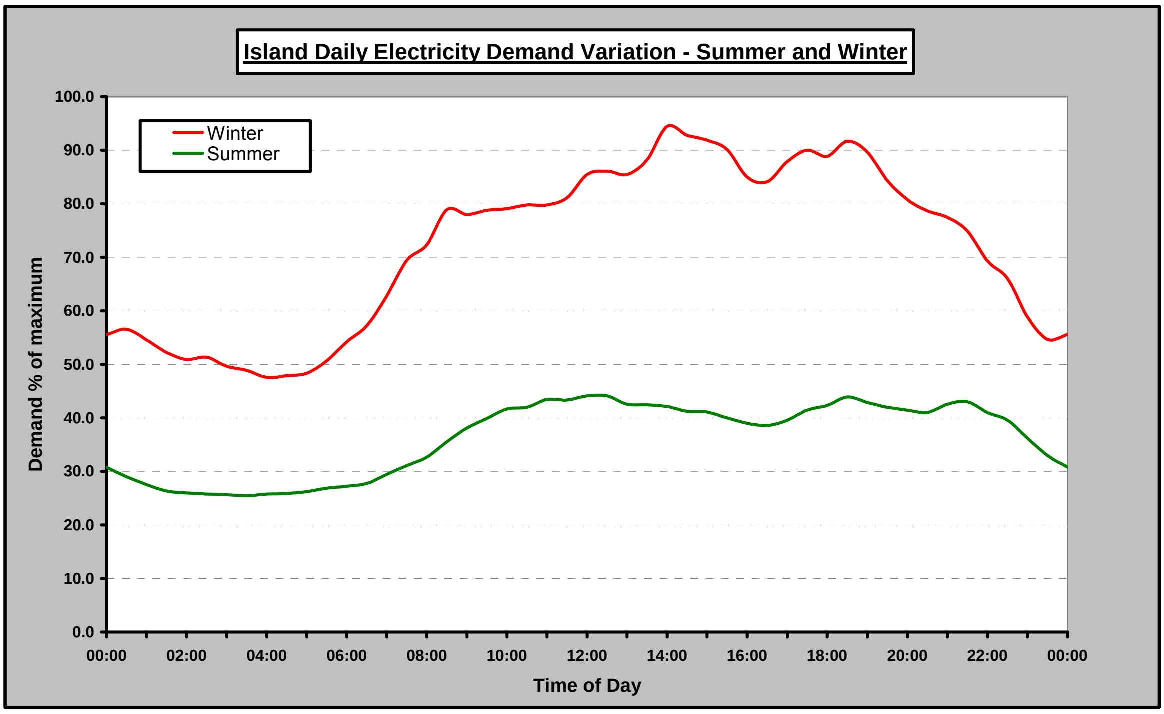

Figure 2: Daily demand fulfilled by island diesel plant – averages for summer and winter

2. CHALLENGES FOR EMISSION REGULATION OF ISLAND DIESEL POWER PLANTS

A. EMISSIONS PERFORMANCE OF LARGE DIESEL ENGINES IS DRIVEN BY THE SHIPPING SECTOR

Although diesel generators are widely used for power generation, and are especially suited for island communities, the vast majority of the large diesel engines sales are to the marine industry. As a consequence, the principal driver for engine technology development tends to come from the marine sector. It is therefore appropriate to examine this, as a starting point for reviewing developments of diesel engine emission legislations.

For diesel engine exhaust emissions, the principal driver for intercontinental (deep sea) emissions developments is the International Maritime Organisation (IMO), via Annex VI to the International Convention for the Prevention of Pollution from Ships (MARPOL).

Key features of MARPOL are summarised in the Annex to this document, however it is worth noting here that the requirements are **much less demanding** than the ELV2 and ELV1 options proposed for the revision of Annex V to the Gothenburg Protocol.

B. MANY EMISSIONS REGULATION TECHNOLOGIES WILL NOT OPERATE EFFICIENTLY ON THE VARIABLE LOAD PATTERN OF ISLAND POWER PLANTS:

As previously stated, NOx emission levels have already been reduced significantly by recent advances in engine design.

Further emission reductions are theoretically achievable, but typically require the use of secondary exhaust gas treatment techniques, such as Selective Catalytic Reduction (SCR). This technology is explained in the 'What is Selective Catalytic Reduction (SCR)' boxed text.

Unfortunately, such measures are not practically available to island generators operating across a variable power range and with frequent starting and stopping. At lower operating loads and during the starting and stopping cycles the exhaust gas temperatures are too low for effective operation of the flue gas treatment equipment. The catalysts become 'poisoned' or fouled by impurities in the exhaust gas, and the exhaust gas treatment system becomes ineffective – resulting in violations of the emission limits.

C. <u>COST OF IMPORTING EMISSION REAGANTS TO ISLANDS AND POSSIBLE DISPOSAL OF BY PRODUCTS</u>

The supply of needed reagents for selective catalytic reduction would imply significant costs and logistical difficulties for islands. Furthermore, the disposal of used SCR catalyst elements and by-products from other secondary abatement techniques (if used) would be problematic and disproportionately expensive for an island. As explained in the introduction, significant further increases in the operating costs of island power generation could have a real economic impact on island economies, given the fact that tariffs may already be much higher that for mainland power systems.

D. <u>EMISSIONS FROM ISLAND POWER PLANTS HAVE LIMITED IMPACT ON POPULATION</u>

It is significant to note that NOx emissions from diesel plants on islands generally only have a limited impact on local populations. This is primarily explained by the location of island diesel plants and prevailing wind conditions, in that the plants tend to be in coastal location where emissions from the plant are often blown offshore. Although most islands do not have significant problems with airborne concentrations of NOx, the main source of emissions is from road transport.

What is Selective Catalytic Reduction (SCR)

SCR is a method of removing oxides of nitrogen from the exhaust stream of a combustion plant. Nitrogen and oxygen, both naturally present in the combustion air, combine during the combustion process under conditions of high temperature and pressure. A number of nitrogen oxide compounds are formed, most notably NO and NO_2, these compounds are normally referred to by the generic term NO_X.

SCR can achieve very efficient NO_X removal from the exhaust stream. It works by injecting a chemical 'reducing agent', most commonly urea [$CO(NH_2)_2$], into the exhaust gas stream, in the presence of a catalyst made from titanium dioxide and vanadium pentoxide. In the exhaust stream, the urea is decomposed to ammonia [NH_3] and carbon dioxide.

In the presence of the catalyst, the ammonia reacts with oxides of nitrogen to form nitrogen and water. Typical reactions include :

$$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$$

$$6NO_2 + 8NH_3 \rightarrow 7N_2 + 12H_2O$$

An overview of an SCR system for a diesel engine is shown in Figure 1 below.

Figure 3: SCR System Overview

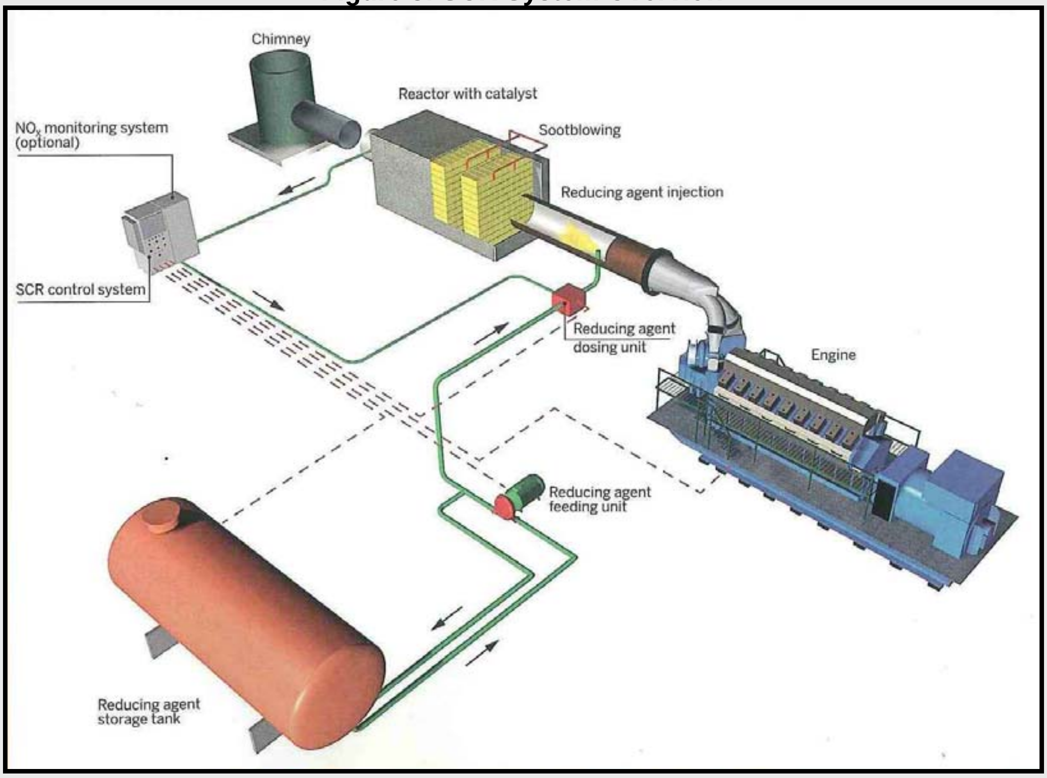

Diagram reproduced courtesy of Wartsila

For diesel engines operating on heavy fuel oil the temperature in the catalytic reactor should be at least 340°C. If the temperature is below this then fouling and deactivation of the catalyst can occur, and the performance of the reactor will be impaired.

3. RECOMMENDED APPROACH FOR UPDATE TO GOTHENBURG PROTOCOL

In the proposed updates to Annex V to the Gothenburg Protocol the emissions limits for new stationary engine generators are split into three tiers, with the ELVs reflecting engine type and fuels, what is feasible regarding the infrastructure present and the ambient air quality situation in the area.

ELV 1 is the strictest followed by ELV 2, with upper level of ELV 3 allowing the highest emission levels of NO_X. A summary of NOx emission limit values in the proposed revision is shown in the table below:

Gothenburg Protocol Draft Revision to Annex V : NO_x Limits for Stationary Engines [mg/Nm^3 at 15% O_2]			
Medium/Slow Speed Diesel Engines > 5 MW_{th}	ELV1	ELV2	ELV3
5 – 20 MW (HFO and bio-oils)	225	[450] [750]	[1300] [1600]
>20 MW (HFO and bio-oils)	190	[225] [450]	[750] [1850]

Figure 4: Proposed emission limit values (ELVs) in update of Gothenburg protocol

Derogations ('flexibilities') for the strict options ELV 1 and ELV 2) are proposed for engines running between 500 to 1500 operational hours per year to achieve NOx values achievable by primary abatement measures of ELV 3.

Derogations are also proposed for certain geographical areas (such as remote islands) where selective catalytic reduction cannot be applied for technical and logistical reasons **or** where availability of sufficient amounts of high quality fuel cannot be guaranteed. Under such situations a transition period of (say) 10 years after the entry into force of the Protocol may be applied for diesel engines, during which ELV3 levels achievable by primary abatement measures are applied.

EURELECTRIC would observe that a simple 'period of grace' will still be highly problematic, especially in the light of the current economic turbulent times. The duty cycle for diesel plant in island communities will not have altered by the end of this period of grace, and the same technical challenges will remain thereafter. It is impossible to predict whether emission abatement technologies and infrastructure development will have advanced during that period to enable the more demanding ELVs to be met within the island scenarios.

In view of the arguments in this paper, EURELECTRIC recommends the adoption of ELV 3 (upper level) as prescribed in the above table, and that this limit should not be time bound. We believe that this would be a practical compromise for the operators of generation in island communities as it would allow;

- The continued operation of existing stationary diesel engine generators, whilst not significantly increasing already high generating costs
- A reasonable reduction in NO_X, SO_X and PM emissions from stationary diesel engine generators
- The application of Best Available Technique for diesel engines operations at varying load and with frequent starting and stopping,
- The continuation of the flexible operation of diesel plant to enable the further integration of intermittent renewable technologies such as wind and solar.

ANNEX : BACKGROUND INFORMATION ON EXISTING EMISSIONS REGULATIONS

1. Introduction

The various targets for approaches to reduce emissions from stationary diesel engines are set out in different directives depending on the country in which the generator resides. The ELVs vary for each directive, with most having a tier system allowing for variance between different types of plant and fuel type.

The use of differing ELVs for areas which are isolated or have less developed infrastructures is seen as a regional or island approach. This approach makes it possible for the operators of diesel generators to reduce emissions to a reasonably practical minimum level whilst still supporting peak loads, network stability and reliable supplies.

Marine Diesel Engines and the International Maritime Organisation

The engines used for marine shipping propulsion and land based diesel generation are very similar – often the same basic engine with certain technical differences (for example, turbo-charging arrangements).

There are a number of differences between the IMO measurement & certification approach to the measurement approach used for land based applications, and these differences can make precise comparison between them somewhat difficult. at the typical load conditions of the power plant (without load weight factors). However, it is possible to make general observations and comparisons.

The revised Annex VI to the International Convention for the Prevention of Pollution from Ships (MARPOL) provides for progressive reductions in NO_x emissions from marine engines. The applicable NO_x emissions limits are dependant on the engine speed (revolutions per minute = rpm) and on the date of the ship's construction, as described in the following paragraphs.

- In the case of diesel engines installed on ships constructed from 1 Jan 2000 to 1 Jan 2011 the **Tier I** NO_x limits range from 17 to 9.8 g/kWh, depending upon engine rpm. This approximately translates to NO_x levels of about 2400 to 1400 mg/Nm^3 at 15% O_2.
- For diesel engines installed on ships constructed on or after 1 Jan 2011 the **Tier II** limits range from 14.4 to 7.7 g/kWh, depending upon engine rpm. This approximately translates to NO_x levels of about 2020 to 1100 mg/Nm^3 at 15% O_2.
- Finally, for new ships constructed on or after 1 Jan 2016, **and operating in specific designated NO_x Emission Control Areas (NECAs**), an ambitious **Tier III** has limits ranging from 3.4 to 1.96 g/kWh, depending upon engine rpm. This approximately translates to NO_x levels of about 500 to 280 mg/Nm^3 at 15% O_2. For such ships operating **outside** the NECAs then the **Tier II** limits remain in force after said date. The future implementation date for Tier III implies that such levels are not currently achievable, but require further R&D in order to design engines & (secondary) after treatment techniques which can achieve such limits.

The above emissions limits from new diesel engines are considered acceptable to the marine sector. However, it is clear that such limits are **much less demanding** than for example the ELV2 and ELV1 options proposed for the revision of the Gothenburg Protocol, especially when taking into account differences between the IMO certification approach and the stationary plant measurement procedures (see above). Only the higher option of ELV 3 can be seen to be close to the "IMO approach",

International Finance Corporation and World Bank

The identification of NO_x Emission Control Areas and “other” areas broadly ties in with the concept of degraded or non-degraded airsheds as adopted by the International Finance Corporation (IFC) World Bank. The categorisation of ‘degraded’ or ‘non-degraded’ airsheds depends upon concentrations of specific pollutants in the surrounding airshed of the power plant.

For the non-degraded airshed, **which would be typical for most island power plants**, the IFC specifies a NOx limit of 1,850 mg/Nm^3 at 15% O_2 for liquid fired diesel engines with a bore size diameter ≥ 400m. Only for plant in a degraded airshed does a limit of 400mg/Nm^3 at 15% O_2 apply.

Hence, for broadly comparable situations (i.e non-degraded airshed being representative of an island installation) the imposition of a more stringent NOx-limit (of the proposed UNECE Gothenburg Protocol update) than ELV 3 (upper level) to diesel engines operating in island communities would be inconsistent with IFC requirements for plant elsewhere in the world.

UNECE Gothenburg Protocol and Proposed Revisions (further information to that in the main paper)

Throughout the report, reference and comparisons are made to the draft proposals for the revision of the United Nations Economic Commission for Europe (UNECE) Gothenburg Protocol on Long Range Transboundary Air Pollution.

The Gothenburg Protocol, which is currently in force in number of jurisdictions, already specifies NOx emission limit values (ELVs) from stationary engines. Article 3 of the Protocol provides an alternative to apply different emission reduction strategies that achieve equivalent overall emission levels for all source categories together (the so-called “emission ceiling” Annex II) This enables deviations from the emission limits in the technical annexes, but only some countries have used this flexibility option. However, the ELVs specified in the Gothenburg Protocol have hindered the ratification of the protocol by several countries since these emission limits are considered to go beyond what can be achieved through the use of ‘Best Available Technique’ (BAT) (as described by Euromot[1] et al), are not technically and economically sound, and do not therefore contribute to improving energy efficiency and usage of renewable fuels.

Some members of the UNECE have expressed their concern regarding their ability to meet the more stringent limits proposed in the Gothenburg Protocol, especially for geographically isolated regions. EURELECTRIC has expressed similar concerns on behalf of their members who operate electricity supply systems in small islands. The concerns focus on the practicalities of operating stationary diesel generators in small islands and isolated regions in Europe whilst employing secondary emission reduction techniques, particularly for $NO_{X,}$ which have been designed for engines operating on a steady state basis supported by mainland infrastructures. Fortunately within these directives there are exceptions or allowed derogations, which need to be applied to support the continued operation of diesel engines in island communities which are largely reliant on such machines to support their often fragile economies.

[1] http://www.euromot.org/download/766a1b34-44e5-4a2a-9247-33300112066a/UNECE%20CLRTAP%20ABC%20analysis%202003%2004.pdf

European Union Large Combustion Plant (LCP) BREF

Stationary reciprocating engines were exempted from the Large Combustion Plant Directive 2001/81/EC (Article 2 item 7 j). The recently adopted Industrial Emissions Directive 2010/75/EU does not provide specific emission limit values for diesel engines, although emission limit values for large ($\geq$ 50 MW_{th}) stationary gas fired spark ignition and dual fuel gas engine plants of lean burn type are specified.

In the EU Large Combustion Plant (LCP) Best Available Technique Reference Document (BREF) no specific BAT emission levels for NOx are given for diesel engines. It is stated in clause 6.5.5.4 that "*SCR* [selective catalytic reduction] *is an applied technique for diesel engines, but can not be seen as BAT for engines with frequent load variation, including frequent start up and shut down periods due to technical constraints*". This conclusion is also included in the Guidance Notes ("7.42 New Stationary Engines", see "References") to the Gothenburg Protocol.

It is expected that the future BREF LCP will be updated to identify BAT NOx emission levels for stationary diesel engines. EURELECTRIC would stress that this updating process should continue to recognise the technical constraints upon diesel generating plant operating in island power utilities, and that the technical difficulties associated with selective catalytic reduction have not been overcome for plant operating with load variations and frequent starting and stopping.

United States Reciprocating Internal Combustion Engine New Source Performance Standards (US RICE NSPS)

The US RICE NSPS (40 CFR Parts 60, 1039, 1042, 1065, and 1068) provides limits for stationary diesel engines in the United States. It prescribes values depending on displacement (per cylinder volume only for large diesel engines) of diesel engines and power output. The CI NSPS ruling is under update (published in June 2010), it takes into account that for example Alaska is not accessible by the Federal Aid Highway System and this will affect feasibility for reductions in emissions, for example the shipping of chemicals and reagents used in the reduction of NO_X emissions Similar provision apply for 'Territories'.

The ELV will be dependant on the maximum speed (rpm) of the engine (for large (displacement $\geq$ 30 liters per cylinder) engines with 'close alignment with IMO'.

It is proposed for the large engine type that e.g. the US territories in the Pacific Ocean (Guam, American Samoa, the Commonwealth of Northern Mariana Islands) will have differing NO_X ELVs after 2016 in comparison to mainland US., i.e. emission levels achievable by primary NOx abatement measures. Again, this could reasonably be expected to be close to IMO limts.

Analysis of existing legislation

The IMO MARPOL Annex VI provides for three tiers of engine exhaust emissions. Only Tier III, which is for new ships after 2016 operating in the specific designated NECA (NOx Emission Control Areas) areas, has NOx limits that even approach the most demanding levels of the proposed revisions to the Gothenburg Protocol.

The International Finance Corporation (World Bank) has set emission limits (based on Good International Industry Practices, GIIP), which ask for the adoption of Best Available Control and Process Techniques (BAT/BACT) that are feasible and cost-effective. The chosen pollution control and process technology should be practical, cost-effective, and suitable for the specific project according to local conditions (taking into consideration the available technical and financial resources, existing environmental conditions and other infrastructure aspects). E.g. in order to fulfil the set NOx-limits, the latest ("modern") engine technique is to be applied, unless the power plant is to be located in a 'degraded airshed'. Most island installations would not fall within this "degraded airshed" category.

The US RICE NSPS prescribes differing ELVs depending on geographical location, partially taking into account the feasibility of implementing NOx reduction systems.

The Gothenburg Protocol ELV tiers contain 3 levels, with ELV 1 (the most onerous). ELV 3 is similar to the minimum OECD approach and ELV 1 to emission levels in some Central Europe country with a very good existing infrastructure and constrained air shed.

- ELV 1 - is a demanding, but technically feasible option only for continuous load operating diesel plant, since it requires the use of selective catalytic reduction. ELV1 **only** focuses on the reduction of **one** pollutant, NOx (not an Integrated Pollution Prevention Control (IPPC) approach). The plant will need to meet the lowest achievable emission rate or highest level of NOx reduction. ELV 1 places a high demand on the existing infrastructure and does not take into account the cost of implementing the strict emission limit. It also requires high quality fuels. Therefore Eurelectric recommend this limit option **only** for base load plant operating in areas with an existing good infrastructure and poor air quality.
- ELV 2 - Also technically demanding however pays some attention to the costs of measures needed to achieve reduction. It should only be applied in polluted industrialized and urban areas with a good existing infrastructure.
- ELV 3 (upper level) - The preferred option for areas with poor or restricted infrastructures such as countries in economic transition, islands and isolated regions. It is designed to be applied in areas with existing good air quality. Represents good practices based on the legislation of a number of parties, more details of which can be found in a Euromot report published in 2009 (see "References").

EURELECTRIC sees ELV 3 (upper level) as a preferred cost-effective and environmental quality need driven option for areas with a restricted existing infrastructure (such as remote areas or islands) and smaller/medium size plants in rural areas in the EU and in general for EECCA countries. The main reason being that to achieve the strict levels of NO_X emissions (ELV 1 and ELV 2), selective catalytic reduction is needed which is technically unsuited to island's power plants, disproportionately expensive and an requires an existing good infrastructure (not the case in many locations).

Therefore ELV 3 (upper level, based on a cost-effective environmental quality need driven approach) is seen as a compromise, which naturally takes into account the wider outlook of reducing the total pollution (IPPC approach) including NO_X emissions.

References

"Draft Guidance document on control techniques for emissions of sulphur, NOX and VOCS from stations sources" found at
http://www.unece.org/env/lrtap/WorkingGroups/wgs/docs45th%20session.htm
Under Other and informal documents Section – No 1: Draft Guidance Document on..- - document 7-42.

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