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Holistic noise and vibration abatement within the EU 7FP. The SILENV Project: Ship Innovative soLutions to rEduce Noise and Vibrations.

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Abstract

Transports are well known to be major contributors to noise pollution. Noise and vibrations (N&V) abatement naturally appears as an important objective for the greening of surface transports. The SILENV project is a response to this requirement for the maritime domain. The consequences of N&V emissions from the ships are multiple. N&V emissions constitute a disturbance for both passengers and harbour area residents, and in some cases it may be a health issue for crew members. Moreover, the increasing ship traffic-generated underwater noise causes ecological nuisances on marine wildlife. The project assesses the problem of reducing the ship-generated Noise & Vibration pollution with a holistic approach. After a definition of realistic target levels, existing experimental data from main types of ships and on-site measurements have been analysed to identify the most critical sources of noise and vibration. Innovative solutions have been individually assessed on technical and economical criteria. Finally a pre-normative requirements formulation, called “Green Label”, is presented, aiming at reducing the noise inside the ships as well as outside in air and water.

Keywords: EU FP7; SILENV Project; ship noise; Green Label.

Résumé

Les moyens de transport sont parmi les principaux responsables de la pollution acoustique. Les réductions de bruit et vibration constituent un des principaux objectifs du développement durable en matière de transports de surface. Le projet SILENV se veut une réponse pour y parvenir dans le domaine maritime.

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Les conséquences des émissions de bruit et vibrations par les navires sont multiples. Elles concernent le confort des passagers et des résidents des zones portuaires mais également, dans certains cas, la santé des membres d'équipage. De plus, l'augmentation du bruit ambiant dans les océans issu du trafic maritime en forte croissance nuit à l'écosystème marin. Le projet SILENV propose une approche globale pour étudier l'ensemble de ces nuisances liées aux bruit et vibrations. Après avoir défini des objectifs réalistes en matière de réduction d'émissions sonores et vibratoires, les données expérimentales existantes ainsi que les résultats des mesures réalisées dans le cadre de SILENV ont été analysées afin d'identifier les principales sources de bruits et vibrations à bord des navires. Ensuite, des solutions innovantes ont été proposées et évaluées d'un point de vue technique et économique. En conclusion, un "Green label acoustique" dont l'objectif est de réduire le bruit à bord des navires et dans l'environnement a été proposé.

Mots-clé: UE ; FP7 ; projet SILENV ; Bruit du navire ; Label Vert.

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1. Introduction

Noise and vibrations (N&V) assessment and control is an important objective for the greening of surface transports, since transportation systems significantly contribute to noise pollution.

As regards marine vessels, this objective is met by the SILENV project (Ship Innovative soLutions to rEduce Noise and Vibrations, Grant Agreement SCP8-GA-2009-234182, http://www.silenv.eu). N&V emissions from ships have an impact on the inner spaces of the ship and on the external environment, both in air and in water. In the first case, the receivers are crew and passengers; in the second case, people living near ports or channels interested by intense ship traffic, while in the latter case, the marine wildlife represents the receiver of noise radiation. The degree of knowledge and the normative framework development in the three above mentioned fields is quite different. As regards noise and vibrations inside the ship, the problem have been faced since a long time and a quite well developed normative framework is already on the field even if the indicators to fix the limits have not evolved with time. In the case of noise radiated in air, the specific problem of ship noise emissions has been partly addressed so far and some European and national norms are available. For what concerns noise radiated in water, despite the novelty of this problem , some requirements to limit the noise emitted in water by ship are already available (see e.g. André et al., 2011) .

In the SILENV project the control of these three kind of noise pollution is assed with a holistic approach with the final aim to issue a "Green Label" in which target levels for each topic (at a pre-normative level) are fixed and justifications & guidelines to reach the recommended targets are provided. The activities are organized in five different work packages (WP) as shown in Figure 1. In the following, each WP will be briefly described and the main outputs of the project will be presented.

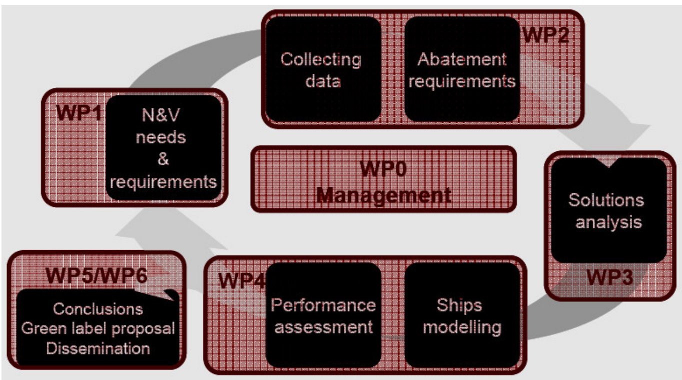

Fig. 1. SILENV project work flow

2. Noise related needs (WP1)

The purpose of WP1 is the identification of the targets for ship's noise and vibration control (SILENV 2012a,b,c). In particular, for the three above mentioned main areas covered by the project (Noise & Vibration on board ships, Airborne Radiated Noise - ARN, Underwater Radiated Noise - URN), the following aspects are considered:

- review of existing requirements and regulatory frameworks;
- identification of the impact of N&V in the context of ships (and in similar fields);
- identification of tools and indicators for the quantification and assessment of N&V impact.

The situation in the three fields as regards the above aspects is different (see e.g. Badino et al., 2012).
The present regulatory framework for noise on board is still to a large extent based on (or at least inspired by) the pioneer formulation of the IMO code (IMO, 1981), in which the focus was on the limitation of the total perceived acoustic power (limits in dB(A)). The trend in the last years has been to lower the limit levels in dB(A) in order to improve the living condition in the spaces on board. The technical progress has made such a generalised reduction possible (the foreseen revised formulation of the IMO code will contain most probably lower limits). The more recent Comfort Classes include more restrictive limits than IMO requirements, because of a different target (comfort, instead of health or performance of the crew), but seem to focus on the same aspect of the control of the overall sound power, fixing limits in dB(A).
Noise emissions from vessels into air feature a less defined normative framework, even though the problem of the annoyance due to airborne noise in densely populated areas near ports, channels and coasts is more and more recognised. The analysis of norms and requirements highlight wide differences from Country to Country, in terms of noise indicators, limit levels and specific features (tonal components, impulsive components, noise change, etc.), which tend to vary also for nations belonging to the same geographical area.
As regards noise in water, requirements having the aim of limiting the noise are already available. This kind of limits, however, can be defined as technology-based requirements, i.e. they are based on the state of the art of the noise emissions from existing ships with good performances not taking into account the actual impact of noise on the receivers. The difficulties in setting requirements based on the reaction of marine fauna are represented by a lack of data as regards the hearing characteristics of the Mysticetes.

3. Noise measurements (WP2)

The main goals of the SILENV WP2 are to create a database for noise radiation from ships covering the various aspects of noise emissions. This is sought by collecting and analysing as many as possible existing experimental data and performing measurements campaigns at sea on various types of ships to gather further data not available in existing databases. In addition dedicated measurements are foreseen to provide specific data to check the models developed in WP4 of the project and to provide validation of the solution identified in WP3. A further application of the same data is to assess the feasibility of the pre-normative requirements set out in WP5 as final outcome of the project.
The total SILENV Database being a combination of new on-site measurements and existing ones, consists of more than 12.000 N&V experimental data out of:

- 171 ships belonging to various vessel families, representing a significant sample of the European fleet;
- 20 'ad hoc' full scale measurements;
- 10 N&V full signatures.

Where with full signature a complete characterisation of the ship's noise radiation is intended, including N&V inside the vessel, ARN and URN.

4. Solutions (WP3)

The activity of WP3 is to identify and analyse all solutions to control the emissions from the ship which are proposed in the design guidelines. For each solution, an individual technical analysis and an economical assessment are performed.
The work has been divided in four sub-tasks corresponding to the different sources:

- Propellers: the study covered conventional propellers, special design propellers (such as controllable pitch and CLT propellers), thrusters (including POD and tunnel thrusters) and water-jets ;

- Machineries: the study covered machinery, gear, couplings and shaft system, AC (including piping, valves and mounts), auxiliary machinery systems, electrical and RIM propulsion systems;
- exhaust and ventilation (interior and exterior noise);
- hull and structures.

For each category, performances of solutions are compared with requirements from WP1 and WP2.

5. Modelisation (WP4)

The overall objective of WP4 is the numerical estimation of the total emission from the ship, integrating the local characteristics of solution adopted into a holistic evaluation of their effectiveness in the global radiation. This activity includes a refinement and assessment of the numerical models available for predictions and development of new ones. Following, a validation of the models is carried out on the basis of the experimental data ad hoc collected in WP2. Benchmark studies among prediction carried out by different partners are also included in the validation process highlighting, for example, that the Ffowcs Williams–Hawkings analogy shows great potential to be an efficient method for URN prediction (Hallander et al., 2012). Critical analyses of the discrepancies, taking into account the hypotheses of the different approaches, are also carried out. The validated models are then applied for a comparison of calculation results with targets to assess the solution effectiveness. The modelling activity of WP4 covers in addition the assessment of the impact of N&V on human, as well as on fishes/marine mammals. The actual human perception of noise is evaluated through a large number of questionnaires, distributed on board ships of different typology to both passengers and crew. They contain objective questions on status (age, gender, etc.) and location on board during the trial and subjective questions about the feeling on noise and vibrations. To correlate the actual human perception to noise to the different noise levels, the answers to the questionnaires filled in by crew and passengers, have been elaborated to correlate N&V levels to annoyance and induced work impairment. Concerning the numerical prediction of the URN, for the first time a well-known methodology for aeroacoustic problems (the *Acoustic Analogy*) has been adopted and successfully applied to marine and maritime context. This approach has allowed to achieve a deeper understanding of the complex generating noise mechanisms taking place underwater and related to a marine propeller or, more in general, to a ship (Ianniello et al. , 2013a,b,c). Advances have been also achieved in the prediction of the performance of CLT end-plate propellers (Haimov et al., 2011 & Sánchez-Caja, 2012) and in the simulation of mitigating techniques as shown in Zoet et al. (2012).

6. Final outputs: derivation of the Green Label requirements (WP5)

The purpose of WP5 is to summarise the technical conclusions of the project and to finalize the “green label” requirements, including targets levels and associated guidelines. In particular, pre-normative limits are set in the three fields of: noise and vibrations inside the ship, airborne radiated noise (ARN) and underwater radiated noise (URN). In the following, a brief explanation of the process followed to reach these goals is presented.

6.1. Requirements for N&V inside the ship

6.1.1. Human response analysis

A large number of questionnaires were distributed on board of different types of ships to both passengers and crew. Such questionnaires contain neutral questions on status (age, gender, etc.) and location on board during the trial and subjective questions about the feeling on noise and vibrations. The answers to these questions has been processed together with the results of noise surveys carried out in the same locations at the same. As it can be seen from Table 1, which represents an excerpt of that study, two different aspects are taken into account: annoyance and induced work impairment for both noise and vibrations. For each of these two categories a percentage of people affected is associated to a specific value.

Table 1: Noise and vibration limits from Human Response (Houben et al., 2012)

People affected	dB(A) levels inducing:		Vibration Levels [mm/s] inducing:	
	annoyance	work quality impairment	annoyance	work quality impairment
5%	48	55	0.8	0.9
10%	55	64	1.4	1.4
15%	60	71	1.9	1.7
20%	65	77	2.4	2
25%	70	82	2.8	2.3
30%	75	86	3.3	2.5

The percentage reported is defined as the portion of people being more than a little annoyed or work quality impaired (evaluated in addition to the portion of people, who, according the questionnaires results, claim the same effect in absence of noise). In the case of noise annoyance the base line percentage is 14.3% and in the case of work impairment is 4.6%.

6.1.2. Measurements on existing vessels

The database has been created in WP2, containing a collection of existing and new data of noise measurements on different types of vessels, has been used to have a picture of the European fleet. In Table 2 the number and the typology of vessels analysed in function of the age is reported. The aim of the database is to compare the limits with the performances of the vessels in service in order to understand if the limit is technically achievable.

Table 2: Number and age of the vessel analysed (SILENV, 2012a)

Type	Construction year from	# of vessels
Merchant	2005	34
Ro-Pax	2005	13
Fishing	2000	2
Fast-Ferries	1993	1
FRV	2005	3
Tug	2005	3
Others	2005	8

6.1.3. SILENV limits definition (internal noise)

In the light of what above, the following general criteria were adopted to define the final limits (SILENV, 2012d).

- the limits must be at least as stringent as the new IMO code (IMO, 2011).
- the highest allowed value in dB(A) in a working area (with the exception of machinery spaces, where personal protections are needed) should be consistent with the proposed exposure limit of 80 dB(A) for a shift of 8 hours (75 dB eq 24h).
- when IMO does not apply, the limit should be at least as stringent as the less restrictive level of Comfort Classes (CC)

Furthermore, in order to precisely define the limit level a balance between performances and feasibility is to be found. The following criteria were then fixed:

- ensuring at least 90% of passenger' and crews' satisfaction
- ensuring that a significant percentage of the existing vessels (e.g. the 25%) reaches the target
- feed-back from end-users

The final formulation of limits was then based on a balance between on one hand comfort and work impairment on board and, on the other one, technical feasibility of the requirement. The SILENV limits defined with the above described procedure are reported in Table 3 (SILENV, 2012d).

Table 3: Pre-normative SILENV limit formulation (noise levels and vibrations inside ships)

#	Type Name	Location Example	Noise dB(A)	Vibrations (mm/s - rms)
1	Cabins	Passenger, crew cabin Hospital	50	1
2	Offices		53	1.5
3	Calm public spaces (A)	Libraries Calm Public Spaces	55	1.5
4	Medium noise public space (B)	Restaurant, lounge Mess room, Shops	60	1.5
5	Noisy public space (C)	Disco, Ballroom Corridor, Staircase	65	2
6	Outdoor Areas	Open recreational area Bridge wings/Open deck working	70	2
7	Wheelhouse	Wheelhouse Radio room	60	1.5
8	Workspace A	Engine control room Galleys	65	2
9	Workspace B	Pantry, Store Laundry ,Workshop, Garage	75	2.5
10	Workspace C	Continuously Manned Machinery Space	90	2.5
11	Workspace D	Not Continuously Manned Machinery Space	105	3

6.2. Requirements for airborne radiated noise

The aim of the requirement is to ensure acceptable living conditions in the inhabited areas around the port by controlling the global noise generated by the machinery and equipment in operation on board the ship.
The noise emitted depends on the ship's operating conditions, which, in general, can be classified as follows:

- ship at quay (no cargo processing);
- ship sailing (along the coast);
- ship manoeuvring (entering/exiting the harbour);
- ship loading or unloading (equipment for cargo processing in function).

Within the scope of the SILENV project, only the first two operating conditions are taken into account. This because the manoeuvring condition represents a transient case usually very limited in time. In the cargo processing, on the other hand, devices not belonging to the ship contribute to the overall noise level, making it difficult to separate their contribution from ship's noise.
The criteria followed for the green label requirements are based on:

- the analysis of existing requirements
- ad hoc measurements of radiation patterns (WP2) highlighting the characteristic of the radiation field from the ship
- numerical investigations of radiation patterns (solution inventory: WP4);
- feed-back from end-users

6.2.1. Ship sailing along the coast

Unfortunately experience and data on the subject of pass by tests of seagoing ships was lacking in the SILENV project, so the final decision was to propose for L_{max} (maximum A-weighted sound pressure level) the same limit that has been set for inland vessels, that is 75 dB(A) at 25 m. Nevertheless the possibility of setting a larger distance to avoid shadow zones, and a larger number of microphones, placed in a vertical array, should be considered for the future. The possibility of setting limits at the nominal distance of 1 m was not considered, to avoid the effects of uncertainties in the definition of the transmission law that should be applied to levels in order to pass from the actual measurement distance to the nominal one.

6.2.2. Ship moored at quay

For the ship moored at quay, the main sources of noise on board may correspond to the same as for the ship sailing, with the difference that propulsion engines are not running (while generators and ventilators are in function).

6.2.3. Analysis of existing procedures (ship at quay)

Significant documents for the noise emitted by moored ships are the EU Directive 2006/87/EC and ISO 2922:2000, referring to inland navigation vessels. Article 8.10 of directive 2006/87/EC reads:

"Apart from transhipment operations the noise generated by a stationary vessel shall not exceed 65 dB(A) at a lateral distance of 25 m from the ship's side".

For the measurements in the directive reference is made to ISO 2922 standard. In such document it is prescribed to carry out measurements along the ship side at a distance of 25 meters at the ground level. For the purpose under investigation, it is interesting to consider also ISO 3746 that is a significant reference for the characterisation of large sources placed on a reflecting plane. The standard refers to the determination of sound power levels by sound pressure surveys carried out on a measurement surface in the proximity of a static source, as a moored ship can be considered. Even if the aim of the present investigation is not a characterisation in terms of power radiation of the ship, the same criteria for the definition of the measurement surface in terms of distance and resolution of the measurements points can be applied.

6.2.4. Notes on existing requirements (ship at quay)

A measurement campaign carried out within the project highlighted some peculiarities of the ship noise pattern. In particular an important aspect is represented by the strong vertical directivity of noise emissions. This phenomenon can be observed making reference to Fig. 2 and Table 4. In Table 4 the measured noise levels in the positions represented in Fig. 2 are reported. The colour scale highlights (in orange) the presence in the two sections of strong sources on the deck (fans). Shadow cones close to the side are present at a lower height. The shape of the shadow cones is different in the two sections and the sound field appears not be regular at 19 m from the side (in the fore section the pressure levels keep on increasing with the distance from the ship up to 19 m). Other analogous data are available from literature (see e.g. Draganchev et al. 2012).

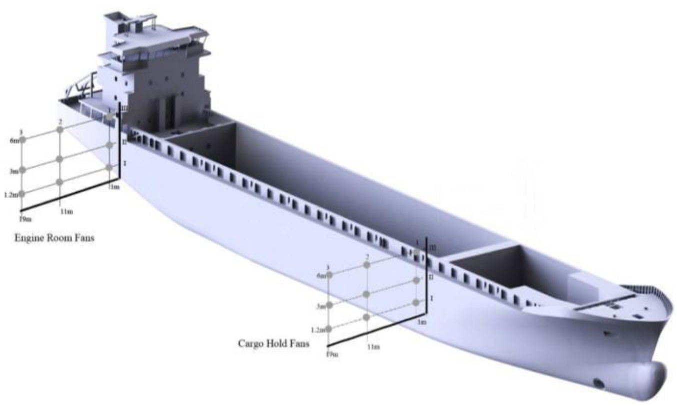

Fig. 2 Points surveyed during the experimental campaign

Table 4: Recorded noise levels (dB(A)) in the positions shown in Figure 2

Position	section in way of engine room fans (aft)			section in way of cargo hold fans (fore)		
horizontal→ ↓ vertical	19m	11m	1m	19m	11m	1m
6m	64.6	68.3	75.6	64.0	65.5	71.8
3m	65.2	67.9	69.8	64.5	66.2	65.1
1.2m	62.8	67.2	68.9	65.9	65.6	62.2

This analysis suggests that measurements carried out on the quay at a small height from the ground, especially for larger ships, can fall in the shadow zone generated by this ship hull and therefore recording lower levels than those that can be radiated at higher heights from the ship. Moreover receivers in buildings around the port areas can be also placed at different heights from the ground.

6.2.5. SILENV limit (airborne noise from the ship at quay)

In the light of what above, the SILENV approach was to characterise and limit the total emission from the ship surrounding it with a 'parallelepiped measurement surface'. The faces of the parallelepiped are oriented in directions parallel to the plane of symmetry of the ship and normal to it (see Fig. 3). Propagation in the upward direction is not considered.

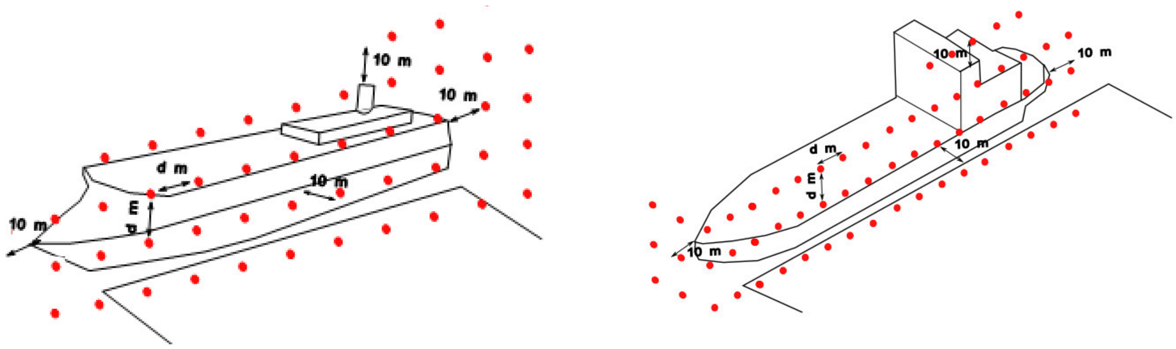

Fig. 3 Grid of points depending on the longitudinal profile of the ship.

A distance of 10±1 m from the ship sides (and from the bow and the stern) is foreseen for the grid of measurement points. Such a distance has been chosen as a compromise between practical and technical issues:

(a) The distance is considered as likely to be free of obstacles for the major part of shipyards / ports layouts.

(b) Within this distance from the quay edge, cranes are often located which can be used to move a microphone in the measurement grid positions.

(c) At this distance, the effects of possible strong directional sources on board should be sufficiently attenuated, thus allowing to relax the spatial resolution of the grid.

As regards the latter aspect (resolution of the grid), a balance is to be found between accuracy and measurement efforts. The distance between the measurement points is influenced by the dimension of the source and by the position of the measurement surface: the farer the surface is placed from the source, the coarser may be the grid of points on the surface (see ISO 3746:2010). In the light of these considerations, the spacing for the points was set to be: d= 6 m for L<100 m and d=10 m for L>100 m.

A limit of 70 dB(A) was set for the levels measured in all points of the grid. The value was set on the basis of quite a small number of experimental campaigns and numerical predictions carried out in the project and of the limit provided in the EU Directive 2006/87/EC.

Differently from the existing requirements, the characterisation of the ship source is extended in the vertical plane and carried out at a fixed (smaller) distance. The reason for fixing a reference distance (with a small tolerance) is to be found in the purpose of avoiding uncertainties in the results of the characterisation due to the use of pre-defined propagation laws to refer measurements to a given nominal distance. As a matter of fact, from the experimental data collected within the project, the propagation in the measurement range appeared to be dominated by near field effects and/or by reflections (from the ground and other surfaces), making it difficult to identify simple formulations for the transmission losses.

Carrying out measurements in a vertical plane is definitely more demanding than along a line at ground level, but the resulting characterisation is certainly better. The new procedure should however be applied to a number of cases large enough to calibrate the limit value and to support the actual feasibility of the procedure itself.

6.3. Requirements for underwater radiated noise

The objective of the requirement is to limit the impact of the ship's URN on the marine fauna, in particular Cetaceans. Again the same process followed as regards noise in air and inside the ship is adopted and the following aspects are taken into account:

- existing requirements (evaluated in WP1);
- state-of-the-art of the European fleet (WP2);
- marine fauna response (WP4).
- feed-back from end-users

The existing requirements in the field are represented by the limits suggested in ICES (Mitson, 1995) and the Det Norske Veritas Silent Class Notation (DNV, 2010). In both cases limit levels for the noise emitted at 1 m for specific ship types are given for frequencies ranging from 10 Hz to 10kHz. It was not possible to link the limits to the actual perception of the marine fauna due to a lack of data in the evaluation of the effects of noise on the different species and to the fact that each species have different sensitivities.
The criterion adopted is therefore to set limits accounting for the technology limitations in the field, more than for the minimisation of the actual impact on marine animals. In the light of these considerations the limits set go in the direction of a decrease of the diffused background noise of the oceans, responsible mainly for communication masking problems for large marine mammals. The underwater signatures of different kind of vessels, specifically measured within the project, are used to assess the feasibility of such limits. The limit curves are set in the levels-frequency space. The limit is fulfilled if the ship spectrum referred to the distance of 1 m from the source is below the limit curve. The levels surveyed by the hydrophones at larger distances are corrected using a spherical propagation law. The limit curves are reported in Fig. 4. Differently from existing requirements, no distinction is made among different ship types apart from fishing vessels for which the ICES curve (Mitson, 1995) is adopted. Two curves are provided, for design speed and reduced speed conditions.

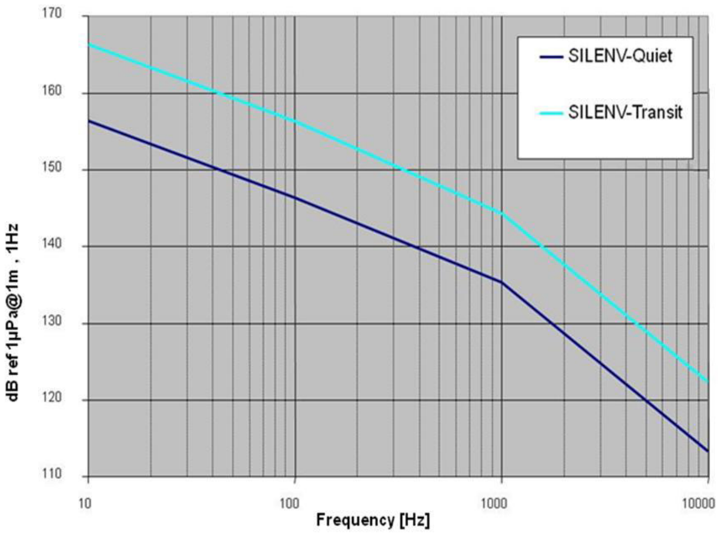

Fig. 4 URN Green Label requirements

7. Conclusions

In the SILENV project the problem of the acoustical impact of ships has been addressed from the threefold aspect of the spaces internal to the vessel and of external emissions in air and in water. The different degree of development of the present state of the art in these three fields is at the basis of the different proposals for pre-normative requirements issued by the project. The motivations and the formulations of such requirements aimed at limiting the overall impact of the ship as a noise source have been analysed in the text. The technical feasibility of the measurement procedures and of the fulfilment of limits is assessed, as well. The structure of requirements is compatible with a possible implementation in the normative framework.

References

André, M., Gaggero T. and Rizzuto, E. (2011): Underwater noise emissions: Another challenge for ship design. *Advances in Marine Structures – Proceedings of the 3rd International Conference on Marine Structures*, Hamburg, Germany.

Badino, A., Borelli, D., Gaggero, T., Rizzuto, E., & Schenone, C. (2012). Normative framework for ship noise: Present situation and future trends. *Noise Control Engineering Journal* 60, 740-762.

DNV 2010. Det Norske Veritas: Rules for the Classification of Ships, Silent Class Notation, Part 6, Chapter 24.

Draganchev, H., Valchev S., & Pirovsky C. (2012). Experimental and Theoretical Research of Noise Emitted by Merchant Ships in Port. *19th International Congress on Sound and* Vibration (ICSV19), Vilnius, Lithuania.

Haimov, E., Vicario, J., Del Corral, J. (2011). RANSE Code Application for Ducted and Endplate Propellers in Open water, 2nd Intern. Symp. on Marine Propulsors, Hamburg, Germany.

Hallander, J., Da Qing, L., Allenström, B., Valdenazzi, F., Barras, C. (2012). Predicting underwater radiated noise due to a cavitating propeller in a ship wake**.** In *Proceedings of the 8th International Symposium on Cavitation* (CAV2012), Singapore.

Houben, M., Kurt, R., Khalid, H., Zoet, P., Bos J., & Turan, O. (2012). Human responses to noise and vibration aboard ships. In *Proceedings of the International Conference on Advances and Challenges in Marine Noise and Vibration* (MARNAV2012), Glasgow, Scotland, UK.

Ianniello, S., Muscari, R., Di Mascio, A. (2013a). Ship underwater noise assessment by the acoustic analogy. Part I: nonlinear analysis of a marine propeller in a uniform flow, *Journal of Marine Science and Technology*, Springer, http://link.springer.com/article/10.1007/s00773-013-0227-0.

Ianniello, S., Muscari, R., Di Mascio, A. (2013b). Ship underwater noise assessment by the Acoustic Analogy part II: hydroacoustic analysis of a ship scaled model, *Journal of Marine Science and Technology*, Springer, http://link.springer.com/article/10.1007/s00773-013-0236-z.

Ianniello, S,. Muscari, R., Di Mascio, A. (2013c). Ship underwater noise assessment by the acoustic analogy, part III: measurements versus numerical predictions on a full-scale ship, *Journal of Marine Science and Technology*, Springer, http://link.springer.com/article/10.1007/s00773-013-0228-z.

IMO (2011). Document DE 56/11/1, Protection against noise on board ships, International Maritime Organization, London, United Kingdom.

IMO, 1981. Resolution A.468(XII): Code on Noise Levels on Board Ships, International Maritime Organization, London, United Kingdom.

Mitson, R.B. (1995). Underwater noise of research vessels: review and recommendations. ICES Cooperative Report 209.

Sánchez-Caja, A. (2012). Unsteady Analysis of Pressure Pulses in a CLT Propeller Using a Lifting Surface Vortex-Lattice Method, *MARNAV201, Glasgow, Scotland, UK.*

SILENV (2012a). Deliverable 1.1 Review of the existing Requirements for Noise & Vibration control. URL: http://www.silenv.eu/issues/SILENV_D_1-1_rev3.pdf.

SILENV (2012b). Deliverable 1.2 Harbour noise nuisance. URL: http://www.silenv.eu/issues/SILENV_D_1-2_rev1-9.pdf.

SILENV (2012c). Deliverable 1.3 Underwater radiated noise. URL: http://www.silenv.eu/issues/SILENV_D_1-3_rev10.pdf.

SILENV (2012d). Deliverable 5.2 Green Label proposal. URL: http://www.silenv.eu/green_label/D5.2_green_label_rev_2.pdf.

Zoet, P., Hallander, J., Sundberg, J., Haimov, E., Turkmen, S., & Turan, O. (2012). Designing ships for low vibrations: A case study, *MARNAV2012, Glasgow, Scotland, UK.*