SHARE

Grant Agreement no. 226967
Seismic Hazard Harmonization in Europe
Project Acronym: SHARE

SP 1-Cooperation

Collaborative project: Small or medium-scale focused research project

THEME 6: Environment

Call: ENV.2008.1.3.1.1 Development of a common methodology and tools to evaluate earthquake hazard in Europe

D2.1 – Hazard output specifications requirement document, jointly approved with EC8 Committee

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Revision: 1

Dissemination Level		
PU	Public	x
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

1. Hazard Output Specifications

The EC8 Committee met with WP2 partners LNEC and UPAV and with WP4 partner METU in Pavia on 8th January to discuss the SHARE project and the needs of EC8 that should be addressed by SHARE. The minutes documenting the discussions arising from this meeting are annexed to this deliverable. This deliverable aims to synthesise those discussions into a simple list of specifications for the SHARE working groups (Table 1). Where necessary, the relevant clauses of Eurocode 8 are cited in the table and any accompanying text.

It should be noted that many parameters, including some made explicit here, are subject to approval and alteration by National Authorities. At the time of production of this report, no National Annexes have been consulted and alternative formulations of seismic design are not considered here. It is anticipated that the envisaged specifications may be sufficient to accommodate most likely alterations to the recommended parameters made by National Authorities. Future deliverables within the SHARE project are intended to address these issues, and guidance from National Authorities is welcomed.

The accompanying minutes (Annex) are intended to act as a guide to the scientific rationale behind the envisaged specifications.

Table 1: Hazard Output Specifications advised by SHARE WP2

No.	Output Specification	WP
1	Hazard maps for a range of return periods between 25 and 5000 years for the median (from the logic tree) of PGA at a reference bedrock level.	WP5
2	Hazard maps for return periods between 25 and 5000 years for median spectral ordinates (acceleration and displacement) on type A ground (reference bedrock) for a range of period ordinates (those covered by all GMPEs in logic tree)	WP5: based on provision of required GMPEs from WP4
3	Hazard maps, for aforementioned return periods, of median F_0[1], T_B, T_C* at a reference bedrock level. [1] F_0 is currently assumed equal to 2.5 (**EN 1998-1 3.2.2.2 (1)P**)	WP2 based on output 2
4	Hazard maps, for the aforementioned return periods, for values of median PGV and median PGD (or appropriate proxies).	WP5: based on provision of required GMPEs from WP4
5	Maps, for the aforementioned return periods, of median T_D* (if possible) at bedrock level[1,2] [1] This might be based on a lower number of GMPEs as output 2. [2] Specification of T_D* may also emerge by other means including disaggregation of intermediate or long period spectral acceleration (see output 8)	WP2: based on output 2
6	Zonation Map for Europe based on PGA (**EN 1998-1 3.2.1 (1)P, EN 1998-1 3.2.1 2**), corresponding to the no collapse requirement (**EN 1998-1 3.2.1 3**).	WP2: based on output 1

7	Zonation map for Europe considering both PGA and spectral shape[1] [1] Zonation may also take into account controlling earthquake scenario as a means of constraining long period motion (e.g. FEMA 450).	WP2: based on output 3, 5, 6
8	PSHA disaggregation in terms of PGA and spectral ordinates (i.e. for the results of the maps of output 2). Note, the surface-wave magnitude (M_s) is needed as output of the disaggregation, though this may be obtained from a conversion of M_w.	WP5
9	Estimation of "*k*" value[1] (a parameter to allow for the scaling of hazard to intermediate return periods) for median hazard, and indication of uncertainty and applicable return period range.	WP2 based on output 2
10	Portal with access for engineers to the above output (details to be determined between WP2 and WP6).	WP2 and WP6
11	Proposals for new spectral shapes for EN 1998 for both acceleration and displacement spectra	WP2 based on output 2

* See Figure 1

Other Acronyms & Definitions

F_0 - amplification factor (see Figure 1), currently assumed equal to 2.5.

FEMA 450 – NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures (FEMA, 2003)

GMPE – Ground Motion Prediction Equation

PGA - peak ground acceleration

PGV - peak ground velocity

PGD - peak ground displacement

"Type A" ground – Rock or other rock like geological formation, including at most 5 m of weathered material at the surface ($V_{s30} \geq 800$ m s^{-1}) (**EN 1998-1 3.1.2 (1) – Table 3.1**)

V_{s30} – Average shear-wave velocity to a depth of 30 m.

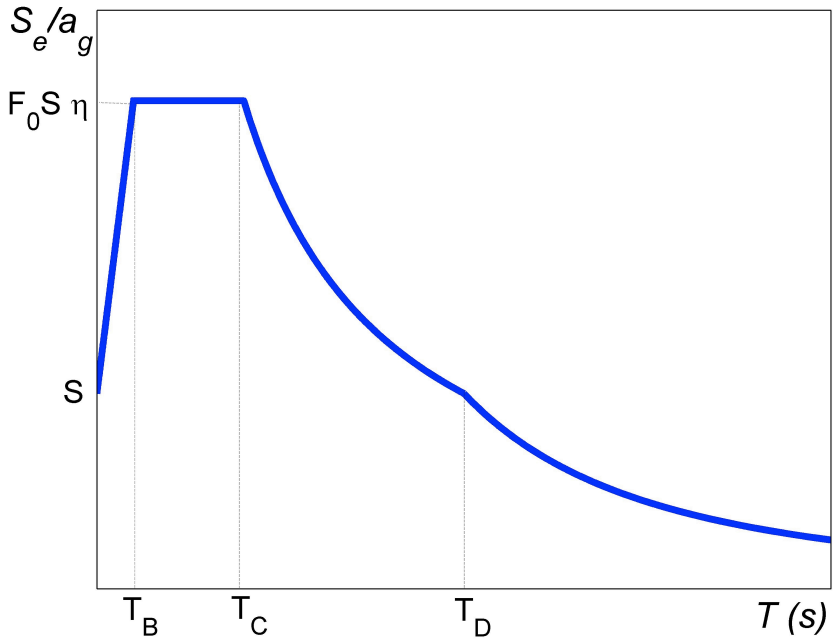

Figure 1. Eurocode 8 acceleration response spectral shape

2. Justification and Support for the Output Specifications

The output specifications listed in Table 1, represent the concurrence of objectives following discussion amongst the participants of WP2 and the EC8 Committee. It is understood that the remit of SHARE, and in particular that of WP2, is to specify outputs that are consistent with the current Eurocode. In addition it is envisaged that the SHARE output should form the basis for revisions to the definition of seismic action in the short- and intermediate-term. As such the output specifications are designed to anticipate future revisions to the code. Some objectives are motivated by the precedent of their application in other codes around the world (of which more discussion will be given in the second deliverable from this project, D2.2), whilst others are motivated by recent developments in best practice in the definition of the input for seismic design.

Objective 1

The current Eurocode 8 provisions explicitly recommend three return periods, corresponding to the "near collapse" (2475 years), "significant damage" (475 years), and "damage limitation" (225 years) limit states (**EN 1998-3 2.1)**. Within the provisions for performance requirements, two return periods are recommended: 475 years, corresponding to the "no collapse requirement" (**EN 1998-1 2.1 (1)P**), and 95 years, corresponding to the "damage limitation" requirement (**EN 1998-1 2.1 (1)P**). However, these parameters are subject to alteration within each country's National Annex. The return period is subject to alteration within each National Annex (**EN 1998-1 2.1 (1)P, EN 1998-1 2.1 (2)P**). It is therefore anticipated that further maps of reference PGA corresponding to alternative return periods will also be required. Seismic hazard values should be produced for a wide range of return periods, with 5000 years being foreseen as a feasible upper limit for application. Seismic hazard analyses for longer return periods require greater constraint of source and site parameters than is possible from regional scale analysis. In the present Eurocode 8 formulation the "reference" PGA refers to peak ground acceleration on type A (bedrock) ground level (**EN 1998-1 3.2.1 (2)**). It shall be assumed that "reference" refers to the median value as determined via logic tree (as the EC8 committee have confirmed that the median should be used).

Objective 2

Whilst the current Eurocode requires only PGA to anchor the elastic response spectrum, it has become widespread practice to define the seismic input in terms of a uniform hazard spectrum (Abrahamson, 2000; 2006**)** or even a conditional mean spectrum (Baker & Cornell, 2006). It is also common practice in state-of-the-art buildings codes to define seismic action from two or more spectral ordinates (FEMA 450; ICC, 2009). For many applications the seismic input should be specified across a range of spectral ordinates to allow the engineer to define seismic hazard at the period of vibration of interest relevant to a given structure. For SHARE to have any application to engineering design in Europe it is imperative that seismic hazard is expressed in terms of spectral acceleration and spectral displacement.

Objective 3

In addition to the definition of seismic hazard at given spectral ordinates, it is also of significance to investigate the spatial variation of key ordinates of the elastic response spectrum (i.e. those ordinates shown in Figure 1). Recommended values for these ordinates are given in Eurocode 8 (**EN 1998-1 3.2.2.2 (1)P**), but are also subject to alteration by National Authorities. The development of uniform hazard spectra for thousands of site across Europe provides a basis to allow for mapping of these key ordinates. The provision of these maps may help guide National Authorities in the modification of the key parameters to ensure that such modifications are consistent with the seismic hazard in the region of interest. Precedent for investigation of the spatial variation of F_0 and T_C, and the application of this to engineering design, can be found in the current Italian Code (Ministero delle Infrastrutture e dei Trasporti, 2008).

Objective 4

The provision of seismic hazard maps for PGA provides only a limited amount of information for engineering design. It is well established that damage to larger structures of greater ductility respond more adversely to ground motion at intermediate and longer periods. Peak ground velocity (PGV) and peak ground displacement (PGD) provide useful proxies to determine strength of motion for intermediate and long periods. Mapping of these ordinates, in particular PGV, provides a basis for zonation taking into account longer period hazard.

PGV and PGD also serve other purposes in the creation of the elastic response spectrum, and ratios of these parameters (and PGA) can provide useful first-order approximations to the corner periods (T_C and T_D) of the ERS (Bommer *et al.*, 2000; Bommer & Pinho, 2006). Zonation maps that take these parameters into account may greatly assist in revising the ERS, not only in future revisions to Eurocode, but also in the modification of the corner periods, which are ascribed as Nationally Determined Parameters in the current Eurocode. The development of recent attenuation models for PGV in Europe (Akkar & Bommer, 2007; 2010) allow for hazard analysis in terms of PGV at negligible additional cost, and without the additional error introduced by estimation of PGV from a spectral proxy (Bommer & Alarćon, 2006). PGV is also a necessary input for analysis in other areas of Eurocode 8. In particular, the peak soil velocity is used to determine strains in buried pipelines (**EN 1998-4 Annex B.2**). This parameter, and the resultant strain tensor, can be derived from PGV. It is therefore common practise to define pipeline damage and losses from the PGV at a site (Paolucci & Smerzini, 2008).

Objective 5

The ordinate T_D refers to the corner period between the constant velocity and constant displacement portion of the response spectrum. Constraint of this period is an important objective for displacement-based design (Priestley *et al*., 2007) and loss assessment (Crowley *et al*., 2004; 2009; Faccioli & Villani, 2009). Ample provision for displacement-based design is given in Eurocode, and much like F_0, T_B and T_C, analysis of seismic hazard for longer period motion provides a sound basis for constraint of this parameter and its regional variation. This too will enable National Authorities to use the best possible science to make judgements for modification of the parameter within the National Annexes.

Objectives 6 & 7

Zonation using PGA is a requirement in the current Eurocode (**EN 1998-1 3.2.1**), and is therefore a necessary deliverable for the SHARE project. If a greater degree of flexibility is required in defining the seismic action, both in terms of the elastic response spectrum or uniform hazard spectrum, then a zonation using PGA exclusively is insufficient. It is therefore envisaged that future zonations for Europe should be based, not only on PGA, but also on hazard at longer spectral periods. For structures with moderate or long fundamental periods

PGA provides little information, and identification of the controlling earthquake scenario on this basis may provide erroneous and non-conservative seismic actions. Zonation for longer period motion provides a basis for better definition of T_D and longer period actions in general. Precedent for this approach, and illustrations of the likely output, can be found in FEMA 450.

Objective 8

Identification of the controlling earthquake scenario is a requirement in Eurocode 8 to determine whether the Type I ($M_S \geq 5.5$) or Type II ($M_S < 5.5$) is appropriate for design (**EN 1998-1 3.2.2.2 (2)P**). It is also a suggested requirement to constrain and modify the earthquake-induced cyclic shear stress threshold required for liquefaction analysis (**EN 1998-5 Annex B2**). The most widespread method for identifying controlling earthquake scenarios from probabilistic seismic hazard analysis is via disaggregation (McGuire, 1995; Pagani & Marcellini, 2007). As noted previously, for longer period structures identification of the controlling earthquake scenario on the basis of PGA exclusively is erroneous. In regions of higher seismic activity the controlling earthquake identified by disaggregation of longer period hazard is more appropriate for design.

It should be noted that whilst EN 1998 uses surface wave magnitude (M_S) to define the controlling earthquake scenario, the input catalogue is homogenised into, and the seismic hazard analysis implemented using, moment magnitude (M_W). Conversion from M_W to M_S may be done using appropriate empirical relations, but will be subject to error. It is expected that conversion will be undertaken after identification of the controlling scenario; however, it may be necessary to consider the impact of this uncertainty within the seismic hazard analysis itself. This will need to be explored within the project.

It is strongly recommended that surface wave magnitude no longer be used as a requirement in any future revision of Eurocode. Instead controlling scenarios should be determined using moment magnitude.

Objective 9

The "*k*" value arises from the approximation given in **EN 1998-1 2.1 (4)** to allow for scaling of intermediate return periods ($H(a_{gR}) \sim k_0 \, a_{gR}^{-k}$), with *k* suggested as being on the order of 3. Discussion within WP2 recognised that *k* is dependent on hazard at a site and spectral

ordinate, and may only be valid within a limited period range. Whilst this approximation is used largely for convenience it is important that *k* be determined for each site, and for spectral periods of interest, to prevent inconsistent or erroneous scaling of hazard where the approximation is applied.

Objective 10

Dissemination of the SHARE results must be done in a transparent and accessible manner. The use of web portals to allow end-users of the hazard analysis to quickly and accurately define the seismic action for design has become widespread. WP2 will work together with WP6 to see which of the previous objectives need to be incorporated into the portal.

Objective 11

On the basis of the seismic hazard results provided by SHARE, and the objectives described here, WP 2 will make recommendations for future revisions to Eurocode. This is intended to ensure that seismic input for design in Europe is consistent with the current hazard analysis and represents the global state-of-the-art.

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Annex: Minutes of the SHARE-EC8 Committee Meeting

8th January 2010 – EUCENTRE, Pavia

Organisers:

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Participants:

UPAV (WP2): Helen Crowley (HC), Rui Pinho (RP), Graeme Weatherill (GW)
LNEC (WP2): Alexandra Carvalho (AxC), Ema Coelho (EC), Alfredo Campos Costa (ACC),
METU (WP4): Sinan Akkar (SA)
CEN/TC250/SC8: Eduardo Carvalho, Michael Fardis (MF), Alain Pecker, Thomas Wenk (TW)

Goals of the meeting:

- Further presentation of SHARE program to the members of CEN/TC250/SC8 committee
- Liaise with representative from WP4 to outline role of WP4 and identify areas of convergence with WP2 (SA).
- Obtain information and agree upon engineering requirements for SHARE in the context of Eurocode 8.

Outline:

- Summary of WP2 in SHARE (H. Crowley)
- Summary of WP4 in SHARE and interface between WP2 and WP4 (S. Akkar)
- Present and future engineering requirements of EC8 (A. Campos Costa, All)

Notes from the Meeting

Summary of WP2 (Presentation given by HC)

- WP2 needs to consider requirements of seismic action in EN 1998 based on present needs, medium term needs (possible revision in 5 years) and long term needs for future revisions of seismic codes.
    - Present needs include seismic zonation, two types of elastic response spectrum shapes and return period for serviceability and no-collapse requirements.
    - Medium term needs mostly focused on matching the shape of the response spectrum more closely to the UHS.
    - Long term needs may include performance-based design, displacement based design and/or cost-benefit design
- Objective to demonstrate the influence of updated hazard maps on loss estimations for cities in Europe (reappraisal of LessLoss trial areas with updated hazard data)
- Outlines objective of Task 2.1, and other tasks in WP2.
- Outline Engineering needs (Task 2.2) – Feedback from expert panel. Summary:
    - Seismic hazard map preferred, zonation map is in any case envisaged (and required in EN 1998-1).
    - Reference zonation map should be an objective – but National Annexes may produce modified zonations.
    - No return periods defined *a priori* – SHARE to produce model from which periods are extracted.
    - Use of both UHS and spectral shapes.
    - Guidelines for selection and matching of accelerograms for analysis should be separated from the code.
    - Online accelerogram database would be beneficial – but not an objective of SHARE.
    - 10 s period objective for long period design – feasibility to be studied in WP4
    - Max. Frequency of interest: 25 Hz proposed – *N.B. impromptu discussion of merits of PGA in seismic design: objection raised by TW.*
- Discussion of spectral shape in new Italian Code

- Amplification factor (referred to as F_0 for the purposes of these minutes) a location-specific parameter – currently fixed at 2.5 in EN 1998-1
- T_C also location-specific
- Clarification of format of Italian Code – hazard values for PGA and UHS given at http://esse1.mi.ingv.it/

Discussion arising from presentation by HC

- Use of peak ground displacement (PGD) for design purposes – should be considered in addition to PGA and PGV.
- SA outlines errors/uncertainties in calculating PGD – influence of LP filter cut-off, baseline correction, damping etc.
- Use of zonation maps (MF/EC notes failure of previous attempt for Europe reference zonation)
  - Similar zonations for snow loads and wind loads found in EN 1991.
  - Seismic actions definition may be moved to EN 1991 in future.

Summary of WP4 (Presentation given by SA)

- Objective of WP4:
  - Derive and modify GMPEs for Europe extending magnitude range.
  - Develop and assess models capable of addressing regional variations in attenuation
  - Investigate characterisation and representation of site conditions in attenuation models – V_{s30}, EC8 approach, central frequency, H/V peak.
  - Develop new GMPEs for duration-dependent ordinates (e.g. Arias Intensity, CAV) as well as conventional spectral ordinates
- About to finish developing strong motion databank.
- Listed candidate GMPEs for global and local scale
- Identified methodology for quantifying model fit to data (Scherbaum *et al,* 2009) – also identified working teams.
- Begun considering site effects.
- Bridge between WP2 and WP4

- Compatibility of ground motion models with EC8 including use of GMPEs for future applications and revisions of EC8.
- Use of WP4 models for structural performance assessment (possible connection to WP2 Task 2.4 – definition of minimum capacity levels)
- Integration of hazard outputs with GEM.

- Aware of the relevance of long periods domain (till 10s), but it could be a difficult task, as most GMPEs covers up to 2-3 seconds and it is not yet clear the feasibility of deriving such period range.

Definition of Engineering Requirements (ACC)

- A. Campos Costa presented some slides to promote discussion on engineering requirements for EC8, addressing some general aspects, such as the definition of the seismic action, the Nationally Determined Parameters (NDP) and the importance factors. See discussion below.

Discussion (11 am – 1pm)

- Expected SHARE output results affecting EC8 criteria for definition of seismic action (ACC):

  - Use NUREG CR6372 – SSHAC Recommendations for Use of Experts (RP notes this has already been applied in previous projects e.g. PEGASOS).
  - WP3 using logic trees to for models of multiple source zones and seismicity rates – likewise WP4 using logic tree formulation of attenuation models. This implies non unique results hazard values for each return period. Decision should be made about the fractile to be used in the definition of seismic action (decided – see current needs)
  - Deaggregation essential for identification of site dependent scenarios and for the definition of expected values associated to a given return period of several parameters (M, T_B, T_C, T_D , F_0).

- Objectives of SHARE given the potential needs of Nationally Determined Parameters:

- Recommendations for return period – currently 95 years for damage limitation requirement and 475 years for no-collapse requirement.
- Recommendation for thresholds of "low seismicity" and "very-low seismicity" classification. Current classification or 0.04 g on bedrock for "very-low seismicity" derived from inherent resistance to lateral loads given building strength – clarification of minimum capacity in WP2 Task 2.4 may form basis for this assessment.
- Standard damping at 5 %, modified by equation 3.6 in EN 1998-1. HC queries influence of damping on long period displacements. EC notes 5 % viscous damping is appropriate in definition of seismic action – different levels of structural damping (viscous and hysteretic) accounted for within q (strength reduction factor).
- EC8 makes distinction between elastic response spectrum and design response spectrum (DRS) – the latter incorporating q factor.
- Decay constant (γ) of constant velocity branch of DRS (S_D (T) α $1/T^{\gamma}$, where $\gamma = 1$ in EN-1998) intended to be conservative. This is to reduce underestimation of the design spectrum if the fundamental period of the structure, or q, is underestimated, by designers.
- Discussion of use of Newmark-Hall spectrum
    - F_0 – Currently 2.5 in EC8, possible medium-term objective to make this parameter variable in future codes. F_0 may be dependent on controlling earthquake – ACC asks whether attenuation model for F_0 can be developed (matter unresolved).
    - Site classification has influence on spectral shape – should be addressed in definition of soil class.
    - Objective of SHARE may be to determine spectra for bedrock condition and apply models for site amplification – linear or non-linear as research develops.
- Discussion on the range of return periods specified in EC 8:
    - Approximately 90 years to 2000 years (no-collapse state for importance class 4 structure)
    - Adjustment according to relation given in EC8: $H(a_{gR}) \sim k_0 a_{gR}^{-k}$.
    - 'k on the order of 3' – but:
        - approximation is only valid over limited return period range (cannot be extrapolated to longer return periods),

        - k varies with spectral ordinate,
        - k is an approximation in log-log space (wider error than conveyed by linear regression)
        - k different from 3 in low and moderate seismicity sites.
    - RP indicates that Portal deliverable should allow user to specify return periods
    - Return periods subject to change as NDPs
    - Modified by importance class

- Discussion on the measures of ground motion
    - Number of ordinates for spectral acceleration
    - Spectral range (SA notes this is investigated in WP4)
    - Need to address damping and its relation to strong motion duration
- Consensus agreement on the need for deaggregations and their output as an objective of SHARE
- Identification of controlling magnitude needed as an output for T_D and for liquefaction potential
- Incorporating epistemic uncertainty into the analysis:
    - Treatment within the code and guidance for selection of branches.
    - Emergence of median branch for use – but not explicit in code.
    - No consensus on fractile range.
    - Accommodation of higher fractile range by importance class.

CURRENT NEEDS (Discussion)

- Aim to improve coordination of seismic hazard analysis across national (and provincial) borders.
- Also aim to support decision of NDPs and creation of National Annexes.
- Definition of hazard maps for different return periods for the more important NDP parameters related for the definition of seismic action in EC8 namely the PGA, T_B, T_C at a reference bedrock level.
- Make the current EC8 spectral shape more compliant with the results Uniform Hazard Spectra derived from PSHA, additional hazard maps, for the different return periods, for

values of PGV and, if possible, for PGD and T_D, at bedrock level are also considered an important contribution of SHARE to EC8.

- Zonation – based on PGA (as the key parameter in order to allow a comparison with the national maps) but may also take into account spectral shape and controlling earthquake scenario.
- The return periods referred above should range between 25 and 5000 years to cope with in EC8 needs in regards to: (1) the possibility of defining a different Tr reference return periods for the life safety and damage control limit states, (2) the range importance factors definition (3) the different structural systems covered by the different parts of EC8.
- Keep elastic response spectra and design response spectra in current format.
- It is important to have a measure of the epistemic uncertainties in the SHARE hazard output estimates. Nevertheless the median values from the logic tree hazard analysis will be the fractile to be used for engineering purposes within EC8.
- Magnitude, epicentral distance and stationary duration of strong motion phase, needed for some analysis (namely liquefaction potential) could also be obtained by PSHA disaggregation to be carried out by SHARE.
- Future improvements of EC8 might allow standard EC8 spectrum to be substituted, for each site, by a UHS or by an elastic spectrum that is a function of magnitude or duration. Furthermore, the elastic displacement response spectrum may be evaluated in the future for each site, instead of being obtained from the elastic acceleration response spectrum of EC8. Hence SHARE should produce such results.
- Hence, from the EC8 committee it was clear that the current needs of EC8 extend beyond the Nationally Determined Parameters and should also provide results which might be used to update EC8.

Date of Next Meeting: To be defined (next SC8 meeting)