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## **D4.1 Functional analysis of System Development process**

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## EXECUTIVE SUMMARY

This report gives a functional analysis of the current system development process among European TSOs. System development deals with taking decisions that change transmission capacities either within a TSO's own system or towards other TSOs systems. Inputs to this report have been gathered from workshops in the GARPUR project and a questionnaire to 10 TSOs that are either part of GARPUR consortium or a member of GARPUR reference group. Despite the limited number of respondents to the questionnaire, the responses are quite representative for European practice since the respondents represent different system sizes, characteristics and control zones within Europe.

It is observed in the questionnaire that all the TSOs build, upgrade or replace new high voltage links and control devices. Further, eight out of ten TSOs work with re-configuration of their grids in terms of building sub-stations or tee points. Seven of the TSOs consider installing power flow control devices, while three TSOs see enhancing system controls as a system development task. Chapter 3 of this report gives an overview of how such investments are made through the system development process.

Data and assumptions are crucial to the system development process. Accurate data and realistic assumptions/expectations are a key to optimal decision-making. Chapter 4 of this report is dedicated to describing how to obtain data sets that could be used by a system development planner for further analysis.

An important element of the system development process is to identify and maintain ideas for future investment projects. This set of candidate projects is based on replacement needs, earlier project ideas and identified future needs. Chapter 5 of this report describes how these future needs are identified in an initial assessment process. The output of this process is a set of prioritized projects that are likely to be built in the future. Detailed assessment and decision making is analysed in Chapter 6.

In line with what is observed in earlier deliverables in the GARPUR project, current practice of system development at TSOs is dominated by the deterministic N-1 criterion. The need for probabilistic reliability management has been recognized for some time. Some operators have modified their operating rules to reflect a crude approximation of such probabilistic reliability measures. This report concludes in Chapter 7 with a discussion on potential for improving the system development process by using probabilistic reliability management. Some insights in how to migrate from deterministic network assessment towards probabilistic reliability assessments are also discussed in this chapter.



## 1 INTRODUCTION

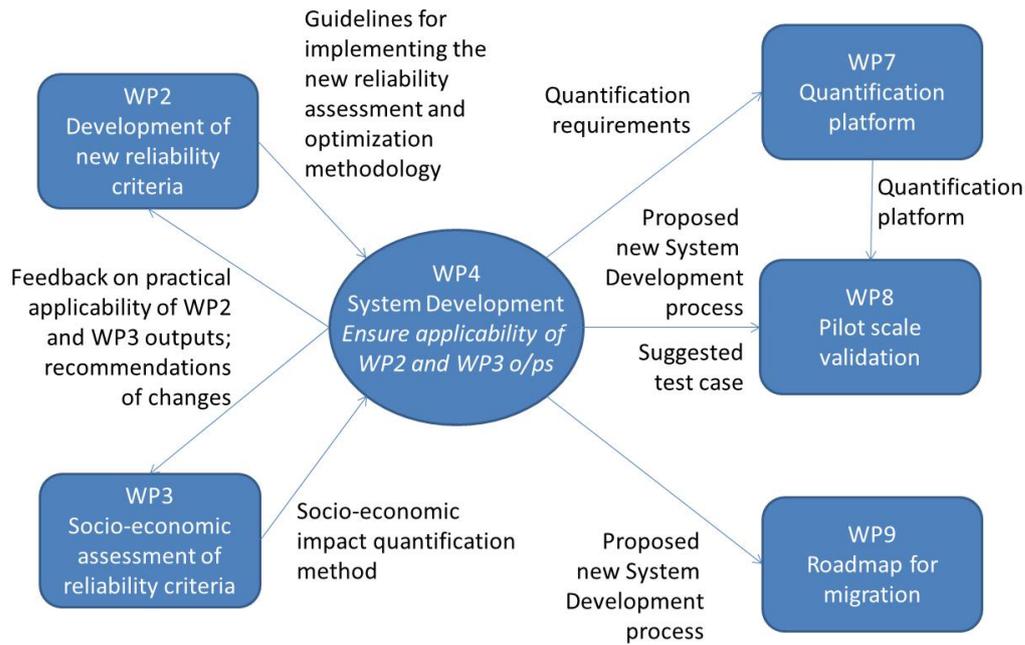
This document is a report from the work in GARPUR task 4.1: *Functional workflow of the system development decision-making process*. Inputs have been gathered from workshops in the GARPUR project and a questionnaire to 10 TSOS that are either a part of the GARPUR consortium or a member of the GARPUR reference group.

Since this report is a first deliverable by GARPUR WP4, in this chapter we shall briefly describe the context and scope of WP4 within the GARPUR project and also its relationship with other work packages. This report is divided into seven chapters. The first chapter sets the scene by introducing role of WP4 in the GARPUR project and defining the context of system development. In the second chapter we give basic vocabulary and definitions of the terms, while we give an overview of system development decision-making process in the third chapter. Chapter 4 gives the essential data and scenarios that are required for system development studies, Chapter 5 and 6 discuss the process of assessment, prioritization and arbitration. Chapter 7 concludes the report and gives some insights into how to improve the reliability management in the system development process, and gives an overview of what is missing in the current process for the TSOs to be prepared for probabilistic reliability management in the future.

### 1.1 WP4 of GARPUR and its relationship with the rest of GARPUR

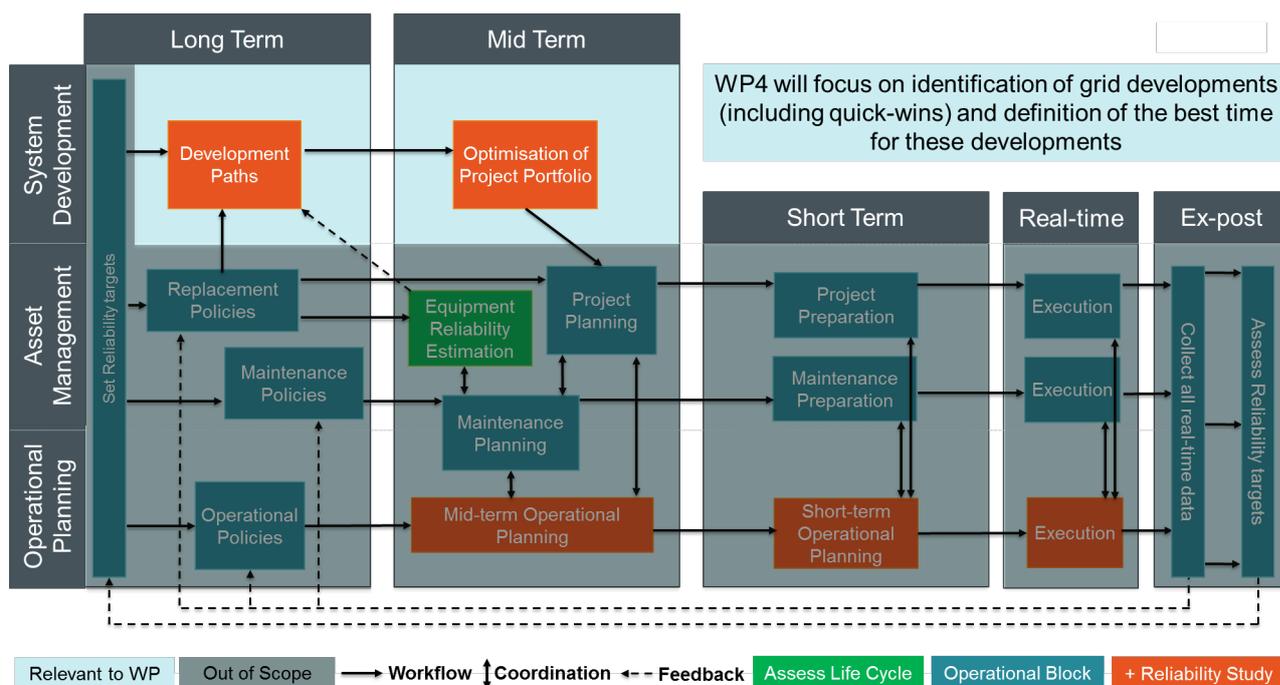
WP4 of GARPUR deals with the process of system development. Figure 1-1 gives an overview of the relationships of WP4 with WP2, WP3, WP7, WP8 and WP9. WP4 takes the reliability criteria, problem frameworks and optimization approaches proposed by WP2 and the socio-economic metrics and quantification approach proposed by WP3 into the context of the system development, and ensures the applicability of their outcomes. Main research focus of WP4 is system development and it takes input from WP2 and WP3 in terms of reliability criterion and socio-economic criteria. These inputs will be used in WP4 as part of the modelling and assessment in system development context. In addition, it develops additional specific methods required by the system development planner and feeds the findings back to WP2 and WP3.

The findings of WP4 are used by WP7 for the quantification platform requirements, by WP8 for proposing a new system development process. Moreover the findings of WP4 will also influence the way in which we would like the future system to look like e.g. the work of WP9 will take up some of the findings in developing the roadmap for new system development reliability criteria.



**Figure 1-1: WP4’s relationship with other WPs in GARPUR**

In system development, the conditions for which reliability criteria and their impact on power transfer and congestion, are known with even much less certainty than in operational timescales, notably regarding outage scheduling (WP5) and system operations (WP6). Figure 1-2 illustrates the timeline and relationship of various activities undertaken by a TSO. WP4 focuses on system development, including infrastructure development paths in the long-term timeframe and optimisation of project portfolio in the mid-term timeframe. These decisions influence how the transmission system is maintained (asset management) and operated (real-time operation in Figure 1-2). A system planner has to accommodate foreseeable challenges that can arise in mid-term and short-term time horizons, as the planning decisions largely effect the management and operation of the system. In this report we will focus on the functional analysis of system development and also discuss relations with other time frames. However, in-depth analysis of asset management, operational planning and real-time operation is out of the scope of this report (they are indeed in the scope of WP5 and WP6).



WP4 will focus on identification of grid developments (including quick-wins) and definition of the best time for these developments

Figure 1-2: Activities of a TSO in different time-scales and their relationship

## 1.2 The Context of System Development

The general role of the system development planner is to ensure that sufficient facilities are installed on the system to enable it to be operated in accordance with relevant operating standards. In particular, the system development planner should ensure that the system’s capability to transfer power from producer to consumer is sufficient. Because any insufficiency may require investment in the network’s facilities and such investment takes time – relevant equipment and its location should be identified, the functional requirements specified, and the equipment procured, installed and commissioned – the system development process is commonly identified with timescales of a year or more ahead of real-time operation. Thus, the process of system development is often described as ‘long-term planning’. However, it may be possible for some equipment identified by the system development planner to be specified, approved and installed in less than a year. In addition, as noted by CIGRE Working Group C1.17, “The [system development] planner [is] responsible not only for providing network capacity but also for providing a system operator with the means of managing the consequences of N-1 violations or combinations of outage events.”

In respect of facilitating system operation in accordance with operating standards, two drivers may be noted:

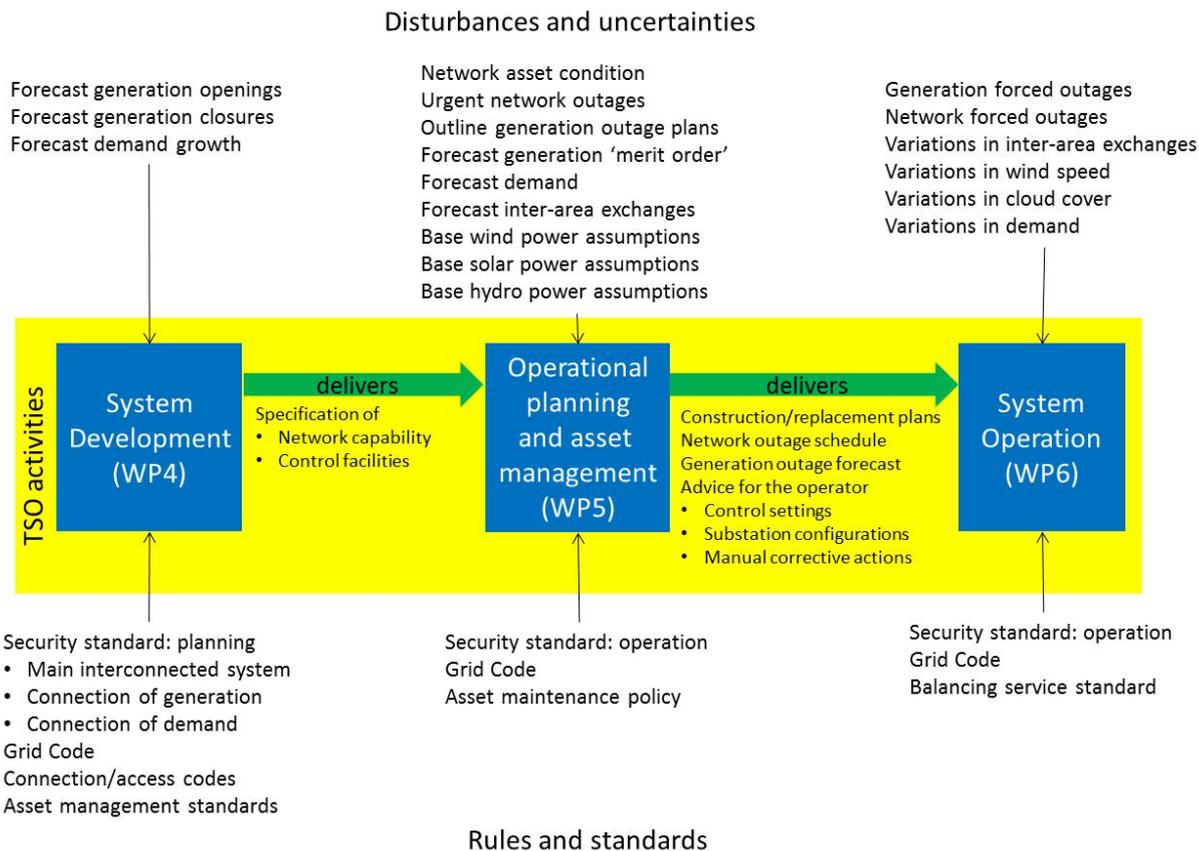
1. Provision of power transfer capability such that the demand for electricity in a given area can be met with a given, minimum level of reliability, i.e. ‘reliability driven’ capability;
2. Provision of power transfer capability such that demand for electricity on the system can be met, over the medium to long term, in an economically efficient manner, i.e. ‘economics driven’ capability.

The second driver involves an assessment of relative costs and benefits of investment in enhancement of power transfer capability compared with network congestion and running of ‘out of merit’ generation. Viewed another way, because a lack of power transfer capability can lead to the opportunity for the exercise of market power by particular generators in liberalized markets, it can be seen as being

concerned with facilitation of competition. To the extent that a price can be put on an inability to utilize low carbon generation due to power transfer limitations, it can also be seen as concerned with carbon reduction.

For the avoidance of doubt, the second of the above drivers is regarded as being a legitimate, indeed fundamental, concern of system development planning and is within the scope of WP4.

The context of the System Development activity in relation to Asset Management and System Operation activities and how they are addressed in the GARPUR project may be viewed as shown in Figure 1-3. In practice, however, as will be discussed later in this document, although the process or task of System Development can be defined quite generally, individual companies' particular organizational structures might dictate that some aspects of ensuring that adequate facilities are installed on the system are carried out by groups other than that with the name of 'system development', 'system planning', 'long-term planning' or 'investment planning'.



**Figure 1-3: The context of System Development**

### 1.3 Scope of task 4.1

The GARPUR Description of Work (DOW) notes the following in respect of Task 4.1 and its output as Deliverable 4.1:

*The purpose of T4.1 is to establish a detailed workflow diagram of a TSO's activities in the context of system development. Input on current practice, and prior knowledge in the literature, are*

*received from WP1. This workflow identifies the different data sets used, as well as the different types of decisions to be taken in the long-term. It explicitly shows the relations between the system development decisions taken in the long-term and those taken in the context of asset management (WP5) and system operation (WP6). It also highlights the possibilities and/or needs for horizontal coordination of system development decision-making in a multi-area/multi-TSO setting in view of the future practical integration of new reliability management approaches.*

*The result of T4.1 is delivered to WP7 to validate the functional specification of the quantification platform.*

The main focus of the overview delivered by Task 4.1 should be to show how the future function of the power system is assured by TSOs today: Which decisions are made in respect of the provision of new network assets to enhance system power transfer capability? How are these decisions taken and how is the reliability taken into account? In addition, because the system development planner should also take account of economics, how is the cost-effectiveness of proposed investments identified?

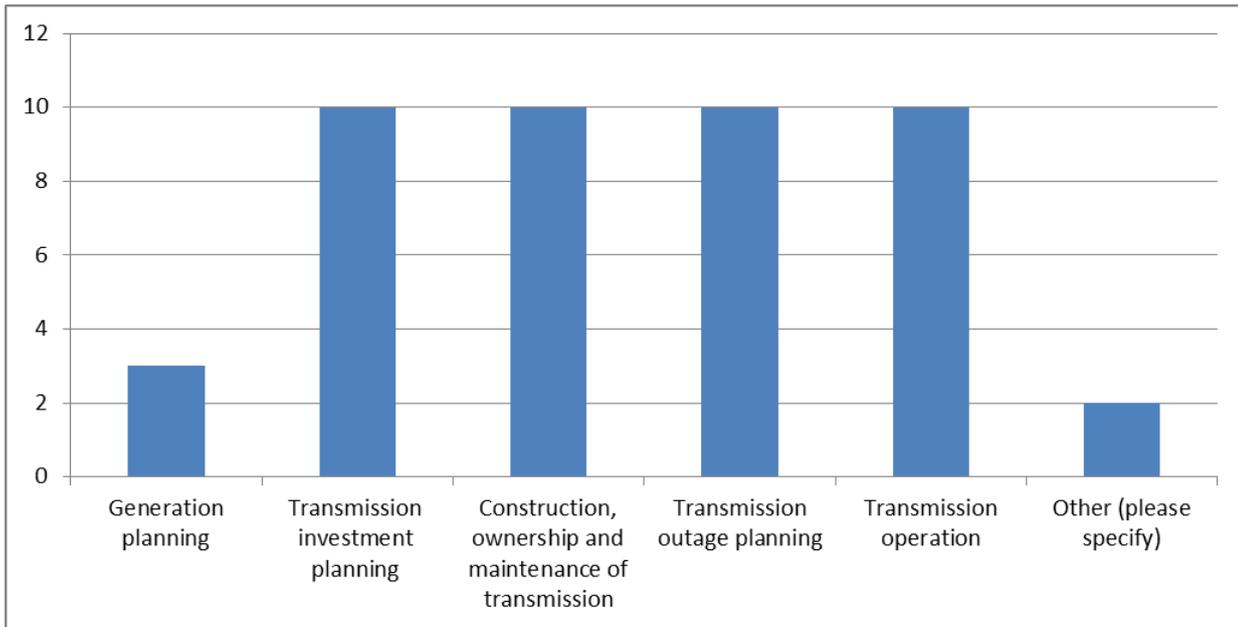
Typically, TSOs use a quite detailed model of their own grid, and a certain set of situations (Generation, demand and import/export) to get a picture of how a particular investment option would influence the reliability of their grid or the facilitation of the electricity market. In order to generate realistic market scenarios for the future, the TSOs need to make some assumptions and forecasts for the future, such as generation mix and demand growth, as well as the spatial and geographical distribution of the demand. Another interesting topic in this setting is how the renewable generation patterns are modelled and generated.

The responses to the questionnaire submitted to TSOs in WP1 serve as a basis for the establishment of a functional workflow of system development activities. A need for a new questionnaire has nonetheless been identified during the WP4-5-6 kick-off meeting to gather more precise and specific information on the current practices of the TSOs.

## **1.4 Questionnaire**

The main source of input to this report is discussions within the GARPUR WP4, 5 and 6 and a questionnaire to the TSO partners and members of the reference group of GARPUR. This questionnaire is a common questionnaire between WP4, 5 and 6 so only a subset of the questions is relevant for this report. This paragraph gives a short introduction to the questionnaire, and the answers to various questions will be reported and used where relevant in the following chapters. The questionnaire can be found in Appendix 1.

10 European TSOs have provided answers to the questionnaire. Figure 1-4 gives an overview of which activities these TSOs are involved with.



**Figure 1-4: Answers to Q1: “Which of the following activities does your organisation address?”**

The answers to this first question underlines that all the TSOs deal with transmission investment, construction, maintenance, outage planning and operation. 3 out of 10 are involved with generation planning. Among other activities, control area balancing, tradable capacity allocation and photovoltaic prediction are mentioned.

In the questionnaire the TSOs were asked to which degree their grid is connected with other TSOs’ grids measured as transmission capacity relative to peak demand (Q2). The answer shows that TSOs normally have 10-30% transmission capacity with other TSOs, while some TSO answers were in the range of 0 and 150%. This large amount of variation depends how an individual transmission system has evolved over the past, but nonetheless study of connections between TSO is in the scope of the system development process. Furthermore, the TSOs were asked about the share of renewable in their systems (Q3). Also here the spread is large. When all types of renewable are included the share of renewable vs peak load varies from 1 to 100%, and for wind and solar only the span is from 0 to 70%.

These first questions underline that the TSO respondents are very diverse, and knowing that they are spread over northern, central and eastern Europe, they are as a group quite representative of TSO behaviour in Europe.

## 2 TERMS AND DEFINITIONS

The majority of the definitions below are taken from GARPUR D2.1 [7]. The other terms were not defined in D2.1; definitions are proposed below. The exceptions are “long-term planning”, “mid-term planning” and “short-term planning” which were defined in D2.1 but are re-defined below.

**Assessment:** To determine whether a power system in its normal state is able to operate normally under a given criteria of assessment.

**Asset management:** Systematic and coordinated activities and practices through which an organization optimally manages its physical assets and their associated performance, risks and expenditures over their lifecycles for the purpose of achieving its organizational strategic plan.

**Automatic system protection scheme:** Automatic procedures used to protect the system; e.g. planned automatic under-frequency or under-voltage load shedding and HVDC link emergency power control.

**Candidate decision:** An alternative that can be selected by means of reliability management in a given context.

**Corrective operation:** In the real-time context, corrective operation concerns the application of post-contingency actions, in the aftermath of specific contingencies.

**Common cause failure:** A common cause failure is defined as a failure in which two or more component fault states exist simultaneously, or within a short time interval, and are a direct result of a shared cause.

**Contingency:** A contingency is the unexpected failure or outage of a system component, such as a generator, transmission line, circuit breaker, switch, or other electrical element. A contingency may also include multiple components, which are related by situations leading to simultaneous component outages.

**Connection Point:** A connection point is the interface point at which the power generating module, demand facility, distribution network or HVDC System is connected to a transmission network, offshore network, distribution network, or HVDC System.

**Control area:** For the purposes of power system reliability management the pan-European electric power system is divided into several parts, denoted as control areas. Within each control area, reliability management is the responsibility of the respective TSO. A control area can be formally defined as a coherent part of an interconnected system, controlled by a single TSO.

**Criticality:** Criticality refers to the extent of the consequences to the users of the infrastructure when a system does not carry out its intended function. The criticality describes how severe the consequences are for users who are dependent on the system.

**Long-term planning:** Long-term planning covers activities in the long-term time horizon, i.e. from a year ahead to 10 years or more ahead of real-time. Activities covered in that horizon include system development, planning of asset replacement and setting of asset policy, e.g. maintenance policy and standard equipment specifications. Asset replacement planning and maintenance policy may be regarded as aspects of asset management. It is recalled that WP4 of GARPUR is concerned with system development and WP5 is concerned with asset management. Furthermore, it may be noted that, in respect of many TSOs’ business processes, the activities of system development and asset management interact, e.g. where the particular option adopted for enhancement of system capability is informed by the need to replace certain assets.

**Mid-term planning:** Mid-term planning is planning in the time horizon ranging from weeks and months to a few years ahead of time. It includes: asset management activities such as planning of maintenance and asset replacement; the enhancement of the system’s power transfer capability through the installation of

new facilities with relatively short specification, procurement, construction and commissioning timescales, i.e. system development; and operational planning.

**Operational planning:** Operational planning is the group of reliability management activities linked to system optimization occurring ahead of real-time operation, within the short-term and mid-term horizons.

**Post-contingency action:** A real-time operation reliability management action that is identified (and scheduled) in advance, to be applied following the realization of a specific contingency.

**Power system adequacy:** The ability of the system to supply the aggregate electric power and energy requirements of the customers at all times, taking into account scheduled and unscheduled outages of the system components.

**Power system planning:** the identification and implementation of actions to enable future operation of the system in accordance with appropriate system operation rules or conventions.

**Power system reliability:** is the probability that an electric power system can perform a required function under given conditions for a given time interval. Reliability quantifies the ability of an electric power system to supply adequate electric service on a nearly continuous basis with few interruptions over an extended period of time. Power system reliability can be sub-divided into security and adequacy.

**Power system security:** Security of a power system refers to the degree of risk in its ability to survive imminent disturbances (contingencies) without interruption of customer service. It relates to robustness of the system to imminent disturbances and, hence, depends on the system operating condition as well as the contingent probability of disturbances. Security is the ability of the power system to withstand sudden disturbances such as short circuits or un-anticipated loss of system components. Another aspect of security is system integrity, which is the ability to maintain interconnected operations. Integrity relates to the preservation of interconnected system operation, or the avoidance of uncontrolled separation, in the presence of specified severe disturbances.

**Pre-contingency action:** A real-time operation reliability management action that is applied before the realization of a contingency.

**Preventive operation:** In the real-time context, preventive operation concerns the potential application of pre-contingency actions to achieve security and improve the ability to withstand the possible effects of potential contingencies.

**Real-time operation:** Real-time operation is exercised within recurring time intervals, beginning with a regular update on the system operating conditions. The duration of these intervals (typically in the range of 15–60 minutes) is such that the system operating conditions can be assumed to be relatively predictable, unless a contingency happens. Real-time operation includes preventive, corrective and emergency operation.

**Reliability criterion:** A reliability criterion is a principle imposing a standard to determine whether or not the reliability level of a power system is acceptable.

**Reliability indicator:** A reliability indicator is an observable or computable quantity that provides insight into the level of reliability of a system in a particular context. It can be used, ex-ante, to formulate a *reliability criterion* used for *reliability management* or alternatively to assess, ex-post, the *reliability* level of a system. Note 1: a reliability indicator is a measure of *reliability*. Note 2: a reliability indicator is a value, for example the number of interruptions.

**Reliability management decisions:** A sub-set of the candidate decisions that have been selected by means of reliability management in a given context.

**Scenario analysis:** a process of analysing possible future events, like demand and generation changes. The process of system development starts with the scenario building process and the outcome of the models are highly dependent on such scenarios.

**Set of candidate decisions :** A set of candidate decisions is an exhaustive set of all distinctive alternatives that can be selected in a given context. Alternatives within this set correspond to the application of available actions as well as to the application of no action.

**Short-term horizon:** The short-term horizon is considered to start from several months ahead of-real time and last throughout the real-time moment of system operation. It includes operational planning and some aspects of asset management.

**System development:** the enhancement, through provision of new facilities on the system, of the system's power transfer capability.

**System operating condition:** A system operating condition is a particular realization of generation and demand levels, as well as flows between interconnected control areas and network configuration.

**Technical Candidate:** A technical candidate is a candidate decision in the system development context. It is a feasible solution that is assumed to satisfy economic and reliability constraints to enhancing the power system transmission capacity.

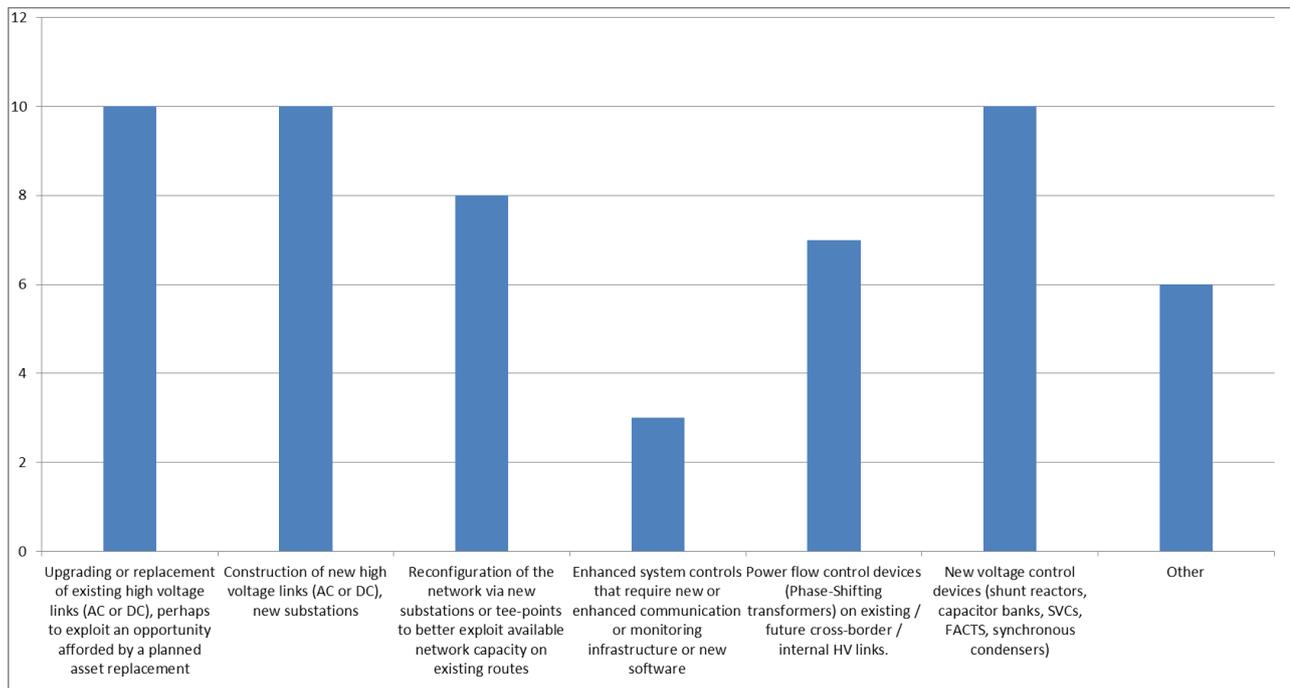
**Vulnerability:** Vulnerability is an internal characteristic of the system and it relates to the inability of a system to perform a required function due to the realization of a threat. More specifically, a system that is likely to fail to carry out its intended function, has problems recovering to normal function or its capacity is significantly reduced upon realization of a threat is vulnerable to the said threat.

**Transmission system operator:** A transmission system operator (TSO) is a natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the transmission system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the transmission of electricity.

### 3 OVERVIEW OF THE SYSTEM DEVELOPMENT DECISION MAKING PROCESS

System development deals with taking decisions that change transmission capacities either within a TSO’s own system or towards other TSOs systems<sup>1</sup>. Figure 3-1 shows an overview of the type of system development decisions that are made at the TSO respondents. From the figure it can be seen that all the TSOs build, upgrade or replace new high voltage links and control devices. Further, eight out of ten TSOs work with re-configuration of their grids in terms of building sub-stations or tee points and seven consider installing power flow control devices, while three TSOs see enhancing system controls as a system development task.

Other system development activities mentioned by the TSOs are typically making or contributing to studies that analyses the future needs of the system (their own or a more regional system) rather than analysing single investment projects. One well known example of such a study is the Ten Year Network Development Plan study of ENTSO-e. Other examples can be internal grid development plans or maintenance and replacement strategies. Outcomes of such studies will typically be a number of candidate investment projects to be more carefully studied in the future.



**Figure 3-1: Answers to Q53 concerning the main type of system development investments**

The TSOs were asked to give an explanation of their system development planning process (Q54). As this was an open question, naturally the answers differed quite much. The TSOs more or less divided themselves into two groups. In the one group each TSO focused on the process of supporting the decision of one single transmission investment project, spanning from idea via market-, grid- and investment cost assessment to the decision and approval at the executive board or regulator and transfer to building stage. The other group of TSOs focused more on the total needs for grid development in the future of, say, 10 years ahead and analysing what the total need for investments would be with some concrete

<sup>1</sup> It should be noted that in some countries, other bodies than the TSOs make investments in the transmission grid. Analysing these types of investments is, however, out of scope of this report.

project proposals as the output of the process. The two groups do not necessarily differ in their overall system development process; they have chosen different parts of the process to describe here. In this report, both views of the overall system development process will be represented.

Figure 3-2 shows a diagram of the overall system development process. The diagram is based on discussions with GARPUR WP4, 5 and 6 at a workshop in Reykjavik in September 2014, inputs from the questionnaire and discussions in the task 4.1 working group. The result is reviewed by the TSO partners of the GARPUR project. The figure highlights the most important processes in system development at the TSOs.

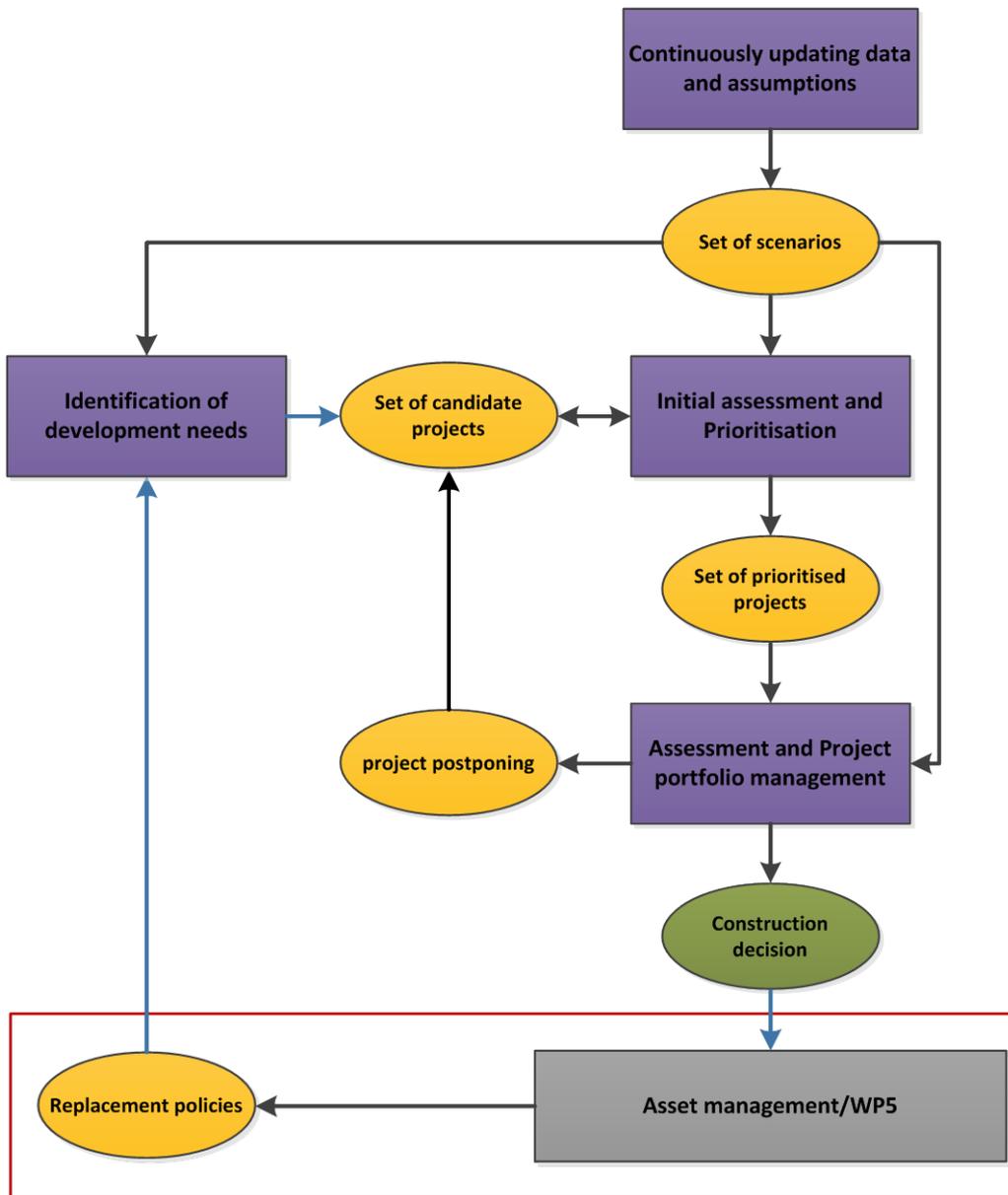
At the top of the figure we have the “continuously updating data and assumptions” process, which is an essential part of system development. Detailed modelling of the system is a key to realistic assessment and optimal decision making. This process takes both internal and external information as input synthesising historical patterns and making assumptions for future development into one single or a set of scenarios against which candidate projects will be evaluated.

“Identification of development needs” is not necessarily a formalized process at the TSOs, but nonetheless it is quite important, since this is the place where ideas for future investment projects are generated. This can be based upon needs observed in earlier rounds of the general or specific assessment processes described below, but also triggered by re-investment needs or technology development in the industry opening new windows of opportunity. The output of this process is a continuously updated set of investment candidates ready for further assessments.

In the “initial assessment and prioritisation phase”, a general appraisal of possible future network problems and needs for modifications of power transfer capabilities is carried out, starting with a set of candidate investment projects to be assessed. The output of the process is an updated set of candidate projects including new project candidates identified in the process. The set of candidates will now be a priority ordered list of projects to be assessed in more detail in the next stage of the system development process. Some TSOs have a formalized process for this, making a future grid development plan. The output of this process is a set of projects that are likely to be built in the future.

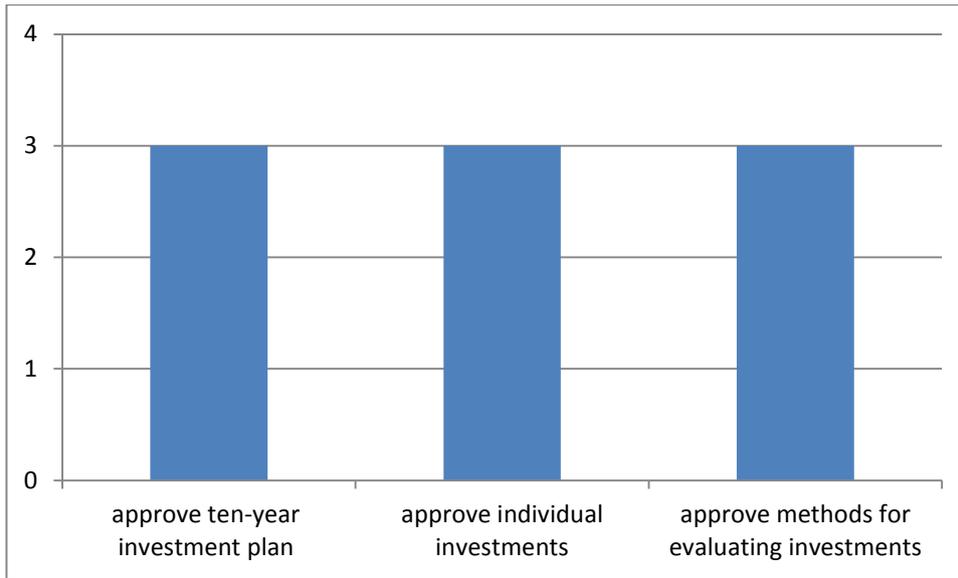
The prioritised projects are not really decided yet. This final decision requires more detailed studies that take one or a small group of projects and the set of scenarios as an input and make assessment of them upon the set of scenarios in the “assessment and project portfolio management” process. The assessment performed here is different in the sense that a more detailed design and hence costing of the technical solutions, synergies with asset replacement needs and more detailed analyses of risks and crucial assumptions can be made. If the projects perform well in this assessment process, and the indicators satisfy the investment criteria, the construction decision is made (by the board or the regulator) and the projects are transferred to the building stage. If not, the projects are retained, but might still be prioritised and decided at a later stage.

Each of the main processes “continuously updating data and assumptions”, “initial assessment and prioritisation” and “assessment and project portfolio management” will be treated separately in the following chapters.



**Figure 3-2: Top level diagram of the long term decision making process**

Figure 3-3 shows how the TSOs answered when asked about the role of the regulator regarding approval of system development investment decisions. It should be noted that only nine out of 10 TSOs answered this question. Here the TSOs are clearly different and split into three groups with various degrees of regulation and to which degree the regulator is involved with details: One group of TSOs where long term investment plans shall be approved by the regulator, another group where the regulator approves individual investments and a third group where the regulator only approves the methods with which the investments are assessed.



**Figure 3-3: Answers to Q55 concerning the role of the regulator**

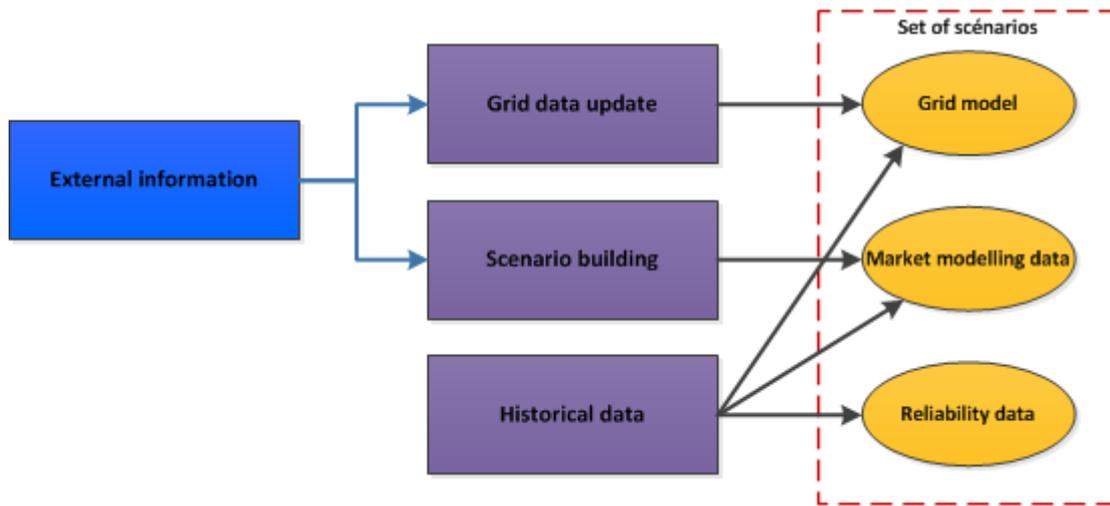
### 3.1 Cross-TSO coordination

There is an obvious need for TSOs to communicate and cooperate with each other during the system development decision making process, especially for transmission lines that cross the boundary between two TSOs, where both TSOs need to accept a potential investment project before it can be commenced. For such projects many of the steps shown in Figure 3-2 must be performed in common between the concerned TSOs in order to reach an agreement.

Additionally there is a need for coordination in the data and assumptions process between neighbouring TSOs, since this can be crucial for the accuracy of assessments and portfolio management process. Further, the TSOs in Europe cooperate in making the ENTSO-E TYNDP [5], which can be seen as an early version of the initial assessment and prioritisation process for the whole group of European TSOs.

## 4 CONTINUOUSLY UPDATING DATA AND ASSUMPTIONS

Data and assumptions are crucial to the system development process. Data sets based on historical patterns and assumptions for the future are necessary elements in all assessments of investment projects. This chapter deals with the processes that creates new and continuously updates data sets used for system development decision making. Figure 4-1 shows a workflow diagram of the process.



**Figure 4-1: A workflow diagram of the continuously updating data and assumptions process**

The figure shows the process of maintaining three types of data that enables TSOs to perform system development investments: Grid models, market modelling data and reliability data. TSOs maintain these data sets and assumptions about the anticipated future for their own transmission grid. A grid data update is performed when new construction decisions are made and new candidate investment projects are found. Data are also updated when new information about external factors such as neighbouring grids, generators or distribution grids is available. The scenario building deals with information about generators and the economical surroundings of the power system to synthesise market modelling data and load and generator data to the grid model. Finally, historical data are used to synthesize load and generation patterns and probabilistic data. These processes are dealt with in detail in the subsections that follow.

### 4.1 Grid data update

The “Grid data update” process is central to any TSO. The grid model contains details of the power transmission grid that a TSO owns and operates. It contains information about the current grid and information and assumptions for future grids. At any time the construction of a new piece of transmission equipment is decided, the grid data has to be updated. And from time to time new assumptions for the future grid are established, and the future grid model needs to be updated. For details on the grid model see section 4.4.1.

### 4.2 Scenario building

Investments in grid components are long-term and will be a part of the power system for 30-50 years or maybe even more. Therefore it is necessary for the TSO to be able to analyse how the grid components will be used by the power system quite far ahead in time. The TSOs were asked about the temporal scope

of their analyses (Q70). All TSOs stated that they do analyses of the system 10 to 20 years into the future, and five of the TSOs even state that they do shorter term analyses around 5 years ahead in time

The grid data is not enough. The TSO also needs detailed information about the generators and loads that are connected to their system as well as information and assumptions for neighbouring grids. For the future it is needed to answer questions like: “How will the load develop?”, “How will the economy for the generators be?” and as a consequence “what type of generation will there be in our system in the future?” Finding answers to these questions is called scenario building and aims at giving concrete images of the future power system in one “best guess” and/or acknowledging the uncertainties of the future in a set of scenarios. Together with the scenarios for its own system, similar information about neighbouring systems and assumptions about transmission capacities between the systems can be used in market models to predict the future prices and flows in the power market. Data about generators and load forecasts are needed both in the market modelling data and the grid model. A well-known example of actual scenarios is the four ENTSO-E visions of the future [6].

To build scenarios the TSO needs to collect external information from a number of sources. The most important sources are:

- *Renewable energy ambitions and actual and future policies.* Makes the TSO able to forecast the renewables share in the future, which is one of the main drivers for grid development.
- *Economic growth and energy savings forecasts.* This is very important inputs to making a reasonable forecast for the load growth, which is one of the main drivers for grid development
- *Local demand and generation forecasts.* DSOs have more information about the particular developments in their areas. This is valuable information for TSOs when distributing demand and small scale generation assumptions between the nodes of the transmission system in their grid model.
- *Investment in or decommissioning of generation capacity.* After the deregulation of the power sector in many European countries, this has become an external factor to the TSO's.
- *Fuel prices and CO2 emission prices.* Together with generation and demand forecasts this is important input into making dispatch scenarios and price forecasts for the future.
- *Development of neighbouring power systems, including grid, generation and load assumptions.* Depending of the degree of interconnection with neighbouring systems this might be crucial input to making realistic dispatch scenarios. Here there is a need for cross-TSO coordination to agree on common images of the future power system.

Due to the many uncertain external factors and general uncertainty of the future, it is a good idea to have several scenarios of the future when you do analyses of long-term investments. Each scenario is a set of assumptions for the future containing specific values for uncertain parameters. From one scenario to another all the uncertain parameters change values. This way an even small number of scenarios span a potentially large part of the future space of uncertain parameters. An alternative way of handling uncertainty is by using sensitivity analysis, where typically one or a small set of uncertain parameters are changed while the rest of the parameters are fixed.

The TSOs were asked how many future scenarios they use in their long term development analyses (Q69). Seven out of ten TSOs claim that they use four scenarios, many of these TSOs answer that they use the ENTSO-e visions. One of the TSOs answer that it uses two scenarios while two of the TSOs only use a single best-estimate scenario when making long term investment analyses. Both these TSOs use sensitivity analyses to account for major uncertainties.

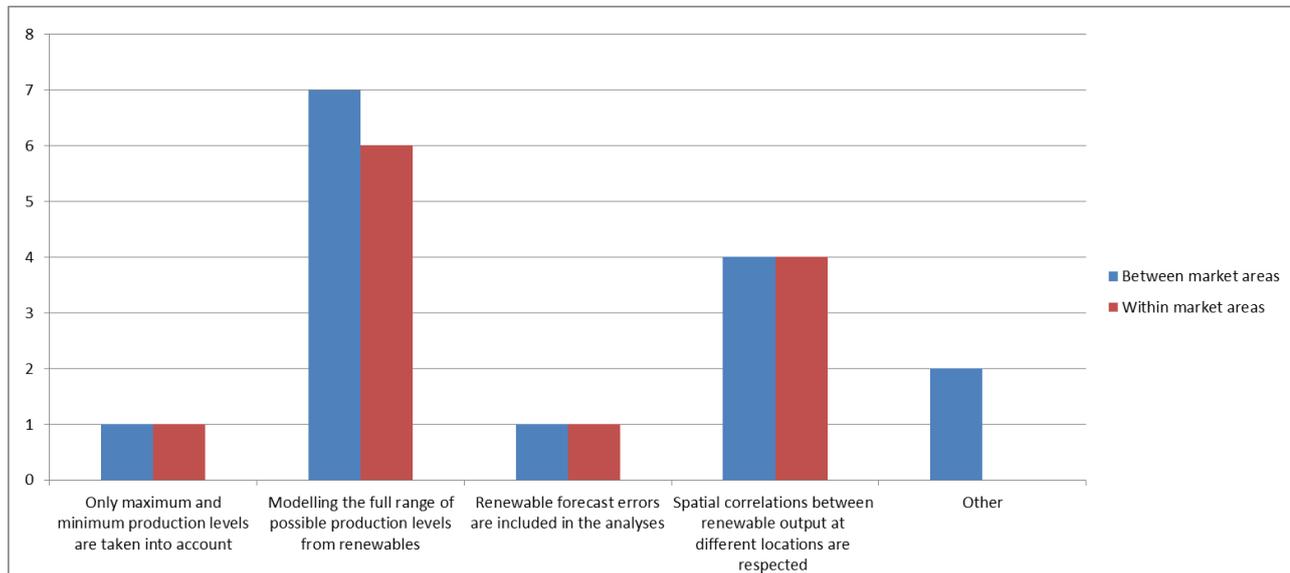
### 4.2.1 External information

In order to investigate the level of coordination between the TSOs answering the questionnaire, they were asked about the geographical scope of their analyses (Q71), and they were asked to separate between multi-TSO investments and internal investments as well as the type of analysis being performed. The answers show that nine out of ten TSOs take several TSOs areas into account when performing between-TSO market analyses. A few TSOs model the whole of Europe while the others have a reduced number of countries included in their data sets. The geographical scope is reduced when analysing internal investments and even further when performing load-flow and dynamic analyses.

### 4.3 Historical data

Historical data is needed to predict future patterns of demand and wind and solar power generation as well as the distribution of load between load points. Finally another kind of historical data is needed to estimate probabilistic data for potential faults in the power system.

The TSOs were asked how renewables are taken into account in the various types of assessments that they make in the system development process. Further, they were asked to separate between investments that increase the transmission capacity between market areas and intra-area investments. The answers are summarized in Figure 4-2.



**Figure 4-2: Answers to Q59 about how renewables are taken into account**

The figure shows that seven of the TSOs use a full range of production levels from renewables in some of their analyses, but only one of the TSOs use only maximum and minimum production levels. One of the TSOs did not answer this question. Four TSOs take spatial correlations into account in their analyses. Further (still Q59), the TSOs were asked in which analyses they use the different approaches. The set of answers are not complete here, but as expected, there is a tendency towards using the most sophisticated renewable modelling in the market studies, and some kind of simplifications in the grid studies.

## 4.4 Data sets

The final set of scenarios include up to three types of data sets. The Grid data are used for network analyses and reliability analyses, while the market modelling data are used for both market and network analyses. Some of the TSOs perform probabilistic reliability analyses, and they need a set of reliability data for that.

### 4.4.1 Grid model

The grid model contains the information necessary to perform static and dynamic grid studies. A detailed description can be found in [1]. As a minimum, the grid model typically contains the following information:

- Positive phase sequence impedances, shunt susceptances and continuous thermal ratings of each network branch.
- Information regarding the nodal connections of each branch.
- Transformer tap ranges and whether taps positions are determined by automatic voltage control or manual setting.
- The nodal location and maximum active power capability and maximum and minimum reactive power capability for each generating unit.
- The nodal location and susceptance of capacitor banks.
- The nodal location and susceptance of shunt reactors.
- The locations and characteristics of phase shifting transformers and any FACTS devices.
- The nodal location and the magnitude of active and reactive power demands, at least at time of system peak demand.
- Configuration and specifics of DC links.

In addition, if stability assessments are to be carried out, the following are required:

- Generating unit dynamic electrical parameters.
- Generating unit governor, excitation system, AVR and PSS characteristics.
- Prime mover models appropriate for use in power system stability assessments.
- Wind turbine main electrical dynamic characteristics and controls.
- Voltage and frequency dependency of loads.
- Special protection schemes and coordinated control schemes.

The following information is required if busbar reconfiguration is commonly carried out:

- The layout of substations such that node/branch connectivity can be revised appropriately to represent running arrangements under different conditions.

The following is required if short circuit level assessments are to be carried out:

- Negative and zero phase sequence network characteristics.
- Any assumptions regarding X/R ratios for decay of the DC component of switching transients.
- Circuit breaker ratings.

Certain additional data are required if credible dispatches of generation are to be synthesised. See the section below on market modelling.

If operational situations other than the system peak demand are to be assessed, time series of nodal demand data should be provided along seasonal and diurnal dependencies of available generation, in particular in respect of renewables. Rules should be provided allowing the synthesis of credible patterns of planned outages in off-peak cases.

Finally a representation of neighbouring grids may be crucial to the correctness of analyses upon the TSO's own grid. This representation could take many forms, from simple equivalents to full representations with many of the aspects mentioned above included.

#### 4.4.2 Market modelling data

The following is required if credible dispatches of generation are to be synthesised and the likely market behaviour assessed:

- Relative prices of generating units.
- Rules and data that allow credible situations to be synthesised regarding the availability of power from wind, solar and hydro power.
- Spinning reserve requirements.
- The availability, size and location of demand response.

At present, system development planners in many countries do not typically postulate generation dispatches in such a way as to take into account limits to operation of generators such as start-up times, min on and off times, ramp rates, ramp profile on start up. However, if they are to do that, such information should be made available.

If emissions are to be quantified, generator emissions characteristics should be provided.

The following further generation information should be provided:

- Bidding zone.
- Fuel type.
- Efficiency.
- For instance for Hydro: Special characteristics such as inflow and reservoir limits.
- Must run profiles.
- CHP generation profiles.

Loads

- Load per bidding zone/price areas.
- Load patterns (load per hour of the year).

In the market modelling data there is a substantial need for representing neighbouring systems. Typically all the aspects mentioned above are needed for external systems as well; however more aggregate data than for the TSOs own system can be acceptable.

Finally there are some market modelling data that are (typically) not price area specific:

Transmission lines:

- Only between bidding zones/price areas.
- GTC (Grid Transfer Capacity).
- Losses.

Fuel prices.

Emission prices.

#### 4.4.3 Interface between market modelling and grid modelling

With market modelling the TSO can forecast future market dispatch, more specifically generating prices, flows and dispatch for a large number of situations, typically covering one year of hour-by-hour simulation. This generates a big span of market situations that are likely to occur during normal circumstances. The power grid should be able to cope with all these situations under the given reliability management scheme, which is currently the deterministic N-1 criterion, see [2]. The TSOs were asked whether they use market modelling results, worst case dispatch scenarios (pre-defined snapshots) or something in between for their grid studies (Q63). The results can be summarised as follows:

Market situation for grid studies:

- Inter-area investments.
  - Two TSO's use a full range of situations from market model runs.
  - One TSO uses both approaches depending on the analysis at hand.
  - The rest use snapshots.
    - Some use pre-defined snapshots.
    - Others use some screening method to select scenarios from a market model run.
      - DC load flow for screening.
      - AC load flow upon snapshots.
- Intra-area investments.
  - All TSOs except one use snapshots, typically based on market modelling runs.

These results indicate that the TSOs are and have already been developing their tools and methods, so that many different scenarios are considered instead of worst case analyses. This can be interpreted as a small step towards using more probabilistic approaches, or at least acknowledging the potential excess cost of analysing worst case scenarios only.

#### 4.4.4 Reliability data

In [2], current reliability management practices as well as drivers for and barriers against probabilistic reliability management practices are described and discussed. There it is shown that the TSOs actually collect reliability data in terms of fault statistics for transmission system components. However the TSOs do generally not use them for probabilistic reliability calculations. This is also underlined by the answers to question Q61 and Q62 where the TSOs were asked how probabilistic reliability calculations were included in their system development process. Most of the TSOs answered that this type of analysis was not performed at all, but some TSOs answered that they were experimenting with it, but it is not used for real decision making.

## 5 INITIAL ASSESSMENT AND PRIORITISATION

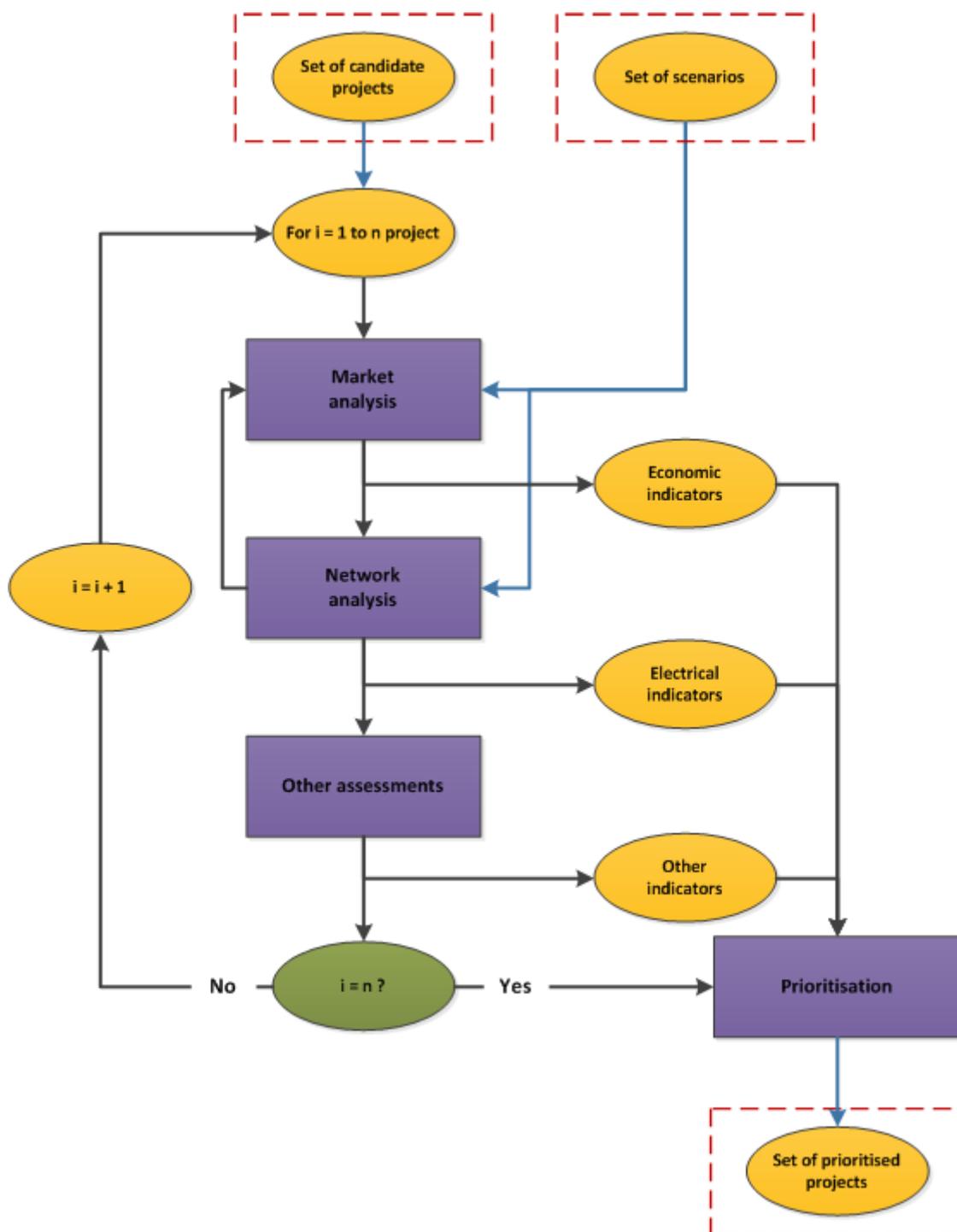
A fundamental question for a TSO in terms of system development is “What are the future needs of my power system?” This is a question the TSO can start answering when the scenarios for the future are built and the data sets are updated. This question can be answered in many ways, but in order to get good answers, performing analyses is necessary.

The TYNDP of ENTSO-e [5] can be interpreted as an attempt to answer this question from a European perspective. In the TYNDP there are both pan-European and regional market and grid studies leading to a non-binding overview of beneficial transmission investment projects from a European and regional point of view. If nothing else was done, this process could serve as an initial assessment for a TSOs system development processes.

In the questionnaire, the TSOs were asked what influence the ENTSO-e TYNDP has on their system development decisions (Q56), and, since it is non-binding, only two out of ten TSOs claim that it has a direct influence on their process. For the majority of the other TSOs it has an impact, either as a basis for their own analyses, or as a second opinion upon analyses they have already done themselves or bilaterally with other TSOs. Two of the TSOs claim that the TYNDP has either little or no influence upon their system development decisions.

It is neither precisely nor completely covered by the questionnaire, but however, four of the TSOs describe that they regularly make their own grid development plan that shall be approved either by the regulator or the government. Making such a plan serves as an initial assessment for the further system development process.

Figure 5-1 shows a workflow diagram of the initial assessment and prioritisation process. The set of candidate projects is based on the replacement needs identified in the Asset Management process, on older project candidates that have not yet proven necessary, and on other ideas. This set might be updated during the process since the analyses might show some future needs that are not covered by the current system models of the future.



**Figure 5-1: A workflow diagram of the Assessment and Prioritisation process**

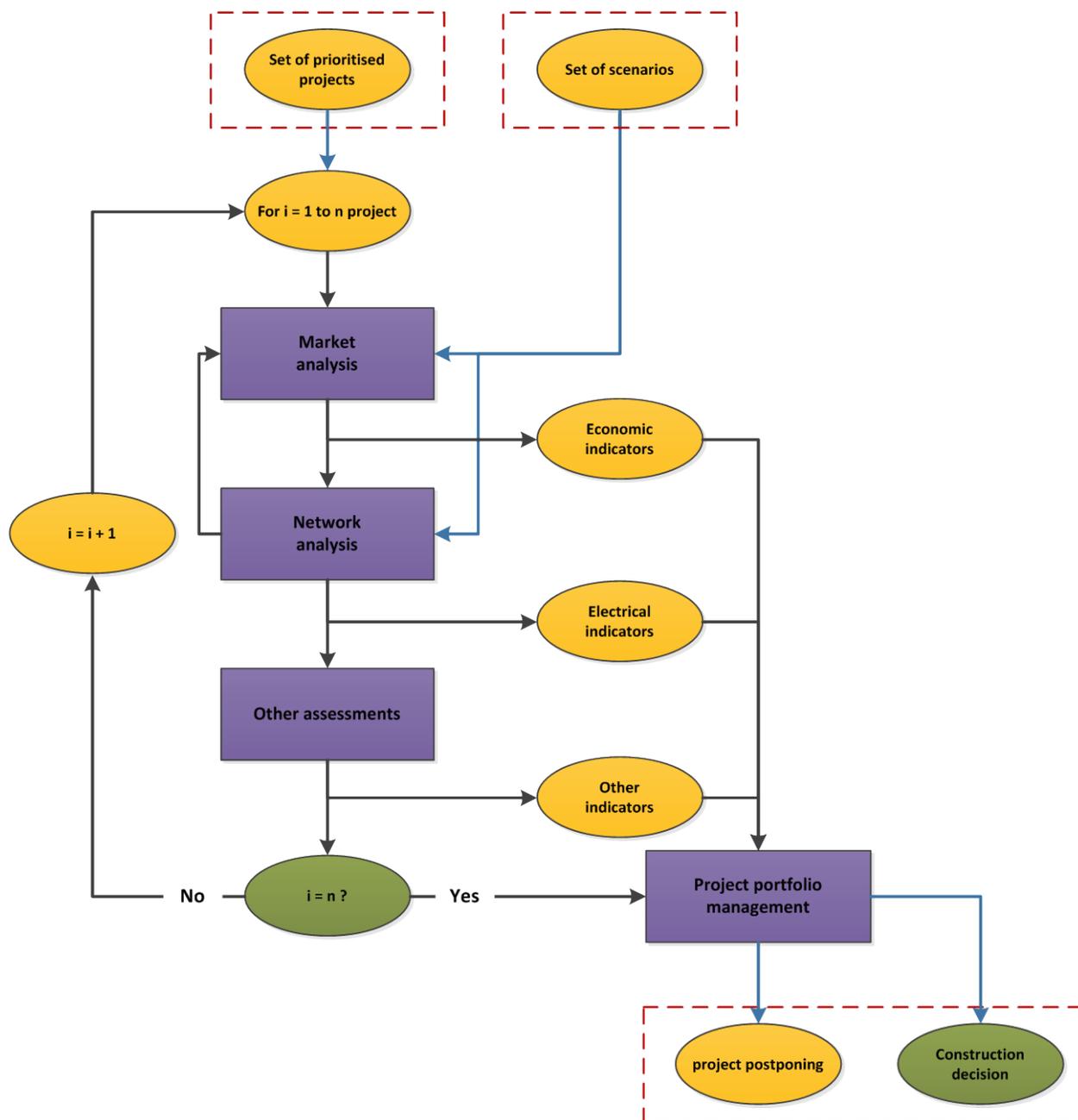
Each candidate project is assessed via market and grid analyses and other assessment such as cost calculations and environmental impact assessments. This initial assessment process might be very different from TSO to TSO, but the analyses made at this stage are less detailed and focused as those made in the “assessment and portfolio management process”. However the elements are the same, and will be described in detail in chapter 6.

In the grid assessment part of the process, technical methods and criteria are used when assessing the planning scenarios, in order to identify future problems and determine the required development of the transmission grid. These needs are determined by comparing the results of the steady state analysis, fault level assessment and stability assessment with the criteria for assessing consequences. This means that new projects might also be conceived during this phase, if the set of candidate projects cannot satisfy the future needs of the power system.

Finally, as an output from these analyses, some of the candidate projects are more interesting than the others, and based on the various economical, technical and other indicators, the TSO needs to prioritize between the projects and decide which projects to analyse further in the “assessment and project portfolio management” process. Since the projects are not necessarily independent of each other, there is a risk that projects that will never be built will be indicated as interesting and hence will be prioritised in this phase. However, the more detailed assessments later on will show which of the prioritised candidates are most beneficial and only these will be sent forward to the building stage.

## 6 ASSESSMENT AND PROJECT PORTFOLIO MANAGEMENT

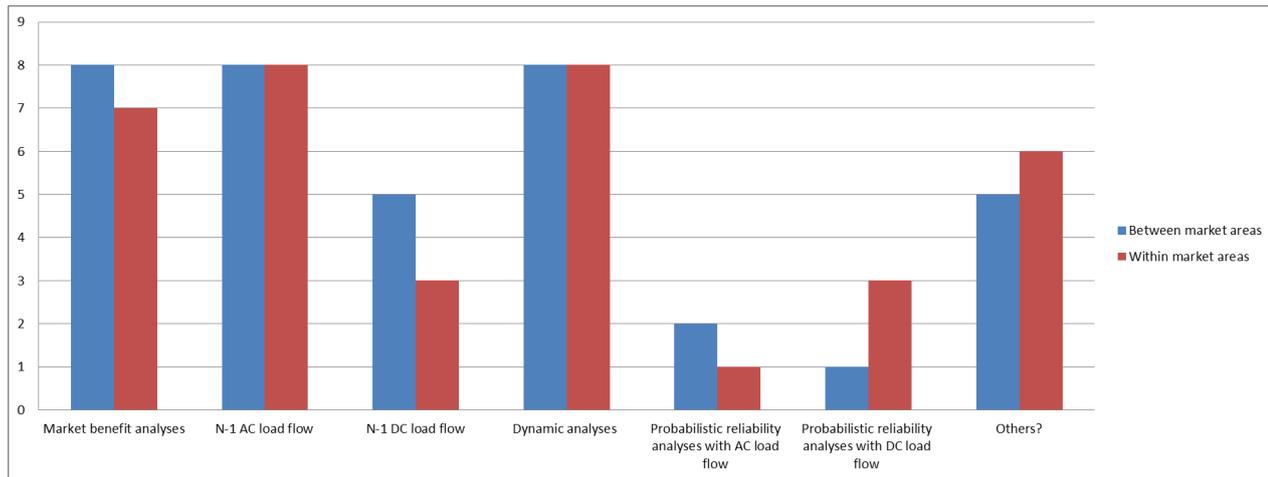
The “Assessment and Project portfolio management” process is described by the detailed work flow diagram below in Figure 6-1. The goal of this process is to assess the impact of prioritised projects in terms of added value for society, in terms of costs and to check whether technical criteria are met.



**Figure 6-1: A workflow diagram of the Assessment and project portfolio management process**

The described process is in relation to the multi-criteria CBA developed by ENTSO-E [8]. By definition, the multi-criteria approach indicates the characteristics of a project and provides sufficient information to the decision makers. The characteristics are defined in the form of indicators. These indicators are obtained using different analyses. Not all TSOs follow all elements of the CBA for their national assessments. In the sections below answers from the questionnaire will be used to relate this process to TSO practice.

Figure 6-2 shows the type of analyses performed by TSO’s in the system development context.



**Figure 6-2: Answers to Q57 and Q58 about the type of analyses performed in order to support investments by TSO’s**

The individual boxes of the workflow diagram are discussed in more detail in the following paragraphs.

## 6.1 Market analysis

Market modelling takes one or more future scenarios as input while the output is the forecast of future market dispatch, more specifically generating prices, flows between market areas and generation dispatch for a large number of situations, typically covering one year of hour-by-hour simulation. Market analysis is typically used for estimating the economic impact of projects increasing the transmission capacity between two market areas.

Prices, dispatch and flows are estimated for the case with and without the investment at stake, and from these the economic indicators for the investment project can be calculated. In the questionnaire, the TSOs were asked about how the result of market analysis is included in investment decisions (Q60). The answer shows that for investment between market areas, the result of market analysis is used by most of the TSOs. Some of the TSOs use national trade benefits while others look at regional benefits. At the national level, several TSOs indicate that congestion costs are used for investment decisions.

### 6.1.1 Economic indicators

Socio-economic welfare (SEW) from market integration is characterised by the ability of a power system to reduce congestion and thus provide an adequate transmission capacity so that electricity markets can trade power in an economically efficient manner.

The new transmission capacity reduces the total cost of electricity supply, since it allows generators in the lower-priced area to export more power to the higher-priced (import) area.

In general, two different approaches can be used for calculating the increased benefit from socio-economic welfare:

- The generation cost approach, which compares the generation costs with and without the project for the different bidding areas. This is adequate for calculating the total socio economic welfare increase from market integration for the given investment project.

- The total surplus approach, which compares the producer and consumer surpluses for each bidding area, as well as the congestion rent between them, with and without the technical candidates. This is needed to calculate the distribution of the socio economic welfare between market areas and the different segments of each market area.

## 6.2 Technical candidates

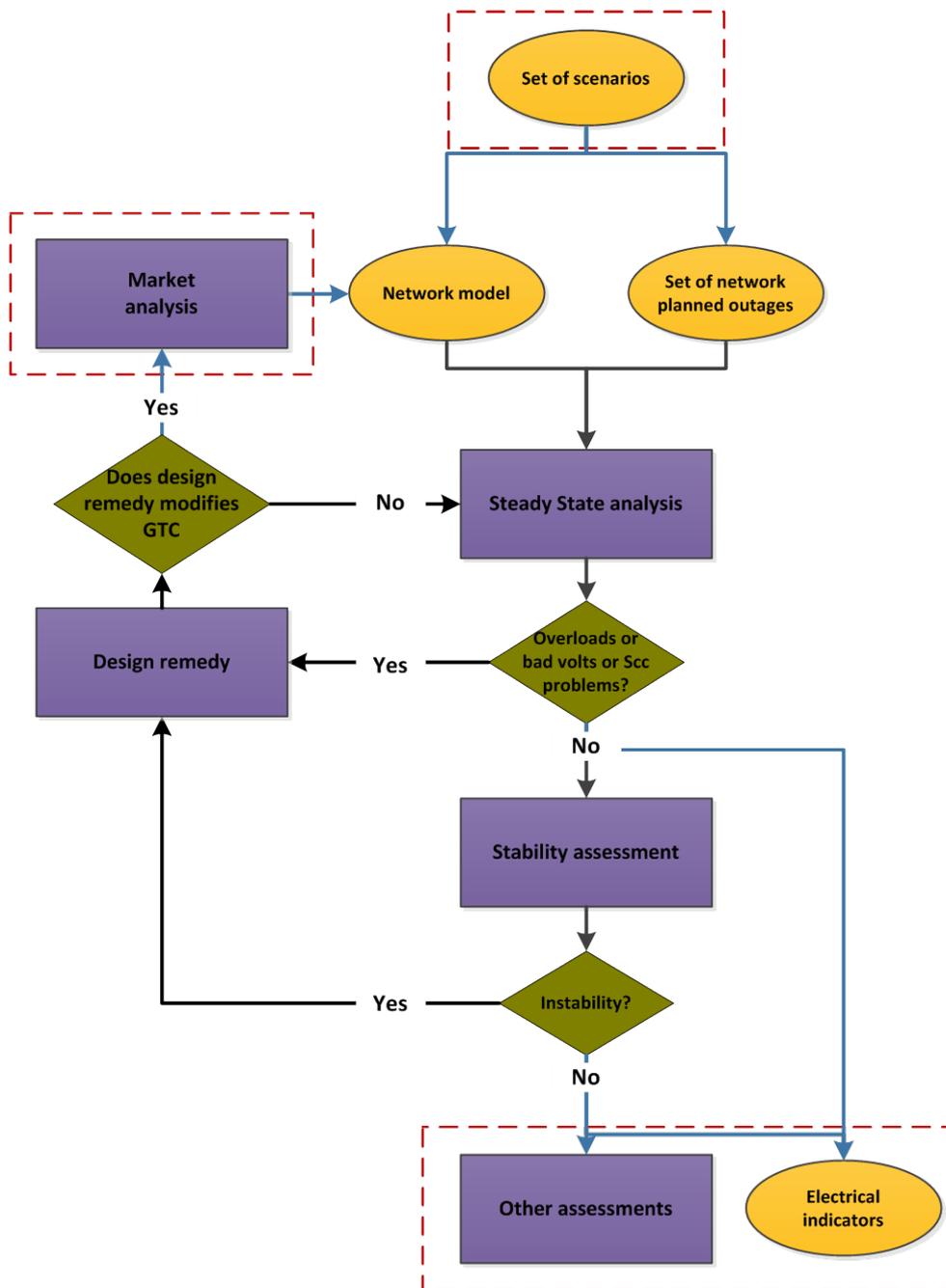
A transmission system investment project comes out of a future need for increased transmission capacity within a certain area or between two areas. This can be solved in several ways by different technical candidates. A technical candidate is a concrete solution to a given project enhancing the power system transmission capacity of the grid. In link with Figure 3-1, this is the list of elements that may be part of technical candidates:

- New circuits, circuit upgrading, reactive compensation, new controls (Results for Steady state analysis).
- Replace over-stressed equipment, add series reactor or reconfigure network (go back to planned outages) (Results from Fault level assessment).
- Reduce system impedance, modify generator controls, install SPS or re-dispatch generation (Results from Stability assessment).
- If the standards described previously are not met, then reinforcement of the grid is planned. These measures can include the following ([3] or [4]):
  - Reinforcement of overhead circuits to increase their capacity (e.g. increased distance to ground, replacing of circuits,).
  - Replacement of network equipment or reinforcement of substations (e.g. based on short-circuit rating).
  - Extension of substations and construction of new ones.
  - Installation of reactive-power compensation equipment (e.g. capacitor banks).
  - Adding of network equipment to control the active power flow (e.g. phase shifter, series compensation devices).
  - Additional transformer capacities.
  - Construction of new circuits (overhead and cable).
  - Prioritization criteria are used to decide between different solutions that solve the same problem.

Additionally, TSOs follow research and development of new technologies closely, and should always consider whether or not new solutions should be included in the design of technical candidates.

## 6.3 Network analysis

The Network Analysis process is described by the detailed work flow diagram below in Figure 6-3.



**Figure 6-3: A workflow diagram of the Network Analysis process**

The main aim of network analysis is to verify that the technical candidates meet the technical criteria, such as the N-1 criterion. In [2] it is shown that the N-1 criterion is the current reliability management scheme among the TSOs and that it is used in all time horizons. Hence, by imposing the N-1 criterion in the network analyses part of the system development process, the TSOs make sure that the reliability management scheme is coherent across time horizons and that their grids can be operated in the future.

The network analyses take the outcomes from the Market analysis into account, and the candidates are evaluated by comparing the results of the steady state analysis, fault level assessment and stability assessment with the criteria for assessing consequences.

Another purpose is to quantify the different projects with electrical indicators. The various elements of Figure 6-3 will be explained in the following subsections.

### 6.3.1 Network model

The network model depends of:

- Geographical scope,
- Type of situations,
- Parameters of committed network,
- Generation initial condition,
- Demand conditions,
- Neighbouring system initial condition.

This information was discussed in “Continuously updating data and assumptions” (Chapter 4)

### 6.3.2 Set of network planned outages

In the current System Development context, planned outages are generally not directly taken into account (Q65). One exceptional TSO states that it uses an N-1-1 criterion that makes the grid ready for maintenance of any major component at any time. Another TSO states that it makes an N-2 assessment in the highest voltage level, but for off-peak periods of the year, to check if maintenance is possible.

In planning, the N-1 criterion is systematically applied without prioritizing between electrical contingencies with different probabilities or consequences. In particular cases, the N-1 criterion is extended to N-2 criterion. Following the TSO's, the N-2 can be considered as:

- Two similar elements: Example: Line-/line to simulate a tower failure<sup>2</sup> or;
- Electrical element and a generator in the area to simulate the planned outage of generator.

### 6.3.3 Steady State Analysis

The Steady State Analysis is generally composed of three studies:

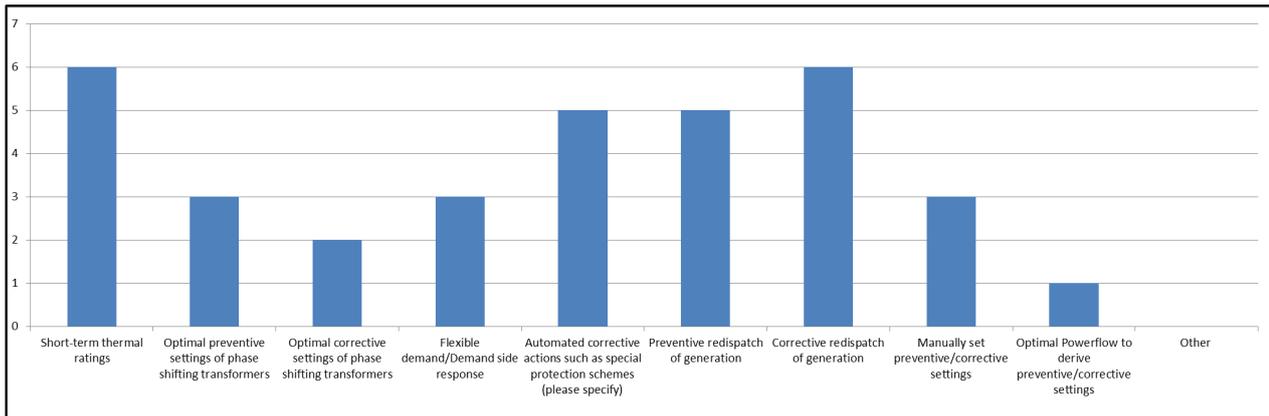
- Load flow analysis (AC or DC),
- Short circuit analysis.
- Voltage study.

The **load flow analysis** examines the situation in N and normal contingencies (N-1) and rare contingencies (N-2, tower failure...). During the contingencies studies, protection schemes have to be taken into account when defining which elements are to be disconnected during each contingency.

In the system development context, preventive or corrective actions can be taken into account in load flow analysis. The Figure 6-4 lists the different types of actions. Nevertheless, the analysis of the different remarks or comments of TSO's on the Q68 reveal that only major actions are taken into account in load flow analysis and while minor actions are evaluated for specific outages. Further, the TSOs were asked how they take reserves into account in the load flow calculation (Q64), but this is clearly not a big issue among the TSOs. Only three out of ten TSOs state that they take reserves into consideration.

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<sup>2</sup> In Britain, a single event leading to both circuits of a double circuit going out of service is referred to as an 'N-D' event whereas 'N-2' is regarded as two independent outage events.



**Figure 6-4: Answers to Q68 about the preventive and corrective actions taken into account for long term investment planning**

The **short circuit analysis** evaluates the maximum and minimum symmetrical and single-phase short circuit currents in every node of the grid.

In a **voltage study**, it is checked whether the voltage on all busbars of the system remain inside the acceptable zone in N and N-1, taking into account the available resources to adjust the Mvar production / consumption level and the possibilities of regulating transformers.

The steady state analysis in the base case allows defining the needs of the network in terms of overload, over or under voltages and too high short circuit level. The base case is an expected case using the assumptions that TSO deems most likely to occur, without the technical candidate. Assessments on the technical candidate are then used for comparison and hence to measure the performance of the technical candidate. The steady state analysis on the technical candidate allows verifying whether or not the technical candidate fulfils the criteria for assessing consequences.

The criteria are ([3] or [4]):

- **Cascade tripping:** A single normal contingency must not result in any cascade tripping that may lead to a serious interruption,
- **Maximum permissible thermal load:** No case must result in an excess of the permitted rating of the network equipment, taking into account duration.
- **Maximum and minimum voltage levels:** No voltage collapse must be observed. Furthermore, the minimum and maximum voltage levels must respect the limits defined by equipment ratings and national regulation, taking into account duration.
- **Maximum loss of load or generation** should not exceed the power available in primary regulation reserve for each synchronous region.
- **Short circuit criteria:** The initial symmetrical and single-phase short-circuit current shall not exceed the limits defined by equipment ratings and national regulation.
- **Voltage collapse criteria:** The reactive power output of generators and compensation equipment should not exceed their rating and transformer taps should not have reached their limits in attempting to maintain voltages.

### 6.3.4 Stability assessment

The stability assessment is based on transient simulations and other detailed analysis. These analyses are oriented to identifying possible instability and they are performed only in cases where problems with stability can be expected, based on TSO knowledge.

According to Q67 of the questionnaire, in the system development context, the stability assessment is generally applied when seen as necessary.

The specific cases are:

- HVDC connections,
- important new 400 kV line,
- Loss of synchronism in case of tower contingency.

The stability assessment is based on three different types of analyses; the rotor angle stability, frequency stability and voltage stability and on three criteria ([3] or [4]).

- **Transient stability:** Any 3-phase short circuits successfully cleared by the primary protection system in service (or forecasted) shall not result in the loss of rotor angle stability and the disconnection of the generating unit (unless the protection scheme requires the disconnection of a generation unit from the grid).
- **Small Disturbance Angle Stability:** Possible phase swinging and power oscillations (e.g. triggered by switching operation) in the transmission grid shall not result in poorly damped or even undamped power oscillations.
- **Voltage security:** Normal contingencies (incl. loss of reactive power infeed) must not lead to violation of the admissible voltage range that is specified by the respective TSO.

### 6.3.5 Design remedy

If a project does not meet one of the criteria described previously, minor adjustments are required.

In overload case, the solutions are:

- New circuits,
- Circuit upgrading,
- Topological change.

In over or under voltage cases:

- Reactive compensation,
- New controls.

In case of exceeding limits of short circuit power:

- Add series reactor,
- Reconfigure network.

In instability case:

- Reduce system impedance,
- Modify generator controls,
- Install Special Protection Schemes.

If the adjustments on the project modify the grid transfer capability (GTC), a new market analysis is necessary.

## 6.4 Electrical indicators

### 6.4.1 Improved Reliability (security) of supply

Reliability of Supply is the ability of a power system to provide an adequate and secure supply of electricity in ordinary conditions, in a specific area. The assessment must be performed for a geographically delineated area with an annual electricity demand of at least 3 TWh [8]. The indicator

measures the improvement to the reliability of supply (generation or network adequacy) brought about by a technical candidate. It is calculated as the difference between the cases with and without the technical candidate, with the defined indicator being either Expected Energy Not Supplied (EENS) or the Loss of Load Expectancy (LOLE). Nevertheless, in the questionnaire, the TSOs were asked about how reliability is taken account in long-term investments (Q61) and many TSOs indicate that the reliability of supply is not monetized and assessed.

- **Methodology:** For network studies, performance assessment is based on the technical criteria defined in 6.3.3 and 6.3.4. Analysis of representative cases may, for example, identify risk of loss of load for ordinary contingencies. The EENS indicator will then show whether the inclusion of the technical candidate triggers a significant improvement of reliability of supply.

#### 6.4.2 RES integration

Support to RES integration is defined as the ability of the system to allow the connection of new RES plants and unlock existing and future “green” generation, while minimising curtailments.

The integration of both existing and planned RES is facilitated by:

1. Connection of RES generation to the main system,
2. Increasing the Grid Transfer Capability (GTC) between an area with excess RES generation and other areas, in order to facilitate higher level of RES penetration.

This indicator intends to provide a standalone value associated with additional RES available for the system. It measures the reduction of renewable generation curtailment in MWh (avoided spillage) and the additional amount of RES generation that is connected by a technical candidate.

- **Methodology:** Although both types of technical candidates can lead to the same indicator scores, they are calculated on the basis of different measurement units. Direct connection (1) is expressed in  $MW_{RES-connected}$  (without regard to actual avoided spillage), whereas the GTC-based indicator (2) is expressed as the avoided curtailment (in MWh) due to (a reduction of) congestion in the main system. Connected RES is derived from network studies, and only calculated for specific RES integration technical candidates. Both kinds of indicators may be used for the technical candidate assessment, provided that the method used is reported. In both cases, the basis of calculation is the amount of RES foreseen in the scenario.

#### 6.4.3 Variation in losses

Variation in losses in the transmission grid is the characterisation of the evolution of thermal losses in the power system. It is an indicator of energy efficiency and is correlated with the socio-economic welfare. The energy efficiency benefit of a technical candidate is measured through the reduction of thermal losses in the system. At constant transit levels, network development generally decreases losses, thus increasing energy efficiency. Specific projects may also lead to a better load flow pattern when they decrease the distance between production and consumption. Increasing the voltage level and the use of more efficient conductors also reduce losses. It must be noted, however, that the main driver for transmission projects is currently the higher need for transit over long distances, which increases losses. In the questionnaire, the TSOs were asked about how the transmission losses are taken account in long-term planning (Q66). The answer shows that transmission losses are monetized during the market analysis. The amount of transmission losses for market analysis are estimated by load flow computation or based on historical data. Furthermore, the transmission losses are integrated in ENTSO-E’s CBA methodology for the regional projects.

At regional level, the result of market analysis is a part of ENTSO-E’s CBA methodology. For the national level, several TSO indicate that congestion costs are used for investment decisions.

- **Methodology:** Variation in losses can be calculated by a combination of market and network simulation tools. The losses in the system are quantified for each technical candidate (covering seasonal variations) on the basis of network simulation. This is done both with and without the

technical candidate, while taking into account the change of dispatch that may occur by means of market simulation. The variation in losses is then calculated as the difference between both values. The TSOs typically only consider losses in their own systems.

#### **6.4.4 Variation in CO<sub>2</sub> emissions**

Variation in CO<sub>2</sub> emissions is the characterisation of the evolution of CO<sub>2</sub> emissions in the power system. It is mainly a consequence of RES integration (unlock of generation with lower carbon content). By relieving congestion, reinforcements may enable low-carbon generation to generate more electricity, thus replacing conventional plants with higher carbon emissions. Considering the specific emissions of CO<sub>2</sub> for each power plant and the annual production of each plant, the annual emissions at power plant level and perimeter level can be calculated and the standard emission rate established.

- Methodology: Generation dispatch and unit commitment used for calculation of socio-economic welfare benefit with and without the project is used to calculate the CO<sub>2</sub> impact, taking into account standard emission rates.

#### **6.4.5 Technical resilience/system safety**

Technical resilience/system safety is the ability of the system to withstand increasingly extreme system conditions (exceptional contingencies). Making provision for resilience while planning transmission systems, contributes to system security during contingencies and extreme scenarios. This improves a project's ability to deal with the uncertainties in relation to the final development and operation of future transmission systems. Factoring resilience into projects will impact positively on future efficiencies and on ensuring security of supply in the European Union.

- Methodology: A quantitative summation of the technical resilience and system safety margins of a technical candidate is performed by scoring a number of key performance indicators (KPI) and aggregating these to provide the total score of the project.

### **6.5 Other assessments**

#### **6.5.1 Cost of different technical candidates**

For each project, costs have to be estimated. The following items should be taken into account:

- Expected cost for materials and assembly costs;
- Expected costs for temporary solutions which are necessary to realise a project;
- Costs mitigated or compensated under existing legal provisions;
- Cost of planning procedures;
- Expected costs for devices that have to be replaced within the given period;
- Dismantling costs at the end of life of the equipment;
- Maintenance costs and costs of the technical life cycle.

The time horizon accounted for in transmission projects is generally shorter than the technical life of the assets, thus, an appropriate residual value will therefore be included in the end year, using the standard economic depreciation formula used by each TSO.

#### **6.5.2 Robustness/flexibility**

The robustness of a transmission project is defined as the ability to ensure that the needs of the power system are met in a future scenario that differs from present projections (sensitivity scenarios concerning input data set). The provision and accommodation of operational flexibility, which is needed for the day-to-day running of the transmission system, must also be acknowledged. The robustness and flexibility of a project will ensure that future assets can be fully utilised in the longer term because the uncertainties

related to development and transmission needs on a regional basis are dealt with adequately. Moreover, special emphasis is given to the ability to facilitate the sharing of balancing services, as we suppose that there will be a growing need for this in the coming years.

### 6.5.3 Environmental and Social impacts

The environmental and social impacts allow the quantification of the local impact of the project on biodiversity and population. To characterise these impacts, preliminary studies are necessary for each project.

The main aspects are:

- For biodiversity, the land protected or with national park,
- For population, the density and the land that is near to schools.

These aspects are generally defined by international or national legislation.

## 6.6 Project portfolio management

Project Portfolio Management (PPM) is the centralized management used by project managers to analyse and collectively manage current or proposed projects based on numerous characteristics. The objectives of PPM are to determine the optimal resource to achieve operational and financial goals.

The main constraints to take into account are:

- Annual budget of investment ,
- Finite development resources in a specified time (Obligation to align the new investment projects with the strategic plan),
- Constraints imposed by customers or commitment with regard to customers,
- Make sure that projects are in relation to the strategic objectives and priorities of the TSO's.

The decision making should be facilitated by the indicators described previously. Some indicators are monetized (Costs, socio-economic welfare and variation of losses) and the others are displayed through the most relevant units ensuring both a coherent measure and an opposable value.

## 7 THE POTENTIAL BENEFITS OF PROBABILISTIC METHODS IN SYSTEM DEVELOPMENT PLANNING

In the preceding chapters of this report we have given a detailed workflow diagram and description of a typical TSO's current activities in the context of system development. In line with what is observed in earlier deliverables in the GARPUR project [2], current practice of system development at TSOs is dominated by the deterministic N-1 criterion. In this chapter we discuss the potential for improving the system development process by using probabilistic reliability management.

Reliability of a power system is associated with unexpected failures of its components or unexpected behaviour of external factors and understanding why these unexpected events occur and correlation of multiple outages and their impacts is key to improving reliability. Statistical methods provide a suitable framework of capturing such random events.

The need for probabilistic reliability management has been recognized for some time. Some operators have modified their operating rules to reflect a crude approximation of reliability measures for example in Netherlands the (N-1) rule has been adapted by adding a phrase "unless the cost exceeds the benefits."

As has been described above, the purpose of system development planning is to enable future operation of the system in accordance with appropriate system operation rules or conventions. One of the main objectives of GARPUR is to propose new operating rules that are more reflective of prevailing risks, both in terms of likelihood of disturbances and their impacts. These new rules should be taken into account in system development planning through appropriate modelling of future performance of a proposed or planned set of network facilities against specific generation, demand and market scenarios under a suitable range of credible operating conditions for each scenario.

As was illustrated in Figure 1-3, the uncertainties that affect system development are greater than those that apply, for example, in system operation. Thus, a key objective within WP4 is to identify efficient improvements to the system development process that provide benefits in terms of better management of risk without imposing an excessive burden on business processes and analysts. The balance sought should make more explicit use of probabilistic information on operating conditions and disturbances and use appropriate metrics to

- a) Identify how much modelling is required to give sufficient confidence with respect to assessment of future operation of the system for a given generation capacity/demand/market scenario;
- b) Make use of information on system performance from a set of scenarios to identify and justify any investments in new network facilities that are required.

Item (a) above is the main subject of Task 4.2 while (b) is the main subject of Task 4.3.

Success in WP4 as a whole promises to deliver the benefits outlined below. They are described under two headings: benefits for reliability; and economic benefits.

### 7.1 Benefits in terms of more precise assessment of improved reliability of the system

In large part because of the difficulty of quantifying the economic benefits of improved reliability or continuity of supply of electricity, system development planners are finding it increasingly useful to distinguish between two drivers for enhancement of network facilities: reliability; and economy. In respect of the former, traditional approaches to system development planning have been tended to be

based on what are generally perceived to be worst-case operating conditions, e.g. peak demand, and then to test the effect of a limited set of contingencies against those conditions. Moreover, although it should be ensured that system operating limits are not breached, the extent of breach is not always taken into account when evaluating network investment options. For example, a simplistic approach might simply regard even a voltage 1kV below a given limit as being unacceptable whereas its actual impact may be minimal. On the other hand, under particular conditions, even if a voltage may be within limits, it might be highly sensitive to small changes in reactive power generation or active power transfer and the margin from voltage instability might be small.

Another issue, relevant also for system operation and operational planning, is that, beyond an order of magnitude assessment that determines whether a particular outage is likely enough to be included on the contingency list, the probabilities of particular disturbances are not taken into account. This includes the possibility of multiple contingencies or of single events triggering cascades. A further issue is that other inherent uncertainties, e.g. on network or generator parameters, are often overlooked.

A more explicitly risk-based approach should allow both the probabilities of different disturbances and their impacts to be taken into account and, as a consequence, investments in enhanced network facilities to be better targeted with ensuing benefits for consumers in terms of reliability of supply.

## 7.2 Economic benefits of probabilistic reliability management

As was noted above, traditional approaches to system development planning have tended to be based on one or just a few 'worst case' operating conditions and a limited set of contingencies. This is less than ideal. For example, one can argue that (a) peak demand represents just one, quite short period within a year and (b) that the probability of a contingency occurring during that short period is low. Also, even if a system withstands the postulated 'worst case' conditions, the system is still not risk-free. On the other hand, while preventive and/or corrective control may succeed in making the system compliant with operating rules for that condition and it incurs a cost, a simplistic approach does not take account of the magnitude of that cost compared with those that arise under other operating conditions and the costs of proposed network enhancements. As we have shown in this report (section 4.4.3), this requested change has already started in the TSO practice. From the answers to the questionnaire (Q63) it can be seen that two out of ten TSOs already use a full set of market situations from a full-year market modelling run as an input to their steady-state analyses.

A probabilistic approach to the assessment of year-around system operation for a given background scenario will allow

- Variations in demand and available power from renewables – wind, solar and hydro – to be taken in account;
- Different situations to be properly weighted;
- Confidence limits to be quantified for a given metric and a specified degree of confidence.
- Incorporating probabilities of contingencies, and allowing them to be situation dependent

In doing so, the economic benefits of proposed enhancements of network facilities can be assessed with greater confidence, and a trade-off between costs of building new equipment with the disutility of inadequate reliability can be made. For a more thorough discussion of drivers for and barriers for a probabilistic reliability framework, see GARPUR Deliverable 1.2 [2].

### 7.3 Expected impacts of GARPUR WP4 on system development process

In this section we give expected impacts of GARPUR WP4 in the context of system development process. The overall objective of WP4 is to adopt such approaches in order to enable the system development planner to have an adequate grasp of the uncertainties between system development and operation without being over-burdensome with the endless possibilities of operating conditions. To achieve this objective WP4 works to refine the generic frameworks developed in WP2 and WP3, to make them comply with the practical needs of system development processes and therefore success of WP4 is heavily dependent on the outputs from WP2 and WP3.

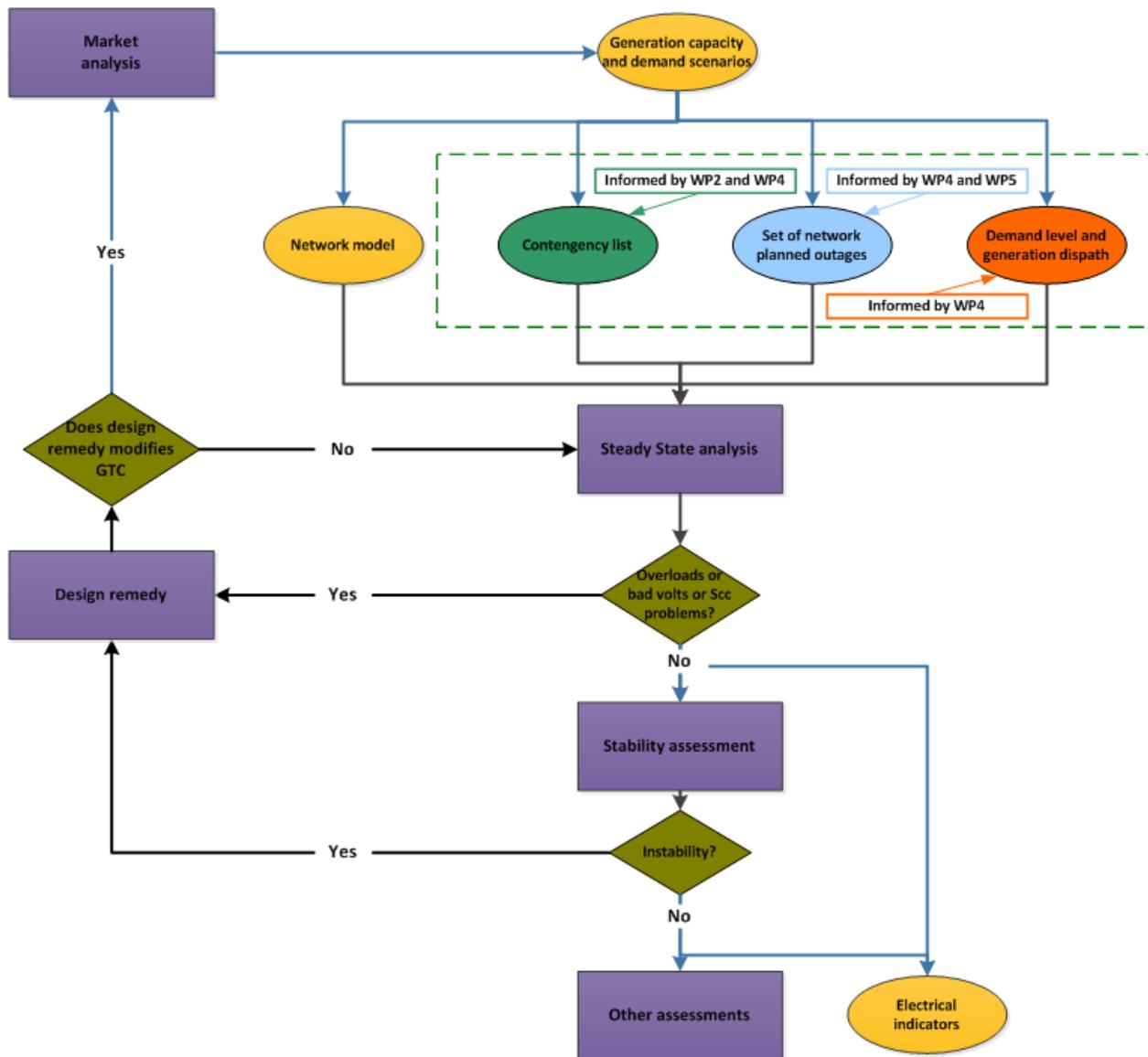
It is expected that WP4 would develop techniques and methodologies to aid the system development process in providing an optimal amount of transmission capacity consistent with new reliability criteria (proposed by WP2) and socio-economic measure (proposed by WP3). The effectiveness of ideas proposed by WP2 and WP3 are assessed and where appropriate additional indices useful to system development process are proposed.

To prepare for new approaches to risk-based reliability management, a key challenge a system development planner faces is how to manage the different uncertainties that occur during future operational activities, notably how to synthesize them while maintaining the credibility of the assumptions and physical meaning. It is planned that WP4 will propose methods for synthesizing operational patterns of uncertainties in renewable generation based on historic data. WP4 will also provide a systematic way of synthesizing planned outages, operating conditions and the effect of constrained dispatch of conventional generation.

The main elements of introducing risk-based reliability management are probabilities and consequences. Having established a reasonable set of operational patterns the planner intrinsically knows the probability of being in a certain operational situation. Furthermore there are a number of things that can go wrong, and this is represented by a list of the most credible contingencies. Nowadays this list does not need to include probabilities, but that will be necessary after the success of GARPUR. Furthermore the probabilities of these contingencies will be dependent upon the initial operational state. Finally, there is a need for the system development planner to be able to estimate the consequence of a given contingency in a given operational situation. Hence, the successful outcome of GARPUR will provide a change in the system development process itself and the type of analyses being made.

The main contributions of WP4 towards system development process are summarised as follows:

- a new modelling framework that is appropriate for system development studies, in particular the inclusion of methods to synthesise possible operating conditions for assessment while respecting the correlations between different variables, e.g. available output of renewables, demand, planned outages, time of day and day of the year (Task 4.2);
- modelling of new risk-based reliability criteria in system development context not least through the articulation of contingency lists - including probabilities - appropriate to the conditions being studied (Task 4.2);
- the quantification of an optimal (minimum) number of credible operating conditions that a system development planner should assess for decision making (Task 4.3);
- proposals of metrics that can be obtained from assessment of the various operating conditions in order to inform investment decision making (Task 4.3);
- proposal of guidelines for system development planners to allow them to adopt the new modelling framework and performance metrics (Task 4.4).



**Figure 7-1: Contributions of WP4 to system development process**

Figure 7-1 shows the contribution of GARPUR WPs to system development process. This figure is adapted from Figure 6-3 and the expected changes are highlighted here. WP4 will come up with a methodology in which the impact of disturbances recommended by WP2 for consideration can be assessed for the set of credible initial conditions. WP4 will investigate the required level of detail for modelling the system behaviour for system development purposes. It is expected that WP4 in the GARPUR project will provide understanding of selecting credible operating conditions against which a system development planner should assess system reliability. Further WP4 will give insight in how to mitigate towards using probabilistic reliability assessments instead of classical grid studies, that is how to deal with probabilities of faults – for instance how to make them situation dependent, and how to estimate consequences of contingencies in the various operational situations. Finally, it is the job of WP4 together with WP2 to provide insights and recommendations into how to deal with probabilities and uncertainties in making system development decisions.

The main differences in the system development process expected to arise from the work in WP4 are as follows:

- WP4 will provide insight in how to migrate towards using probabilistic reliability assessments instead of classical grid studies;
- many more credible initial conditions in respect of possible future system operation will be considered;
- special protection schemes and real-time ratings will be modelled;
- the list of disturbances to be assessed for each initial condition, i.e. the contingency list, will include the probability of occurrence and will not be fixed but will be dependent on the initial conditions and the approach to risk management emerging from WP2 and adapted to system development in WP4;
- planned outages will not be modelled in a simplistic way, e.g. by augmenting a contingency list with single other elements out of service, but will address patterns of outages that credibly may be present on the system at different times of year, as informed by work on asset management in WP5;
- there will be a new set of metrics allowing a more consistent appraisal of different possible future scenarios than is commonly used in many utilities now and guiding the need or otherwise for development of the system through investment in new network facilities. This will be based on WP4's own work on risk management in investment timescales and will be informed by the recommendations emerging from WP2.

Finally WP4 would make recommendations for the formulation of new system development approaches and will also give a roadmap of migration towards new reliability management.

Further discussion of the questions to be addressed and the principles underpinning system development planning is given in Appendix 2.

## 7.4 Concluding remarks

In this report we have given a detailed workflow diagram and description of a typical TSO's current activities in the context of system development.

We have given a description of how the TSOs work with their data (Chapter 4), how new ideas and initial assessments are performed (Chapter 5) and how market, network and other assessments are made to support system development investment decisions (Chapter 6).

In line with what is observed in earlier deliverables in the GARPUR project [2], system development activities are currently dominated by the deterministic N-1 criterion, which is the practically used criterion for reliability management in Europe.

Finally, in this chapter, we have discussed the potential for improving the system development process by using probabilistic reliability management by linking the workflow diagrams of this report with different work packages of the GARPUR project. WP4 will provide insights in how to migrate from deterministic network assessment towards probabilistic reliability assessments both in terms of synthesizing operational situations and dealing with probabilities and uncertainties in data and results, while WP2 together with WP4 will provide insights into how these new types of assessments can be used in system development decision making.

## 8 REFERENCES

- [1] <http://www.ee.washington.edu/research/pstca/formats/cdf.txt>
- [2] GARPUR Consortium. Current practices, drivers and barriers for new reliability standards. 7th framework programme, EU Commission grant agreement 608540, 2014. Available at: <http://www.garpur-project.eu/deliverables>
- [3] ENTSO-E Standards for European Transmission Grid Planning
- [4] UCTE contribution for Planning Code
- [5] ENTSO-E. TYNDP. Available at <https://www.entsoe.eu/major-projects/ten-year-network-development-plan/tyndp-2014/Pages/default.aspx>
- [6] ENTSO-E SOAF 2014-2030. Available at <https://www.entsoe.eu/major-projects/ten-year-network-development-plan/tyndp-2014/Pages/default.aspx>
- [7] GARPUR Consortium. Functional analysis of reliability management. 7th framework programme, EU Commission grant agreement 608540, 2014. Available at: <http://www.garpur-project.eu/deliverables>
- [8] ENTSO-E Guideline for Cost Benefit Analysis of Grid Development Projects

## APPENDIX 1: QUESTIONNAIRE

# Functional workflow of the decision making processes

### Introduction

This questionnaire is a part of the GARPUR project in the EU's seventh framework programme for research. The GARPUR project designs, develops, and assesses new reliability criteria and evaluates their practical use and effect on social welfare. The objective of the questionnaire is to collect representative information on the current reliability management practices in use by the different TSOs, and, as much as possible, on what they think should become the future practices.

The questionnaire has been split into five parts, a first part with a few general questions followed by three sections dealing with three different time horizons (namely short-term, mid-term, and long-term), and a last part about coordination and environmental issues (covering all time horizons). Depending on your own internal organization, the questions may have to be answered by different people/departments.

### Use of the results

The responses of this questionnaire will be kept confidential and internal to the GARPUR consortium and anonymous outside the consortium. In results that are to be presented externally to the consortium, the TSOs will be made anonymous and only aggregate results will be shown.

### Providing answers in the questionnaire

Wherever relevant, we are mainly interested in the practices concerning the highest voltage levels (transmission system), 220 kV and above.

Our primary interest is in the current practices. However, if there are practices for which you have concrete plans or proposals for future improvement, please feel free to describe these.

## Part I – General questions

Q1. Which of the following activities does your organisation address :	1 <input type="checkbox"/> Generation planning 2 <input type="checkbox"/> Transmission investment planning 3 <input type="checkbox"/> Construction, ownership and maintenance of transmission 4 <input type="checkbox"/> Transmission outage planning 5 <input type="checkbox"/> Transmission operation 6 <input type="checkbox"/> Other (please specify)
Comments/remarks:	

<p>Q2. To what degree is your transmission network interconnected with other TSOs? (Total max NTC vs peak load)</p>	<p>Please answer:</p>
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<p>Q3. What is the rate of penetration of renewable generation (especially wind and solar) in your system...</p>	
<p>a) as a ratio between total renewable generation and total demand?</p>	<p>Please answer:</p>
<p>b) as a ratio between peak renewable generation and peak demand?</p>	<p>Please answer:</p>

## Part IV – System development/long term planning

The focus of this section is to investigate how the long-term reliability of the power system is assured by the TSO's today, reflected by how system development decisions are made.

### IV.1 General

<p>Q53. List the main tasks/studies performed by TSOs in the long term horizon seen from your point of view</p> <p><u>Examples of tasks:</u></p> <ul style="list-style-type: none"> <li>• Upgrading or replacement of existing high voltage links (AC or DC), perhaps to exploit an opportunity afforded by a planned asset replacement</li> <li>• Construction of new high voltage links (AC or DC), new substations</li> <li>• Reconfiguration of the network via new substations or tee-points to better exploit available network capacity on existing routes</li> <li>• Enhanced system controls that require new or enhanced communication or monitoring infrastructure or new software, e.g. 'special protection schemes' (SPS) or 'system integrity protection systems' (SIPS), automatic generation control (AGC), secondary voltage control or system defence measures</li> <li>• Power flow control devices (Phase-Shifting transformers) on existing / future cross-border / internal HV links.</li> <li>• New voltage control devices (shunt reactors, capacitor banks, SVCs, FACTS, synchronous condensers)</li> </ul>
<p>Please describe:</p>

#### IV.2 System development decisions

<p>Q54. Can you give an overview (written, graphical or both, referring to published documents where appropriate) of your decision process for:</p>	
<p>a) Investments that increase the transmission capacity <i>between</i> market areas</p>	<p>Please describe:</p>
<p>b) Investments that increase the transmission capacity <i>within</i> a given market area</p>	<p>Please describe:</p>

<p>Q55. What is the role of the regulator in relation to approval of transmission investments (does the regulator approve individual investments, and if so which investments? Or does the regulator only approve rules and methods that the investments are evaluated with?)</p>	<p>Please describe:</p>
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<p>Q56. How do the ENTSO-E TYNDP results influence your investment decisions?</p>	<p>Please describe:</p>
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<p>Q57. What type of analyses do you perform in order to support investments that increase the transmission capacity <i>between</i> market areas?</p>	<p>1 <input type="checkbox"/> Market benefit analyses</p> <p>2 <input type="checkbox"/> N-1 AC load flow</p> <p>3 <input type="checkbox"/> N-1 DC load flow</p> <p>4 <input type="checkbox"/> Dynamic analyses</p> <p>5 <input type="checkbox"/> Probabilistic reliability analyses with AC load flow</p> <p>6 <input type="checkbox"/> Probabilistic reliability analyses with DC load flow</p> <p>7 <input type="checkbox"/> Others? (Please specify)</p>
<p>Comments/remarks:</p>	

<p>Q58. What type of analyses do you perform in order to support investments that increase the transmission capacity <i>within</i> a market area?</p>	<ol style="list-style-type: none"> <li>1 <input type="checkbox"/> Market benefit analyses</li> <li>2 <input type="checkbox"/> N-1 AC load flow</li> <li>3 <input type="checkbox"/> N-1 DC load flow</li> <li>4 <input type="checkbox"/> Dynamic analyses</li> <li>5 <input type="checkbox"/> Probabilistic reliability analyses with AC load flow</li> <li>6 <input type="checkbox"/> Probabilistic reliability analyses with DC load flow</li> <li>7 <input type="checkbox"/> Others? (Please specify)</li> </ol>
<p>Comments/remarks:</p>	

### IV.3 Renewables

<p>Q59. How are renewables taken into account when you do analyses for long term investment planning for: Please check appropriate boxes and describe in which type of analyses they are included (market/load flow/dynamic/reliability)</p>	
<p>a) Investments that increase the transmission capacity <i>between</i> market areas?</p>	<ol style="list-style-type: none"> <li>1 <input type="checkbox"/> Only maximum and minimum production levels are taken into account</li> <li>2 <input type="checkbox"/> Modelling the full range of possible production levels from renewables</li> <li>3 <input type="checkbox"/> Renewable forecast errors are included in the analyses</li> <li>4 <input type="checkbox"/> Spatial correlations between renewable output at different locations are respected</li> <li>5 <input type="checkbox"/> Other (Please specify)</li> </ol>
<p>Please describe:</p>	
<p>b) Investments that increase the transmission capacity <i>within</i> a market area?</p>	<ol style="list-style-type: none"> <li>1 <input type="checkbox"/> Only maximum and minimum production levels are taken into account</li> <li>2 <input type="checkbox"/> Modelling the full range of possible production levels from renewables</li> <li>3 <input type="checkbox"/> Renewable forecast errors are included in the analyses</li> <li>4 <input type="checkbox"/> Spatial correlations between renewable output at different locations are respected</li> <li>5 <input type="checkbox"/> Other (Please specify)</li> </ol>
<p>Please describe:</p>	

**IV.4 Market benefit analyses**

<p>Q60. How are market benefits included in your investment decisions? Do you take national market benefits or regional/international benefits into account? Do you look at congestion rents only or do you consider consumer and producer surplus as well?</p>	
<p>a) For investments that increase the transmission capacity <i>between</i> market areas</p>	<p>Please describe:</p>
<p>b) For investments that increase the transmission capacity <i>within</i> a market area</p>	<p>Please describe:</p>

**IV.5 Reliability**

<p>Q61. How is reliability taken into account in your long term investments for: (please check the alternatives that are true, and elaborate below)</p>	
<p>a) Investments that increase the transmission capacity <i>between</i> market areas?</p>	<p>1 <input type="checkbox"/> Unplanned outages are considered deterministically (N-1 or similar shall be satisfied at any time)</p> <p>2 <input type="checkbox"/> Reliability of supply is assessed but not monetized (should satisfy a given criterion)</p> <p>3 <input type="checkbox"/> Reliability of supply is assessed and monetized</p> <p>4 <input type="checkbox"/> Other (Please specify)</p>
<p>Comments/remarks:</p>	
<p>b) Investments that increase the transmission capacity <i>within</i> a market area?</p>	<p>1 <input type="checkbox"/> Unplanned outages are considered deterministically (N-1 or similar shall be satisfied at any time)</p> <p>2 <input type="checkbox"/> Reliability of supply is assessed but not monetized (should satisfy a given criterion)</p> <p>3 <input type="checkbox"/> Reliability of supply is assessed and monetized</p> <p>4 <input type="checkbox"/> Other (Please specify)</p>
<p>Comments/remarks:</p>	

<p>Q62. If you use probabilistic reliability calculations in any of your long-term investment decisions, please describe:</p>	
<p>a) Which uncertainties that are included</p>	<p>Please describe:</p>
<p>b) How the consequences of faults/contingencies are</p>	<p>Please describe:</p>

calculated (For instance, do you use Optimal Power Flow for generation redispatch before performing load shedding?)	
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#### IV.6 Load flow calculations

The following questions are related to how load flow calculations are performed:

<p>Q63. Describe what type of situations (load, generation dispatch, etc.) that are analysed when doing load flow: (for instance worst case only, a set of snap shots, or market situations from a full year market simulation)</p>	
a) For investments that increase the transmission capacity <i>between</i> market areas	Please describe:
b) For investments that increase the transmission capacity <i>within</i> a market area	Please describe:

<p>Q64. How are reserves taken into account in load flow calculations? Please elaborate if different type of reserves are treated differently.</p>	
a) For investments that increase the transmission capacity <i>between</i> market areas	Please describe:
b) For investments that increase the transmission capacity <i>within</i> a market area	Please describe:

<p>Q65. How are planned outages taken into account in your long-term planning analyses?</p>	
a) For investments that increase the transmission capacity <i>between</i> market areas	Please describe:
b) For investments that increase the transmission capacity <i>within</i> a market area	Please describe:

<p>Q66. How are transmission losses taken into account in your long-term planning analyses?</p>	
a) For investments that increase the transmission	Please describe:

capacity <i>between</i> market areas	
b) For investments that increase the transmission capacity <i>within</i> a market area	Please describe:

#### IV.7 Dynamic analyses

Q67. How are dynamic analyses used in your long term investment decisions?	
a) For investments that increase the transmission capacity <i>between</i> market areas	Please describe:
b) For investments that increase the transmission capacity <i>within</i> a market area	Please describe:

#### IV.8 Preventive and corrective actions

Q68. How are preventive and corrective actions taken into account when you do analyses for long term investment planning? Please check appropriate boxes and describe in which type of analyses they are included (load flow/dynamic/reliability)	1 <input type="checkbox"/> Short-term thermal ratings
	2 <input type="checkbox"/> Optimal preventive settings of phase shifting transformers
	3 <input type="checkbox"/> Optimal corrective settings of phase shifting transformers
	4 <input type="checkbox"/> Flexible demand/Demand side response
	5 <input type="checkbox"/> Automated corrective actions such as special protection schemes (please specify)
	6 <input type="checkbox"/> Preventive redispatch of generation
	7 <input type="checkbox"/> Corrective redispatch of generation
	8 <input type="checkbox"/> Manually set preventive/corrective settings
	9 <input type="checkbox"/> Optimal Powerflow to derive preventive/corrective settings
	10 <input type="checkbox"/> Other (Please specify)
Comments/remarks:	

#### IV.9 Data and tools

Q69. How many future scenarios of generation capacity, load and fuel prices do you take into account when analysing market benefits of an investment?	
a) For investments that increase the transmission capacity <i>between</i> market areas	Please describe:

b) For investments that increase the transmission capacity <i>within</i> a market area	Please describe:
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Q70.  
 What is the temporal scope of your analyses? Do you look for instance 5, 15 or 30 years ahead in time when you do analyses for long term investments? Please indicate whether there are differences between types of analyses (market/load flow/dynamic/reliability)

a) For investments that increase the transmission capacity <i>between</i> market areas	Please describe:
b) For investments that increase the transmission capacity <i>within</i> a market area	Please describe:

Q71.  
 What is the geographical scope of your analyses - how far away from your own market area are you looking? Please indicate whether there are differences between types of analyses (market/load flow/dynamic/reliability)

a) For investments that increase the transmission capacity <i>between</i> market areas	Please describe:
b) For investments that increase the transmission capacity <i>within</i> a market area	Please describe:

Q72.  
 Please indicate what data you are using in your long-term investment analyses and that you are able and willing to share with the GARPUR consortium

a) For investments that increase the transmission capacity <i>between</i> market areas	Please describe:
b) For investments that increase the transmission capacity <i>within</i> a market area	Please describe:

Q73.  
 Please name the tools that you use for long term planning and indicate whether some of these tools can be used by the GARPUR consortium

a) For investments that increase the transmission capacity <i>between</i> market areas	Please describe:
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b) For investments that increase the transmission capacity <i>within</i> a market area	Please describe:
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## APPENDIX 2: PRINCIPLES AFFECTING SYSTEM DEVELOPMENT

The total costs of transmission may be described as constituting three parts<sup>3</sup>:

- the cost of transmission infrastructure;
- the cost of operating the transmission system in the delivery of power including the impact of transmission in restricting use of the cheapest generation;
- the impact on consumers of supply unreliability.

These three terms may be denoted by the symbols T, O and X respectively so that the total cost of transmission is  $T + O + X$ . The most efficient transmission service is one in which the expected total cost  $T + O + X$  is minimised over some given period of time (with some discounting of future costs).

As well as providing adequate power quality, a transmission system operator (TSO) will be concerned with the sustainability of operation of transmission infrastructure, in particular that current, voltage and stability limits are observed. The system is 'adequate' when power is supplied to customers with appropriate quality and system limits are observed. However, a power system is always exposed to unplanned and uncontrollable external events that are uncertain in their nature and timing.

Faced with such uncertainties, an operator may seek a probabilistic minimisation of the expected value of  $O + X$ , but the possible unplanned events are so numerous and their effects so complex that to do so with any confidence has hitherto been regarded as a practical impossibility. Thus, current practice says that in order that the risks of failure to deliver power and protect power plant can be managed, a 'security standard' should be used that specifies not only that the system should be 'adequate' in the state that it is planned to be in shortly before real time, but also that certain limits should be observed following particular unplanned events. Each set of security standards defines both the limits and the 'secured' unplanned events, i.e. the disturbances on the contingency list. These both set the broad expectation of  $O + X$  and put the task of minimising  $O + X$  within a practical context: the more extensive the set of secured events, the higher O would be expected to be but the lower the expected value of X.

In the system development timescales in which investment in system infrastructure takes place, the planner must deliver a system that can be operated safely, and must be mindful of future  $O + X$ . A relative lack of investment in transmission infrastructure would lead either to greater O (the operation of the ideal generation is restricted which implies that other generation should run, which implies a higher cost, i.e. a direct economic impact) or greater X (some additional loss of supply takes place from time to time which has some generally indirect economic impact that may be particularly difficult to quantify)<sup>4</sup>.

Given the cost of infrastructure, the overall cost of  $T + O + X$  should be minimised in the long-term. However, while the expected  $O + X$  are hard to determine in operational planning and operation because of the uncertainty of unplanned events, they are even harder to estimate further out from real time when the state of the planned system is also uncertain. Thus, further conventions, or 'planning standards', have often been developed to allow the planner to make approximately the right investments for management of  $T + O + X$ . In order to do so, these 'planning standards' must be consistent with the operating standards.

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<sup>3</sup> National Grid, *Response to the Ofgem/DTI Consultation Document: Planning and Operating Standards Under BETTA*, April 2003

<sup>4</sup> Quantification of X is, broadly speaking, one of the objectives of WP3.

In system development timescales, the background conditions against which reliability criteria should be applied are known with much less certainty than in operational planning. A practical response in some countries, e.g. Britain, is for the planning criteria in reliability standards to specify, to some degree, the background conditions to be considered as well as a particular set of secured events and the level of supply quality. In addition, they may make specific and separate references to two criteria that would indicate a need for investment:

1. reliability of supply; and
2. the economics around restriction of 'market-led' generation outputs<sup>5</sup>.

The consequences of specifying some particular future background conditions against which the need for additional transmission capacity is to be assessed are:

- the number of individual analyses that need to be conducted by the planner is reduced;
- a certain 'margin' may be built into the design of the network, i.e. implied within the planning standard. This would be such that, when the system is finally operated, operation in compliance with the operating standard is possible albeit that it is not guaranteed always to avoid constraints on the operation of generation or loss of load though it should normally be possible to facilitate planned outages (such as for maintenance) either of generation or of network components.

However, some fundamental issues now arise:

- given a move towards a more explicitly risk-based transmission system operating standards as envisaged by GARPUR, should planning standards also be more explicitly risk-based?
- are common conventions within system development of planning only against a very limited number of scenarios, e.g. a peak demand condition, still valid given that wind and solar power, in particular, have operating patterns that give rise to export constraints at some times in a typical year of operation but not at others?

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<sup>5</sup> In practice, different market arrangements and different system development conventions will lead to different ways of quantifying  $O$  in the  $T+O+X$  expression. For example, in a set of market arrangements based on locational marginal pricing,  $O$  might be the total paid in a market clearance by the demand side. If the complete supply and demand curves are both known, the total social welfare (sum of producer and consumer surpluses) might be quantified. Alternatively, the system development planner might consider that the main influence of transmission capacity is on congestion surplus, i.e. the difference between what the demand side pays and the generation side receives in a market clearance though, in all cases, care should be taken not to double count the contribution of congestion surplus to meeting the cost of transmission infrastructure. Given that centralised electricity markets are generally cleared some time ahead of real time, e.g. day ahead, the costs of intra-day balancing adjustments may also be taken account if they are significantly affected by transmission capacity and operational facilities. In a decentralised market such as that in GB, the system development planner typically treats  $O$  as simply the cost of balancing services given some assumptions on generators' self-dispatch decisions. In all of these cases, while the immediate objective seems to be the minimisation of the total cost of electricity, if generators' revenues are not sufficient, generation capacity is likely to be closed and not replaced. This would have the consequence of an increase in  $X$ . Given the difficulty of quantifying  $X$ , a particular system reliability metric might be used and treated as a constraint. In a liberalised electricity supply industry in which the ownership and operation of generation is separate from that of transmission, it may be difficult for a transmission system operator or development planner to ensure that there is sufficient generation capacity and where it is located relative to transmission capacity. Some countries either already have or are planning to introduce a generation capacity market to address that issue. This is likely to go some way to reducing the transmission system developer's uncertainty about future generation capacity scenarios.

- with wind and solar power, in particular, making only a limited contribution to reliability of supply, would it be useful within the system development process for there to be a specific focus on loss of load risk in an importing area?
- do system development conventions and tools need to be updated to allow the robust evaluation of options such as 'embedded' HVDC, special protection schemes, automatic generation control, co-ordinated use of phase shifting transformers, real-time thermal ratings and demand side management, all of which provide operational flexibility perhaps in place of primary assets and which can often appear more cost-effective than primary assets?
- with increasing use of options such as those mentioned above which might be used to minimise investment in new primary assets, can it be ensured that a system development planner will provide sufficient margin on the system to allow planned outages to be taken?
- how does asset management need to be revisited in order to be able to take into account a risk-based approach used in system development, operational planning and system operation?

It is suggested that the changed generation mix, the greater use of operational measures and the continuation of a trend of last few years across Europe of separation of generation ownership and operation from that of transmission mean that

- a) the different uncertainties should be more explicitly modelled and risks quantified;
- b) a greater range of potential operating conditions should be assessed by the system development planner than has normally been the case in the past; and
- c) the facilitation of planned outages should be addressed explicitly.

This work package is concerned with the above issues and with the development of techniques and methodologies that will aid the system development planner in providing an optimal amount of transmission capacity consistent with more explicitly risk-based operating standards.

## Innovation - research questions

The above issues give rise to a number of quite specific research questions. In many respects, they relate to the way different TSO activities interact, the progression through time from system development planning through operational planning and finally into real-time system operation. In order that real-time operation can finally be carried out successfully for the prevailing conditions in accordance with relevant standards and rules, the tasks of system development and operational planning should have been carried out with due regard for the variety of conditions that might be faced by the operator and the tools that they will have available. One of the jobs of the system development planner is to anticipate what the operator might face and make additional facilities or network infrastructure available, provided these can be justified. These relationships were illustrated in Figure 1-3 above.

In Figure 1-3, in order that a set of facilities can be delivered such that the operator can operate the system, the system development planner should take into account not only the main disturbances and uncertainties that arise in system development timescales but also all of those that occur in operational planning and real-time operation. This is clearly a major challenge and has, hitherto, motivated certain conventions used by system development planners, often encapsulated in a 'planning standard', which involves some specification of the background conditions to be studied (mainly, demand level and generation dispatch) plus outages (the classical 'N-1' or 'N-2' approach in which the '2' might be one outage of a transmission element plus an outage of a generator or an unplanned transmission outage combined with a planned outage for maintenance or construction). If any overloads, voltage violations or instability is found for the specified conditions and outages, a number of existing standards would treat

that as an indication of need for investment in additional network facilities (so that the limit violation under these conditions can be avoided). One of the effects of the combination of background conditions and outages (which are, inevitably, a small subset of those that might arise in the course of operation of the system in the future year with which the plan is concerned), should be that sufficient margin is built in to allow uncertainties to be managed but without excessive risk of stranded assets.

It has been argued as part of the case for support of the GARPUR project that various changes the electricity supply industry is now facing and the possibilities now offered by technology and new analytical methods make it possible to improve on present approaches and manage risk in a more robust and transparent way.

The specific research questions that arise out of the foregoing discussion are, in essence, concerned with formulating approaches that allow the system development planner to get an adequate grasp on the uncertainties between system development planning and operation – the two lists towards the top right of Figure 1 as well as that on the top left – without being over-burdensome or complex and while approximating a minimisation of T+O+X. The questions include the following.

- Generation of credible operational conditions against which the system developer should assess the sufficiency of network capacity
  - What are the simple but accurate methods that can be used to synthesise patterns of availability of wind, solar and hydro power in different locations through a year of operation? To what extent should they be developed to show inter-annual variability?
  - What are the credible patterns of planned outages of generation and network components that can arise?
  - What is the spinning reserve that is likely to be carried and how would this reserve be spatially distributed?
  - Are the realistic constraints on operation of generation in real-time such as ramp rates, minimum stable generation and minimum on and off times significant enough relative to the uncertainties regarding the background conditions to require the use of sequential simulation in modelling the dispatch of generation on the system? What is the difference between the 'ideal' plan with and without these constraints?
- How should system responses to disturbances be simulated by the system developer?
  - A system developer can assume that the control facilities available to the system operator are optimally utilised. How should this be modelled in system development studies? Should optimal utilisation always be assumed? If not, how should errors or failures be modelled?
  - What disturbances should be modelled for each initial condition?
  - What are the practical steps to be taken to model in software the following equipment options that are being increasingly widely considered by system developers: HVDC, special protection schemes (SPS), automatic generation control (AGC), phase shifting transformers (PST), flexible AC transmission systems (FACTS), demand side management (DSM), real-time thermal ratings (RTTR) or dynamic thermal ratings (DTR) among others?
- What are the methods that can be used to make sense of the results of system simulations? (Can some filtering approaches be used to identify representative snapshots that can be modelled in detail?)
  - How many different cases are required to be studied and what weighting should be given to each?

- Risks: what are the thresholds of acceptability in respect of probability and magnitude of adverse outcomes?
  - Should thresholds be treated for all parts of the system on the basis of a single, common metric, or might there be different metrics in respect of reliability of supply to consumers and restriction of operation of generation?
  - Is it useful to think of 'import risk' in respect of the former and 'export risk' for the latter, with different acceptability thresholds? (Can particular areas of the system be identified that are normally subject only to 'import risks' or 'export risks'?)
- Framing of a system development approach for planners working in utilities: will it be sufficient for planners to be told, only in general terms, the kinds of uncertainties and variations to model and the risk metric to use, or should something more prescriptive be set down? Or, should it be spelled out that certain values of risk would require action to reduce the risk? (It is likely that judgements on acceptability of risk, i.e. the thresholds, will vary country by country).