A NEW APPROACH
TO RELIABLE AND AFFORDABLE ELECTRICITY SUPPLY IN EUROPE

THE GARPUR PROJECT RESULTS

Using Probability and Risk to Allow Power Systems to Operate Closer to their Optimum

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GARPUR

EEGI
EUROPEAN ELECTRICITY GRID INITIATIVE

SEVENTH FRAMEWORK PROGRAMME

EXECUTIVE SUMMARY

Historically in Europe, power system reliability management has been predominantly relying on the “N-1” criterion - whereby the system should be able to withstand at all times an unexpected failure or outage of a system component – in such a way that the system is capable of accommodating the new operational situation without violating security limits.

Today, the increasing uncertainty of generation due to intermittent energy sources, and the growing complexity of the pan-European power system, increases the need for new reliability criteria - with a better balance between reliability and costs.

In this perspective, the GARPUR EC-funded project was launched in September 2013. Coordinated by SINTEF Energy Research, the project unites 7 TSOs, 12 R&D providers and 1 innovation management expert. After 4 years of work, GARPUR has designed, developed and assessed new probabilistic reliability criteria for the pan-European power system and its evolution beyond 2020.

GARPUR has also evaluated the relevance of the criteria and their practical use, while seeking to maximize social welfare. In simple terms, this new methodology allows TSO’s to assess the probability and consequences of failures in their power system, expressed as the potential cost of power interruptions to consumers.

With this information, TSO’s can make decisions and investments that provide the best balance between power supply security and cost. This new approach has been designed to seamlessly fit in with existing TSO processes. Four TSOs have tested the methodology for planning or operating their grids and the results are very promising.

The new criteria are developed for system development, asset management and system operation in order to ensure a consistent treatment of reliability across all time horizons.

This brochure summarizes the keys results of the project and their potential benefits to TSOs. For more details, please refer to the delivera-bles available on the website:

www.garpur-project.eu

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DECISION-MAKING CHALLENGES IN RELIABILITY MANAGEMENT

In today's world, a reliable and affordable electricity supply is the prerequisite to most societal and economic activities.

European Transmission System Operators (TSOs) have the mission to ensure electricity supply in Europe by building, operating and maintaining the electric power transmission system.

Power system reliability describes the level of confidence in ensuring a continuous electricity supply to consumers. Reliability management is about gathering all of the information that enables TSOs to make better short-term and long-term decisions, with the aim to achieve an optimal balance between the costs of ensuring a secure power supply and the socio-economic costs of an interruption.

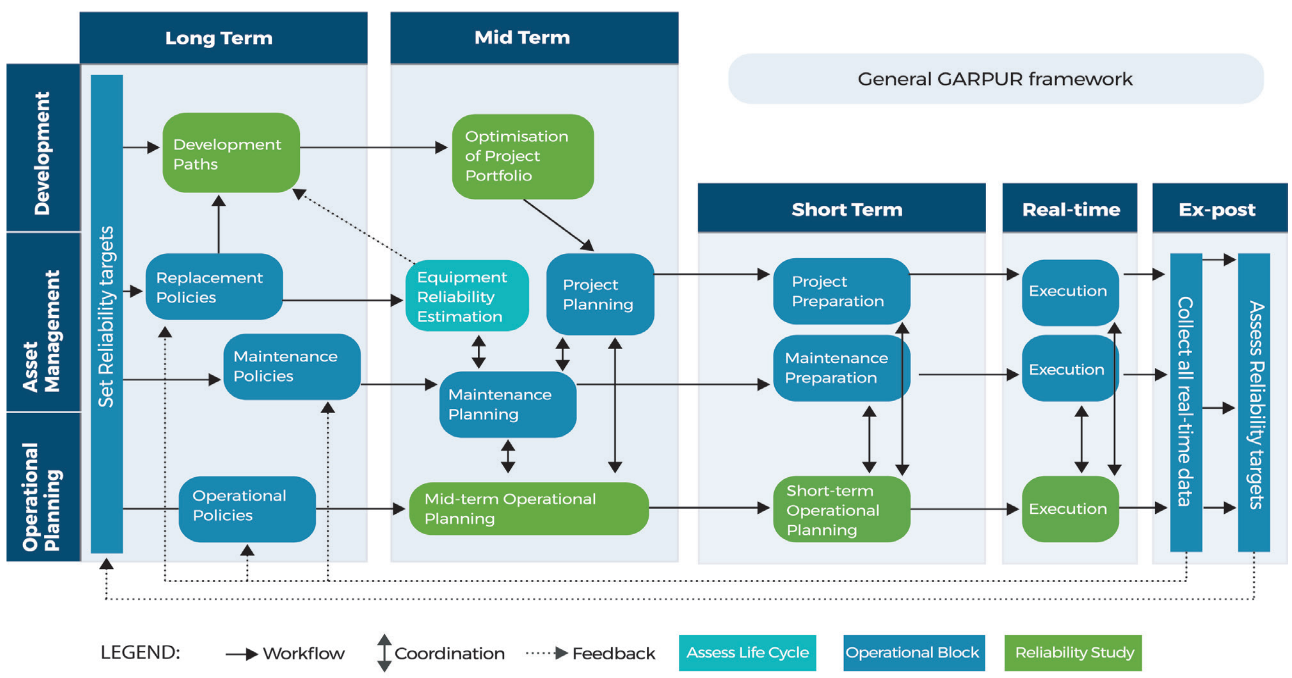
Power system reliability management means making decisions under uncertainty. It aims at meeting a reliability criterion, while minimising the costs of doing so.

A *reliability criterion* is a principle imposing a standard to determine whether or not the reliability level of a power system is acceptable. *Reliability management* is commonly broken down into reliability assessment and reliability control.

Reliability assessment concerns quantifying the (anticipated) performance of a system, taking into account the uncertainties in its operational conditions over specified time periods.

Reliability control is the process of selecting the most appropriate actions to solve the problems revealed by the reliability assessment process. Reliability management also covers a wide range of activities over several timescales, from long-term infrastructure planning to real-time system operations (see figure below).

THE TIME-SCALES AND CONTEXTS OF RELIABILITY MANAGEMENT



In **system development,** decisions are taken about whether and where to build new transmission lines and substations, in order to adapt the physical network capacities to meet the future needs of the power system.

In **system operations,** decisions are taken for operational planning and for real-time operation. In operational planning, maintenance schedules and transmission system capacities provided to the market are fine tuned, and generation reserves are purchased, to ensure reliable operation for the next hours and days. In real-time operation, system topology and generation schedules are adjusted to avoid that component failures lead to power supply interruptions.

In **asset management**, the maintenance and replacement policies determine the various activities that will be undertaken in the coming decades to ensure that the grid assets will be in reliable working condition. GARPUR has also tackled the question of the scheduling of the outages for such activities, which need to be planned at times where they have the least possible impact on the system reliability.

Historically in Europe and also today power system reliability management is based on the N-1 criterion, with some variations. In general terms, the N-1 criterion means that in case of any fault of one relevant element in the power system, the TSO must be still capable of supplying electricity to all consumers.

The increasing penetration of intermittent and distributed energy sources, ageing infrastructure and the European objective of a single electricity market has rendered the current N-1 criterion inadequate.

A new, more responsive approach to reliability management is needed that exploits more information and that can lead to more optimal decisions that are better for everyone.

GARPUR: A RISK-BASED APPROACH TO RELIABILITY MANAGEMENT

The GARPUR R&D project was established in 2013 under the European Commission's 7th Framework Programme to investigate a new reliability management approach which would allow networks to operate much closer to their economic optimum, by taking explicitly into consideration:

- the probabilities of failures of the different system components, by carefully modelling their dependence on weather conditions, maintenance history and real-time conditions.
- the uncertainties in generation and load forecasts.
- the possible costs of the power supply interruptions that could occur, by modelling the socio-economic impact of power supply interruptions on end-users.
- the flexibility provided by the demand-side, energy storage and distributed electricity generation from renewables.

GARPUR has developed a comprehensive probabilistic risk-based reliability management framework and demonstrated its technical feasibility, scalability and practical interest of the proposed methods to support TSOs in their reliability management activities over all relevant time scales and system areas. This framework targets on optimized socio-economic benefits while maintaining the security of supply at an adequate level.

GARPUR METHODOLOGY

FOR RISK-BASED RELIABILITY MANAGEMENT

GARPUR has developed a new methodology that has the potential to transform reliability management. It moves from the current N-1 practice to a risk-based approach by allowing transmission system operators to take into account the probabilities of grid component failures, how big an impact the failure will have and what will be the the socio-economic costs associated with it. The methodology has been named Reliability Management Approach and Criterion (RMAC) which relies on four components, described below.

A SOCIO-ECONOMIC OBJECTIVE

One of the functions of reliability management is to optimize the socio-economic costs and benefits for a given activity, including its impact on the market surplus, on the capital (CAPEX) and operating expenditures (OPEX) of TSOs, and the potential cost of power supply interruptions for end-users.

The socio-economic objective function of the RMAC balances the costs and benefits of reliability management to all electricity system stakeholders, from TSOs to end-users.

In real-time operations, for example, the socio-economic objective would be to minimize the total sum of different types of costs – including the costs associated with preventive and corrective measures (both actual costs and potential costs) and the costs incurred by end-users in the case of a power supply interruption.

A RELIABILITY TARGET

Taking decisions that optimize the above-mentioned socio-economic objective may cause unacceptable situations in terms of system performance. In some situations, it might lead to a system operating with a too high probability of large-scale power supply interruptions. Or it may lead to increased probability of interruptions in some of the smaller, more vulnerable areas of the network.

Therefore, a range of acceptable situations (network states and level of service) are specified, together with the overall probability that they should hold with. As an example, the real-time reliability target could be expressed as *"ensuring with 99.9 % probability that no severe power supply interruptions should occur".*

The methodology described above lays the groundwork to perform reliability management based on a better knowledge and evaluation of reliability of supply and of the risk of power supply interruptions. The methodology has been designed to be:

1 **FLEXIBLE**

Suit all time horizons and type of decisions covered by the reliability management activities.

2 **COMPATIBLE**

Be compatible with the computational and data resources that most TSOs are in capacity to currently deploy.

3 **SUSTAINABLE**

Be sustainable, i.e. usable in the future, as more data and computational resources become available.

4 **INTERPRETABLE**

Be interpretable, in particular for comparison with the traditional N-1 approach.

A DISCARDING PRINCIPLE

In practice, strictly applying the previous two components in large-scale electric power systems is not feasible, as one could not consider all the possible events.

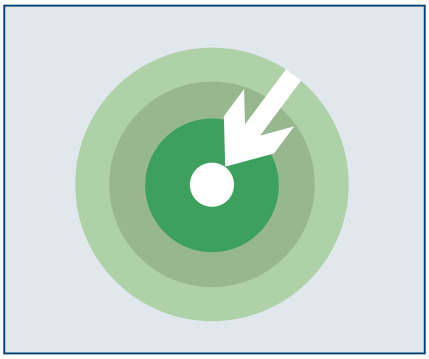
Therefore, the discarding principle allows one to ignore a number of possible events, provided that their risk (i.e., expected socio-economic impact in case of power supply interruptions) contribution is below a defined threshold. In other words, the discarding principle specifies in a dynamic manner which events can be ignored. As an example, in real-time operations the discarding principle may lead to replacing the current fixed set of N-1 events with a smaller set of events (under good weather conditions/low risk situations) and a larger set of events (under severe weather/high risk situations).

A RELAXATION PRINCIPLE

It is possible then that in the event of a decision to be made, none of the available options are compliant with the reliability target & discarding principle that has been adopted. In this situation, the threshold for discarding can be progressively increased until a satisfactory option can be found. In practice, this would mean ignoring even more events than specified in the discarding principle starting with those that have the lowest risk in relative terms.

In this situation, the threshold for discarding can be progressively increased until a satisfactory option can be found. In practice this would mean ignoring events that relatively have the lowest risk.

Certains events can be discarded (ignored) provided that their total risk falls below a defined threshold.



Reliability Target

If needed, the threshold can be increased (relaxed) so more events can be discarded until a satisfactory option can be found.

TRANSLATING THE RISK-BASED METHODOLOGY

INTO PRACTICAL ALGORITHMS

A key objective with GARPUR was to ensure that the proposed risk-based approach for reliability management could be practically implemented. To this end, reliability assessment and control algorithms were developed in order to demonstrate the feasibility and tractability of the proposed methodology. The algorithms were implemented to test the scalability of the methodology (its ability to be applied to any TSO control zone in Europe) and its flexibility (its ability to address all the required time scales).

The algorithms were incorporated into research-grade software for the specific contexts of real-time operation, short-term operational planning, and mid-term outage scheduling.

REAL TIME OPERATION

The algorithms were designed as adaptations of existing methods currently used by TSOs in view of:

- Optimizing the combination of preventive and corrective control decisions - Probabilistic Security Constrained Optimal Power Flow (PSCOPF).
- Evaluating the expected value of potential power supply interruptions according to real-time weather data (probabilistic contingency screening algorithm).

SHORT TERM OPERATION PLANNING

The algorithms developed allow for the:

- Study of different operating scenarios for immediate timeframes (next hours) and the ability to evaluate their expected socio-conomic impact and probability of meeting the defined reliability target in real-time operation (Monte-Carlo simulations).
- Optimization of operational planning decisions in the case of uncertain renewable generation and weather conditions that could impact the real-time operation (PSCOPF in look-ahead mode).

MID-TERM OUTAGE SCHEDULING

The algorithm developed uses massive parallel simulations and stochastic optimization (Cross-Entropy method) that make it possible to compare planning scenarios and to determine an outage schedule over a period of several months that minimizes the impact of planned outages on system operation.

These developments demonstrate that the risk-based Reliability Management Approach and Criterion (RMAC) can indeed be translated into practical tools that can help TSOs better assess, compare, and optimize their decisions.

PROXIES

A system to enable scalability and speed for longer-term decision making.

When addressing longer-term decisions, reliability management algorithms are challenging to implement, as they need to model the shorter-term decision-making stages of TSOs over several scenarios spanning the longer-term time horizons.

This is often not computationally feasible, so approximations (proxies) are used to quickly determine a realistic behaviour of the TSO for the shorter-term decision-making stages.

In the case of mid-term outage scheduling, two proxies were designed to model respectively day-ahead and real-time operation decisions, using machine-learning methods and high-performance computing infrastructures.

The use of these proxies was able to reduce computation time by several orders of magnitude, which made possible the reliability assessment of larger systems.

Proxies have also been proposed for the operational planning context to speed up the evaluation and identification of scenarios over a few hours or days.

A proxy takes the place of an accurate simulation of shorter-term reliability management processes of TSOs, when considering longer-term reliability management problems.

Further Reading
Deliverable 2.2
Guidelines for implementing the new reliability assessment and optimization methodology

A SOCIO-ECONOMIC IMPACT

ASSESSMENT METHODOLOGY TO COMPARE RELIABILITY MANAGEMENT APPROACHES

In order for the proposed probabilistic reliability management approach to be widely adopted, convincing arguments must be formulated to establish how these methods can outperform the current practice.

At the heart of this new probabilistic approach to reliability management is determining the best trade-off between the costs of providing a secure electricity supply and the socio-economic costs of power interruptions. A key challenge therefore is how to calculate these socio-economic costs, which are incurred not just by TSOs and electricity producers but are also incurred by consumers and the environment. It is also necessary to calculate congestion costs.

To that end, a new methodology was developed that compares the socio-economic impacts of different reliability management approaches. The Socio-Economic Impact Assessment (SEIA) methodology analyses the social welfare of the electricity market and quantifies the costs, benefits, and surpluses of all market stakeholders including electricity consumers, producers, TSOs, the regulatory authorities and policy makers (taxes on electricity) and the environment (externalities).

A general mathematical formulation is developed that allows a wide range of costs to be quantified. The formulation is applied to a range of inputs, including different nodes, generation technologies, consumer types, time of occurrence, duration of interruptions, and pollutants.

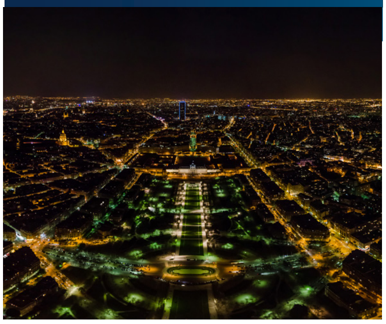
Guidelines are used to show how the SEIA methodology can be applied to test cases that cover a range of time horizons – from short-term to long-term. The methodology also analyses the possible responses of electricity market stakeholders to changes in reliability level, electricity prices and taxes.

A multi-actor approach is adopted by analysing the interaction of TSOs, countries and consumer types, and how their decisions affect welfare.

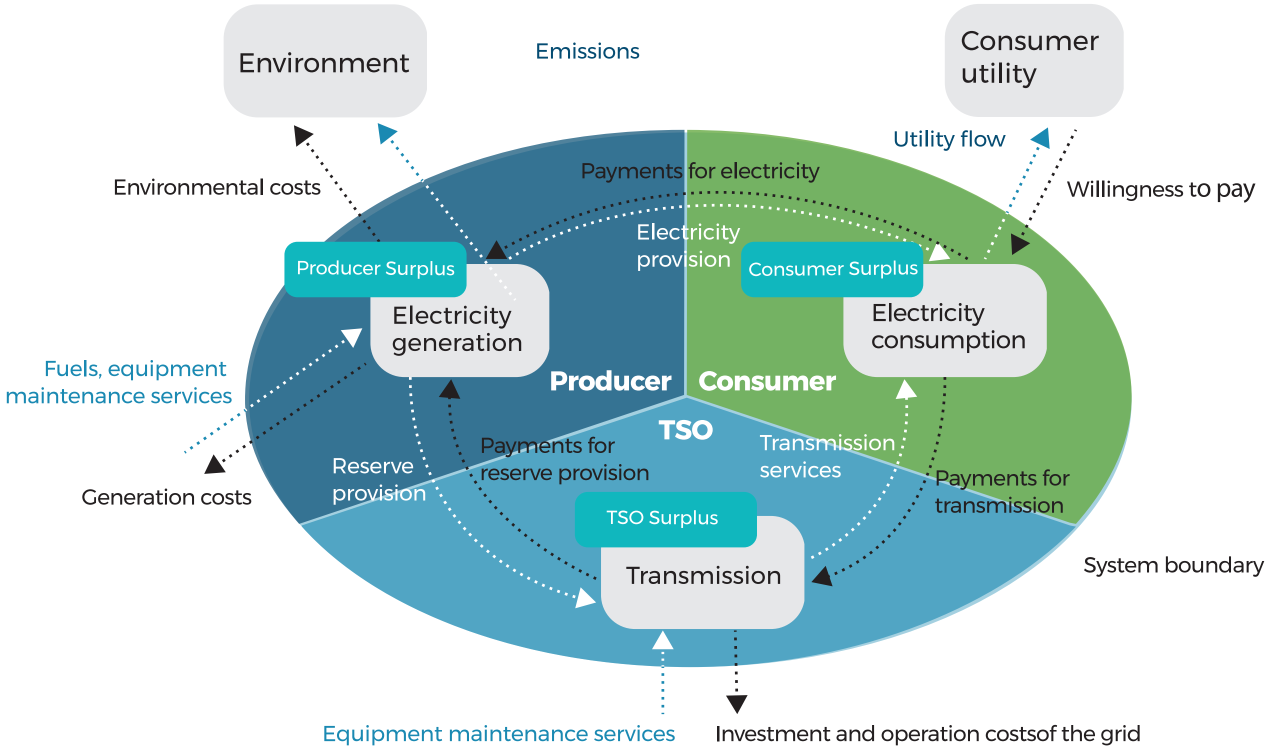
Three types of phenomena are studied:

Interaction between TSOs, where there is cross-border cooperation on reserves, which can increase reliability of supply and decrease costs.

Interaction between countries, where changes in reliability criteria may impact the interconnector transmission capacity.



Impact of reliability management decisions on different consumer types and locations, affecting the welfare distribution between consumers.



System costs and benefits, and transfer payments between stakeholder groups

RECOMMENDATIONS DRAFTED

A set of recommendations was drafted to support the practical implementation of the socio-economic impact assessment methodology, especially in regard to data requirements. A range of data inputs are required, including data about energy not supplied and the value of lost load. In the case that such data is not available, alternative data types are proposed. And finally, a roadmap for further development of the methodology was designed, which includes an estimation of consumer responses to price and reliability.

This methodology makes possible a full comparison between the traditional reliability management approach based on the N-1 criterion and the new probabilistic approach. Its integration into TSO handbooks and guidelines will pave the way for a widespread adoption of the probabilistic approach to reliability management.

Further Reading
Deliverable 3.2
Recommendations for implementing the socio-economic impact assessment methodology over the pan-European system in a tractable way

PROOF OF CONCEPT

ON THE SYSTEM DEVELOPMENT PROCESS

The system development process is about making decisions related to changing transmission capacities, either within a TSO's own system or with other TSOs systems. A system planners job is to ensure that the system's capability to transfer power from producer to consumer is sufficient. Those decisions, on whether to build, upgrade or replace high voltage links and control devices, require accurate data and realistic assumptions on future production, demand and transmission capacities on a long-term time horizon.

The GARPUR probabilistic approach is able to provide system planners with better data and better assumptions, that are linked with a specific grid structure at a given future target year.

It provides a clearer understanding and greater visibility of the risks related to the reliability of electric power supply and of the costs incurred in the operational context.

Such information allows the planner to make sound decisions; to compare different grid reinforcement variants and to identify if an investment is worth it. This is illustrated in the Figure below. This detailed assessment is based on the analysis of a large number of representative, possible operating states. It is also based upon the ability to identify reliability and operational constraints, that take into account the need to provide market capacities and to operate and maintain the grid in a secure manner.

At the end of the process, the system development planner is provided with a set of identified system weaknesses, which provide valuable guidance when making decisions on how to mitigate system weakness. The different system development options proposed by the planner are analysed with quantified metrics, which support the investment decision-making.

The methodology was first tested on a 10-bus system using realistic demand and wind data to build a set of credible operating states, and a market model to determine the set points of thermal generation units whilst considering temporal constraints like ramp rates and minimum up and down times.

The test demonstrated how a traditional approach to system development planning based solely on a few generation and demand conditions and not taking into account the probability of occurrence of situations (i.e. market clearing, planned and unplanned outages) nor their impacts would have missed some impacting system situations or would have overestimated the impact of other system situations and would have led to a sub-optimal investment decision.

This proof of concept on system development paves the way to improved appraisal mechanisms for future investments in the transmission system.

The proposed system development methodology relies on three main components:

TIMEFRAMES

A target year is selected to perform the system development studies, in order to identify the main bottlenecks in terms of reliability and transmission capacities and their impact on the electricity markets. It also helps engineers to formulate system development options and to assess their impact both on reliability and market performance. Two types of questions are looked at: the identification of major transmission bottlenecks and the cost-benefit analysis of upgrades of the transmission system

SCENARIOS

A large number of scenarios are built to simulate the way the system could be operated and maintained during the target year. In order to limit the volume of simulations and to ensure a good compromise between the volume and the level of detail of each simulation, a two-stage approach is used. Firstly a set of 'representative snapshots' are identified, and in the next stage these snapshots are analysed in greater details.

PROXIES

Proxies (model approximations) are used to model the way outages would typically be planned, allowing to assess the operability of the system given such outage plans. They are also used to assess the maintainability of the network while still being secure against contingencies (unplanned outages), i.e. to determine if there is margin for planned outages to be taken.

Further Reading
Deliverable 4.2
Upgrading of the decision-making process for system development

PROOF OF CONCEPT
ON THE ASSET MANAGEMENT PROCESS

The decisions on asset management policies are of utmost importance to the TSOs given the financial amounts at stake, and because those decisions will condition the reliability of supply for several decades. Probabilistic methods are adapted to define how to make the best use of the resources available for this purpose. However, a clean implementation of such a probabilistic method is challenging due to the data requirements, as well as the overall complexity when one tries to model the various actions that are going to happen later once in operation.

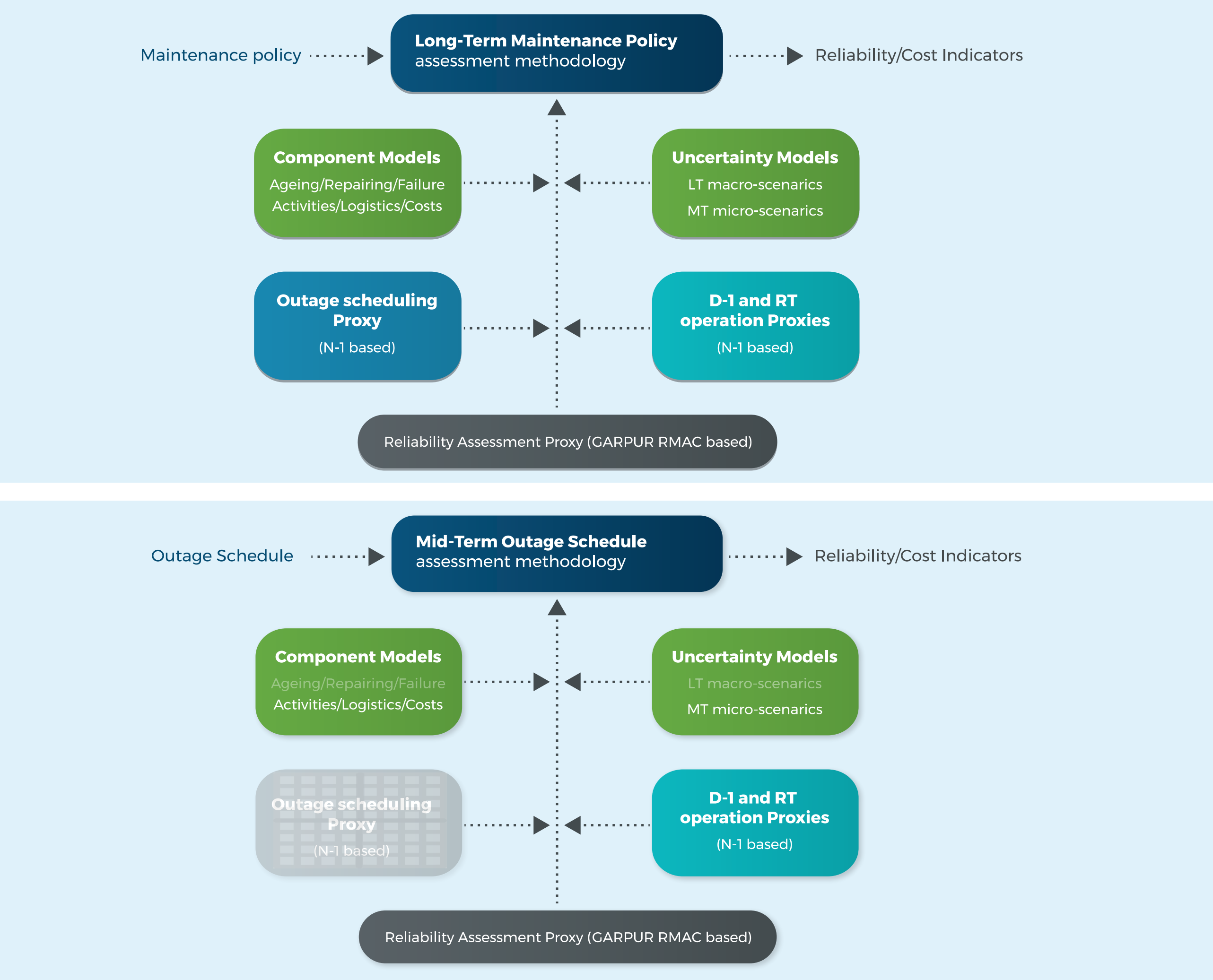
Another problem faced by the TSOs is the question of scheduling the various asset management operations, especially for those which require the outage of the asset for the duration of the operation. Indeed, such outages make the grid more vulnerable, therefore the TSO has to wisely schedule them at times when they do not jeopardize the reliability of supply. This process usually starts one or a few years in advance, and is regularly updated in order to adjust to any unexpected events.

The GARPUR theoretical approach has been derived to respond to each of these two questions, thus enabling the assessment of asset management policies and outage schedules to be determined in a more accurate manner, which eventually will lead to better informed decision-taking.

ASSET MANAGEMENT POLICY ASSESSMENT

In the case of asset management policy assessment, the method developed enables to simulate, over a period of 20 years, the impact of specified asset management policies. In the simulations, the ageing process of grid components is modelled, and its impact is then translated into component failure rates varying time-and space-wise across the grid. The future reliability of supply is evaluated probabilistically through a Monte-Carlo approach where the uncertainties on external factors are sampled in the form of yearly trajectories at the hourly time-step.

Regarding the grid simulation once in exploitation and the evaluation of the expected power supply interruption costs, the various decisions such as generation redispatching or the recourse to corrective measures are also taken into account in the simulation through proxies. Due to obvious tractability reasons when one considers real size systems, proxies based on OPF cannot be envisaged, which prompted us to consider building proxies based on machine-learning techniques. Such an approach, combined with parallel computing, would enable us to overcome the computational burden.



Schematic representations of the assessment proposals for maintenance policy and outage scheduling highlighting the methodology and the use of shorter-term proxies.

In addition, we have constructed a full-fledged proxy for outage scheduling. This proxy is based on a greedy algorithm that takes as an input a list of outage requests and computes an efficient outage schedule.

In addition, this method could also be adapted to investigate whether investments should be made in condition monitoring devices. The above-mentioned proxies are also core elements of our methodology to probabilistically evaluate an outage schedule. This methodology can help to spot the weaknesses of a tentative outage schedule or to compare a few alternative ones. As a future step, it should be possible to build optimization schemes that would automatically compute good outage schedules in a probabilistic context.

For both the asset management policy assessment problem and the outage scheduling problem, the results of the simulation provide an evaluation of the OPEX, CAPEX, workforce requirements, and interruption costs, at the global level as well as at a more local resolution. Such outcome enables the TSO to use the GARPUR reliability management approach and criterion.

Proof-of-concept examples have been published in academic papers. It is recommended to pursue the validation of these methods beyond the frame of the GARPUR project through pilot tests on real-life systems.

Further Reading
Deliverable 5.2 | Pathways for mid-term and long-term asset management

PRACTICAL IMPLEMENTATION
OF GARPUR FOR SYSTEM OPERATION PROCESSES

A key focus for GARPUR was to develop the probabilistic reliability management methodology on real-time operations and short-term operational planning. It was important that the methods developed:

1. **Produce results easily understandable by the operator.**
2. **Be implementable with the current data and models existing at TSOs.**
3. **Be scalable for a pan-European system and give outputs close to real-time.**
4. **Fit within the current TSO workflows.**
5. **Be scalable for a pan-European system and give outputs close to real-time.**

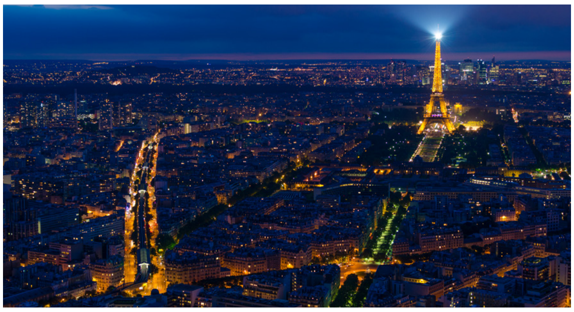
It is expected that such methods would provide operators with information that would increase their situational awareness for decision-making.

SHORT TERM OPERATIONAL PLANNING

Regarding short-term operational planning, methods and algorithms were developed that allowed TSOs to assess risk levels hours or days into the future by factoring in possible weather conditions, failure rates of components, and forecasting errors on load and renewable energy production. The algorithm generates and selects a number of scenarios to manage the forecast uncertainty. Uncertainty makes the short-term problem more complex to deal with than the real-time problem, as multiple time-steps leading up to real-time must be taken into account, including decisions made by the operator. The resulting short-term reliability evaluation would enable TSOs to have a more comprehensive assessment of reliability of supply in the context of operational planning.

REAL-TIME OPERATIONS

For real-time operations, methods and software were developed to assess the system reliability in real-time, using operational data, models of the system response to contingencies, the weather conditions and other external factors impacting the failure rates of the components of the power system. It was also important to take into account the possible failure of corrective actions. If this was neglected the results may be optimistically biased towards corrective actions instead of preventive actions. The proposed real-time operation methods were tested and validated as part of the pilot tests in GARPUR on a live system.



HIGHER RESOLUTION RELIABILITY ASSESSMENT

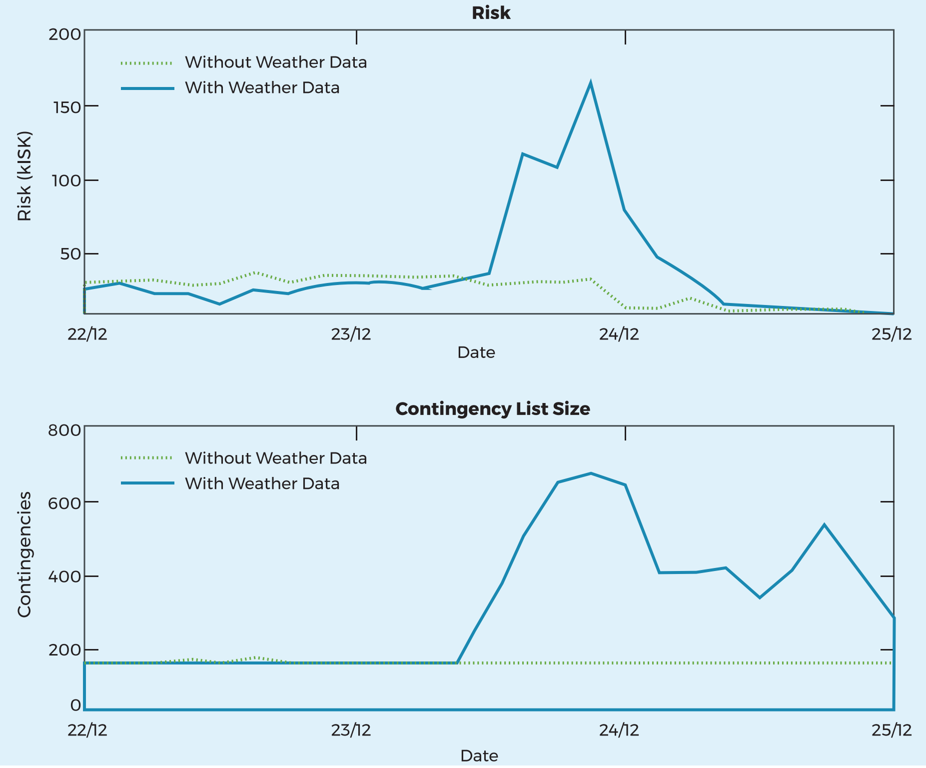
Overall, these methods will provide a much higher resolution to reliability assessment, resulting in improved reliability management in operations, which can lead to more efficient system operation.

The development of a sound reliability assessment methodology can provide a basis for comparing control actions and thereby optimizing system operations from a socio-economic perspective.

More generally, quantifying the risk related to reliability of the system in socio-economic terms, rather than in technical terms, allows for easier communication to non-technical stakeholders and is valuable for direct cost-benefit analyses in reliability management.

Finally, the use of weather-dependent failure rates is a fundamental part of the methodology and greatly impacts the result compared to static failure rates.

An example of the impact of weather data consideration on reliability risk assessment



The blue curve of the upper graph shows how the residual risk (risk implied by contingencies not covered by the N-1 criterion) changes over time because of changing weather conditions. The blue curve in the lower graph shows how the GARPUR approach adapts the number of contingencies considered when the weather conditions are taken into account. The two dotted curves show what would have been the result of neglecting the impact of weather conditions.

> Further Reading
Deliverable 6.2 | How to upgrade reliability management for short-term decision-making

PROTOTYPE SOFTWARE PLATFORM

TO COMPARE RELIABILITY MANAGEMENT APPROACHES AND CRITERIA

One of the challenges in implementing a new reliability management methodology is being able to clearly compare different approaches. To this end, a prototype software platform was developed that made it possible to perform numerical simulations of the different reliability management approaches - in particular allowing a comparison between the N-1 approach and the probabilistic approach developed by GARPUR. The key idea behind this tool was to allow any member of the power system community to actually test and grasp the benefits of a probabilistic reliability management approach.

The software platform aims to facilitate off-line studies on how to move away from the N-1 approach towards the probabilistic approach, by making it possible to compare how the same system would perform from a socio-economic point of view using each approach. This involves performing massive simulations at a realistic temporal and spatial resolution over several areas of the European interconnected power system.

The prototype that has been developed uses Matlab (Matpower package), Python and various other existing software packages. It includes in particular a CIM (Common Information Model) parser to convert input files, and implements ‘DC’ Optimal Power Flow modules to optimize day-ahead and real-time decisions, both according to the N-1 criterion and according to the RMAC.

TESTING

The prototype was tested on small academic benchmarks and on a real medium-size power system - which allowed the evaluation of the quality and the scalability of its computations for real-world applicability. The key challenges encountered during the tests were to clarify the quality of the input data and how to handle possibly missing data, as well as dealing with the significant computational and human resources required to run the platform to meet the needs of TSOs.

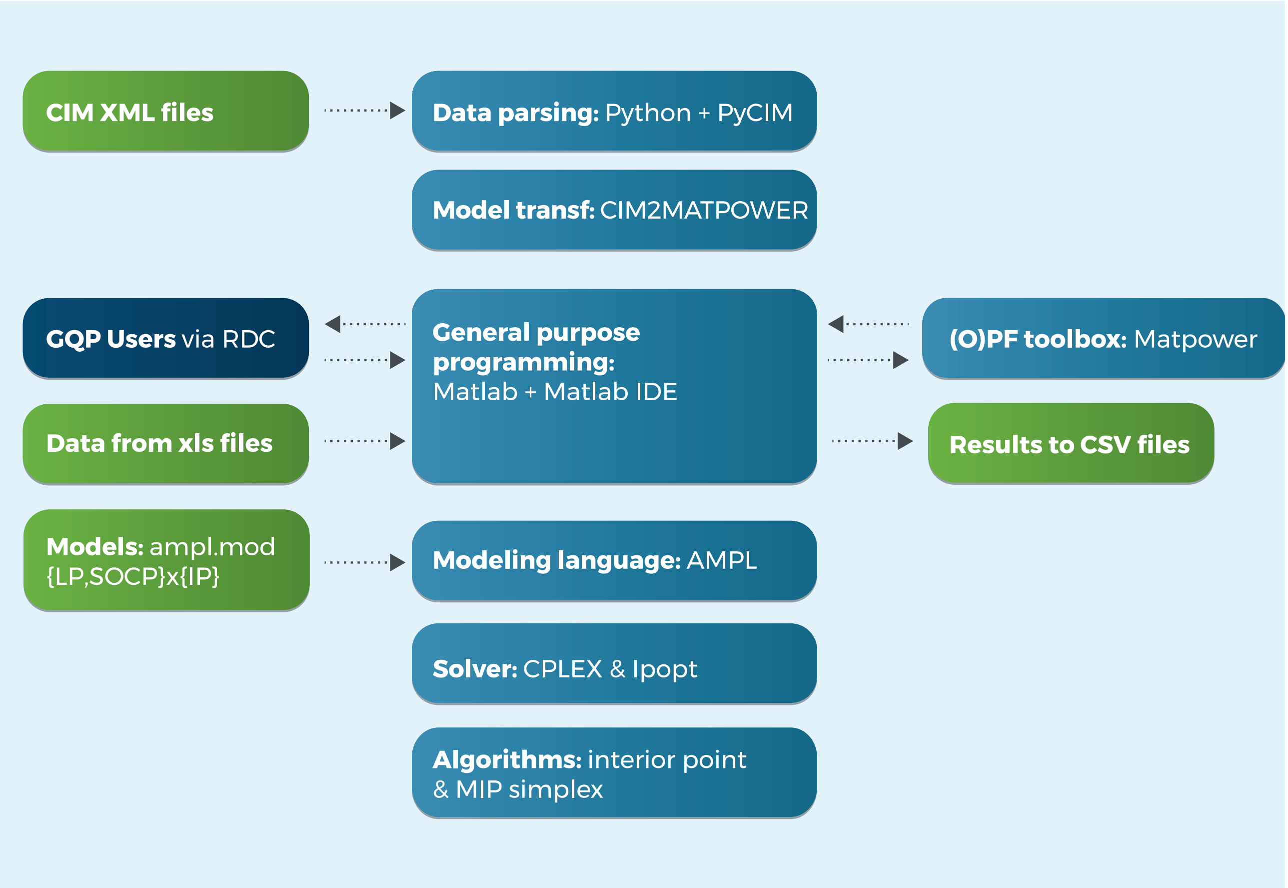
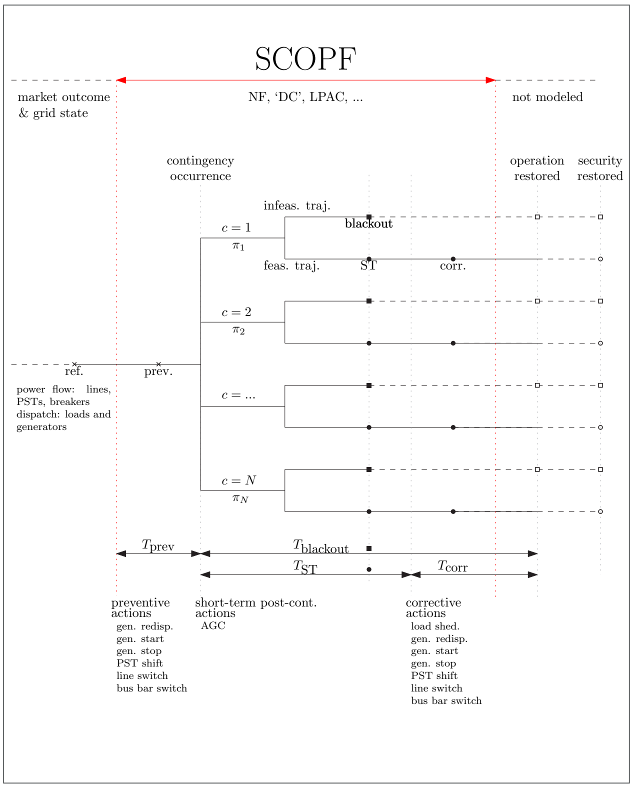


Illustration of calculation core supporting comparison of reliability criteria

INDUSTRY GRADE SOFTWARE

The analysis of the test results and the lessons learnt led to recommendations for the development and use of an industry-grade version of the platform. For industrial use, there is a need to upgrade the platform to accommodate AC optimal power flow, to implement it on massively parallel computing hardware, and to incorporate state-of-the-art computational techniques.



Further Reading Deliverable 7.3 | Report on a broader comparison of different reliability criteria including recommendations on how to evolve into an industry grade tool

TESTING THE METHODOLOGY
ON REAL SYSTEMS

A key factor in the successful adoption of the GARPUR methodology is to ensure it can be practically implemented in real-life. To this end, pilot tests were designed and performed to evaluate the stakes of implementing and using the method and its scalability.

Real-time risk information in the control room through probabilistic reliability assessment

This pilot test was carried out at the control centre of Landsnet, the Icelandic TSO. It implemented probabilistic reliability assessment in the context of real-time operation of the Icelandic system, assessing system snapshots collected every few minutes from their Energy Management System. In this study, rather detailed models for system response, value of lost load, and weather dependent failure rates were implemented for the Icelandic system using efficient parallel computing to ensure results were computed fast enough for on-line use. Several prototype visualization tools were developed, to display the computed indicators in a meaningful way to the operators sitting in the control room. Based on this test, the probabilistic approach was found to provide quite useful information, complementary to the result of classical N-1 security assessment and well in line with operators' experience and intuitions.

In addition, the study highlighted the operational value of system integrity protection schemes currently used at Landsnet. Recommendations fostering the development of real-time reliability control tools and look-ahead mode reliability assessment tools were also issued as a result of this pilot test.

Greater transparency in system development through clustering and optimal power flow techniques

The near real-life pilot test was realised in the planning department of ELIA, the Belgian TSO. It concerned an actual system development study focusing on a part of the Belgian transmission system.

It assessed the GARPUR approach for system development, showing how clustering techniques can be applied to system snapshots to create a set of credible future operating states for a future year.

A DC-OPF assesses these snapshots to estimate the operability and maintainability of the system, and to identify the main reliability problems to be expected in the future year. The conditions under which a given asset can be taken out for maintenance are therefore possible to know in advance. The test showed also the trade-off between the number of clusters and risk estimates. It is shown that the proposed framework can be implemented for real transmission networks. However, the need for a Security Constrained OPF model for the rapid and convenient assessment of risk of various operating conditions, and for simulating the preventive/curative actions, was identified. In addition, there is also room for further improvement of the clustering techniques.

A probabilistic approach can identify and enable savings for society

Two additional case studies were carried out on the Nordic power system to show the benefits of the probabilistic reliability assessment approach.

The system development study of the Norwegian TSO Statnett concerned the expansion of the grid in the south-western part of Norway. It was conducted by using an in-house tool of Statnett and demonstrates how the probabilistic approach can influence investment decisions. The probabilistic approach enabled Statnett to quantify the value of security of supply and allows therefore to properly rank system expansion alternatives regarding the highest socio-economic benefit.

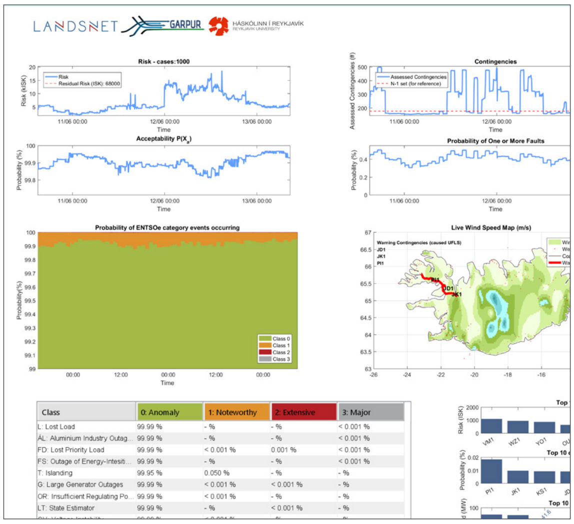
In this case, it showed that the alternative with a higher level of security of supply was not beneficial since the increase of investment costs significantly outweighs the reduction of the expected interruption cost. The study shows that large socio-economic savings of about 25 % can be reached mainly to lower investment costs compared to the alternative with a higher level of security of supply. This equals in this specific case to around 130 million EUR.

The case study of SINTEF assesses the long-term impact of the amount of transmission capacity given to the power market both on the market costs and on the interruption costs. This study used a probabilistic methodology developed at SINTEF that integrates a hydrothermal market analysis for the purpose of reliability assessment in the context of long-term planning studies. The study found that increasing the transmission limits for a specific region of the Norwegian power system did not significantly change expected interruption costs, although it would relax the constraints placed on the market and hence significantly reduce the power market costs. It was also shown that the impact of climatic variability and uncertainties can be substantial. In general, the study illustrates how a probabilistic approach and flexible transmission limits may allow for higher socio-economic surplus.

Comparison of the probabilistic approach against the classical N-1 criterion

Another test was performed by the French TSO RTE using the GARPUR Quantification Platform (see popular summary quantification platform prototype). The test focused on short-term operation and it involved the “Tavel-Realtor” corridor, which is in the south-eastern part of the French grid. Four reliability management strategies were simulated on the software prototype in order to compare their socio-economic impact. The four strategies tested were the N-0, the strictly preventive N-1, a first probabilistic approach that just considered N-1 contingencies, and a second one that considered in addition some N-2 contingencies. Some sensitivity analyses were performed on the main input parameters, to observe which ones were most influential for each of the 4 strategies tested. The results confirmed that implementing a probabilistic approach should lead to similar reliability levels as today, but at a lower cost of operating the system. This study showed the interest of socio-economic impact assessment studies, in order to better understand the main advantages of the probabilistic approach.

Altogether, these tests demonstrated that the probabilistic framework designed in GARPUR is possible to put into practice and that it can give valuable contribution in assessing the system reliability. There exists many opportunities for using the methodologies in order to improve decision-making and to optimally balance security of supply and socio-economic costs. The achievements of the tests can also pave the way for developing scalable tools that may help TSOs justify actions and investments in terms of socio-economic benefits.



Web-based GUI for live risk outputs developed for the Landsnet pilot test’

Further Reading

D8.1 Pilot testing methodologies, models, scenarios and validation approach

D8.2 Public summary - pilot testing using the quantification platform prototype

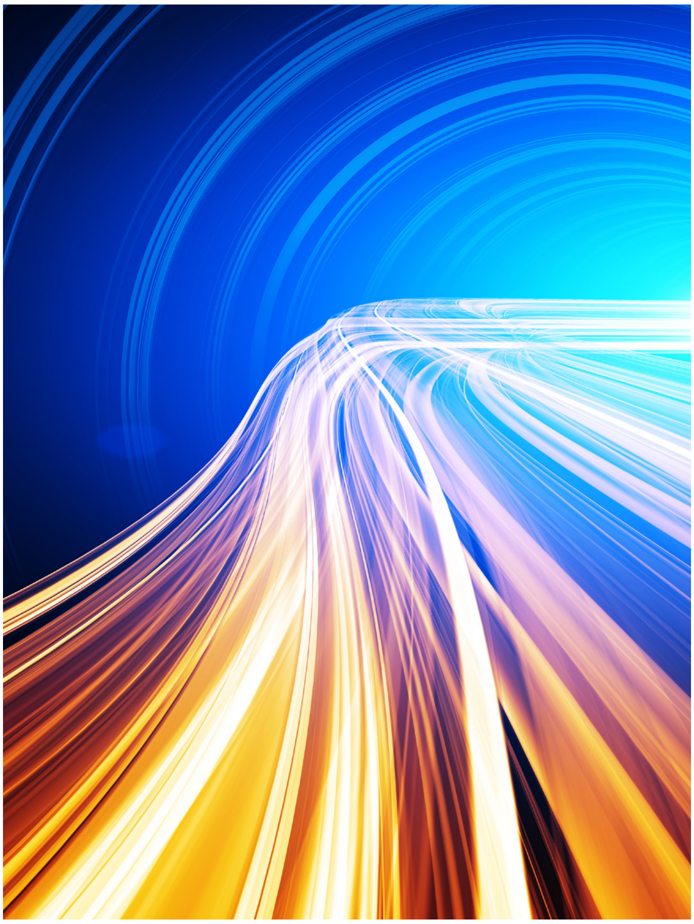
D8.3 Public summary - results from near-life pilot testing

OUR VISION FOR THE FUTURE OF RELIABILITY MANAGEMENT

Over its four years, the GARPUR project has both developed and tested a comprehensive probabilistic reliability management framework aiming at effectively guiding Transmission System Operators (TSOs) in their investment, asset management and operational decisions. The results and experiences obtained in the GARPUR project, especially the demonstration of the methodologies and tools in close to real-life pilot test and studies, show that moving towards probabilistic reliability management in the interconnected pan-European transmission system is possible, but challenging.

This lead to the formulation of the GARPUR vision regarding the future of power systems reliability management:

"An adoption of probabilistic reliability management by all stakeholders dealing with electric power systems reliability management, from experts in the TSO organizations who have the practical responsibility to ensure the security of electricity supply, to the persons in charge at regulators and governments whose responsibility it is to ensure the electric power system performs for the benefit of all parts of society".



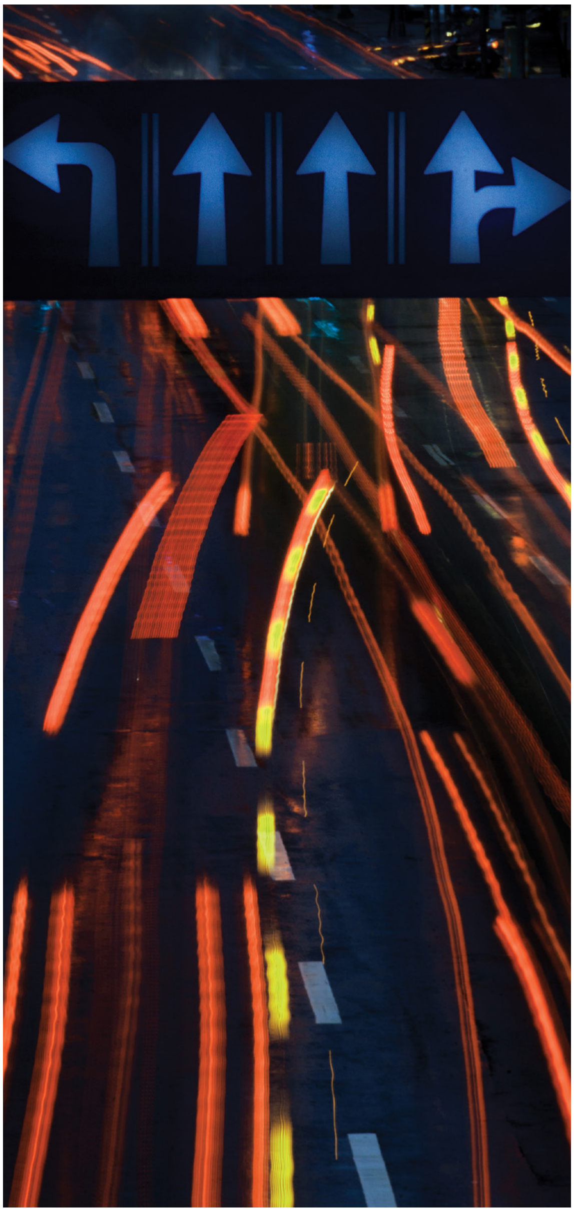
Migration towards a systematic use of the developed probabilistic reliability management approaches can only happen in a gradual fashion. It will also require significant investments and a gradual change of attitudes towards probabilistic methods to make this migration possible and sustainable. Furthermore, several challenges need to be overcome progressively to realise the GARPUR vision and to gain fully the benefits of probabilistic reliability management.

Building upon the project findings as well as a wide consultation among European stakeholders, a roadmap for the migration towards GARPURs vision by 2030 has been designed. This roadmap addresses the main challenges and suggests actions that can thus serve as template for the different stakeholders. By using a common roadmap, stakeholders can communicate and co-ordinate their plans with their neighbour TSOs and countries.

In addition, it is of paramount importance that the national and historical contexts of each TSO are considered. Different countries and TSOs will possibly prefer different pathways to progressively implement a probabilistic approach. Some TSO's might want to start to focus on managing short-term risks and exogenous uncertainty, while others see value in refining methods and data for long-term development of the system, impacting cross-border transmission capacity.

The GARPUR consortium recommends that further experience sharing among the different departments of TSOs responsible for system development, asset management, and system operation, and between different TSOs in close cooperation with ENTSO-E, should be fostered in order to speed up the transition. GARPUR suggests also that ENTSO-E should play a major role and could initiate and coordinate these activities among different TSOs and Regional Security Coordinators, especially in the context of system operation. All these local, regional, and European initiatives can in principle proceed in parallel, but they need to be monitored at the European scale and if necessary, be coordinated to ensure the swiftest possible progress.

The recommended actions have been classified in four different clusters in the roadmap:



REGULATION AND SOCIO-ECONOMIC CONSIDERATIONS

Currently, the regulatory framework organising and incentivising the power sector is in general not fitted to probabilistic reliability management. Incentives, remunerations, roles and responsibilities are defined to ultimately ensure that the power system is N-1 secured. Therefore, a next step should be to expand the regulation to take into account the probability of failure and risk associated with the N-1 faults that TSO's are already assessing and to encourage the use of the new reliability targets and socio-economic evaluation criteria.

The remuneration mechanisms of TSOs should also be adapted so as to incentivize them to implement the new approach in the most efficient way. For this decision-making, the regulators need information and a better understanding of the benefits and the socio-economic consequences of the probabilistic reliability management approach compared to the existing reliability management.

Further Reading
Deliverable 9.1 | Report on recommendations towards stakeholders

DATA AND MODELS OF UNCERTAINTIES

The accuracy of the probabilistic reliability management approach is dependent upon the availability and quality of data. As a first step, TSOs have to collect relevant reliability data, i.e. failure data, outage and restoration durations and interruption cost data. Based on the data, improved models have to be developed. Gradually these actions will provide the TSOs with more precise results from the use of the probabilistic reliability management approach and support an iterative improvement of models. It is also recommended to put in place common guidelines to persistently ensure the collection of data, maintain the databases, and the inferred models, and share the relevant parts of these data and models among the different stakeholders concerned.

TESTING AND IMPLEMENTATION AT THE OPERATIONAL LEVEL

A transition towards reliability management based on probabilities and expected consequences requires a change towards a risk-aware mind-set of all the main actors in the power sector - and especially in TSOs. The operation of the grid must be based on balancing the costs of providing security of electricity supply with socio-economic costs of power supply interruptions and should not focus just on achieving high security of power supply independently of all costs and measures that accompany that.

Pilot scale testing of the new methods and approaches are an important next step to change the mind-set and to increase the trust in probabilistic reliability management at the same time.

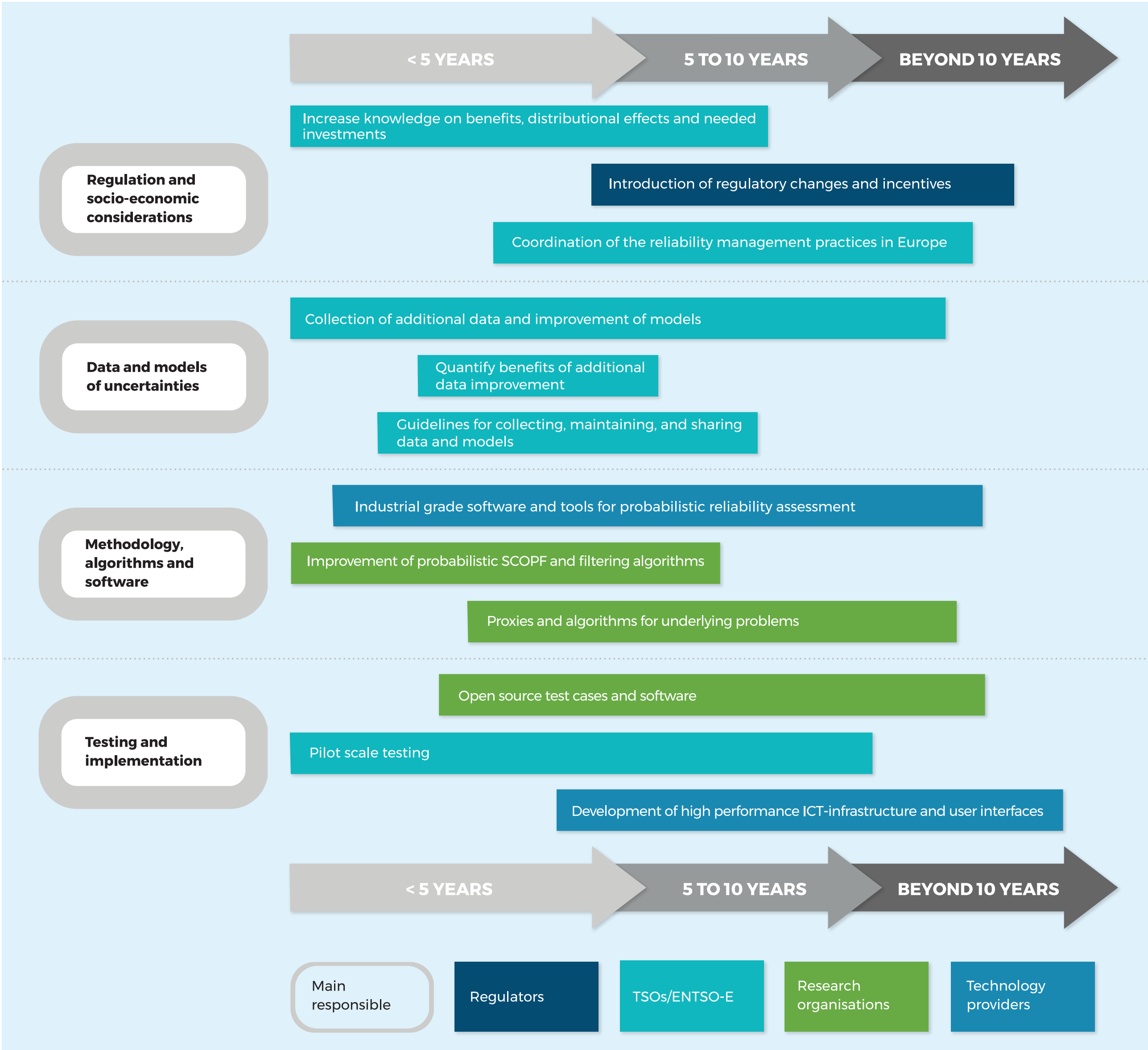
The first practical step for a TSO to take is to calculate the probabilities and risks of the N-1 contingencies that they are already assessing.

This brings into light which data and models are required to develop the probabilistic approaches further and an increased understanding of grid reliability and it’s variations over time and space. Even though GARPUR has performed several pilot tests with different TSOs, a main focus has to be on further testing of the new approach in parallel to the existing N-1 approach to convince more people in the TSOs and other stakeholders of the applicability and benefits of the risk-based approach. Such testing will also provide more insights into how the probabilistic reliability management approach works in specific use-cases and on challenges for the implementation.

METHODOLOGIES, ALGORITHMS AND SOFTWARE

When applying the probabilistic reliability management approach, the resulting stochastic simulation and optimization problems are significantly more complex from the computational point of view compared to those used for N-1 based reliability management. Even though GARPUR has developed several methods and software prototypes, few have been implemented in TSOs practices and in industrial grade software.

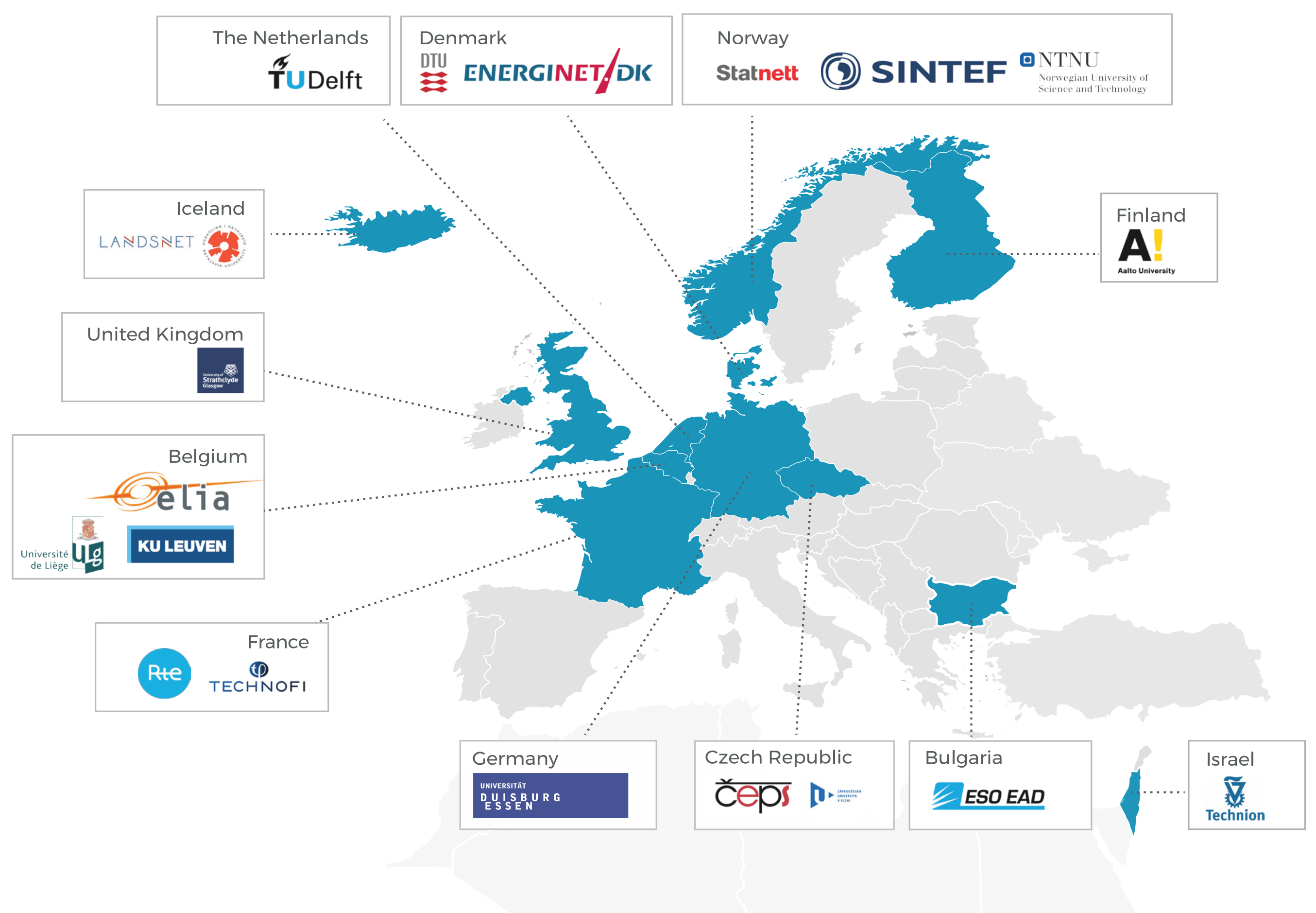
Therefore, a next generation of industrial grade software and tools needs to be developed with the goal of reaching the necessary robustness, efficiency and availability to support a large community of both industrial and academic actors for the progressive implementation of probabilistic reliability management approaches.



The resulting roadmap illustrates this transition in 3 time horizons for each cluster of recommendation.

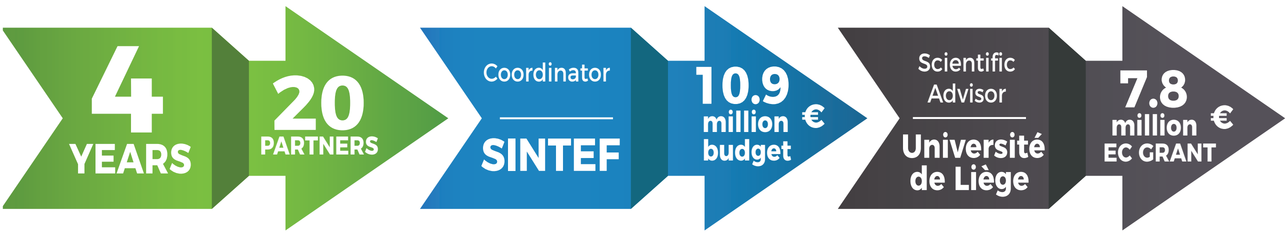
Further Reading Deliverable 9.2 | A tentative transition roadmap to evolve from the current N-1 practices

GARPUR PARTNERS



GARPUR is a collaborative effort that draws on the collective experience and expertise of 7 European Transmission System Operators, along with 12 universities and research centres, and one innovation management expert.

GARPUR KEY FIGURES



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COORDINATOR

Oddbjørn Gjerde, Research Manager

SINTEF ENERGY RESEARCH, NORWAY

email: oddbjorn.gjerde@sintef.no

SCIENTIFIC ADVISOR

Louis Wehenkel, Professor at the University of Liège

UNIVERSITÉ DE LIÈGE, BELGIUM

email: louis.wehenkel@ulg.ac.be

DISSEMINATION

Athanase Vafeas, Director Innovation Management

TECHNOFI, FRANCE

email: avafeas@technofi.eu

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