A PAN-EUROPEAN CAPACITY MARKET PROSPECT ANALYSIS BASED ON IRENE-40 SCENARIOS

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ABSTRACT

This paper focuses on justification and a prospect analysis of capacity market mechanism for pan-European countries in coming decades, set under an established, credible, detailed, and diversified energy supply scenarios synthesis originating from IRENE-40 project works [1]. The study not only concludes with a suggestion on forward capacity requirement / reliability options mechanism, but also reveals subtle trade-offs such as minimizing capacity investments versus reducing curtailed renewable energy in regard to the design of balancing circle scales.

INTRODUCTION

As the integration process of intermittent renewable energy sources (RES) speeds up across Europe, the task of maintaining power balance with limited peaking generators would inevitably become more of a serious challenge over time. As a consequence, a major goal within Work Package Task 3.5 of EU FP7 research project "IRENE-40" is to analyze the potential necessity, form and basic features of prospective EU capacity market(s). In this paper, the justification, methodology, and main outcomes of this pan-European capacity market analysis are briefly explained.

ON CAPACITY MARKET AND ITS NECESSITY UNDER FUTURE EUROPEAN CONTEXTS

In short, a capacity market is generally an auxiliary market place where peaking units can gain economic incentives via offering their capacity instead of generated electricity. As an attempt to clarify the future EU need of capacity market mechanism, the origin, challenges, and major forms of this concept are explained briefly below.

The Origin of Capacity Market

Capacity market is envisaged to address a number of new and persistent issues found in energy-only market designs. Discussed below are four critical problems—amongst them 1 and 2 are persistent ones, while 3 and 4 are new ones:

1. Demand Inelasticity
The difficulty of storing electricity in an economic and efficient manner [3] causes a very inelastic demand side behaviour [4], thus capacity adequacy becomes a long-term problem [2] [11] that always calls for extra attention.

2. 'Missing Money' Problem and Investment Cycles
The 'missing money' problem occurs when revenues from energy-only market is insufficient to motivate [7] existing peaking units to generate and new peaking units to enter the market, which is basically the cause of commonly found under- and over-investment cycles [3] [9] [10].

3. Liberalization and Unbundling
In a liberalized electricity market, regulators can interfere with capacity sufficiency problem but cannot directly influence the revenues of peaking units—this gap between technical requirement and economic incentives to eligible parties [9] can thus best be settled in a market environment.

4. Renewable Integration
The fact that most renewable energy sources are intermittent [8] and are not firm capacities has two implications: firstly, new additional peaking capacities still need to be installed despite presence of installed intermittent RES units [2]; and secondly, the utilization ratio and revenue margins of both new and old peaking units will be reduced [2][3].

Design and Implementation Challenges

Design and implementation of capacity market are no easy tasks due to a variety of challenges. Four typical challenges are presented below:

1. Investment Lead Time
Price signals in a capacity market normally have a long lead time in the range of years [3] before the capacity can actually meet forecasted demand [6]. A forward capacity market design is thus needed to avoid such causality issues.

2. Mitigation of Market Power
In order to prevent peaking generators from "gaming" during a scarcity event (i.e. withholding capacity instead of offering it) [2], a capacity market should shift most of peaking generators' revenue stream during scarcity hours to a more steady and predictable forward payment [4].

3. Price VS. Quantity Regulation
A choice must be made between fixing capacity price (i.e. leave quantity to be settled by market) and fixing capacity quantity (i.e. leave price to be settled by market) [7] by regulation—most researchers have argued in favour of quantity-based solution [3] [9] [10] [11], mainly due to the difficulty of determining the value of reliability [10].

4. The Importance of Locational Signal
A locational price [4] or capacity obligation [3] mechanism is mainly raised to handle the problem that new capacities are not built in places where they are most needed [3] [5]. Prospective unification of European wholesale electricity market would surely add more complexity to a locational price design, on top of decentralized nature of infrastructure ownership across and within different regions.

Major Forms of Capacity Market

When it comes to the choice of capacity market form, a handful of very different options are available; three typical variants are explained briefly below:

1. Capacity Payment
In a capacity payment system, the regulator determines a monthly or annual [9] unit-specific capacity remuneration rate for each generator [3] based on its cost level; and the regulator also determines which generators will receive the payments [3] [7]. This design is known to have issues such as inability of providing timely investment signals for new capacity [7] [3], non-discriminate remuneration to almost all generators, i.e. regardless of their contribution to reliability [7] [9] [3], and susceptibility to gaming behaviours [11].

2. Regulated Reserve Market / Strategic Reserve
A regulated reserve market / strategic reserve system will arbitrarily determine both remuneration price (as average value of lost load) and quantity of peaking capacity; and it inherently runs parallel to a traditional energy-only market [3]. However, it normally does not provide a sufficiently strong incentive for new peaking units to enter market when a scarcity problem is forecasted [2], thus investment cycle problems are likely to persist in such combo-systems [3].

3. Forward Capacity Requirement / Reliability Options
In a forward capacity requirement / reliability options system the system operator will firstly determine a desired near-future capacity margin through load and generation forecast [3]; then an open auction will be held where generators bid their capacity in consecutive rounds until excess supply equals zero [2]. Despite complexities of design and potential deficiencies, such a system is widely seen as the most efficient mechanism in the long run.

Summary and Suggestion

Future requirements for creating EU capacity market(s) will be mainly driven by integration of renewable resources and unification of electricity markets in Europe. A localized version of the US-originated forward capacity requirement / reliability options system would be the most efficient option in the long run. However, potential design deficiency issues such as market power and investment cycles etc. should be duly addressed to avoid repeating mistakes that early US capacity markets already had experienced in the past.

A QUANTITATIVE CAPACITY MARKET ANALYSIS: DIMENSIONS AND METHODS

Dimension 1: Overview of 5 IRENE-40 Scenarios

The quantitative EU capacity market prospect analysis is performed under a number of sensitivity dimensions—the first one is a total of five future EU energy supply scenarios defined within IRENE-40 project, namely BAU, CCS, DES, RES, and EFF, as illustrated in *Figure 1*. Note that the full data set is country-specific per time and scenario [1].

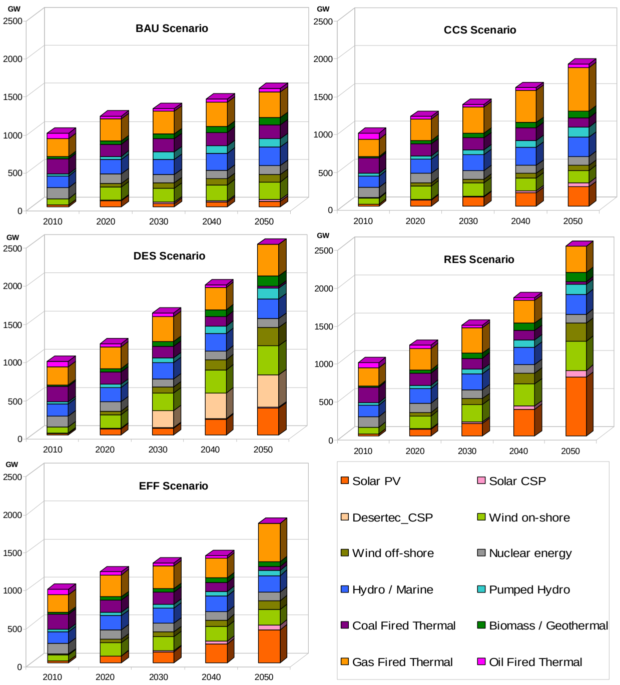

Figure 1: EU Generator Capacities of IRENE-40 Scenarios

Dimension 2: 4 Levels of Capacity Market Unification

The second sensitivity dimension is four variants of EU capacity market unification level, as shown in *Figure 2*.

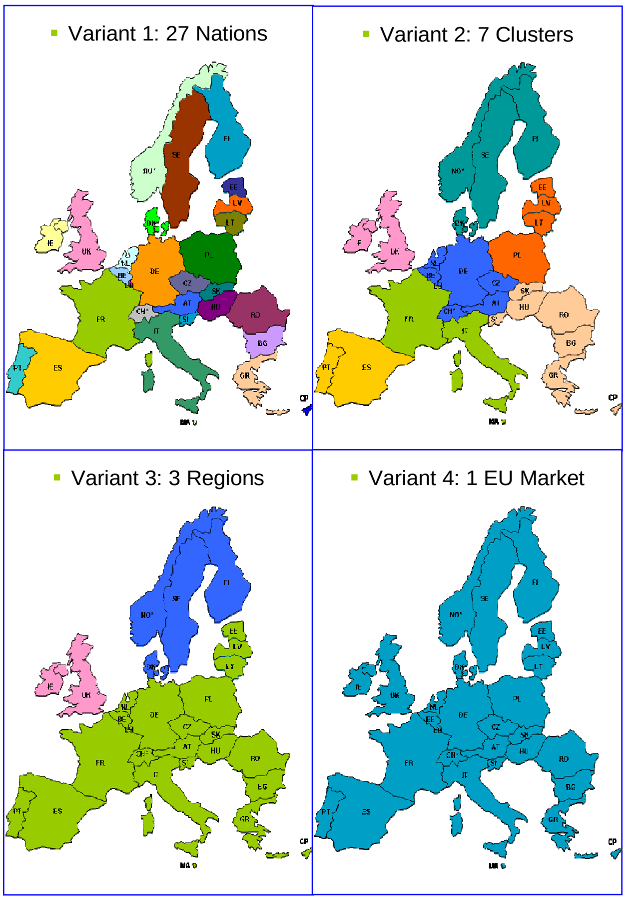

Figure 2: Considered Capacity Market Unification Levels

Obviously, the four variants in *Figure 2* are assumed to simulate the locational design aspects of capacity market, such that total number of balancing circles (differentiated in colour here) varies between 27 and 1 according to market unification level. In this study, the impact of balancing circle size is examined under a simplified setting, such that cross-border power flows between any two neighbouring balancing circles are assumed to be zero, and no internal transmission constraints are assumed to exist within each balancing circle. This assumption renders each balancing circle as an ideal island to facilitate power balance analysis.

Quantitative Capacity Market Evaluation Method

Firstly, on top of the previously explained 5 energy supply scenarios and 4 balancing circle settings, additional data have been synthesized in terms of standard annual profiles of load, wind, PV, CSP, and hydro resources for each EU country, as well as generator production costs, revenue curves, and installation costs. The availability of these data makes it possible to quantitatively estimate the development of potential EU capacity market volumes in coming years.

The estimation of capacity market volume is performed via a combination of two sub-steps: firstly a generalized resource dispatch process is done at hourly resolution for a chosen year of a given balancing circle (under a defined scenario) to obtain full load hours of each type of resource; and then an economic evaluation process is executed to extract annual profits of gas and oil peaking units in all respective balancing circles, so as to calculate a weighted sum profit to compare with unit installation costs and deduce potential capacity market volumes accordingly.

The resource dispatch procedure is modelled as a simplified quadratic programming problem that behaves similarly to a priority list dispatch routine, in which each type of resource represents a collection of individual generator units. In *Figure 3* a sample dispatch result is shown as a reference.

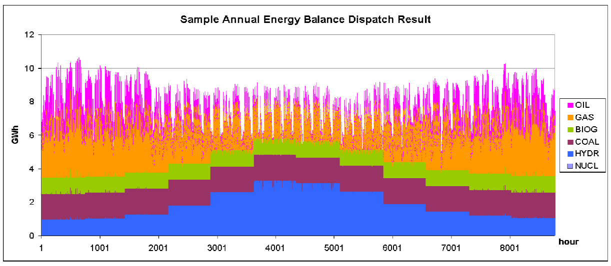

Figure 3: Sample Annual Energy Balance Dispatch Result

In the economic evaluation process capacity market volume of a given year is approximated as the 'missing money' between initial installation cost and the NPV value of annual profit, as represented in the following formulas:

$$Annual\ Profit_{circle} = \sum_{hour=1}^{8760} (Revenue_{hour} - Cost_{hour});$$

$$Capacity\ Market\ Volume_{variant} = 1 - \frac{\sum_{circle=1}^{N} (Annual\ Profit_{circle} \times NPV\ \ factor)}{\sum_{circle=1}^{N} (Power\ Capacity_{circle} \times Per\ kW\ \ Installation\ Cost_{circle})}$$

SIMULATION RESULTS

1. Trend Estimation of Capacity Market Volume

In *Figure 4* to *Figure 7*, estimations of peaking gas units' capacity market volume (not shown here: similar results for oil units) as percentage of installation cost are shown for variant 1 to 4. It can be seen that CCS stands out as the most profitable scenario for peaking gas units, whereas DES is the most demanding scenario under variants 3 and 4, where it raises peaking gas units' capacity market demand to 45% (variant 3) respectively 65% (variant 4) of installation cost.

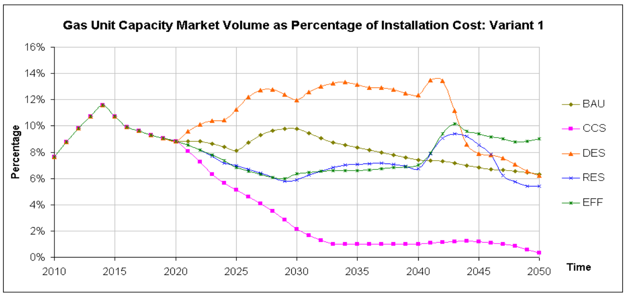

Figure 4: Gas Unit Capacity Market Estimate, Variant 1

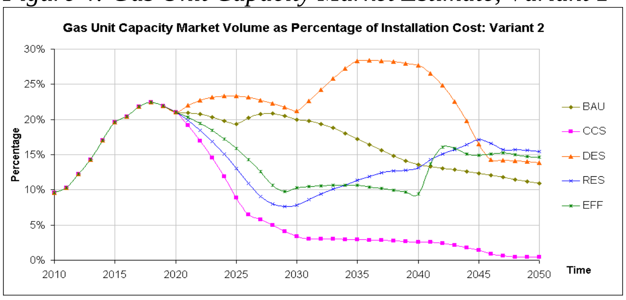

Figure 5: Gas Unit Capacity Market Estimate, Variant 2

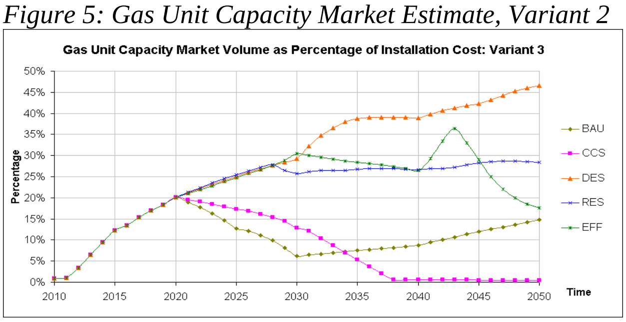

Figure 6: Gas Unit Capacity Market Estimate, Variant 3

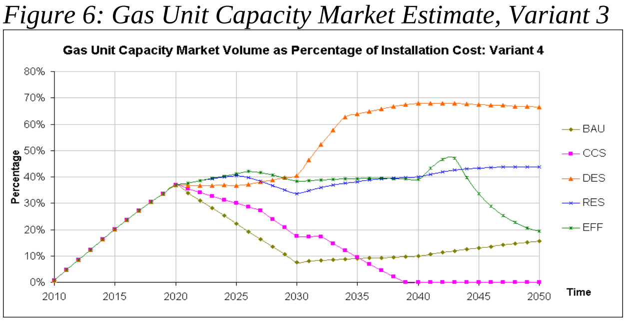

Figure 7: Gas Unit Capacity Market Estimate, Variant 4

In addition, an important trend can be seen: as unification process of EU electricity market merges more nations into larger balancing circles, capacity market volumes would rise due to reduced full load hours of peaking units—alongside increasing cross-border flows, more shares of peaking units' original loads are likely to be served by base units instead.

2. Observations on Curtailed Renewable Output

In *Figure 8*, the relative amount of curtailed RES output are shown for all simulated cases. Obviously, the unification of EU market helps to reduce the amount of curtailed RES energy in future scenarios as more countries share peaking units to handle renewable intermittency. Another noticeable fact is that DES scenario gradually outperforms RES scenario as EU capacity markets become unified.

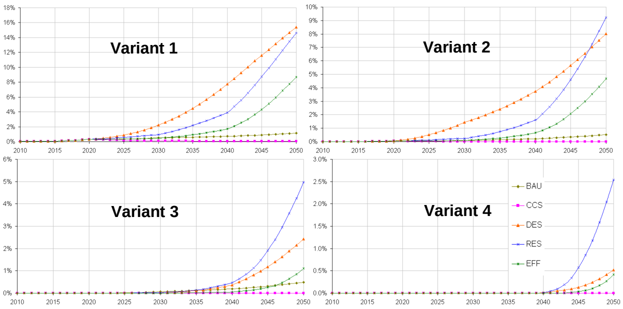

Figure 8: Curtailed Renewable Energies, Variants 1—4

3. Energy Supply Mix of Min- and Max-Demand Cases

As mentioned, the CCS scenario under variant 1 calls for minimum capacity market demand; whereas DES scenario under variant 4 calls for maximum capacity investment. A contrast of both cases' energy supply mix over coming years can be seen from *Figure 9* and *Figure 10*, which clearly shows the major underlying cause of difference to be the development of gas peak units' utilization ratio over time.

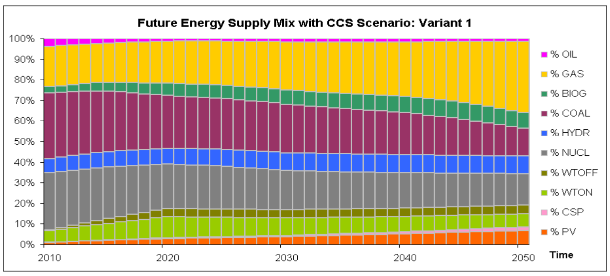

Figure 9: Energy Mix of Min-Demand: CCS & Variant 1

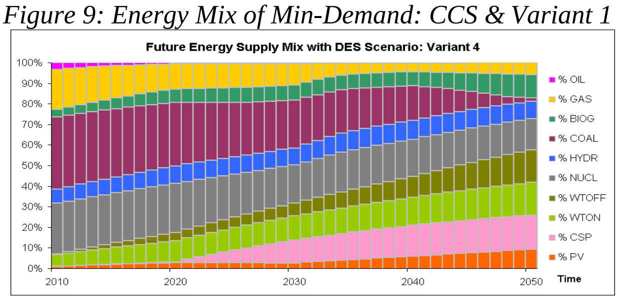

Figure 10: Energy Mix of Max-Demand: DES & Variant 4

CONCLUSION

In coming decades, Europe is about to face a considerable challenge in establishing a capacity market mechanism, for which a localized forward capacity requirement / reliability options system should be the best form to adopt. The total volume of EU capacity market in future would be highly dependent on both generation portfolio changes and size of balancing circles. The study reveals that out of five IRENE-40 future scenarios, CCS leads to minimum capacity market volumes, while DES proves to be the worst-case scenario. Merging balancing circles from national to single EU scale, however, will gradually increase capacity market demands but reduce amounts of curtailed RES energy—this is mainly due to sharing of both peaking and base units across EU.

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