Energy and Ancillary Services Market Reforms in Greece

A Path to Enhancing Flexibility and Adopting the European Target Model

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Executive Summary

Greece's wholesale electricity market needs to undertake significant reforms in order to integrate large quantities of intermittent renewable resources and to meet regulatory requirements. Absorbing significantly more intermittent renewable resources will require Greece to enhance its energy and ancillary service markets to incentivize greater flexibility and maintain system reliability. At the same time, Greece must enhance its markets to integrate more fully with neighboring systems and to conform to the European Target Model. The Hellenic Association of Independent Power Producers (HAIPP) has commissioned us to offer high-level design recommendations for how to achieve immediate improvements and make progress toward a long-term vision.

The Greek market has several features that facilitate the relatively efficient operation of the controllable fossil-fuel plants for which it was designed. However, the day-ahead market and balancing mechanism are not well designed to integrate intermittent renewables, which are producing an ever-increasing share of system needs. They do not effectively leverage the flexibility potential of existing generation resources, Greece's interconnectors, or new technologies. The market suffers from several underpricing problems that cause under-remuneration for flexibility services, such as inefficiently low energy and ancillary service price caps that are below marginal system costs when shedding load, inefficiently low prices during scarcity events, and *ex post* hourly balancing prices that smooth out the intra-hour price variations that would otherwise incentivize greater flexibility. Further, Greece does not currently incorporate market coupling and so is not able to capture the full efficiency benefits of interconnectors related to trading or intraday flexibility.

To address these concerns and comply with Greek and European policy requirements, Greece must develop or enhance its markets at the forward, day-ahead, intraday, and balancing timeframes. Throughout this reform effort, we recommend that the following principles guide the market design:

- Energy and ancillary service products should accurately reflect Greece's flexibility needs;
- All resources should be able to compete on a level playing field;
- Market coupling should be enabled at all timeframes and as close to real time as possible;
- The procurement of energy and ancillary service products should be co-optimized whenever ancillary service products are procured to the extent consistent with the European Target Model;
- Prices should reflect all system technical constraints to the extent possible, again to the extent consistent with the European Target Model;
- Dispatch, pricing, and settlement intervals should be aligned;
- Prices should reflect the marginal value of reliability during scarcity events and should rise up to the value of lost load (VOLL) during involuntary load shedding events;

- Prices should be allowed to drop to efficiently low levels (and below zero) during surplus generation events;
- Out-of-market actions and uplift payments should be minimized; and
- The potential for the exercise of market power should be mitigated.

In this report, we discuss how to apply these principles and leverage existing infrastructure to achieve the Target Model requirements in Greece in the near term. This will require a new market designed to support the cleaner, more intermittent, and more distributed electricity system of the future. To make progress toward a more efficient market design, we offer a number of specific recommendations that can be immediately pursued, as well as higher-level recommendations for achieving further enhancements over time.

Figure 1
Overview of Recommended Market Design in Greece

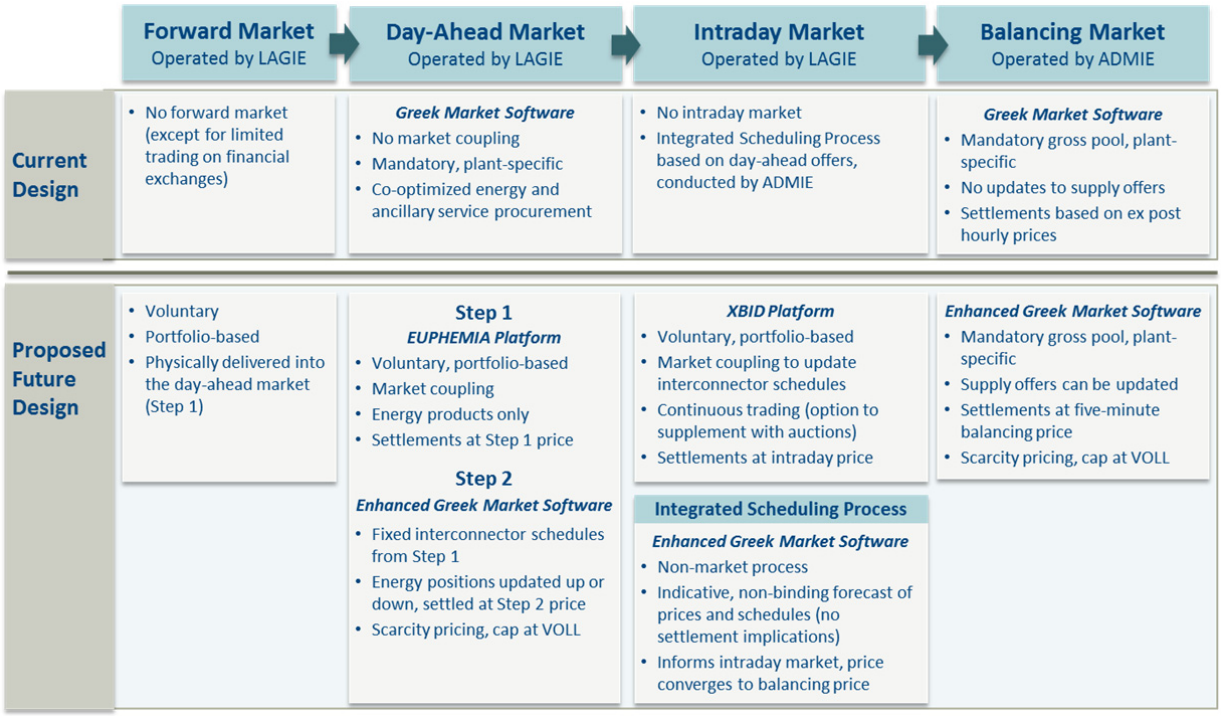

Figure 1 provides a summary description of our recommended approach to implementing or enhancing Greece's forward, day-ahead, intraday, and balancing markets. This recommended structure aims to leverage the advantages of existing market systems in Greece as well as those supporting other European markets. This integrated set of markets will achieve a number of immediate efficiency and flexibility improvements, as well as supporting progress toward a longer-term vision as follows.

- Forward Market: Greece will need to implement a new forward energy market consistent with Greek Law 4425/2016, which mandates that forward trades be physically delivered into the day-ahead market and that the Regulatory Authority for Energy (RAE) impose maximum procurement quantities for individual retail suppliers. We recommend that the forward market:
  - Support voluntary, portfolio-based trades.

- Incorporate provisions that would prevent individual market participants from sidestepping full participation in the mandatory, centralized day-ahead market (that will rely on plant-specific unit commitment and economic dispatch to minimize total system cost).[1]

- **Day-Ahead Market:** We recommend that Greece use a benefit-cost analysis to choose from among a full spectrum of options for achieving market coupling. Pending the results of such an analysis, our preliminary recommendation is to adopt a two-step day-ahead market that is likely to capture the majority of efficiency benefits from both market coupling and an enhanced version of Greece's current market software.

  - *Step 1* would be a voluntary, portfolio-based market cleared in the Pan-European Hybrid Electricity Market Integration Algorithm (EUPHEMIA) software platform, which is consistent with the Target Model and is used to support market coupling in most European countries. It would incorporate schedules consistent with forward market trades, and voluntary bids and offers from producers, consumers, and traders.[2] The results from Step 1 would determine the final interconnector schedules for the day-ahead market, and may create net supply (or demand) positions for individual market participants. Forward market positions would be treated as price-takers in the Step 1 clearing, *i.e.* they would not set the Step 1 prices. All incremental quantities cleared in Step 1 would be settled at the Step 1 price.

  - *Step 2* would be a mandatory gross pool, with plant-specific zonal market clearing based on an enhanced version of the current Greek market software. As it does now, the software would run a system-wide cost-minimizing unit commitment, economic dispatch, and co-optimized ancillary service procurement, considering all plant commitment costs, variable costs, and technical constraints. The optimization would take as inputs the physical interconnector schedules from Step 1, and would produce as outputs the final energy and ancillary service schedules (generators' sales may increase or decrease compared to their voluntary Step 1 positions, depending on the least-cost system-wide solution). All incremental quantities of energy purchased or sold (compared to the Step 1 position) would be settled at the Step 2 energy price; all ancillary services would be remunerated at the Step 2 ancillary service clearing price.

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[1] For example, the RAE is working on ongoing efforts to reform the price and quantity of hydro offers in the day-ahead market in order to prevent artificial price suppression. If the forward market was instead designed as a physical exchange with individual resources treated as price takers day-ahead, this would effectively undo and eliminate the hydro bidding rules.

[2] Traders that do not have a physical supply or demand position could take a long or short position in Step 1 based on their offer or bid price. If cleared, the same quantity would be inserted as an offsetting, price-taker position in Step 2 resulting in no net position at the conclusion of the day-ahead market. Allowing for this type of trade would create an incentive for traders to participate in ways that minimize the potential for price differentials between Steps 1 and 2.

- Both steps of the day-ahead market would be enhanced to conform to the flexibility, ancillary service, and scarcity pricing recommendations described in the context of ancillary services and the balancing market below.

- Market monitoring and mitigation measures would need to be implemented to mitigate the potential for exercise of market power. Specifically, large net buyers may need to have some restrictions placed on the quantity of net demand submitted into Step 1.[3]

- **Intraday Market:** Greece does not currently have an intraday market, but must implement one to conform to the European Target Model. We recommend that Greece implement that market by integrating with the XBID platform that is planned to go live later in 2017 and will support market coupling across most of Europe. The platform will support continuous intraday energy trading and updated interconnector schedules. For Greece's implementation, we suggest that:

  - The intraday market should be conducted on a voluntary, portfolio-based, continuous-trading basis. We do not make a recommendation regarding whether the intraday market should be supported by periodic intraday interconnector capacity auctions, but we do recommend that Greece carefully coordinate with any neighboring markets, including Italy, when considering such auctions.

  - Intraday market transactions should not be subject to any plant-specific or technical feasibility provisions. Instead, we recommend that the intraday scheduling processes implemented by the Independent Power Transmission Operator (IPTO or ADMIE) should be conducted as an entirely parallel and separate function. The results of ADMIE's intraday scheduling processes would provide indicative schedules and prices for the remainder of the trading day and help to inform price formation in the voluntary intraday market (and the two would be expected to converge at the close of the intraday market).

  - Market closure should be as close to real time as possible, and the granularity of scheduling intervals should be as small as possible (ideally, the settlement periods should be 15 minutes, consistent with the European Target Model). Over time Greece can work with other participating member states to make further enhancements to increase granularity and reduce latency. Ultimately these enhancements will improve the value of interconnected systems to support the flexibility needs across the integrated European market.

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[3] A large net buyer within Greece may in some circumstances have an incentive to create artificially large demand and induce uneconomic imports in Step 1, such that the excess quantity of imports could artificially suppress prices in Step 2. The net result of such a strategy would be to lose money on a small transaction in Step 1 in order to benefit from price suppression on a larger transaction in Step 2. This potential incentive to overschedule imports already exists on Greece's interconnectors as a consequence of the market structure, and is not a product of the two-step day-ahead market design proposed here.

- **Balancing Market:** We recommend that Greece enhance its current balancing market to improve economic efficiency and better incentivize flexibility services. These changes will correct a number of underpricing and under-remuneration concerns with Greece's current balancing mechanism, but can likely be implemented with modest enhancements to the current market software. We recommend that Greece:
  - Incorporate the final interconnector schedules from the intraday market as the starting point for the balancing market. Energy product settlements would be based on the net incremental or decremental balancing position in the balancing market compared to the last intraday market position.[4]
  - Increase the price cap in the balancing market (as well as in the forward, day-ahead, and intraday markets) to the value of lost load (VOLL). This price cap increase could be phased in over time, and should be based on a study of the appropriate VOLL in Greece using the European Network of Transmission System Operators for Electricity (ENTSO-E) methodology as foreseen in the European Commission's draft Electricity Regulation.[5] As reference points, most other European markets have estimated VOLL values of €1,250–36,800/MWh and have implemented balancing market price caps of €3,000–9,999/MWh. This suggests that Greece can increase its price cap from €300/MWh to at least €1,200/MWh without waiting for the results of a complete VOLL study.
  - Develop a comprehensive administrative scarcity pricing framework that ensures prices will rise to efficiently high levels and will be consistent with marginal system costs during all types of scarcity events (with more severe events producing higher prices). One component of that scarcity pricing framework would be to impose administrative penalty factors or operating reserve demand curves reflecting the marginal system cost of triggering each type of scarcity intervention (*e.g.*, reflective of the marginal increase in probability of lost load times the VOLL during each event type). As an interim transitional measure, additive penalty factors of €100/MWh whenever the market is short of a particular type of reserve would correspond to the €300/MWh, €200/MWh, and €100/MWh transitional price caps for primary, secondary, and tertiary reserves discussed below. Over time, these penalty factors should be increased consistent with the price cap and the VOLL.
  - Reduce the price floor to below zero and conduct an economic efficiency review of the interactions among pricing, unit commitment decisions, uplift payments, and clean energy policies (such as feed-in tariffs and feed-in premiums) that affect surplus generation events. The overall objective of such a review would be to ensure that the combination of the clean energy policies and energy market prices

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4 The ancillary services settlements would be based on the incremental or decremental ancillary service quantities compared to the day-ahead market, which would not be traded in the intraday market.

5 See European Commission (2017b).

together provide incentives to minimize societal costs of meeting environmental objectives (considering both system-wide investment costs and operating costs).

  - Explore options for enabling updated supplier offer prices closer to real time (rather than maintaining day-ahead offers without updates as is done now). This would help to create more accurate price formation when market conditions change significantly between the day-ahead and balancing markets (for example in response to gas market shortages).

  - Align pricing and settlement intervals with the five-minute intervals that are already used for system dispatch. The current approach of hourly pricing intervals with prices set on an *ex post* basis dampens incentives for fast-responding resources to react quickly to meet system flexibility needs.

  - Enhance dispatch and price formation to allow a wider range of resources to fully participate, not just traditional fossil plants. Most urgently, based on its significant share of the resource base, we recommend continuing the efforts to represent hydro plants more accurately. We also recommend focused efforts to integrate a range of different demand response resource types, given the growing role of demand response in Greece and the importance of producing efficient scarcity prices. In the future, we expect it may become more important to focus on the dispatch price formation issues related to other resource types such as storage and distributed technologies.

  - Incorporate plant start-up costs into price formation, particularly during peak times when intraday unit commitment instructions might otherwise tend to suppress prices.

- **Ancillary Services Markets:** We recommend that Greece comprehensively review its ancillary service markets to ensure that: (a) product definitions and quantities match changing system needs and align with the European Guidelines; (b) qualification requirements result in a level playing field for different resource types; and (c) price formation is consistent with economic principles. Specific reforms we recommend include:

  - Remunerating tertiary reserves based on the marginal system cost as Greece already does for other types of ancillary services (replacing the current practice of non-remuneration for tertiary reserves). We further recommend revising the definition of the tertiary reserve product (or replacing it with one or more alternative products) so that tertiary reserves procured in the day-ahead market is not, as currently, released into the balancing market as available to provide energy. The current system artificially suppresses prices that would be calculated on a five-minute basis, and prevents efficient scarcity pricing at that timeframe. We note that RAE is already working to implement reforms in this area. However, as currently proposed, the reform would not fully address the underpricing concerns.

  - Aligning the pricing, settlement, and dispatch of ancillary services to the market in which they are procured. The quantities of hourly reserves procured in the day-ahead market would be paid for at a day-ahead price; the incremental (or

decremental) quantities of five-minute reserves procured in the balancing market would be paid for at the five-minute balancing price.

- Increasing the price caps of all ancillary services from the current €10/MWh to a level that more accurately reflects system costs at times of operating reserve shortage, including accounting for the marginal increase in the probability of lost load times the VOLL during scarcity events. As a transitional measure we suggest immediate increases to €300/MWh, €200/MWh, and €100/MWh for primary, secondary, and tertiary reserves respectively.[6] Over time we suggest that these price caps should increase to an economically efficient level supported by an economic analysis and according to a schedule of increases consistent with the energy price cap increasing to the VOLL.
- Maintaining co-optimization of energy and ancillary service procurement with the second step of the day-ahead market, as well as within the five-minute balancing market.

By following these recommendations Greece can achieve significant efficiency gains and better support the flexibility needs in a market relying much more heavily on intermittent clean energy resources, while at the same time conforming to the European Target Model. Greece can in a moderate timeframe achieve market coupling with other member states, and work together over the longer term to develop an efficient integrated market.

[6] Note that these price caps are consistent with administrative "penalty" factors of €100/MWh each that could be imposed in an additive fashion on each of the three types of reserves, as discussed in the prior recommendations on scarcity pricing in the context of the balancing market.

I. Motivation and Regulatory Context

Greece's wholesale electricity market needs to be significantly reformed in order to integrate large quantities of intermittent renewable resources and to meet regulatory requirements. Absorbing significantly more intermittent renewable resources will require Greece to enhance its energy and ancillary service markets to incentivize greater flexibility and maintain system reliability. At the same time, Greece must enhance its markets to integrate more fully with neighboring systems and conform to the European Target Model. The Hellenic Association of Independent Power Producers (HAIPP) has commissioned us to offer high-level design recommendations for how to achieve immediate improvements and make progress toward a long-term vision.

Intermittent renewables, including wind and solar, are producing an increasing share of Greece's electricity, driven by clean energy policies. By the end of 2016, around 2,047 MW of wind and 2,445 MW of photovoltaic solar (both nameplate capacities) were installed in Greece's approximately 10,000 MW peak load electricity system.[7] More generation from intermittent renewables increases the need for flexible resources to compensate for their variable and uncertain output. This need will intensify as Greece aims to meet its national renewable target of 18% of economy-wide energy consumption by 2020, which may require renewable energy to provide approximately 35–40% of electricity consumption.[8]

Greece's current electricity market is not designed effectively to integrate such a large quantity of variable energy resources, or incentivize the provision of the needed flexibility services. Greece's Regulatory Authority for Energy (RAE) and others have found that power plants are not properly compensated for the flexibility services they currently provide.[9] The RAE also found that, absent additional remuneration for flexibility services, some existing flexible plants are likely to retire and that this would impede the ability to meet future flexibility needs. In its recent study on resource adequacy, the Independent Power Transmission Operator (IPTO or ADMIE) has identified a growing risk of flexibility-driven reliability events, even if the total quantity of available capacity appears adequate when individual plants' flexibility characteristics are ignored.[10] The cold weather power shortage experienced last winter further highlighted the need for stronger availability and performance incentives than the current market provides.[11] To address these concerns, the RAE is working with the European Commission Directorate-General for Competition (DG

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7 See LAGIE (2016), p.2 and ADMIE (2017a), p. 2/16.

8 See International Energy Agency (2013).

9 See Capros (2014), RAE (2014), and RAE (2016c).

10 See ADMIE (2014) and RAE (2016c).

11 To avoid power outages during the cold weather and heavy snowfall in winter 2016/17, the Greek government asked consumers to reduce unnecessary power consumption and required no export of any electricity during peak hours.

Comp) to develop market mechanisms to more efficiently incentivize availability and flexibility in both the short and long term.[12]

At the same time as addressing flexibility challenges, the Greek electricity market must make progress towards implementing the European Target Model. In 2009, the European Commission issued the Third Energy Package requiring member states to develop a single electricity market in Europe to ensure affordable and secure energy supplies and to tackle climate change.[13] The third memorandum of understanding for stability support signed in August 2015 by the Greek government and its international partners further confirmed that Greece is required to adopt the European Target Model by December 2017 and to implement a compliant balancing market by June 2017.[14] In March 2016, DG Comp reiterated this requirement along with several other requirements such as increasing the price caps and introducing further efficiency improvements in Greece's current markets.[15] Subsequently, in September 2016, the Greek Parliament issued a new Law 4425/2016 dictating high-level requirements regarding how Greece's market reforms should comply with the Target Model.[16]

The European Target Model requirements have been established via a number of different regulations approved since the enactment of the Third Energy Package. This report focuses on the adoption of the portion of the Target Model relevant to the energy and ancillary services markets. The Guidelines on Forward Capacity Allocation (FCA) set out rules for forward markets that will enable market participants to secure interconnector hedge positions prior to the day-ahead timeframe.[17] The Guidelines on Capacity Allocation and Congestion Management (CACM), approved in 2014, define the day-ahead and intraday market requirements of the Target Model.[18] Finally, the Guidelines on Electricity Balancing, approved in March 2017, focus on the Target Model rules for the balancing market.[19] Throughout this report, we will interchangeably refer to these as Guidelines or Network Codes.[20]

In this report we offer high-level recommendations for how Greece can reform its energy and ancillary services markets to provide better incentives for the provision of flexibility and to comply with the European Target Model. We review the current status of the Greek

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12 See European Commission (2016a).

13 See European Commission (2009).

14 See European Commission (2015b), p. 26.

15 See European Commission (2016a), pp. 7–9.

16 Although the memorandum of understanding required that Greece adopt a Target-Model-compliant balancing market by June 2017, and a fully compliant market by December 2017, the new Greek law does not include any timeline requirements. See Greek Republic (2016a).

17 See European Commission (2016c).

18 See European Commission (2015a).

19 See European Commission (2017a).

20 The Guidelines were initially drafted by the European Network of Transmission System Operators for Electricity (ENTSO-E) as Network Codes.

electricity market, provide insights from experiences and lessons of other jurisdictions facing similar challenges, evaluate available options, and offer recommendations on immediate next steps and longer-term reforms to support a more flexible and economically efficient electricity market.

II. Evolution Towards the European Target Model in Greece

As a first step in evaluating potential market reforms in Greece, we describe the primary characteristics of the current energy and ancillary services markets in Greece and compare these to the European Target Model requirements. We also describe a high-level, long-term vision for how Greece's forward, day-ahead, intra-day, and balancing markets for energy and ancillary services could evolve to reliably and cost-effectively support system flexibility needs. We then provide a more detailed discussion of specific design elements and transitional arrangements in subsequent sections of this report.

As an overview of Greece's market, the total installed capacity in Greece's interconnected system was 16,710 MW in 2016, including 4,337 MW of lignite coal, 5,221 MW of natural gas, 3,170 MW of hydro, 2,047 MW of wind, 2,445 MW of solar photovoltaics, 58 MW of biomass, 223 MW of small hydro units, and 100 MW of small co-generation units.[21] In 2016, the system's peak load was approximately 9,207 MW.[22]

All the lignite plants, large hydro plants, and approximately 50% of the natural gas plants are owned by the state-owned utility Public Power Corporation (PPC), while the rest of the natural gas plants are owned by independent power producers (IPPs).[23] PPC also acts as the retail supplier for the large majority of the energy demand on Greece's interconnected system. However, PPC's dominant position will decline over time due to European Commission policies aimed at reducing its shares of the retail and wholesale markets to below 50% by 2020.[24] On 22 May 2016, the Greek Parliament approved Law 4389/2016 to enforce these requirements.[25] Given PPC's significant (though declining) share of generation and retail supply, any reforms in Greece will need to be developed in a way that supports market efficiency even with the participation of a dominant market player.

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21 See ADMIE (2015) and ADMIE (2016).

22 See ADMIE (2015) and ADMIE (2016).

23 The 50% gas capacity number is reported as a percentage of installed MW basis.

24 See European Commission (2015b), p. 26.

25 See Greek Republic (2016b), Law 4389/2016, amended on June 6 2016 through Law 4393/2016. It requires the PPC to unbundle the transmission system operator (ADMIE) from it and partially privatize it.

II.A. Description of Greece's Current Market Design and Existing Challenges

Greece's current wholesale market design for energy and ancillary services is largely the result of market reorganization implemented between 2005 and 2010.[26] The wholesale power market is organized as a mandatory gross pool market with centralized commitment and dispatch.

Forward Market

In the forward timeframe prior to the day-ahead market, there is no organized market for physical energy products in Greece, although there is very limited forward trading on financial exchanges.[27] Greece does however coordinate with each of the neighboring electricity markets to conduct forward annual, monthly, weekly, and daily auctions for physical transfer rights (PTRs) on the interconnectors. Greece is interconnected with five neighbouring systems (Bulgaria, Albania, Italy, Turkey, and the Former Yugoslav Republic of Macedonia), with an aggregate interconnection capacity of approximately 3,800 MW based on thermal limits (of which, approximately 1,700 MW is commercially available).

Day-Ahead Market and Scheduling Process

The market operator Hellenic Energy Market Operator (HEMO or LAGIE) runs Greece's day-ahead market, which co-optimizes procurement of energy and ancillary services for each hour in the following day. The energy market has two bidding zones covering the north and south of the country, although in practice there are rarely binding transmission constraints between the two zones. The day-ahead market is a centralized, gross mandatory pool in which all generating resources are required to participate. LAGIE conducts both unit commitment and economic dispatch processes to minimize total system costs, subject to observing individual units' technical constraints such as start-up times and ramp rates. Market participants can submit offers until gate closure at 12:30 and are notified of the system marginal prices and their scheduled quantities by 14:00 on the day before delivery. Sellers can offer to provide energy and ancillary services and be paid up to the price cap of €300/MWh for energy and €10/MWh for ancillary services.[28] Greece's day-ahead market is not coupled with any neighboring markets, although energy provided through interconnectors can be submitted into the Greek market on a price-taker or price-offer basis.

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[26] See RAE (2016b).

[27] See EEX (2017) and Economic Consulting Associates (2016), p. 108.

[28] However, as noted later in the text, ancillary services are paid the prices estimated in the day-ahead market but for quantities determined in the balancing mechanism. The RAE issued a decision increasing the energy price cap from €150 to €300/MWh effective 23 June 2016, see Greek Government Gazette (2016a).

In terms of ancillary service products, there are primary reserves, secondary reserves, tertiary reserves, standing reserves, voltage control, and black start services.[29] Primary, secondary, and tertiary reserves are scheduled in the day-ahead market as part of the energy and ancillary services co-optimization. Market participants are paid for providing primary and secondary reserves at the day-ahead market prices but the volumes for which they are compensated are determined in balancing mechanism. Tertiary reserve volumes are determined on a day-ahead basis, but generators are not compensated for providing that service. Tertiary reserves are maintained throughout the scheduling day but are released to provide energy in the five-minute balancing dispatch.

After the day-ahead market concludes and the market operator publishes the prices and awarded quantities at 14:00, the TSO ADMIE runs another day-ahead scheduling process. This process reruns the same unit commitment and economic dispatch software underpinning the day-ahead market, and so should produce the same supplier schedules if given the same inputs. However, the schedules produced in the day-ahead scheduling process differ from the day-ahead market because ADMIE incorporates updated plant availability data, intermittent resource forecasts, and a centralized load forecast (rather than retail suppliers' forecasts). Offer prices are maintained from the day-ahead market. The updated producer schedules are not financially settled, but producers that receive new unit commitment instructions can be paid out-of-market uplifts in order to allow them to recover the fuel and variable costs.

Greece's day-ahead market and scheduling process have both advantages and disadvantages. The advantages are that, unlike many European day-ahead markets, Greece's market considers the majority of system technical constraints and co-optimizes energy and ancillary service procurement. This means that the resulting commitment and dispatch schedules are technically feasible. Further, the day-ahead market operated by LAGIE and the day-ahead scheduling process operated by ADMIE run on the same clearing software, which should reduce the scale of inconsistencies between market clearing and non-market scheduling processes. Some other European markets face larger inconsistencies between the day-ahead market and day-ahead scheduling processes, which can create a greater need for out-of-market interventions and uplift payments that distort incentives and introduce inefficiencies.

However, Greece's day-ahead market has several limitations. The separation between the day-ahead market and day-ahead scheduling process does create discrepancies, and the out-of-market commitments can undermine in-market signals, although the associated distortions tend to be smaller than in some other European markets. Greece's day-ahead market also systematically underprices both energy and ancillary services during shortage conditions due to factors including: (a) inefficiently low price caps, which are well below the value of lost load (VOLL); (b) a lack of efficient scarcity pricing; (c) the absence of payments for tertiary

[29] In Greece, primary reserve is provided by the generation units to respond to the change of the active power following an automatic response of the frequency regulator; Secondary reserve seeks to minimize the Area Control Error; And tertiary reserve is an ancillary service activated periodically in order to restore the system secondary reserve level, in case the latter has been reduced as a result of the operation of the system secondary control. For more discussions about these reserves in Greece, please see Andrianesis, et al. (2011).

reserves; and (d) a lack of opportunities for demand response to participate in price-setting. Even in non-shortage conditions, daily peak prices are inefficiently low when peaking hydro plants are at the margin; the incumbent utility PPC does not have an incentive to increase hydro offer prices to more efficient levels.[30] The RAE has already begun to address these hydro pricing issues by more accurately reflecting hydro offer prices and quantities in the wholesale market, but additional reforms are in progress. Finally, Greece's day-ahead market is behind many other European markets in that it does not couple with any neighboring systems to optimally schedule its interconnectors.

Intraday Operations

Greece does not have an intraday market and does not have any market-based means of updating interconnector schedules after the day-ahead market ends. However, ADMIE does continue to update generator schedules at regular intervals based on updated system information. Similar to the day-ahead scheduling process, the intraday scheduling processes are conducted on an out-of-market basis. The updated schedules for the most part do not have any settlement implications (unless those schedules are carried through to the balancing timeframe). However, if ADMIE issues additional unit commitment instructions, the generator will be guaranteed to recover commitment costs and may (under certain conditions) earn an out-of-market uplift payment.

Balancing Mechanism

ADMIE operates Greece's mandatory centralized balancing mechanism for co-optimized dispatch of energy and ancillary services. In real-time operations, ADMIE dispatches generators every five minutes based on generator offers submitted in the day-ahead market. Settlement is based on the average hourly output that generators actually produce. For energy output above their day-ahead schedule, generators are paid the hourly Zonal Imbalance Settlement Prices, which are calculated on an *ex post* basis. The *ex post* settlement prices are calculated by rerunning the software algorithm used for real-time dispatch, but with realized load, plant availability, and renewable generation calculated on an hourly average basis. The price at which generators get paid (or pay back) for increases (decreases) in energy compared to their day-ahead schedule depends on whether the schedule

[30] The incumbent utility PPC has the incentive to inflate off-peak prices and suppress peaking prices based on its current position as the dominant retail provider serving the large majority of all customers, and the producer that owns all of the infra-marginal lignite and hydro resources. During off-peak conditions, PPC's supply and demand are almost balanced, with nearly all energy produced by its own low-variable-cost resources. At those times PPC has an incentive to increase wholesale energy prices high enough to price other potential retail suppliers out of the market (but not high enough to make wholesale competitors' gas plants economical). During peaking times when PPC's peaking hydro is marginal, PPC is a net buyer from the wholesale market with part of the generation supplied by IPPs' gas plants. In these hours, PPC as a net buyer has the incentive to suppress peak prices to just above the costs of competitors' gas plants. For a more comprehensive discussion, see Capros (2014). The European Commission and Greek Government are currently undertaking structural reforms to reduce PPC's market share.

adjustment was instructed or uninstructed.[31] Renewables do not incur any cost for deviations in output compared to the day-ahead forecast. Generators are compensated for ancillary service provision based on their five-minute balancing quantities, but at a price determined in the day-ahead market. Tertiary reserves are not retained or paid for in the balancing timeframe.

Greece's balancing mechanism has several limitations. Like the day-ahead market, the balancing mechanism: has the same inefficiently low price cap, produces inefficiently low prices when hydro plants are at the margin, does not incorporate scarcity pricing mechanisms, does not compensate for the provision of tertiary reserves, and does not integrate demand response into price setting. Further, the balancing mechanism is subject to even more significant price suppression because a large quantity of tertiary reserve capacity is held throughout the day and then released to provide energy in the five-minute balancing mechanism, effectively eliminating the potential for scarcity pricing in the five-minute balancing mechanism.[32] Another concern is that supply offers are carried over from the day-ahead market and so do not incorporate the most updated market information, such as the impact of gas shortages that may not have fully materialized prior to day-ahead gate closure. In addition, interconnector schedules are not updated during or close to the balancing timeframe in response to changed market conditions. Finally, although real-time dispatch instructions are updated and issued every five minutes, resources are paid only according to hourly settlement prices calculated on an *ex post* basis. This approach diminishes the incentives for flexible, fast-responding resources and over-remunerates inflexible resources.

Overall, the Greek market has several core features that enable the relatively efficient operation of the controllable fossil plants for which it was designed. However, the day-ahead market and balancing mechanism are not well designed to integrate the large and growing share of intermittent renewables that are producing a larger share of system needs, or to leverage the flexibility potential of existing generation resources, interconnectors, or new technologies.

II.B. Consistency with Legal and Regulatory Requirements

To conform to the Target Model and other outstanding legal and regulatory requirements, Greece's electricity market will need to make significant reforms as briefly summarized in Table 1. Greece will need to support forward, day-ahead, intraday, and balancing markets that are compliant with the relevant Guidelines and Legislation. Greece does not currently have forward or intraday markets, and so these will need to be created. The day-ahead and intraday markets will also need to be coupled with other member states to jointly set prices and interconnector schedules.

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[31] Instructed decreases are paid back at the generator's cost. Uninstructed increases in generation are not paid; uninstructed decreases are paid back at the Zonal Imbalance Settlement Price.

[32] The tertiary reserve constraint *is maintained* when calculating the *ex post* settlement price. However, the hourly granularity of that settlement price will still tend to under-reflect scarcity compared to pricing on a five-minute basis with accurate scarcity pricing.

Table 1
Electricity Market Enhancements Needed to Conform to the European Target Model, DG Comp Decision on Flexibility, and Greek Law 4425/2016

Market	European Target Model	DG Comp Decision on Flexibility Remuneration	Greek Law 4425/2016
Forward	• New forward market must be created • Comply with Guidelines on Forward Capacity Allocation	• n/a	• Physical delivery into the day-ahead market • Operated by LAGIE • Option to impose a cap on the fraction of energy procured forward (for market power mitigation)
Day-Ahead	• Market coupling for interconnector schedules • Comply with Guidelines on Capacity Allocation and Congestion Management	• Increase price cap gradually to the VOLL • Improve efficiency of pricing when hydro is marginal (assessing both price and quantity of hydro offers) • Increase ancillary service price caps above €10/MWh • Remunerate spinning tertiary reserves	• Operated by LAGIE (ADMIE will continue to manage commitment and dispatch) • Mandatory
Intraday	• New intraday market must be created • Comply with Guidelines on Capacity Allocation and Congestion Management	• n/a	• Operated by LAGIE (ADMIE will continue to manage commitment and dispatch)
Balancing	• Comply with Guidelines on Electricity Balancing	• Mirror day-ahead market reforms	• Operated by ADMIE

Sources and Notes:
See European Commission (2015a; 2016a–b; 2017a), Greek Republic (2016a).

DG Comp has laid out several more specific requirements for enhancing the efficiency of Greece's electricity markets in its decision approving the Transitory Flexibility Remuneration Mechanism proposed by the RAE.[33] The RAE proposed this mechanism as a means of retaining the needed quantity of flexible capacity in the market, thus avoiding the reliability concerns that would arise should the capacity be retired. DG Comp approved the mechanism on a temporary basis but made it clear that Greece must continue to pursue a permanent market-based solution to incentivizing and remunerating flexibility. Enhanced energy and ancillary services markets that comply with the Target Model, and directly compensate suppliers for flexibility services they provide, must be a central component of those reforms. To that end, DG Comp outlined a series of reforms that will increase the currently low prices to more efficient levels by increasing the energy price cap to the VOLL, increasing the ancillary service price caps above €10/MWh, increasing prices when hydro plants are at the margin, and remunerating suppliers for providing tertiary reserves. To date, RAE has made progress on two of these reforms by doubling the price cap from €150 to €300/MWh (still far

[33] See European Commission (2016a), pp. 7–9.

below the likely VOLL), and making improvements on hydro participation/pricing (reforms are ongoing regarding actual availability).[34] DG Comp also made it clear that these specific measures may not be sufficient to adequately support system flexibility needs, and that additional improvements may be needed to the energy and ancillary services markets.

To follow through the required transition to the European Target Model, the Greek Parliament issued Law 4425/2016 in September 2016. The Law provided high-level requirements and organizational responsibilities for pursuing the Target Model but did not provide specific design details. The Law does state that the market operator LAGIE will operate the forward, day-ahead, and intraday markets, while the ADMIE will oversee physical unit commitment and dispatch instructions at all timeframes and operate the balancing market. The RAE has begun a public consultation to develop the specific market designs.[35]

II.C. Vision for Achieving the Target Model and Addressing Flexibility Needs

Greece has a pressing need to reform its electricity markets to address the reliability and economic challenges introduced by the transition to a cleaner power sector, and to achieve the Target Model. Reforming the markets will involve prioritizing efforts and balancing conflicting objectives. Such logistical challenges can sometimes become roadblocks to progress or tempt reformers to adopt second-best interim solutions that can create new barriers to a more efficient long-term design.

To help avoid these problems, we suggest that it will be helpful to articulate a long-term vision for an efficient, reliable, and clean electricity market in Greece. This vision can be used to guide both near-term and longer-term reform efforts, and avoid interim or *ad hoc* solutions that could introduce roadblocks in the future. As a set of principles to follow in this process, we recommend that Greece, and all efficient electricity markets, should aim to:

- **Define Energy and Ancillary Service Products that Accurately Reflect Greece's Flexibility Needs.** The starting point for an efficient market is good product definition. For a system like Greece that is integrating large quantities of intermittent resources, it may be that product definitions need to evolve over time to reflect new challenges and flexibility needs. New types or larger quantities of ancillary services may be needed, and energy requirements may need to be defined at more granular time intervals.
- **Enable All Resource Types to Compete on a Level Playing Field.** The existing market infrastructure and rules were designed based on the operational characteristics of traditional fossil plants. But the future electricity market must enable a wider variety of resource types to compete on a level playing field. The RAE is presently making progress on improving the representation of hydro in the market, but more advanced

[34] See Greek Government Gazette (2016a) and Greek Government Gazette (2016b).

[35] For example, see an initial RAE consultation document, RAE (2016a).

software and design solutions may be needed to account fully for hydro facility constraints at different timescales.[36] The market will need reform appropriately to integrate interconnectors, demand response, renewables, storage, and other distributed resources into dispatch and price-setting at all timeframes and for all products. This may require revising product definitions and performance standards to make reasonable accommodations for different resource types, while maintaining the technical standards necessary for reliability. Taking a resource-neutral approach levels the playing field in ways that can minimize costs in the short term and spur innovation in new technology solutions over the longer-term.

- **Support Market Coupling at All Timeframes and as Close to Real Time as Possible.** To maximize efficiency and be consistent with the Target Model, Greece should work to couple markets at all timeframes and as close to real time as possible. Right now, there is no pan-European infrastructure that enables market coupling in the balancing timeframes, but the underlying technology and market solutions needed to make that work have been implemented in other regions.[37]
- **Co-Optimize the Procurement of Energy and Ancillary Service Products at All Timeframes when Ancillary Services Are Procured.** Procuring energy and ancillary services in a co-optimized procurement, as Greece already does in the day-ahead market, minimizes the combined system costs for providing all products. We recommend that Greece pursue this efficient, co-optimized approach in both the day-ahead and balancing timeframes. In Section IV below we explain how Greece can maintain co-optimization while achieving market coupling consistent with the Target Model within the Pan-European Hybrid Electricity Market Integration Algorithm (EUPHEMIA).
- **Set Efficient Prices that Recognize All System Technical Constraints.** To the extent allowed under the Target Model, prices should be set using an efficient optimization formulation that recognizes all physical and technical constraints, such as transmission constraints, unit commitment constraints, and ramping limits.

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[36] For example, accounting for energy limitations, cascading hydro system interactions, and opportunity cost pricing are complex economic and technical issues that likely will not be fully addressed within current reform scope. Finding a complete solution and implementing market clearing and pricing software would be a significant challenge but one that may eventually be warranted to address current underpricing incentives and maximize the energy and flexibility value of Greece's large hydro resource.

[37] For example several of the U.S. Regional Transmission Organization markets operate across broad geographic regions spanning what were previously distinct service territories that were independently dispatched and operated. Further, the California Independent System Operator's (ISO's) Energy Imbalance Market (EIM) used for setting imbalance schedules across increasing portions of the Western U.S. and Southwest Power Pool's Energy Imbalance Service (EIS) market could be useful case studies for how to achieve balancing market coupling in Europe; these approaches enable five-minute economic re-dispatch of generators and interconnectors across many different sub-regions, though the individual balancing authorities maintain responsibility for providing reliability functions such as scheduling ancillary service commitments.

- **Align Dispatch, Pricing, and Settlement Intervals.** The time intervals used for dispatching resources should also be used to set prices and determine payments. Currently, Greece has separate processes for setting prices and dispatch schedules at both the day-ahead and balancing timeframes. Better alignment between dispatch and pricing will incentivize better performance for meeting system needs.

- **Create an Efficient Scarcity Pricing Framework with Prices Rising up to the VOLL.** Efficient electricity markets should enable prices to reflect efficiently high prices during scarcity events, rising to the VOLL at times of involuntary load shedding. This conforms to the European Commission's requirement.[38] Lower-level scarcity events requiring other types of emergency actions should similarly produce high prices commensurate with the severity of the event. A graduated scarcity pricing framework that enables prices to rise to these efficiently high levels can create better incentives for integrating demand response and remunerating the flexibility services needed in a system with significant levels of intermittent resources.

- **Enable Prices to Drop to Efficiently Low Levels (including Below Zero) During Surplus Generation Events.** Increasing levels of intermittent renewable resources also tend to increase the frequency and severity of surplus generation events. During such events, prices should reflect generators' willingness to pay to stay online and avoid incurring cycling costs and missing revenues in subsequent higher-price periods, in order to provide efficient signals for generators to reduce output. In addition, efficient price setting mechanisms should consider the interactions with the investment signals created through clean energy policies, such as feed-in tariffs and feed-in premiums for renewables, and make sure these policies do not distort the market price signals and affect dispatch decisions during surplus generation events under the clean energy policies.

- **Minimize Out-of-Market Actions and Uplift Payments.** The aim should be to design a market that avoids and minimizes out-of-market dispatch instructions and uplift payments. Such actions and payments are an indicator of market inefficiencies such as physical constraints that are missing from the market, incomplete consideration of costs, or misalignment between pricing and dispatch. By transparently monitoring uplift payments and addressing the underlying problems that give rise to their payment, the market can become more efficient and effective over time.

- **Mitigate the Potential for Manipulation and Exercise of Market Power.** Efficient prices should reflect marginal system costs without being influenced by exercise of market power or manipulative behavior. This sometimes requires placing restrictions on the actions of some market participants, such as those with large market shares.

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[38] See European Commission (2017b), Article 9, price restrictions: "There shall be no maximum limit of the wholesale electricity price unless it is set at the value of lost load as determined in accordance with Article 10. There shall be no minimum limit of the wholesale electricity price unless it is set at a value of minus 2000 € or less and, in the event that it is or anticipated to be reached, set at a lower value for the following day…."

We recognize that existing infrastructure systems and institutional arrangements do not make it possible to move immediately to a market design that fulfills all these requirements. There is also some outstanding uncertainty regarding how the institutions and market structures to support the Target Model will evolve over time to more fully address flexibility needs not only in Greece but across the entire European market. These limitations and uncertainties point to the need for some staging and prioritization while pursuing this long-term vision of electricity markets in Greece. Throughout the remainder of this report, we discuss how Greece can apply these principles to take immediate steps toward the longer-term vision and avoid interim solutions that have the potential to introduce new inefficiencies or barriers to longer-term progress.

III. Forward Market

Greece does not currently have an organized forward energy market. It is possible to take financial positions on the Greek electricity market on exchanges outside of Greece, but there is only modest liquidity in such trades.[39] Greece also coordinates with neighboring countries to conduct forward auctions for PTRs on each of the interconnectors, creating opportunities to hedge cross-market positions. Greek Law now requires the introduction of a new forward market operated by LAGIE as an additional opportunity for buyers and sellers to hedge their forward electric energy positions.[40] Positions in the forward market will need to be translated into physical positions in the day-ahead market, and the RAE will be responsible for determining a cap on the volume of forward positions that any individual supplier can take, as a measure for addressing structural market power.[41] We do not offer a specific recommendation for what cap should be imposed, but do stress that such a cap (and other potential measures to mitigate the potential for exercise of market power) will be needed given Greece's market structure with PPC representing a dominant (though declining) share of the retail market.

The European Target Model requirements in the forward timeframe are described in the Guidelines on Forward Capacity Allocation.[42] The Guidelines are focused on guaranteeing an efficient calculation and allocation of cross-border transmission capacity to enhance the integration of the national markets. The European Commission has recently proposed additional provisions intended to reduce barriers for private entities to develop forward markets, but has not established binding requirements.[43] Greece's proposed market is already

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39 See EEX (2017), Economic Consulting Associates (2015), p. 108.

40 See Greek Republic (2016a).

41 See Greek Republic (2016a), par. 6 of Article 14.

42 See European Commission (2016c).

43 See European Commission (2016e), Article 3, Principles regarding the operation of electricity markets, par. 1(n): "Long-term hedging opportunities, which allow market participants to hedge against price volatility risks on a market basis, and eliminate uncertainty on future returns on investment shall be tradable on exchanges in a transparent manner subject to compliance with EU treaty rules on competition." Article 8, Forward markets, par. 3: "Subject to compliance with treaty rules on competition, market operators shall be free to develop forward hedging products

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consistent with European Commission policy related to forward markets, and so the primary consideration will be to maintain this consistency and avoid a situation where the new physical market could crowd out opportunities for private entities to create a wider range of forward products if there is sufficient demand.[44]

Our primary recommendation with respect to the forward physical market is that it should be viewed as an opportunity for market participants to take voluntary (rather than mandatory) forward positions. Voluntary positions can reflect underlying business needs and consumer preferences, and support efficient decision-making and hedging practices. However, the mere existence of a forward market does not guarantee that there will be demand for such hedging products.[45] Some European countries have tried to foster forward contracting by imposing regulated requirements for forward positions.[46] We do not recommend that liquidity in forward hedging products be pursued as an objective in its own right and so we do not recommend any mandatory participation in the forward market to that end.[47]

Finally, we recommend that Greece carefully evaluate the interactions between the forward market and the day-ahead market, and to avoid any design whereby the forward market can be used as a means of bypassing market power mitigation measures in the day-ahead market. To that end, we recommend that the day-ahead market continue to operate as a mandatory gross pool with cost-minimizing unit commitment and dispatch, but with a revised approach as described in the next section. Under that approach, market participants' net positions from the forward market can be physically delivered into the day-ahead market, but all generators' day-ahead schedules would be increased or decreased consistent with least-cost dispatch.

IV. Day-Ahead Market

To comply with outstanding obligations to the European Commission and Greek Law 4425/2016, Greece needs to enhance its day-ahead market to be consistent with the European

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including for the long-term to provide market participants, in particular owners of generation facilities using renewable energies, with appropriate possibilities to hedge financial risks from price fluctuations. Member States shall not restrict such hedging activity to trades within a Member State or bidding zone."

44 For example, these could be created by entities such as the Intercontinental Exchange (ICE) and Nasdaq which are both active in most European energy markets.

45 For example, Portugal and Spain agreed to create a common forward market, OMIP, in the context of the integration of both countries' markets. Trading in this market has been at low volumes.

46 These requirements have been motivated, at least partially, as a way to promote liquidity in the forward market. Regulators also sometimes use forward contracting as a means to mitigate market power. For example, Spain and Portugal require regulated retailers to procure part of their energy in quarterly auctions and France, Belgium, Germany, and Spain require some generators to auction part of their production as Virtual Power Plants.

47 It is outside the scope of this paper to comment on any forward procurement or sales activities that could be mandated as measures intended to address structural market power concerns, but we do not intend for this recommendation to be misinterpreted as a view against any such mandates.

Target Model.[48] The core requirement is that Greece needs to couple its day-ahead market with other European countries.[49] A large number of other member states have already coupled or are working to couple their day-ahead markets through the Price Coupling of Regions (PCR) project, using the EUPHEMIA algorithm.[50] Greece can join these other member states in coupling its day-ahead market.

However, there are a number of options, challenges, and tradeoffs involved in this integration. EUPHEMIA has the advantage of being fully coupled with other markets, but does not support the full functionality of Greece's current day-ahead market software. EUPHEMIA's algorithm accommodates a simpler representation of supply and demand that does not include optimized unit commitments, co-optimized ancillary service procurement, a full representation of plants' technical constraints, or a complete scarcity pricing framework, as will be described in Section VI. As a result of these simplifications, the results of EUPHEMIA on their own do not necessarily reflect technically feasible market solutions and do not establish ancillary service commitments. This raises a number of complex questions regarding how Greece can achieve market coupling while maintaining the efficiency advantages of its current day-ahead market platform.

In this section we describe the high-level principles that we suggest should be used to navigate these tradeoffs. We then recommend a path forward that achieves market coupling through a two-step day-ahead market in the near term, and a longer-term vision for enhancing European market coupling sufficiently to address the current limitations.

IV.A. Overview of Recommended Design Enhancements

Greece's day-ahead market is a mandatory gross pool system, meaning that the market results determine unit commitment and economic dispatch decisions for all power plants. Sellers participate in the day-ahead market on a mandatory basis so that the centralized scheduling process can minimize total system cost to meet demand.[51] Greek Law 4425/2016 requires that

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[48] These requirements related to day-ahead markets are described in the Guidelines on Capacity Allocation and Congestion Management, see European Commission (2015a).

[49] As the Guidelines state: "This Regulation therefore sets out minimum harmonised rules for the ultimately single day-ahead and intraday coupling, in order to provide a clear legal framework for an efficient and modern capacity allocation and congestion management system, facilitating Union-wide trade in electricity, allowing more efficient use of the network and increasing competition, for the benefit of consumers". See European Commission (2015a). Recital (3).

[50] PCR is used to couple the following countries: Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Italy, Latvia, Lithuania, Luxembourg, the Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and the UK. For more information, see EPEX SPOT (2017).

[51] This approach is different from many other European markets that rely on individual market participants to make most unit commitment and dispatch decisions; those markets are designed such that individual participants have privatized incentives to minimize their own costs and balance their own supply and demand. However, TSOs regularly intervene in all of these markets

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the day-ahead market will continue to be a mandatory, centralized dispatch system.[52] Part of the rationale, and need, for this centralized dispatch approach stems from the lack of structural competition in both the wholesale market and in the retail supply market, as well as the relatively small total market size.

Greece needs to reform its day-ahead market to achieve market coupling and comply with other Target Model requirements.[53] At the same time, Greece needs to enhance its day-ahead market to improve efficiency and meet flexibility needs (as discussed further in the remaining sections of the report). We suggest that an efficient day-ahead market in Greece and in other European markets should:

- **Achieve Market Coupling and Other Target Model Requirements.** Consistent with the Target Model requirements and economic principles, the day-ahead market should be fully coupled with other European countries. Cross-border transmission capacity schedules should be established consistent with, and at the same time as, day-ahead market prices are established in each country. Greece should continue to actively participate in establishing the common rules for the internal electricity market and implementing those rules in Greece, for example including the transition from hourly to 15-minute trading intervals.
- **Adopt Efficiency Enhancements for Scarcity Pricing and Flexibility Needs.** There are a number of inefficiencies in Greece's current electricity markets, as discussed more fully in Sections VI and VII below in the context of the balancing and ancillary services markets. We recommend that the same enhancements we propose for those markets should be reflected in an enhanced day-ahead market, to maintain consistency and efficiency across all timeframes. This means that the day-ahead market should: (a) adopt a comprehensive scarcity pricing framework that supports prices up to the energy price cap at the VOLL; (b) increase ancillary service market price caps; (c) pay for tertiary reserves; and (d) enable all resource types to sell all defined services and set prices. We offered a more detailed discussion on each of these recommendations in Sections VI and VII.
- **Continue to Conduct Optimized Unit Commitments and Recognize All Plant Technical Constraints in the Day-Ahead Market.** We recommend that Greece continue to incorporate all plant technical constraints in a fully optimized day-ahead unit commitment and economic dispatch software platform. It will be important for

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to correct physical infeasibility problems and maintain reliability, creating the need for out-of-market uplift payments.

52 See Greek Republic (2016a).

53 Though the Guidelines have been established, the European Commission and Nominated Electricity Market Operators are still completing the design of the day-ahead market. In February 2017, the European Commission put forward draft new market design rules as part of its "Clean Energy for All Europeans" legislative package, including day-ahead market provisions such as maximum and minimum price requirements, and defining a 15-minute trading period. See European Commission (2017b).

Greece's market to continue reflecting these technical realities in order to maintain consistency between market clearing and physical schedules, avoid out-of-market interventions, minimize out-of-market uplift payments, and avoid uneconomic distortion of incentives. The current day-ahead market software platform does reflect all of these physical constraints including ramp limitations, plant ancillary service capabilities, and unit commitment constraints, but the EUPHEMIA platform supporting European market coupling does not. This creates an immediate tradeoff and challenge that must be navigated as we discuss further in Section IV.B below.

- **Maintain Co-Optimized Ancillary Service Procurements.** We recommend that Greece continue to procure energy and ancillary services in a fully co-optimized fashion. Co-optimization of energy and ancillary services offers significant efficiency benefits and prevents inconsistencies between market clearing and physical dispatch as discussed further in Section VII. The importance of co-optimization will increase over time as flexibility challenges grow. The current day-ahead market software platform already supports co-optimization, but the EUPHEMIA platform does not, as discussed further in Section IV.B below.

Currently, there is not an existing market platform in Europe that supports all components of this vision for an efficient day-ahead market in Greece. This suggests that Greece must navigate trade-offs among these different elements of an efficient day-ahead market. We recommend that this be done using a benefit-cost approach to balance among conflicting objectives, and select interim solutions that represent a clear path toward the end state where all of these objectives can be achieved at the same time.

IV.B. Relative Advantages of Day-Ahead Market Platforms

As a starting point for understanding the options available for achieving market coupling and other elements of an efficient day-ahead market, we describe here the relative advantages of the existing market software solutions available for Greece to build upon. Table 2 summarizes how several core design components of the day-ahead market are supported in the software currently underpinning the Greek day-ahead market and in the EUPHEMIA software platform that supports day-ahead market coupling throughout most European markets. The coloring in the table distinguishes highly efficient (green), less efficient (red), and partially efficient (yellow) design solutions. Both of these software platforms have the potential to be enhanced over time, though at very different costs and timeframes.

Table 2
Comparison of Greek Market Software with EUPHEMIA Platform

Design Component	Current Greek Market Software	EUPHEMIA Platform
Market Coupling	Not supported Interconnector schedules offered as price-takers or through priced offers (not coupled with external markets)	Fully supported
Co-Optimized Energy & Ancillary Service Procurement	Fully supported	Not supported
Unit Commitments	Fully supported	Partially supported based on complex order structures
Plant Technical Constraints	Fully supported through detailed representation of plant characteristics	Partially supported based on complex order structures
Administrative Scarcity Pricing	Not presently supported, but likely possible with moderate enhancements	Not presently supported, but likely possible with moderate enhancements
Transmission System Constraints	Zonal constraints/pricing (node-level pricing is supported by the software vendor but not used in Greece)	Zonal constraints and flow-based constraints (no node-level pricing)

Sources and Notes:
Coloring distinguishes highly efficient (green), less efficient (red), and partially efficient (yellow) design solutions.
Price Coupling of Regions (2016).

Greece's current day-ahead market and balancing mechanism operate based on software developed by GE/Alstom. This software supports a fully optimized day-ahead unit commitment and economic dispatch algorithm representing plant-specific commitment and dispatch constraints.[54] The software co-optimizes energy and ancillary service procurements. It is possible for Greece to enhance the software to support the evolution of the day-ahead and balancing markets in ways that improve efficiency and enhance system flexibility. In fact the software vendor supports all of the design solutions that we recommend in Sections VI and VII for an efficient and flexible balancing market. The critical limitation of this software is that it does not support market coupling, and there is no obvious path for that capability to be developed in a timely fashion.

EUPHEMIA is the currently-available day-ahead market clearing solution that supports market coupling across most of Europe, providing a clear efficiency advantage. However, in its current form the software has significant room for efficiency improvements, primarily associated with representing plants' technical constraints. EUPHEMIA does not at present support unit commitment or co-optimized energy and ancillary service procurement. It provides some support for accommodating producers' plant characteristics through a number of different types of complex products that can be offered, but it does not reflect a full suite of plant technical constraints. EUPHEMIA can, and will, be enhanced over time, but Greece

[54] These plant characteristics include, but are not limited to, ancillary service capabilities, minimum and maximum output capability, start-up time (and other commitment limitations), ramp rates, start-up and shut-down costs, and variable costs at different output levels.

will likely have limited opportunities to suggest enhancements before achieving market coupling. In the longer term, Greece's market operator LAGIE will be responsible, along with all other Nominated Electricity Market Operators, for revising and proposing the products accepted in the common price coupling algorithm.[55] Over time it is possible that EUPHEMIA, or some successor platform, may eventually evolve to support the other components of the efficient day-ahead market that we describe in Section IV.A but this is by no means certain.

IV.C. Recommended Approach to Achieving Market Coupling

Given the tradeoffs between Greece's current market software and EUPHEMIA discussed above, we recommend Greece take a staged approach to market evolution as summarized in Table 3. In the immediate market reform stage, we recommend that Greece adopt a two-step day-ahead market clearing approach that leverages the advantages of both EUPHEMIA and its current market platform.[56] The two-step approach would achieve market coupling and comply with Target Model requirements, while still maintaining most of the efficiency advantages of the current market software. Over time, we recommend that Greece work with other European countries to continue to enhance EUPHEMIA, or a successor platform, so that it incorporates the full functionality of both systems.

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[55] "By two years after the entry into force of this Regulation and in every second subsequent year, all [Nominated Electricity Market Operators] shall consult, in accordance with Article 12: (a) market participants, to ensure that available products reflect their needs; (b) all TSOs, to ensure products take due account of operational security; (c) all regulatory authorities, to ensure that the available products comply with the objectives of this Regulation." See European Commission (2015a), Art. 40.3 3.

[56] Another option for complying with the Target Model that we do not fully discuss would be to adopt EUPHEMIA as the day-ahead market platform without a second market step. In that case, Greece would eliminate its current day-ahead market and daily transmission capacity auctions, replacing those functions by participating in EUPHEMIA. Because EUPHEMIA does not yet support ancillary service procurement, Greece would need to procure ancillary services in a separate process conducted either before or after the day-ahead market. Finally, because the results from EUPHEMIA and the ancillary service procurement would not necessarily be technically feasible, the ADMIE would need to conduct an out-of-market day-ahead scheduling process to resolve inconsistencies. We view this option as less attractive than the two-step approach that we describe. Both options would achieve the primary benefits of using EUPHEMIA to couple with other European day-ahead markets. But using EUPHEMIA as a single-step approach has several disadvantages in that it would introduce new inefficiencies, out-of-market adjustments, and uplift payments associated with lack of co-optimization with ancillary service procurement, unit commitment, and full representation of plant constraints.

Table 3
High-Level Proposal for Day-Ahead Market Evolution

	Design and Software Platform	Market Coupling	Ancillary Services	Unit Commitment	Plant Technical Constraints	Priced Network Constraints
Current	**Current Design**					
	Current Greece Market	Not supported	Co-optimized procurement	Fully supported	Full representation	Zonal
Recommended	**Recommended Two-Step Market Design**					
	Step 1: EUPHEMIA • Market coupling in EUPHEMIA determines interconnector schedules • Separate procurements for ancillary services	Fully supported	Not procured in Step 1	Partially supported through complex orders	Partially supported through complex orders	Zonal
	Step 2: Enhanced Greece Software • Mandatory gross scheduling & clearing	Take the outputs from Step 1	Co-Optimized procurement	Fully supported	Full representation	Zonal
Long Term	**Long-Term Vision**					
	Future EUPHEMA or Successor platform	Fully supported	Co-optimized procurement	Fully supported	Full representation	Zonal

Sources and Notes:
Coloring distinguishes highly efficient (green), less efficient (red), and partially efficient (yellow) design solutions.

The two-step day-ahead market design, would work as follows

- **Step 1: Market Coupling in EUPHEMIA.** Step 1 would be a voluntary, portfolio-based market using the EUPHEMIA software platform. It would incorporate positions from the forward market, and voluntary bids and offers from producers, consumers, and traders.[57] The results from Step 1 would determine the final interconnector schedules for the day-ahead market, and may create net supply (or demand) positions for individual market participants. Forward market trades would be treated as price-takers in Step 1 clearing. All incremental quantities cleared in Step 1 would be settled at the Step 1 price. Market monitoring and mitigation measures would be implemented in order to mitigate the potential for exercise of market power.[58]

[57] Traders could take a long or short position in Step 1, but would need to settle that position in Step 2 resulting in no net position at the conclusion of the day-ahead market. Allowing for this type of trade would create an incentive for traders to participate in ways that minimize the potential for price differentials between Steps 1 and 2.

[58] Specifically, a large net buyer within Greece may in some circumstances have an incentive to create artificially large demand and induce uneconomic imports in Step 1, such that the excess quantity of imports could artificially suppress prices in Step 2. The net result of such a strategy could be to lose money on a small transaction in Step 1 in order to benefit from price suppression on a larger transaction in Step 2. This potential incentive to overschedule imports already exists

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- **Step 2: Full Commitment, Dispatch, and Ancillary Service Clearing.** Step 2 would be a mandatory gross pool, with plant-specific market clearing based on an enhanced version of the current Greek market software. As it does now, the software would run a system-wide cost-minimizing unit commitment, economic dispatch, and co-optimized ancillary service procurement, considering all plant commitment costs, variable costs, and technical constraints. The optimization would take as inputs the physical interconnector schedules from Step 1, and would produce as outputs the final energy and ancillary service schedules (generators' sales may increase or decrease compared to their voluntary Step 1 positions, depending on the least-cost system-wide solution). All incremental quantities of energy purchased or sold (compared to the Step 1 position) would be settled at the Step 2 energy price; all ancillary services would be remunerated at the Step 2 ancillary service prices. As a mandatory gross pool clearing approach, Step 2 can also incorporate other effective measures for preventing the exercise of market power if needed, such as a day-ahead must-offer requirement and offer caps for suppliers with the incentive and ability to exercise market power.[59]

The advantages of this approach are that it maintains the efficiency benefits of the current market system but allows for coupled market clearing consistent with the European Target Model. This approach relies primarily on existing systems and software platforms, which could expedite the timeframe for implementation. The primary disadvantage is that as a two-step process, interconnector schedules are not finalized at the same time as ancillary service and generator schedules.

We do not presently have a benefit-cost analysis that quantifies the relative magnitude of the efficiency gains and losses of this two-step approach compared to a range of other options, but recommend that Greece conduct such a study. Pending the results of such a benefit-cost assessment, our initial expectation is that this proposed two-step approach is likely to be a good way forward that will quickly achieve most of the efficiency benefits from market coupling while maintaining the efficiency benefits of the existing approach. As additional near-term enhancements, we recommend implementing ancillary service and scarcity pricing enhancements consistent with those described in Section VI and VII below.

Over time, we suggest that Greece monitor the performance of the two-step market to identify opportunities for improving consistency between the two steps, and work with other European countries to enhance EUPHEMIA's capabilities. Eventually, EUPHEMIA, or some successor platform, may become robust enough to support ancillary service procurement and produce technically feasible schedules. At that point Step 2 could be eliminated from

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on Greece's interconnectors as a consequence of the market structure, and is not a product of the two-step day-ahead market design proposed here.

[59] The introduction of a higher price cap and efficient administrative scarcity pricing mechanisms as discussed in later sections will enable the imposition of supplier offer caps without artificially suppressing market prices during scarcity events.

Greece's day-ahead market and the long-term vision for a fully efficient day-ahead market can be achieved.

V. Intraday Market

Intraday markets allow market participants to update their positions and revise interconnector schedules based on updated market conditions. Greece does not currently have such a market. However, the TSO ADMIE does account for updated market conditions and plant availability in its intraday scheduling processes, using new information to issue revised unit commitment instructions and provide indicative updated schedules to market participants.

To achieve the European Target Model and comply with outstanding regulatory and legal requirements, Greece will need to introduce an intraday market consistent with the Guidelines on Capacity Allocation and Congestion Management.[60] The Target Model envisions a common grid model to update cross-border interconnector schedules within a single continuous trading platform. The algorithm is intended to couple markets across different countries, and allocate the available transmission capacity to buyers and sellers in a way that maximizes economic surplus. A group of European market operators and TSOs are developing this algorithm under the XBID market project, which is expected to launch in the third quarter of 2017.[61] According to Greek Law, LAGIE will be responsible for operating the intraday market, while ADMIE will maintain responsibility for physical operations.

For Greece, the clear path to developing a coupled intraday market is to integrate with the XBID platform once it is launched. Greece also has the option to complement continuous trading with periodic, coupled intraday auctions. We do not make a recommendation at this time as to whether the intraday interconnector capacity auctions would provide incremental benefits beyond continuous trading. However, we do recommend that if Greece does decide to pursue intraday auctions they should be fully coordinated with neighboring systems' auctions, including with Italy.[62]

While the specific design of the intraday market and XBID platform is still being enhanced according to rules decided by the Nominated Electricity Market Operators Committee, we envision an efficient intraday market in Greece should operate similar to the implementation in other countries. Physical interconnector schedules and market participant positions would first be determined in the day-ahead market, after which continuous trading in the intraday market could begin (possibly supplemented by intraday auctions). Market participants would submit incremental buy bids or sell offers into the intraday market to adjust their positions on

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60 See Greek Republic (2016a) and European Commission (2015a).

61 ADMIE and LAGIE are both part of the members of the project developing the market algorithm for the single intraday market. However, they are part of the group of market operators and TSOs committed to early implementation of the algorithm called "Accession Stream". See XBID (2016).

62 Italy is currently in the process of determining its approach to setting intraday auction and continuous trading schedules. EPEX SPOT, *et al.* (2016).

an entirely voluntary basis, with positions cleared based on the XBID algorithm. The intraday market would support two different prices for the two different energy zones in Greece. The intraday market would not need to have mechanisms for representing ancillary service requirements or detailed technical constraints, such as we recommend for the day-ahead and balancing markets.[63] Because the intraday market will be coupled with other countries, it will produce updated interconnector schedules throughout the day. To maximize efficiency, the intraday market should continue operating as close to the balancing timeframe as possible and with the shortest scheduling interval possible. We recommend Greece work with other Member States and participate in the continued enhancement of the intraday market design and clearing within the XBID algorithm.

In parallel but entirely separately, ADMIE would continue to re-optimize generation schedules on a periodic basis on the intraday timeframe. These schedules would incorporate updated interconnector schedules from the intraday market, as well as updated plant availability, load data, and intermittent resource forecasts. Each time it carries out a re-optimization, ADMIE would publish a forecast of indicative (non-binding) prices and plant schedules to market participants for the remainder of the operating day. These updated forecasts would inform market participants' trading behavior in the intraday market and any decentralized unit commitment decisions that might be made outside ADMIE's instruction. We expect that ADMIE will sometimes issue new unit commitment instructions to generators as one output of the intraday scheduling process.[64]

VI. Balancing Energy Market

Traditionally, the day-ahead market has been viewed as the primary or "spot" market for electric energy in Europe. This is one reason that significant effort has been devoted to enhancing the efficiency of day-ahead markets through market coupling and achieving the Target Model requirements. The design and operation of balancing markets have sometimes received less attention than they deserve.

This viewpoint is changing. In Greece and across Europe, efficient and reliable balancing markets are becoming increasingly vital as the electricity sector decarbonizes and attempts to achieve better integration of intermittent clean energy resources. Intermittency is introducing new reliability challenges and flexibility needs that are often addressed through uneconomic, out-of-market measures. Modernized and more efficient balancing markets are needed to manage these challenges through in-market incentives. Efficient prices in this

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63 The XBID platform does not support the representation of such technical constraints and so cannot be used to provide physical plant schedules that are technically feasible. However, it can be used to determine economic and technically feasible interconnector schedules, and the market can rely on the indicative price forecast that comes out of the ADMIE's intraday scheduling process to inform efficient price formation in the voluntary intraday market.

64 To prevent these intraday unit commitment instructions from undermining balancing market prices, we recommend that the balancing market be refined to incorporate start-up costs into price formation as discussed in Section VI below.

context will become much more volatile than they are currently, with very high prices during short periods of supply shortage when intermittent resources are suddenly scarce, and very low or negative prices during short periods of supply excess. The greater volatility and range of prices will more effectively remunerate flexibility, incentivizing existing resources to operate in ways that maximize their flexibility value and encouraging new, innovative solutions to these challenges. These developments will also support more efficient intraday, day-ahead, and forward market prices by creating a more efficient final balancing price, against which net positions are ultimately settled. In this Section we discuss several balancing market enhancements that Greece could pursue to comply with policy requirements and to address its flexibility needs. We then provide a more detailed discussion of a subset of specific enhancements that we view as highly beneficial and achievable in the relatively near term.

VI.A. Overview of Recommended Design Enhancements

The European Commission has recently approved the Guidelines on Electricity Balancing, but the institutional arrangements needed to support their implementation may not be fully available to Greece for some time. In the meantime, Greece has immediate flexibility challenges that must be addressed to cost-effectively and reliably integrate a significant and growing intermittent resource base. To that end, we recommend that Greece pursue, or at a minimum conduct feasibility and benefit-cost analyses of, the following balancing market design enhancements:

- **Developing a Comprehensive Administrative Scarcity Pricing Framework with an Efficient Price Cap at the VOLL:** We recommend that Greece implement an comprehensive scarcity pricing framework in the balancing market (as well as day-ahead market) that will enable prices to rise consistent with marginal system costs during increasingly severe scarcity events, and finally up to a price cap at the VOLL when firm load shedding is needed. We provide a more detailed discussion of our recommendations and options in the following Sections VI.B and VI.C.

- **Enabling Updated Interconnector Schedules through the Intraday Market as Close to Real Time as Possible:** We view a pan-European balancing market that fully accounts for each country's technical constraints as the most economically efficient solution for achieving market coupling in the balancing market. However, at present there is no infrastructure solution available for achieving market coupling in the balancing market, and, given the complexities of developing one, there may not be such a solution for some considerable time to come. Therefore, we recommend that Greece develop an effective intraday market than enables market coupling as close to real time as possible, as discussed in Section V below.

- **Enabling Prices to Drop to Efficiently Low Levels (including Below Zero) During Surplus Generation Events:** Increasing levels of intermittent renewable resources tend to increase the frequency and severity of surplus generation events. Efficient prices during these events should reflect marginal system cost in order to provide the signals for generators to reduce output. Identifying the "efficient" price during such events is a complex task, but, at a minimum, the price should be low enough to reflect traditional generators' willingness to pay to stay online and avoid incurring cycling

costs and missing revenues in subsequent higher-price periods. We recommend that Greece conduct an economic efficiency review of the interactions among pricing, unit commitment decisions, uplift payments, and clean energy policies that affect surplus generation events when reducing the price floor to below zero.[65] In addition, Greece currently has feed-in tariffs for existing renewables and feed-in premiums for new renewables. These subsidies create incentives to offer into the energy market at large negative offer prices to avoid curtailment. We recommend that Greece examine these effects and interactions when pursuing a negative price floor, and develop bidding rules to make sure the market still sends efficient price signals for renewables to reduce outputs during surplus generation events.

- **Enabling Updated Supply Offers Closer to Real-Time:** Currently, Greece's balancing mechanism operates using the same offer prices that were submitted by 12:30 the day before delivery. These offers do not reflect the changes to market conditions that can occur between the day-ahead and balancing timeframes, such as gas market shortages. We recommend that Greece review options for enabling updated schedules closer to the balancing market timeframe.

- **Aligning Settlement, Pricing, and Dispatch on a Five-Minute Basis:** Currently in Greece, ADMIE dispatches resources every five minutes during real time operations, but conducts settlements on an hourly basis and based on prices calculated two to six weeks after delivery.[66] This approach can create a significant disconnect between the value that resources are providing, and what they are paid. This disconnect will continue to grow with the share of intermittent resources. For example, the Texas market has an advanced balancing market with five-minute pricing intervals, fifteen minute settlement intervals, robust administrative scarcity pricing, and a price cap at USD $9,000/MWh. It is common for short-term scarcity events driven by intermittency or ramping constraints to temporarily introduce very high prices of a few thousand dollars per MWh, but only for a brief time of a few pricing intervals. This incentivizes fast-responding, flexible resources to quickly react, capture the value of those high prices, and by doing so quickly resolve the scarcity problem. It also incentivizes investments in innovative technologies like flexibility enhancements at existing plants, flexible demand response, and storage that can capture more value with greater pricing volatility. However, Greece's market does not currently incentivize these efficient behaviors. Prices calculated on an hourly average basis over-remunerate slow-responding resources and under-remunerate fast-responding resources. Further, prices calculated on an *ex post* basis far after delivery create significant price uncertainties that make it impossible for producers to know when their production would be most valuable. We recommend shortening the pricing and settlement intervals down to the five-minute interval used for dispatch.

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[65] The same logic would dictate that the higher-price hours may need to be even higher in order to incentivize efficient commitment schedules without awarding uplift payments.

[66] Specifically, settlement prices are calculated on an *ex post* basis the 12th day of the month following delivery.

- **Incorporating All Resource Types into Price-Setting and Dispatch:** We recommend that all resource types be enabled to actively and efficiently participate in the balancing market, to help ensure that they are called upon at the most opportune times and can contribute to efficient price formation. This may require revised market rules, qualification standards, or software enhancements to integrate resource types that are different from the traditional thermal plants that the Greek market was designed to accommodate. The RAE is presently working to more effectively incorporate hydro plants, which is the most pressing need given hydro's large share of the resource base, role as a price-setting resource in many peak hours, and potential to provide additional flexibility services. However, it is becoming increasingly important to find ways to better incorporate demand response and intermittent resources into price setting and dispatch, given their increasing share of the resource base. Demand response will also have an increasingly important role to play in setting efficiently high prices during scarcity events, bringing an efficient representation of demand into price formation and avoiding approaches to calling on these resources using out-of-market heuristics and payments. For example, in PJM demand response resources offer their load reductions over a wide range of prices from USD $400/MWh to USD $1,800/MWh and can set prices commensurate with their willingness to pay for electricity.[67] It is important to find ways to accommodate different types of demand response ranging from very flexible, fast-responding resources that can provide ancillary services and react to five-minute dispatch instructions every day, to much slower-responding resources with high curtailment costs that wish to be called on only during the most extreme events every few years. Farther in the future, it will likely become important to enable other new technologies such as storage and different types of distributed resources to participate.

- **Integrating Intraday Unit Commitments into Price Formation:** Another sometimes problematic interaction occurs between unit commitment decisions and price-setting. Prices in Greece are set based only on the variable cost of the most expensive unit dispatched and do not consider the commitment (*i.e.*, start-up) costs of that plant. In some cases this could mean that prices are set at only €50/MWh when a peaking turbine is needed for just one hour, when the combined start-up plus variable costs could actually cost €500/MWh on a combined basis. The higher commitment costs then need to be remunerated through out-of-market uplift payments rather than through competitive market prices. More efficient pricing that incorporates commitment costs can incentivize more cost-effective solutions like demand response, avoid the need for out-of-market payments to make the peaking resource whole for the start-up costs, and prevent out-of-market intraday unit commitment decisions from artificially suppressing peak prices. There are a variety of solutions for better integrating commitments, dispatch, and price-setting.[68]

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[67] Resources offering at the maximum allowed level likely have even higher willingness to pay for electricity, suggesting that a higher offer cap for demand response would enable a wider range of prices and more efficient behaviors. See McAnany (2017).

[68] For example, the California ISO is currently enhancing its market with a full unit commitment and economic dispatch solution conducted every five minutes. The solution incorporates a multi-

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This series of recommendations incorporates a number of enhancements that are likely to provide significant flexibility benefits to Greece over the near and medium-term, although it is not a comprehensive list of the potentially beneficial reforms that could be pursued. We recommend that Greece examine which of these enhancements can be pursued quickly as part of its immediate reform efforts or that can be staged into the balancing market over the coming years. We more fully discuss the recommendations associated with scarcity pricing and administrative penalty factors below, given that these are aligned with European Commission policies, can be implemented relatively quickly compared to some of the other enhancements, and will immediately begin supporting Greece's flexibility needs.

VI.B. Scarcity Pricing and a Price Cap at the VOLL

Both DG Comp and the RAE have recognized the importance of enhancing the electricity market with more efficient scarcity pricing and a price cap that will eventually rise to the VOLL.[69] This is consistent with broader European Commission policies for enhancing the internal electricity market.[70] The RAE has made some progress by increasing the current price cap from €150 to €300/MWh, but the updated cap is still far below the VOLL. As shown in Table 4, most other European markets have estimated VOLL values ranging €1,250–36,800/MWh and have implemented balancing market price caps of €3,000-9,999/MWh (or no cap). As long as Greece's markets are capped at this low level, it will not be possible to efficiently remunerate flexible resources, incentivize demand response, or fully incentivize imports during scarcity events.

We therefore recommend that Greece proceed with an economic analysis evaluating an appropriately high price cap considering: (a) an estimate of the appropriate VOLL in Greece; (b) the price caps in neighboring markets (such as the €3,000/MWh cap in Italy); and (c) the unique circumstances in Greece.[71] The price cap can be increased in stages over a few years

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hour look-ahead period that minimizes the combined commitment and dispatch costs over the multi-hour period, with price-setting in the immediate interval accounting for the constraints and shadow price of dispatch costs imposed on future intervals.

69 See European Commission (2016a).

70 See European Commission (2017b), Article 9: "There shall be no maximum limit of the wholesale electricity price unless it is set at the value of lost load as determined in accordance with Article 10. There shall be no minimum limit of the wholesale electricity price unless it is set at a value of minus 2000 € or less and, in the event that it is or anticipated to be reached, set at a lower value for the following day. This provision shall apply, inter alia, to bidding and clearing in all timeframes and include balancing energy and imbalance prices."

71 As in all systems, Greece will face uncertainties in the appropriate VOLL based partly on the wide range of values that would apply for different types of customers. For example, residential customers typically have the lowest VOLL of a few thousand Euros per MWh, while some types of commercial and industrial customers can have a much higher VOLL up to a few hundred thousand Euros per MWh. The appropriate VOLL to use for wholesale market purposes depends on which customers are most likely to face involuntary load shedding, for example if protocols protect the highest-value commercial centers and critical public services from service

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until it reaches the level supported by an analysis according to the new methodology for VOLL's calculation that will be developed by ENTSO-E.[72] In the immediate timeframe, Greece can move ahead with increasing the price cap to at least €1,200/MWh even before a full VOLL study is completed, given that evidence from other markets suggests this as a minimum level.

Table 4
Wholesale Price Caps and Estimates of VOLL in European Markets

Country	Price Cap			Estimated VOLL
	Day-Ahead *(€/MWh)*	Intraday *(€/MWh)*	Balancing *(€/MWh)*	*(€/MWh)*
Belguim	€ 3,000	€ 9,999	€ 4,500	n/a
Denmark	€ 3,000	no cap	€ 5,000	€ 2,933 – € 36,800
Croatia	€ 3,000	n/a	no cap	n/a
France	€ 3,000	€ 9,999	€ 9,999	€ 26,000
Germany	€ 3,000	€ 9,999	no cap	n/a
Ireland	€ 3,000	€ 3,000	n/a	€ 11,018
Italy	€ 3,000	€ 3,000	€ 3,000	€ 3,000
Poland	€ 350	no cap	€ 350	€ 1,250 – € 2,100
Portugal	€ 180	€ 180	no cap	€ 3,000
Spain	€ 180	€ 180	no cap	n/a
Sweden	€ 3,000	no cap	€ 5,000	€ 2,800 – € 7,600

Sources and Notes:
See European Commission (2016d), p. 30.

Beyond just increasing the price cap to the VOLL, we recommend that Greece develop a comprehensive scarcity pricing framework that enables prices to rise gradually, consistent with the severity of scarcity events. As summarized in Table 5, Greece's current market does not presently differentiate prices based on the range of marginal system costs under different types of scarcity events; some emergency events will produce prices at the cap while others introduce no scarcity pricing at all.

To more effectively support efficient pricing across this spectrum, we recommend that Greece: (1) comprehensively review the range of low-level to high-level emergency events that could be encountered; (2) evaluate the marginal system costs during those conditions considering the starting point in Table 5; (3) ensure that emergency procedures will result in lower-cost actions being taken before higher-cost actions; and (4) review and amend market price formation as needed to ensure that prices will be set equal to system costs during each type of event. In many cases, administrative scarcity pricing can be achieved through "penalty factors" on market clearing as discussed further in Section VI.C. Scarcity events

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interruption. The price cap also should not consider any VOLL estimate exceeding the cost of maintaining on-site backup power, as such customers will have already invested in backup power systems to protect against distribution system outages.

72 See European Commission (2017b)

imposing system costs above €300/MWh should be priced at the cap for now, but eventually can be priced consistent with marginal system costs as the cap increases to the VOLL.

Table 5
Scarcity Pricing Levels During a Range of Emergency Event Types

Scarcity Event Type	Current Price-Setting Mechanism in Greece	Potential Marginal Cost-Based Pricing Approach
Peaking Generation	• Variable costs or hydro offer	• Incorporate variable plus start-up costs for peakers • Enhanced hydro pricing accounting for opportunity-costs and potential energy shortages
Gas Supply Shortages	• Day-ahead offer prices	• Within-day offer prices (though gas prices may be hard to define)
Emergency Imports and Export Curtailments	• Price cap	• External market's balancing price
Demand Response & Load Curtailment	• No demand response offers enabled in market • Calling load curtailment suppresses prices by making demand appear lower	• Resource-specific offers for enabling demand response • Incorporate a proxy strike price when load curtailments are instituted
Ancillary Service Shortages	• Price cap	• Varying price levels based on the type of service • Prices set at marginal increase in probability of lost load times the value of lost load when operating with a shortage of each reserve type (see Section VI.C)
Calling Cold Reserves	• Price cap	• Likely price at the cap despite inconsistency with variable cost (to avoid price suppression from out-of-market supply)
Involuntary Load Shedding	• Price cap	• Value of lost load

A final critical component of a comprehensive scarcity pricing framework is an approach to enabling high scarcity prices while managing and mitigating against the potential for abuse of market power. In most European markets, scarcity pricing is achieved by allowing sellers to offer into the market at high (or very high) prices that exceed their marginal production costs. Market power abuse is prevented through a combination of approaches including structural reforms to prevent excess market share by one entity, incorporation of active retail supply activity, competition from new entrants, and the potential for *ex post* enforcement actions.

Another option for Greece either in the near term or permanently is to maintain generator offer caps that are below (possibly significantly below) the price cap. For example Texas has a relatively strict monitoring and mitigation framework that prevents generators from offering

at prices that are substantially above their marginal costs.[73] However, prices do reach very high levels through uncapped demand response offers and robust administrative scarcity pricing mechanisms that increase prices gradually up to the cap at USD $9,000/MWh.[74]

VI.C. Efficient Pricing During Operating Reserve Shortage Events

As a relatively straightforward and well-tested method of introducing scarcity pricing into the Greek electricity markets, we recommend adopting administrative penalty factors into the pricing algorithm in order to create efficient scarcity prices during operating reserve shortage events. Creating high prices during these shortage events creates strong incentives for market participants to react quickly to resolve these shortages through incremental generation, attracting more imports, and inducing demand response. Penalty factors and related scarcity pricing mechanisms are used throughout the U.S. markets and in some other international markets to produce high prices whenever the system must run with a shortage of operating reserves. To illustrate how these mechanisms work we describe the ISO New England approach based on fixed penalty factors, and an alternative approach used in the Electric Reliability Council of Texas (ERCOT) based on an operating reserve demand curve.

As a first example, Table 6 summarizes the penalty factors implemented in the ISO New England electricity markets. On a system-wide basis, ISO New England procures four types of operating reserves ranging from the lowest-quality "replacement reserve" to the highest-quality "10-minute spinning reserve".[75] Resources qualified to sell the highest-quality reserves are also qualified to sell lower-quality reserve. During shortage events, the system operator does not always have sufficient resources to maintain the target quantity of all operating reserves because it may need to deploy some of the reserves to meet energy needs. In these circumstances, the market clearing software incorporates a "penalty factor" representing the marginal system costs of falling short on operating reserves. The penalty factor is added to the marginal energy offer to create a higher energy price. If the system must operate with a shortage of more than one type of reserve, then multiple penalty factors are added into the energy price.

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73 "Small fish" with less than 5% offer share are allowed to offer at very high prices, with the offer share tests being conducted on both a system-wide and locational basis. In addition, larger suppliers are allowed to submit Voluntary Mitigation Plans that may permit higher offers on some of their capacity under some circumstances. Newell, *et al.* (2012), Section V.A.5.

74 See Newell, *et al.* (2014).

75 Additional reserves are procured for locational needs, but we do not discuss those here for simplicity.

Table 6
ISO New England Penalty Factors for Depleting Operating Reserves

Operating Reserve	Penalty Factor *($/MWh)*	Energy Price When Short *($/MWh)*
Replacement Reserve	$250	$1,250
30-Min Operating Reserve	$1,000	$2,000
10-Min Non-Spinning Reserve	$1,500	$3,500
10-Min Spinning Reserve	$50	$3,550

Sources and Notes:
Reported in USD. Assumes the marginal offer for energy is $1,000/MWh.
Replacement Reserve penalty factor is not additive, but all others are. Additional penalty factors can apply for locational reserve shortages.
See ISO New England (2016).

To show how the penalty factors create higher energy prices consider two examples, one with a relatively low-level scarcity event and a second with more extreme shortage events. In both cases, assume that the marginal energy offer is from a $1,000/MWh demand response resource:

- **Low-Level Scarcity Event:** If the system must run short of replacement reserves but no other reserves, then prices for: (a) the replacement reserve product will be at the penalty factor of $250/MWh; and (b) energy will be at $1,250/MWh (or the $1,000/MWh marginal energy offer plus the $250/MWh penalty factor).
- **Extreme Scarcity Event:** If the system must run short of multiple products, the lowest-quality products will be fully depleted first to the extent possible. If all four products are in shortage, then the prices for: (a) the highest-quality 10-minute spinning reserve product will be $2,550/MWh (reflecting the sum of the additive penalty factors $1,000/MWh, $1,500/MWh, and $50/MWh); and (b) energy will be at $3,550/MWh (or the $1,000/MWh marginal energy offer plus the same additive penalty factors).[76]

The combined effect is to create a graduated scarcity pricing system where higher prices are created in conditions of greater scarcity. Many of these scarcity events are driven by operational shortages that last only for a few five-minute pricing intervals, but others can be more sustained if they are driven by resource adequacy shortages. Penalty factor-based pricing is relatively straightforward to integrate into energy market pricing software systems, with the penalty factor contributing an additional cost on the system for running short compared to the targeted quantity of reserves. In fact, Greece's energy market software

[76] As implemented in ISO New England, the penalty factor for replacement reserves is not additive to the other penalty factors. If all four penalty factors were additive, then the energy and 10-minute reserve prices would both be $250/MWh higher in this example.

vendor GE/Alstom already incorporates penalty factors as a tested design solution in other jurisdictions including ISO New England, PJM Interconnection, and Midcontinent ISO.

As another example, ERCOT has incorporated a different scarcity pricing concept into energy and ancillary service market pricing.[77] The basis of this design is the operating reserve demand curve (ORDC) shown in Figure 1.[78] The ORDC reflects the willingness to pay for spinning reserves. To calculate the shape and magnitude of the ORDC, the system operator conducted a simulation analysis to estimate the loss of load probability (LOLP) at each quantity of reserves. The LOLP is low when there is a surplus of reserve, and so the willingness to pay for more than 5,000 MW of reserves is very low and approaching zero. The LOLP becomes very high when reserves are in shortage, with the ORDC causing energy prices to reach the price cap at the VOLL of $9,000/MWh.[79]

Similar to the ISO New England penalty factor approach, ERCOT's ORDC creates strong scarcity prices during shortage conditions with more extreme events creating stronger price signals. It has the additional advantage of producing prices tied explicitly to an administrative estimate of the marginal value of operating reserves to help avoid involuntary load shedding events. Disadvantages of the ORDC approach are that it is relatively more complicated to estimate marginal value and to implement in market pricing software.

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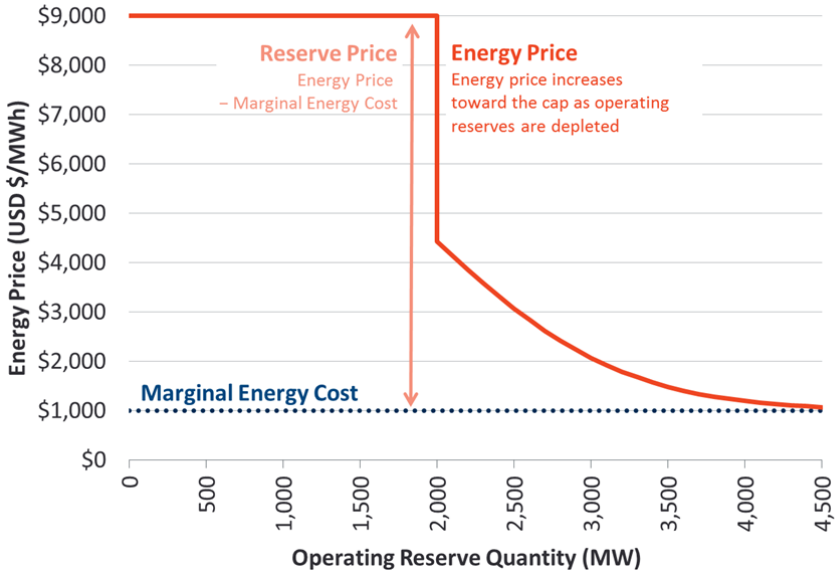
77 See ERCOT and Hogan (2013).

78 For simplicity, we show only the ORDC for spinning reserves in this figure. There is a separate ORDC representing the willingness to pay for non-spinning reserves. The maximum price for non-spinning reserves is half of that for spinning reserves.

79 The ORDC is implemented as additive to the marginal energy offer, but the price cap for energy is $9,000/MWh. Because the marginal energy offer can be at any height, the vertical scale of the ORDC varies with system conditions as VOLL minus the marginal energy offer. As a result, the maximum energy price is always $9,000/MWh, but the maximum price for spinning reserves can be close to the VOLL (if the marginal energy offer is very low) or fairly small (if the marginal energy offer is very high).

Figure 1
Operating Reserve Demand Curve in Texas



Sources and Notes:
Represents the curve in Summer Hours 15–18, assumes marginal energy cost of $1,000/MWh.
See ERCOT and Hogan (2013).

Adopting operating reserve penalty factors or demand curves would offer significant advantages in Greece. Particularly if combined with more granular pricing and settlement intervals, this mechanism could introduce strong price signals to incentivize flexible supply and demand to react quickly to resolve system shortages.

A system of fixed penalty factors is likely easiest to implement in the near term. In any case, the price levels for each quantity and reserve type could be informed by probabilistic analysis of marginal system value as is done in Texas. A final advantage of administrative scarcity pricing in Greece is that it avoids the concerns of economic withholding that can arise from scarcity pricing regimes that rely on high producer offer prices, making it more feasible to adopt scarcity pricing more quickly and with less need for additional protections against abuse of market power.

VII. Ancillary Services Markets

Well-designed ancillary service markets will be a critical component of the solution to meeting flexibility needs in Greece and other countries incorporating large quantities of intermittent renewables. Unfortunately, many markets have not placed sufficient emphasis on the design of modernized ancillary service products that match system needs, efficient market-based procurement approaches, and enabling efficient price formation across energy and ancillary products.

Greece's ancillary services markets, like its energy market, are designed in a way that produces inefficiently low prices. Primary and secondary reserves are subject to an inefficiently low price cap of €10/MWh, while tertiary reserves are not yet paid at all. DG Comp requires Greece to correct these problems as part of its reform efforts.[80] We view these reforms as relatively straightforward to pursue in the near term using Greece's existing market software platform in the day-ahead and balancing markets. However, to achieve the Target Model in the day-ahead and balancing timeframes, Greece will need to navigate some efficiency and regulatory tradeoffs. For example, the pan-European day-ahead market solution EUPHEMIA does not yet support co-optimized energy and ancillary service procurement. To help balance among these tradeoffs as they arise, we recommend that Greece use benefit-cost analyses to inform the path forward and avoid any interim solutions that could create barriers to the long-term vision laid out in Section II.C above.

VII.A. Overview of Recommended Design Enhancements

Greece's ancillary service products and market, which were designed for a fully controllable system of traditional resources, will not necessarily support the needs of Greece's future electricity system that relies increasingly on intermittent resources. Enhancing Greece's ancillary service markets to efficiently and reliably support emerging flexibility needs will require focus on three fundamental market design components:

- **Product Definitions and Quantity Requirements** that are consistent with the evolving system reliability needs;
- **Qualification Standards** that make reasonable accommodations for enabling emerging technologies such as storage and demand response to provide ancillary services, as long as they are technically able to support the relevant system reliability needs; and
- **Procurement and Price Formation** that incorporates efficient, market-based approaches to achieve least-cost procurement and accurately reflect the marginal system value of providing each service.

Greece's ancillary service markets currently consist of primary reserves, secondary reserves (with separate secondary-up and secondary-down products), and tertiary reserves; these reserves correspond roughly with the frequency containment reserves, frequency restoration reserves, and, replacement reserves defined in the draft Guideline on Electricity Transmission System Operation.[81] Over time, Greece may need to review the definitions and procured quantities of these products to ensure that they adequately support the flexibility needs of the evolving system. The need to adopt revised product or qualification requirements can also arise from a desire to enable emerging technologies to participate in these markets and contribute to system reliability without undue barriers. Other markets incorporating large quantities of intermittent renewables have responded by developing new or revised services

[80] See European Commission (2016a), p.8.

[81] See European Commission (2016f).

such as Midcontinent ISO's and California ISO's ramping products or Texas's proposal for a fast frequency response service.[82]

It is possible that in some cases the reliability needs and ideal product definitions in Greece may not exactly correspond to the needs of other European systems. This challenge is not unique to Greece and we expect that it will affect many countries across Europe as the region moves toward achieving the Target Model in the balancing timeframe. To manage this evolution effectively, we recommend that Greece ensure that the Target Model is achieved, enhance product definitions as necessary to reflect its unique system challenges, and actively engage with other Member States to refine the Guidelines as needed to continue adapting to new technologies and reliability needs.

Finally, efficient ancillary services markets should support least-cost procurement and settle those procurements at efficient prices. Greece already supports efficient least-cost co-optimized scheduling of energy and ancillary services in the day-ahead market and balancing mechanism, but provides inadequate incentives for resources to participate in ancillary service sales based on inefficiently low prices. The current approach also does not align pricing, dispatch, and settlement intervals in that prices determined based on day-ahead market conditions are used to settle delivered quantities consistent with real-time balancing conditions. We recommend reforming this approach to set efficient day-ahead prices that are settled against day-ahead quantities, and setting efficient five-minute balancing market prices that are settled against five-minute balancing quantities.

We provide detailed descriptions for how Greece can quickly address the most significant underpricing problems in Sections VII.B and VII.C below. In Section VII.D we describe the importance of maintaining co-optimized procurement of energy and ancillary services, even though the infrastructure to support co-optimization and market coupling at the same time is not yet available.

VII.B. Market-Based Remuneration of Tertiary Reserves

Greece has a defined requirement to maintain approximately 600–1,000 MW of tertiary reserves to support system reliability depending on the hour of day.[83] The day-ahead market clearing software imposes a constraint ensuring that tertiary reserve requirements are maintained in all hours and that they are met through least-cost procurement. However, this is an unpriced constraint in market clearing, and sellers are not compensated for providing this service. DG Comp has required that Greece correct this problem by identifying a market-based mechanism for procuring and remunerating tertiary reserves.[84] The RAE is now reviewing options for remunerating spinning tertiary reserves, but is not currently

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82 See CAISO (2016), pp. 223–235; MISO (2016), pp. 50–51; ERCOT (2013).

83 Currently tertiary reserve requirements are defined as one combined requirement, but ADMIE and RAE are currently proposing the separation of spinning and non-spinning reserve products. See ADMIE (2017b).

84 See European Commission (2016a), p.8.

reviewing options for remunerating non-spinning tertiary reserves or for addressing associated price suppression issues in the balancing timeframe (as discussed below).

In the balancing market, the current approach to tertiary reserves creates a different sort of price suppression problem (beyond failing to compensate the providers of that service). Tertiary reserves are defined as the reserves that are needed to support five-minute load following capability over the hour and contingencies (*i.e.*, generating unit outages). The associated 600–1,000 MW quantity requirement is maintained throughout the day-ahead and intraday scheduling processes, ensuring that significant quantities are available. However, the tertiary reserve requirement is eliminated when running five-minute dispatch in the balancing mechanism, meaning that a significant quantity of excess supply is suddenly made available for energy dispatch. This creates a structural disconnect that artificially suppresses the five-minute balancing price compared to the day-ahead price and prevents scarcity pricing from materializing.[85]

We suggest that it will be relatively straightforward to correct these problems within the existing market software by maintaining the same quantity of tertiary reserve requirements in both the day-ahead and in the five-minute balancing markets. The quantity of tertiary reserves procured from a particular resource in the day-ahead market would be paid the day-ahead price, and any incremental (decremental) quantities of tertiary reserves procured from that resource in the balancing market would be paid (charged) at the five-minute balancing market price.

We expect that over time the definition of the tertiary reserve product may need to be adjusted (or replaced with a different product) to better reflect the underlying system need in a consistent way at both timeframes. For example, if spinning and non-spinning reserves are separated into two products as the RAE proposes, then we recommend that the same quantity of spinning and non-spinning reserve requirements be adopted in the day-ahead and real-time markets.

VII.C. Increasing Ancillary Service Price Caps

Greece currently imposes an inefficiently low price cap of €10/MWh for ancillary services, a problem that DG Comp requires Greece to correct.[86] However, DG Comp did not recommend a specific level at which it would be appropriate to cap these prices.

We recommend that Greece adopt ancillary service price caps consistent with the overall scarcity pricing framework described in Section VI.B above. Under this framework the price

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[85] The *ex post* price currently used for settlement does not have this particular type of underpricing problem however, because the tertiary reserve constraint is maintained when calculating the *ex post* hourly price. The ex post price is still under-reflective of scarcity pricing however, given the hourly granularity. If adopting settlements based on the five-minute realized balancing price as we recommend, it would be essential to correct the five-minute underpricing concern caused by the release of tertiary reserves to provide energy.

[86] See European Commission (2016a), p.8.

paid for each type of ancillary service would be based on its marginal system value, which is the marginal increase in probability of lost load times the VOLL. Achieving prices consistent with this marginal value can be implemented into the existing market software as a series of penalty factors imposed for running short of operating reserves. Estimating the most efficient price levels consistent with marginal value will require a probabilistic analysis of the probability of lost load based on the quantity of each reserve type, similar to the analysis regularly conducted in Texas for this purpose.[87]

As an interim and transitional solution until such an analysis can be completed, Greece could impose moderate-to-low penalty factors for each type of reserve. For example, imposing penalty factors of €100/MWh for running short on each of primary, secondary, and tertiary reserves would translate to price caps of €300/MWh, €200/MWh, and €100/MWh respectively. The resulting prices would still be below marginal system value during shortage conditions, but would provide sufficient room to produce efficient prices during most non-shortage conditions and would enable a relatively low-risk approach to implementation and testing.

VII.D. Co-Optimized Procurement of Energy and Ancillary Services

Greece's current market design incorporates the co-optimized procurement of energy and ancillary services in the day-ahead market and balancing mechanism. This enables Greece to procure all of its energy and reserve requirements at the lowest combined cost from among all available and qualified resources. Further, once the pricing inefficiencies discussed in the prior sections are addressed, this approach will produce efficient scarcity prices with energy and ancillary services priced in a coherent way. Depending on system conditions, ancillary services prices would be set at:

- **Non-Scarcity Conditions:** Ancillary service prices would reflect the marginal resource's incremental cost of providing that service including: (a) incremental variable operations and maintenance costs incurred (if any), plus (b) lost opportunity cost of not selling energy in that pricing/dispatch interval;[88] and
- **Scarcity Conditions:** Ancillary service prices would reflect marginal system value to be gained if it were possible to procure more of each reserve, as represented by the penalty factor for that reserve (plus the penalty factors for any lower-value products that are also in shortage).

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87 See ERCOT and Hogan (2013).

88 For example, consider a generator with a variable cost of €50/MWh for producing energy, in an hour when the energy price is €75/MWh. That generator would earn €25/MWh in profit from selling energy and so would not wish to sell secondary reserves unless the price paid for those reserves is at least €25/MWh. If, on top of that, selling secondary reserves would impose additional maintenance costs of €5/MWh, then the generator will need to earn at least €30/MWh to voluntarily sell secondary reserves. Co-optimized energy and ancillary service procurements automatically take this opportunity cost into account to set efficient prices across multiple products.

Given the significant pricing and efficiency benefits, we recommend that Greece continue to use a co-optimized energy and ancillary services procurement approach even as it reforms its markets to meet the Target Model requirements. As described in Section IV above, Greece can continue to use a co-optimized procurement approach even though most other European countries do not. Instead, most other countries secure ancillary services through separate procurement processes such as daily, weekly, or monthly auctions.[89] These approaches can create a range of different inefficiencies, among them: (a) uncertainties in energy prices and schedules creating uncertainty in opportunity cost that should be factored into the ancillary service offer price; (b) inconsistencies in clearing results that cause higher-cost resources to produce energy rather than ancillary services; and (c) inflexibility to readjust energy and ancillary commitments after market conditions are realized. The nuances of how these inefficiencies manifest differ based on the exact approach in each region, and we optimistically expect that eventually these inefficiencies can be resolved through enhancements that support co-optimization and market coupling within the integrated day-ahead market. In the meantime, we recommend that Greece should attempt to maintain the benefits of a co-optimized approach while adopting the Target Model's provisions and using EUPHEMIA for market coupling with the other European markets, as discussed in Section IV above.

[89] ENTSOE (2016).

VIII. Summary of Recommended Market Design in Greece

Greece must implement significant reforms to its wholesale electricity market over the coming years to comply with Greek and European policy mandates and to support the cleaner electricity system of the future. The existing market design that was designed primarily to accommodates the capabilities and limitations of fossil plants will not be the same market design needed to support the cleaner, more intermittent, and more distributed electricity system of the future. To make progress toward a more efficient market design, we offer a number of specific recommendations that can be immediately pursued, as well as higher-level recommendations for achieving further enhancements over time.

Figure 2
Overview of Recommended Market Design in Greece

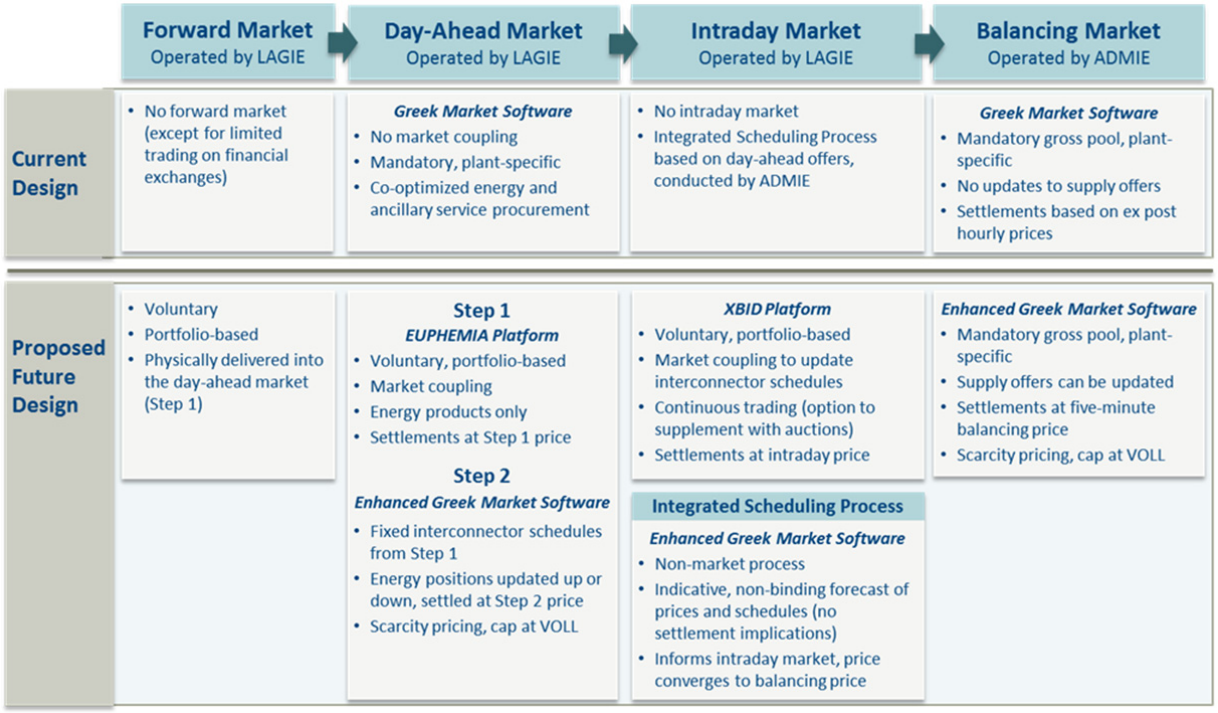

Figure 2 provides a summary description of our recommended approach to implementing or enhancing Greece's forward, day-ahead, intraday, and balancing markets. This recommended structure aims to leverage the advantages of existing market systems in Greece as well as those supporting other European markets. We envision this integrated set of markets to achieve a number of immediate efficiency and flexibility improvements, as well as supporting progress toward a longer-term vision as follows:

- Forward Market: Greece will need to implement a new forward energy market consistent with Greek Law 4425/2016, which mandates that forward trades be physically delivered into the day-ahead market and that the RAE impose maximum procurement quantities for individual retail suppliers. We recommend that the forward market:
  - Support voluntary, portfolio-based trades.

- Incorporate provisions that would prevent individual market participants from sidestepping full participation in the mandatory, centralized day-ahead market (that will rely on plant-specific unit commitment and economic dispatch to minimize total system cost).[90]

- **Day-Ahead Market:** We recommend that Greece use a benefit-cost analysis to choose from among a full spectrum of options for achieving market coupling. Pending the results of such an analysis, our preliminary recommendation is to adopt a two-step day-ahead market that is likely to capture the majority of efficiency benefits from both market coupling and an enhanced version of Greece's current market software.

  - *Step 1* would be a voluntary, portfolio-based market cleared in the EUPHEMIA software platform, which is consistent with the Target Model and is used to support market coupling in most European countries. It would incorporate schedules consistent with forward market trades, and voluntary bids and offers from producers, consumers, and traders.[91] The results from Step 1 would determine the final interconnector schedules for the day-ahead market, and may create net supply (or demand) positions for individual market participants. Forward market positions would be treated as price-takers in the Step 1 clearing, *i.e.* they would not set the Step 1 prices. All incremental quantities cleared in Step 1 would be settled at the Step 1 price.

  - *Step 2* would be a mandatory gross pool, with plant-specific zonal market clearing based on an enhanced version of the current Greek market software. As it does now, the software would run a system-wide cost-minimizing unit commitment, economic dispatch, and co-optimized ancillary service procurement, considering all plant commitment costs, variable costs, and technical constraints. The optimization would take as inputs the physical interconnector schedules from Step 1, and would produce as outputs the final energy and ancillary service schedules (generators' sales may increase or decrease compared to their voluntary Step 1 positions, depending on the least-cost system-wide solution). All incremental quantities of energy purchased or sold (compared to the Step 1 position) would be settled at the Step 2 energy price; all ancillary services would be remunerated at the Step 2 ancillary service clearing price.

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[90] For example, the RAE has already implemented reforms and is working on ongoing efforts to reform the price and quantity of hydro offers in the day-ahead market in order to prevent artificial price suppression. If the forward market were instead designed as a physical exchange with individual resources treated as price takers day-ahead, this would effectively undo and eliminate the hydro bidding rules.

[91] Traders that do not have a physical supply or demand position could take a long or short position in Step 1 based on their offer or bid price. If cleared, the same quantity would be inserted as an offsetting, price-taker position in Step 2 resulting in no net position at the conclusion of the day-ahead market. Allowing for this type of trade would create an incentive for traders to participate in ways that minimize the potential for price differentials between Steps 1 and 2.

- Both steps of the day-ahead market would be enhanced to conform to the flexibility, ancillary service, and scarcity pricing recommendations described in the context of ancillary services and the balancing market below.
- Market monitoring and mitigation measures would need to be implemented to mitigate the potential for exercise of market power. Specifically, large net buyers may need to have some restrictions placed on the quantity of net demand submitted into Step 1.[92]

- **Intraday Market:** Greece does not currently have an intraday market, but must implement one to conform to the European Target Model. We recommend that Greece implement that market by integrating with the XBID platform that is planned to go live later in 2017 and will support market coupling across most of Europe. The platform will support continuous intraday energy trading and updated interconnector schedules. For Greece's implementation, we suggest that:
  - The intraday market should be conducted on a voluntary, portfolio-based, continuous-trading basis. We do not make a recommendation regarding whether the intraday market should be supported by periodic intraday interconnector capacity auctions, but we do recommend that Greece carefully coordinate with any neighboring markets, including Italy, when considering such auctions.
  - Intraday market transactions should not be subject to any plant-specific or technical feasibility provisions. Instead, we recommend that the intraday scheduling processes implemented by the Independent Power Transmission Operator (IPTO or ADMIE) should be conducted as an entirely parallel and separate function. The results of ADMIE's intraday scheduling processes would provide indicative schedules and prices for the remainder of the trading day and help to inform price formation in the voluntary intraday market (and the two would be expected to converge at the close of the intraday market).
  - Market closure should be as close to real time as possible, and the granularity of scheduling intervals should be as small as possible (ideally, the settlement periods should be 15 minutes, consistent with the European Target Model). Over time Greece can work with other participating member states to make further enhancements to increase granularity and reduce latency. Ultimately these enhancements will improve the value of interconnected systems to support the flexibility needs across the integrated European market.

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92 A large net buyer within Greece may in some circumstances have an incentive to create artificially large demand and induce uneconomic imports in Step 1, such that the excess quantity of imports could artificially suppress prices in Step 2. The net result of such a strategy would be to lose money on a small transaction in Step 1 in order to benefit from price suppression on a larger transaction in Step 2. This potential incentive to overschedule imports already exists on Greece's interconnectors as a consequence of the market structure, and is not a product of the two-step day-ahead market design proposed here.

- **Balancing Market:** We recommend that Greece enhance its current balancing market to improve economic efficiency and better incentivize flexibility services. These changes will correct a number of underpricing and under-remuneration concerns with Greece's current balancing mechanism, but can likely be implemented with modest enhancements to the current market software. We recommend that Greece:
  - Incorporate the final interconnector schedules from the intraday market as the starting point for the balancing market. Energy product settlements would be based on the net incremental or decremental balancing position in the balancing market compared to the last intraday market position.[93]
  - Increase the price cap in the balancing market (as well as in the forward, day-ahead, and intraday markets) to the value of lost load (VOLL). This price cap increase could be phased in over time, and should be based on a study of the appropriate VOLL in Greece using the European Network of Transmission System Operators for Electricity (ENTSO-E) methodology as foreseen in the European Commission's draft Electricity Regulation.[94] As reference points, most other European markets have estimated VOLL values of €1,250–36,800/MWh and have implemented balancing market price caps of €3,000–9,999/MWh. This suggests that Greece can increase its price cap from €300/MWh to at least €1,200/MWh without waiting for the results of a complete VOLL study.
  - Develop a comprehensive administrative scarcity pricing framework that ensures prices will rise to efficiently high levels and will be consistent with marginal system costs during all types of scarcity events (with more severe events producing higher prices). One component of that scarcity pricing framework would be to impose administrative penalty factors or operating reserve demand curves reflecting the marginal system cost of triggering each type of scarcity intervention (*e.g.*, reflective of the marginal increase in probability of lost load times the VOLL during each event type). As an interim transitional measure, additive penalty factors of €100/MWh whenever the market is short of a particular type of reserve would correspond to the €300/MWh, €200/MWh, and €100/MWh transitional price caps for primary, secondary, and tertiary reserves discussed below. Over time, these penalty factors should be increased consistent with the price cap and the VOLL.
  - Reduce the price floor to below zero and conduct an economic efficiency review of the interactions among pricing, unit commitment decisions, uplift payments, and clean energy policies (such as feed-in tariffs and feed-in premiums) that affect surplus generation events. The overall objective of such a review would be to ensure that the combination of the clean energy policies and energy market prices

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93 The ancillary services settlements would be based on the incremental or decremental ancillary service quantities compared to the day-ahead market, which would not be traded in the intraday market.

94 See European Commission (2017b).

together provide incentives to minimize societal costs of meeting environmental objectives (considering both system-wide investment costs and operating costs).

  - Explore options for enabling updated supplier offer prices closer to real time (rather than maintaining day-ahead offers without updates as is done now). This would help to create more accurate price formation when market conditions change significantly between the day-ahead and balancing markets (for example in response to gas market shortages).

  - Align pricing and settlement intervals with the five-minute intervals that are already used for system dispatch. The current approach of hourly pricing intervals with prices set on an *ex post* basis dampens incentives for fast-responding resources to react quickly to meet system flexibility needs.

  - Enhance dispatch and price formation to allow a wider range of resources to fully participate, not just traditional fossil plants. Most urgently, based on its significant share of the resource base, we recommend continuing the efforts to represent hydro plants more accurately. We also recommend focused efforts to integrate a range of different demand response resource types, given the growing role of demand response in Greece and the importance of producing efficient scarcity prices. In the future, we expect it may become more important to focus on the dispatch price formation issues related to other resource types such as storage and distributed technologies.

  - Incorporate plant start-up costs into price formation, particularly during peak times when intraday unit commitment instructions might otherwise tend to suppress prices.

- **Ancillary Services Markets:** We recommend that Greece comprehensively review its ancillary service markets to ensure that: (a) product definitions and quantities match changing system needs and align with the European Guidelines; (b) qualification requirements result in a level playing field for different resource types; and (c) price formation is consistent with economic principles. Specific reforms we recommend include:

  - Remunerating tertiary reserves based on the marginal system cost as Greece already does for other types of ancillary services (replacing the current practice of non-remuneration for tertiary reserves). We further recommend revising the definition of the tertiary reserve product (or replacing it with one or more alternative products) so that tertiary reserves procured in the day-ahead market is not, as currently, released into the balancing market as available to provide energy. The current system artificially suppresses prices that would be calculated on a five-minute basis, and prevents efficient scarcity pricing at that timeframe. We note that RAE is already working to implement reforms in this area. However, as currently proposed, the reform would not fully address the underpricing concerns.

  - Aligning the pricing, settlement, and dispatch of ancillary services to the market in which they are procured. The quantities of hourly reserves procured in the day-ahead market would be paid for at a day-ahead price; the incremental (or

decremental) quantities of five-minute reserves procured in the balancing market would be paid for at the five-minute balancing price.

- Increasing the price caps of all ancillary services from the current €10/MWh to a level that more accurately reflects system costs at times of operating reserve shortage, including accounting for the marginal increase in the probability of lost load times the VOLL during scarcity events. As a transitional measure we suggest immediate increases to €300/MWh, €200/MWh, and €100/MWh for primary, secondary, and tertiary reserves respectively.[95] Over time we suggest that these price caps should increase to an economically efficient level supported by an economic analysis and according to a schedule of increases consistent with the energy price cap increasing to the VOLL.
- Maintaining co-optimization of energy and ancillary service procurement with the second step of the day-ahead market, as well as within the five-minute balancing market.

By following these recommendations Greece can achieve significant efficiency gains and better support the flexibility needs in a market relying much more heavily on intermittent clean energy resources, while at the same time conforming to the European Target Model. Greece can in a moderate timeframe achieve market coupling with other member states, and work together over the longer term to develop an efficient integrated market.

[95] Note that these price caps are consistent with administrative "penalty" factors of €100/MWh each that could be imposed in an additive fashion on each of the three types of reserves, as discussed in the prior recommendations on scarcity pricing in the context of the balancing market.

List of Acronyms

ADMIE or IPTO	Independent Power Transmission Operator
CACM	Capacity Allocation and Congestion Management
CAISO	California Independent System Operator
DG Comp	Directorate-General for Competition
EIM	Energy Imbalance Market
EIS	Energy Imbalance Service
ENTSO-E	European Network of Transmission System Operators for Electricity
ERCOT	Electric Reliability Council of Texas
EU	European Union
EUPHEMIA	Pan-European Hybrid Electricity Market Integration Algorithm
FCA	Forward Capacity Allocation
FRM	Flexibility Remuneration Mechanism
HAIPP	Hellenic Association of Independent Power Producers
ICE	Intercontinental Exchange
IPPs	Independent Power Producers
IPTO or ADMIE	Independent Power Transmission Operator
ISO	Independent System Operator
I-SEM	Integrated Single Electricity Market
LAGIE or HEMO	Hellenic Energy Market Operator
LOLP	Loss of Load Probability
MISO	Midcontinent Independent System Operator
MW	Megawatt
MWh	Megawatt Hour
NASDAQ	National Association of Securities Dealers Automated Quotations
ORDC	Operating Reserve Demand Curve
PCR	Power Coupling of Regions
PPC	Public Power Corporation
PTR	Physical Transfer Right
RAE	Regulatory Authority for Energy
RTO	Regional Transmission Organization
TSO	Transmission System Operator
VOLL	Value of Lost Load

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