# ENERGY SECURITY BOARD

## POST 2025 FUTURE MARKET PROGRAM

*DEEP-DIVE WORKSHOP SLIDES*

## OPERATING RESERVES

22ND APRIL 2021

# IMPORTANT NOTES

- This content does not represent the official position of the Energy Security Board or any related body.

- The material is provided in good faith for the sole purpose of enabling diverse stakeholders to meaningfully engage with content and may include various options that the ESB is seeking stakeholder input and feedback on.

## **WEBINAR-WORKSHOP LOGISTICS** (TEAMS PLATFORM)

- We will pause at key points for questions.
- Please use the **Raised Hand** to signal that you would like to speak.


- Please remain self-muted until invited to speak.
- If you wish to record a comment without discussion, please type it into the chat.
- Today’s event is being recorded for transcription purposes only.

# TODAY'S WORKSHOP

# DEEP-DIVE WORKSHOP – SECTOR REPRESENTATIVES

## ESSENTIAL SYSTEM SERVICES

| Name | Organisation | Nominated by |
|---|---|---|
| **Alison Demaria** | CS Energy | AEC |
| **Bradley Woods** | Energy Australia | AEC |
| **Ben Skinner** | AEC | AEC |
| **Sonja Lekovic** | Citipower-Powercor | ENA |
| **Alastair Andrews** | Powerlink | ENA |
| **Verity Watson** | ENA | ENA |
| **Joel Gilmore** | Infigen Energy | CEC |
| **Martin Hemphill** | RES Group | CEC |
| **Rhys Albanese** | Tilt Renewables | CEC |
| **Craig Memery** | PIAC | Self - TWG |

| Name | Organisation | Nominated by |
|---|---|---|
| **Claire Richards** | Enel X | Self - TWG |
| **Bridgette Carter** | Bluescope | Consumer Reps |
| **David Heard** | ECA | Consumer Reps |
| **Gavin Dufty** | Vinnies | Consumer Reps |
| **Lesley Silverwood** | Rio Tinto | Consumer Reps |
| **Mark Grenning** | EUAA | Consumer Reps |
| **Bruce Mountain** | Victoria University | Referred |
| **Jon Sibley** | ARENA | Self - TWG |
| **Steven Frimston** | AGL | AGL |
| **Simon Brooker** | CEFC | CEFC |

# ‘RULES OF THE GAME’

This is meant to be a **collegiate and creative space** focused on what Australia needs for the future.

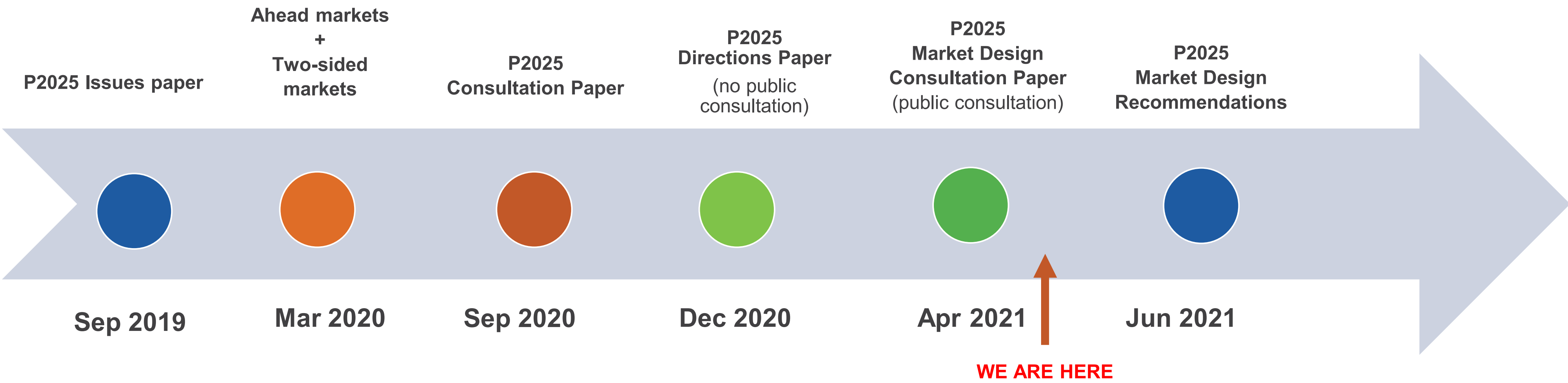
Key expectations for how we operate:

- ✓ Pre-reading will be taken ‘as read’
- ✓ Chatham House rule applies (no attribution to persons / organisations)
- ✓ Diversity of contributions from all participants encouraged: 2-minute rule will be applied.
- ✓ Representation of your sector is expected (not just your own personal / proprietary views)
- ✓ Respectful, constructive and robust engagement.

# P2025 PROGRAM CONTEXT

# POST-2025 PROGRAM – KEY DELIVERABLES

- **January 2021** – Directions Paper to identify key themes discussed by stakeholders and provide ESB response / steer
- **April 2021** – Options paper to set out detailed market designs for evaluation and consultation
- **Mid 2021** – Final recommendations and implementation program



# ESSENTIAL SYSTEM SERVICES PATHWAY OVERVIEW

## PATHWAY

**Time / VRE-penetration**

| Drivers | System need | Historical provision VRE=0% | Today VRE → 50% | Future VRE→ >75% |
|---|---|---|---|---|
| | | *Default self-provision from synchronous resources* | **ESB P2025 Proposed Products** | |
| Increasing uncertainty | demand to meet supply (even with large forecast uncertainty) | **Operating reserve** | Today's topic: Operating reserve market | Operating reserve market |
| | | **Resource adequacy** | (RAM Workstream) | (RAM Workstream) |
| Synchronous resources replaced by inverters | robust frequency control | **Frequency control**<br>Within the normal operating band<br>With faster response to contingency events | Frequency Control Workplan<br>• Enduring PFR arrangements<br>• FFR procurement | Frequency Control Workplan<br>• Enduring PFR arrangements<br>• FFR procurement |
| | | **Inertia** | *Structured procurement of synchronous resources*<br>Inertia: Minimum/efficient levels and UCS/SSM | Possible inertia spot-market<br>Possible ahead market |
| | system strength and power system stability | **System strength (fault levels)** | System strength (fault levels): Minimum/efficient levels and UCS/SSM | New TNSP resources, additional markets and/or specifications? |
| | | **Operating limits (stability)** | Operating limits: Ensuring min sync unit configurations UCS/SSM | Gradual unbundling of services as operator confidence at v. high VRE grows. |

## NARRATIVE

- The system is rapidly progressing towards having must-run configurations of synchronous generators to maintain power system stability – including for system strength and inertia - at high VRE-penetration. There is a need to establish competitive structured procurement and scheduling mechanisms to provide for power system security and dispatch efficiency without relying on system operator interventions.
- Current procurement mechanisms for frequency services require augmentation. These include enduring PFR arrangements and FFR procurement and can broadly be pursued within existing frameworks.
- A new mechanism is required to support confidence that sufficient flexibility is operationally available in the face of growing forecast uncertainty. This is proposed to be addressed with a new Operating Reserve Market.
- As confidence grows in operating the system at very high levels of VRE penetration (and very low levels of synchronous generation), and as various components of system services are able to be identified/quantified, additional markets for missing services (for example inertia) should be implemented as and when required, allowing the evolution to more sophisticated design and greater market efficiency where possible.

# ESB P2025 PROGRAM AND AEMC RULE CHANGES

**ESB P2025 Program**

- *"Tasked with developing advice on a long-term fit-for-purpose market framework to support reliability that could apply from the mid-2020's…. To enable the provision of the full range of services to customers necessary to deliver a secure, reliable and lower emissions electricity system at least-cost."* COAG 2019

- *"Many stakeholders noted that valuing and procuring missing system services is a priority that cannot wait until 2025. The ESB intends to use the Australian Energy Market Commission (AEMC) rules change process to accelerate this agenda consistent with this direction."* ESB January 2021 Directions Paper

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**AEMC Rule Change Process**

- AEMC Draft Determination on Operating Reserves due June 24 2021

  This Deep-Dive is an essential part of the AEMC Rule Change Process

AEMC

- AEMO and AER are participating in the Rule Change Process (and this deep dive) as stakeholders.

# RESERVES RULE CHANGES

MODELLING DEEP DIVE WITH STAKEHOLDERS

22 APRIL 2021

# Agenda

| | |
|---|---|
| 1. | AEMC rule change context and objective for deep dive |
| 2. | Flexibility issues in the modelled world |
| 3. | Energy adequacy issues in the modelled world |
| 4. | What does it mean for the NEM? |
| 5. | Next steps |

# 1.

# CONTEXT AND OBJECTIVE FOR THE DISCUSSION

# 1.1 AEMC rule change requests and deep dive objectives

**This discussion will inform our views on the two "reserves" rule changes**

**Operating Reserve Market (ERC0295)**

Proponent: Infigen

Draft Determination: by June 2021

Infigen proposes the introduction of a market to procure 'reserves' that have the capability to become energy within 30 minutes, alongside the existing NEM spot and frequency control ancillary services (FCAS) markets.

**Introduction of a Ramping Service (ERC0307)**

Proponent: Delta Electricity

Draft Determination: by June 2021

Delta recommends the introduction of 30-minute raise and lower ramping services using the existing FCAS market design framework.

**The purpose of this stakeholder deep dive** is to:

- Present and explain the modelling that has been done, and
- Through collaboration and discussion here, form views on what the modelling means for the real world
    - what signposts might show an emerging issue with operational flexibility of the fleet?
    - are we reading those signposts in the real world now, or could we in the future?

## 1.2 Matters out of scope for detailed discussion today

### Out of scope

- Detailed discussion of specific operating or ramping reserve models and how they work
- Detailed discussion on cost recovery and mechanisms for risk allocation

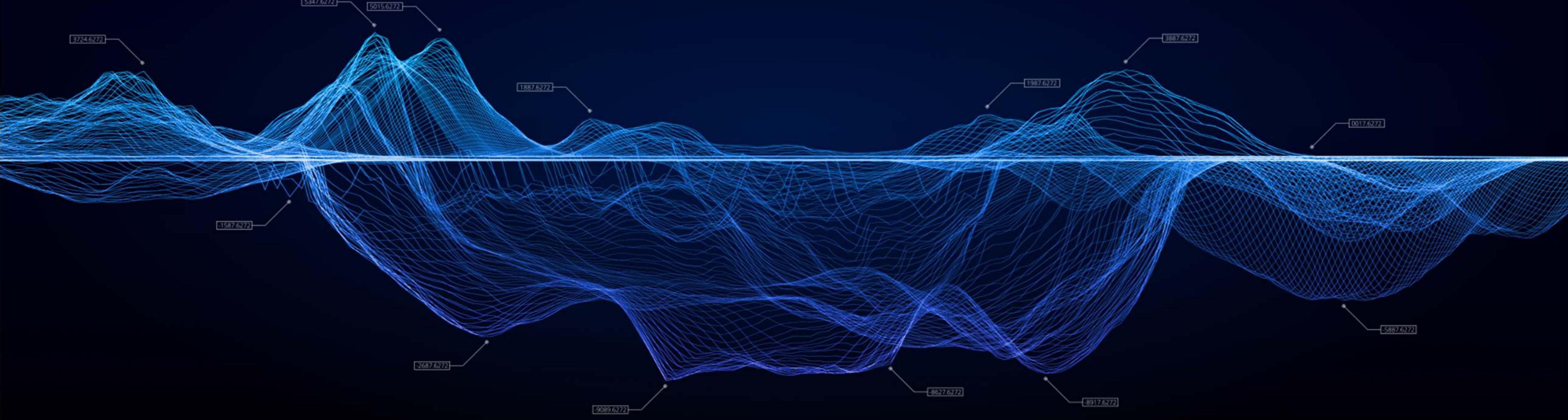
### Rationale

Based on feedback at the February deep dive session, the primary focus is on the need for an operating or ramping reserve service, rather than specific design options (which will form the focus of future discussions if needed)

# MODELLING OF AN OPERATING RESERVE

AEMC/ESB Deep-dive Workshop

2021.04.22



# Overview

01 **Context**

02 **Appreciation of the task**

03 **The method employed**

04 **The principal assumptions**

05 **Results and observations**

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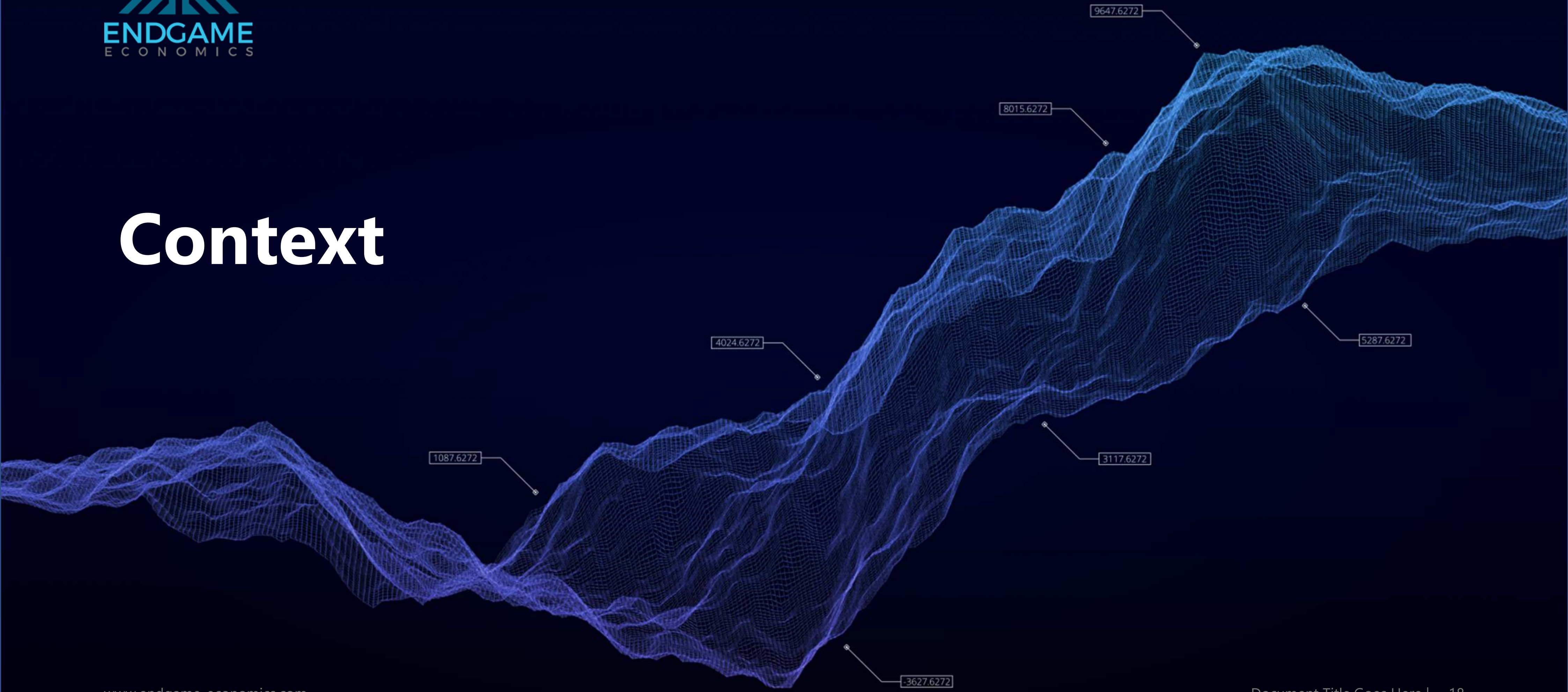
# Context



# Overarching modelling philosophy

Understand the nature of a currently non-existent service

Reason rather than forecast

Force us to come to terms with details that might be overlooked

Wide variety of input assumptions

Test our reasoning under different world

Recognising the limitations of the model for drawing conclusions

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# Appreciation of the task

# Key questions to be answered by this modelling exercise

### Is there a need?

**Is there a need for OR to unbundle operating reserves from the spot price?**

- OR should increase reliability of the system
- When might this be valuable

### Forecast uncertainty

**If there is a need for OR, how do different events give rise to that need?**

- How to measure forecast uncertainty?
- How do we confect events and their attendant forecasts?

### Other variables

**How does our assessment change depending on:**

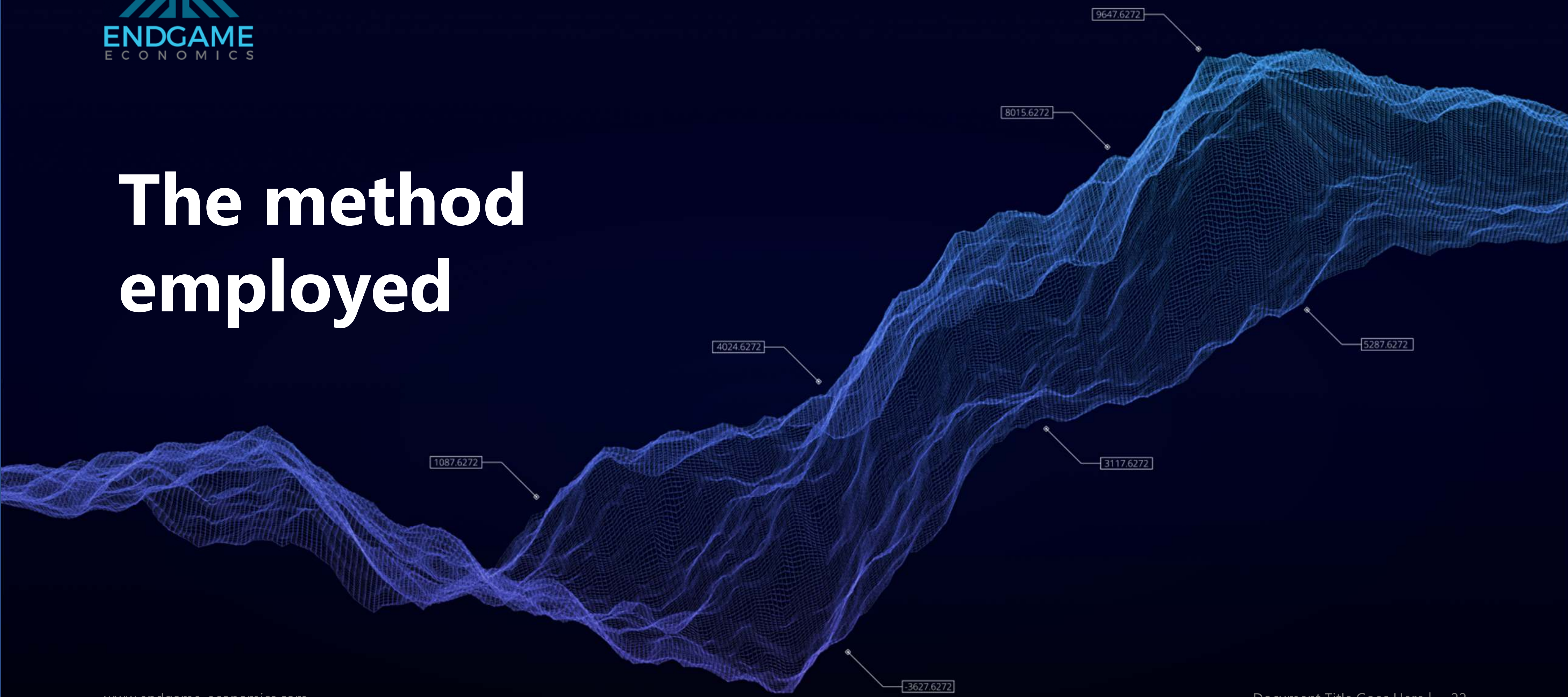
- Nature of events
- Technology mix

### Options

**Consequences for OR implementation options**

- Need
- Characteristics
- Strengths
- Weaknesses

# The method employed



# Overview of method

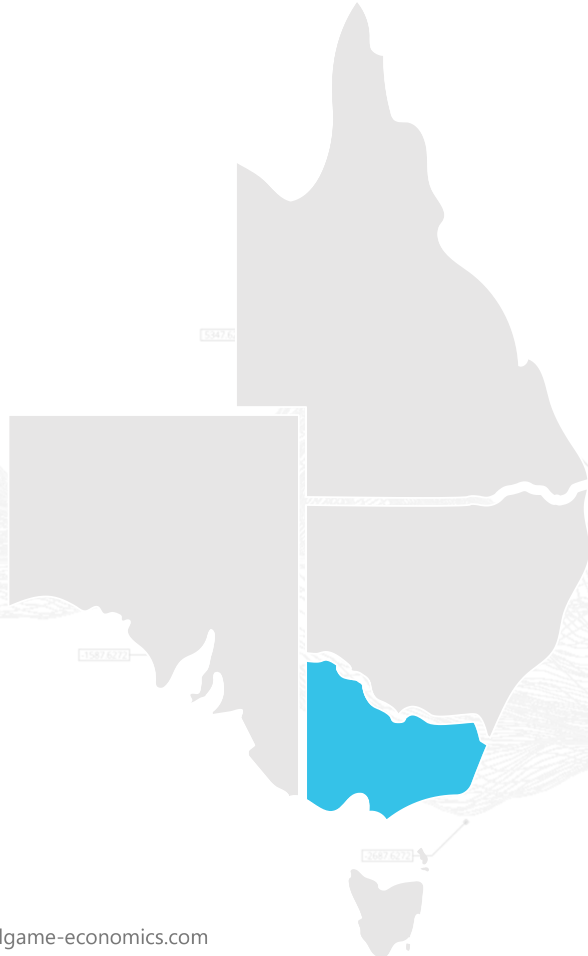
01 Single region model

02 Modelling of illustrative days (case studies)

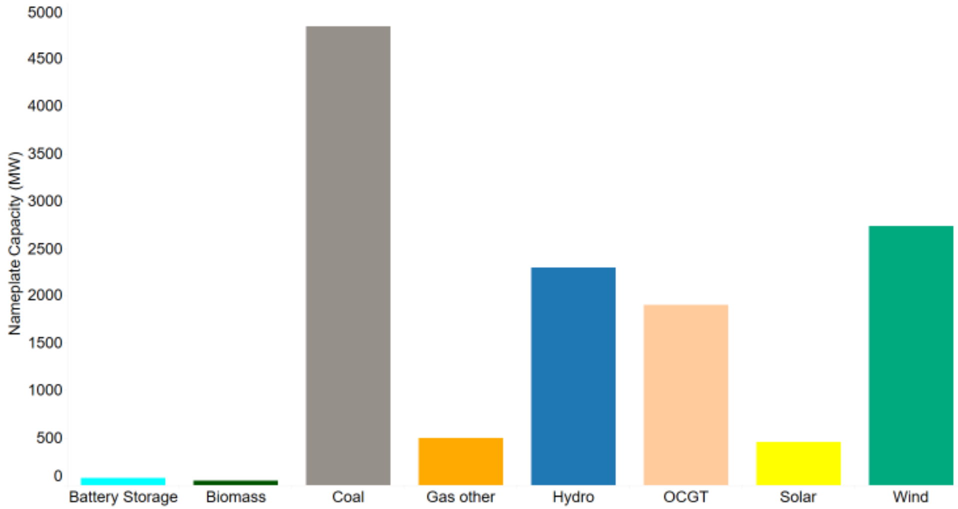
03 Generation fleet scenarios

04 Sequential process for modelling each day

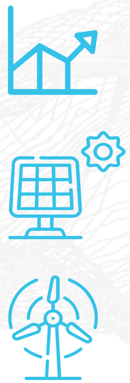
# Single region model



Used generation mix that roughly aligns with Victoria

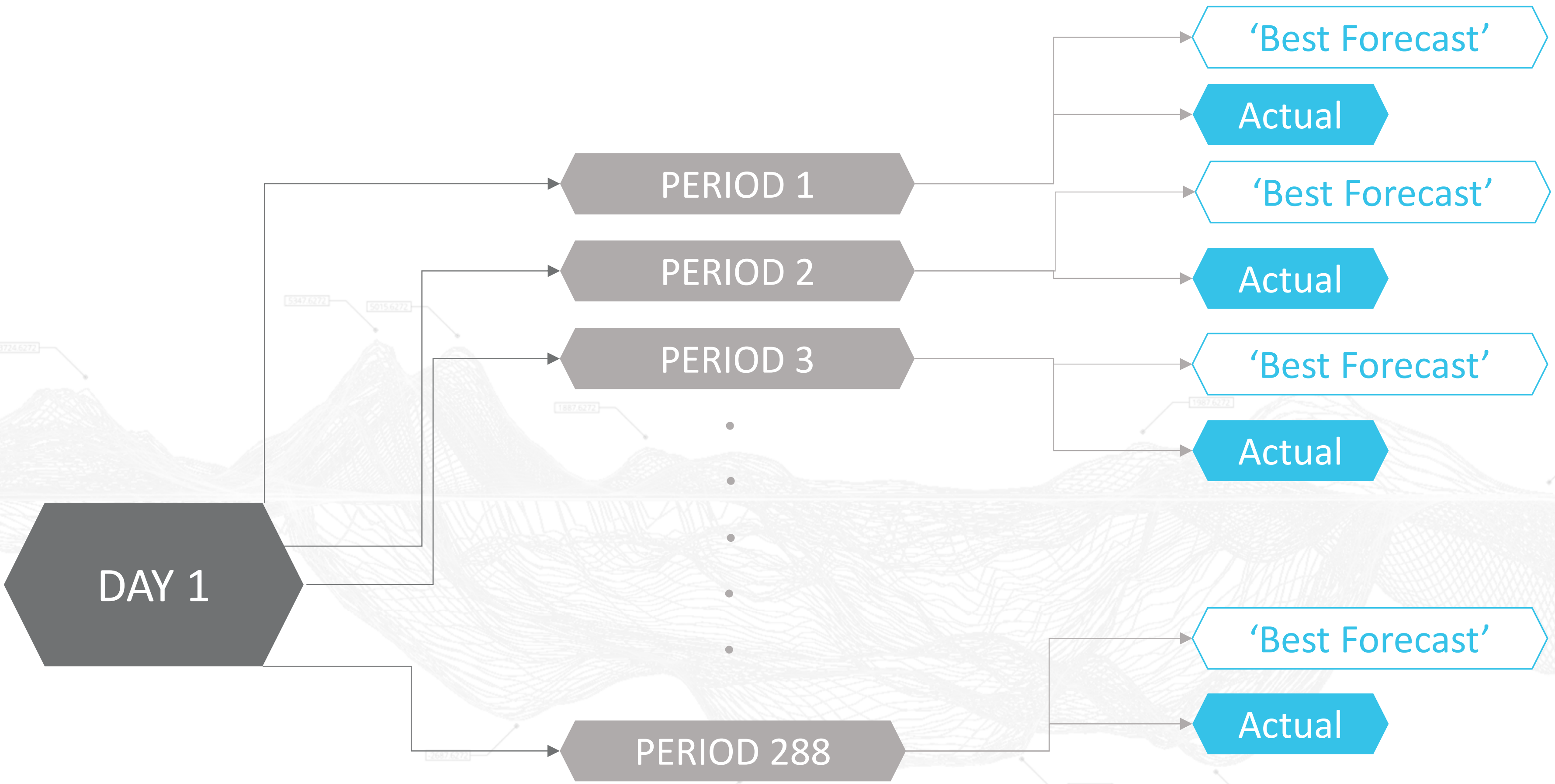



Used Victoria traces for:



- Demand
- Solar
- Wind

# Process for modelling each day (1)



# Process for modelling each day (2)

**00:00**
**Optimise for**

Units: on/off
Output: MW
Current demand forecast: MW
Current wind forecast: MW

**00:05**
**Optimise for**

Units: on/off
Output: MW
Current demand forecast: MW
Current wind forecast: MW

**00:10**
**Optimise for**

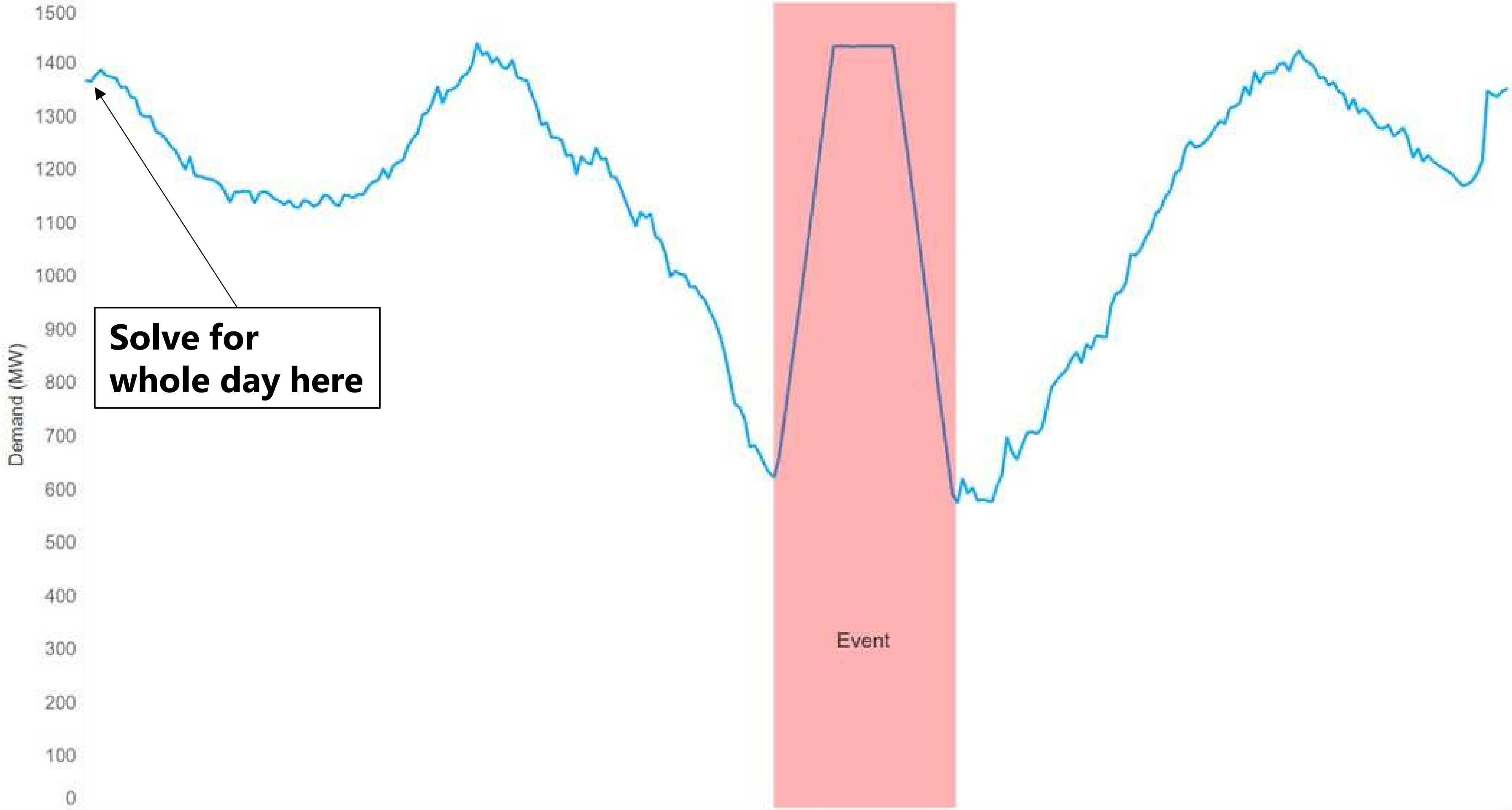
Units: on/off
Output: MW
Current demand forecast: MW
Current wind forecast: MW

**00:15**
**Optimise for**

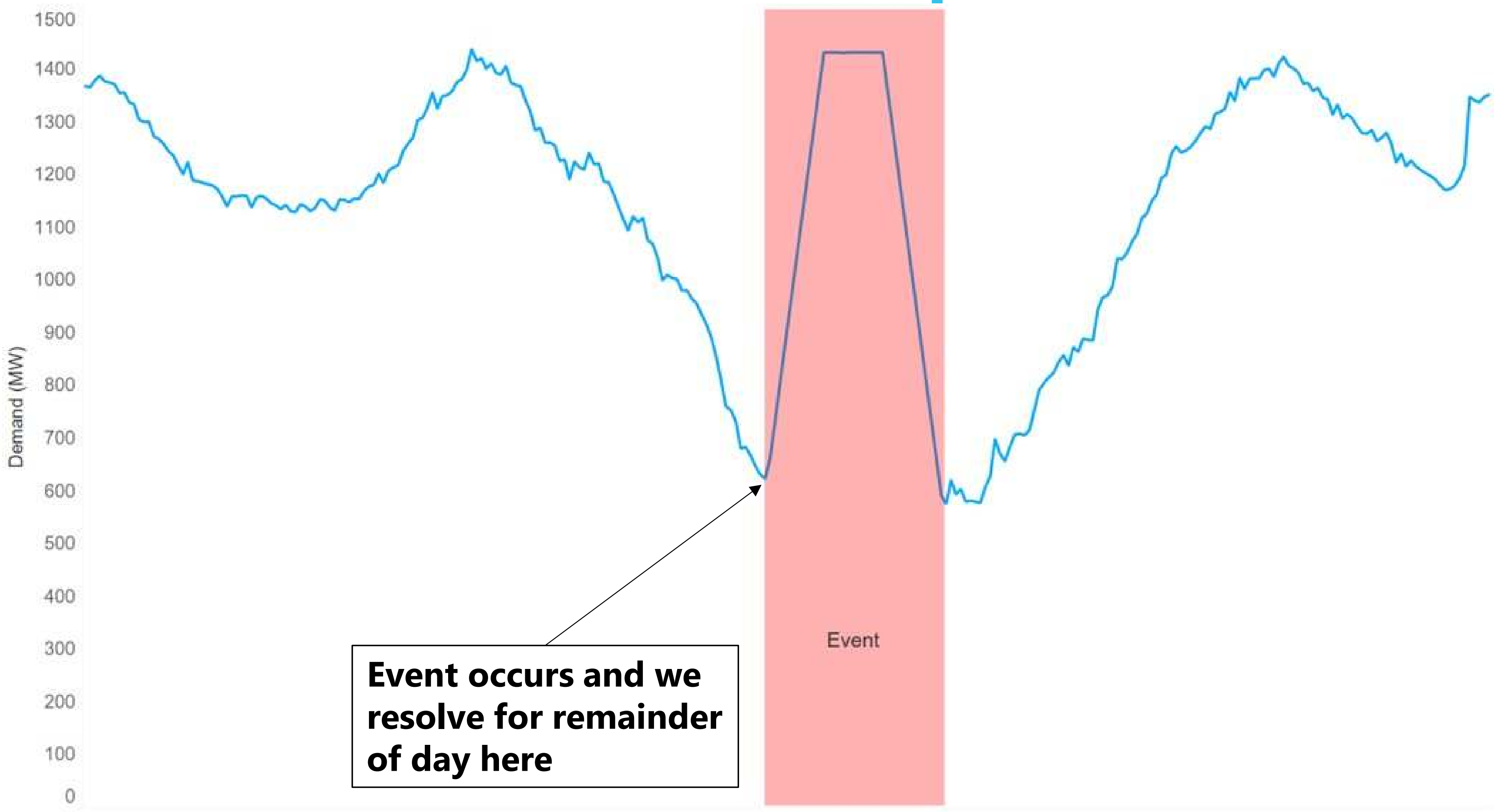
Units: on/off
Output: MW
Current demand forecast: MW
Current wind forecast: MW

If supply < demand, then energy gap occurs

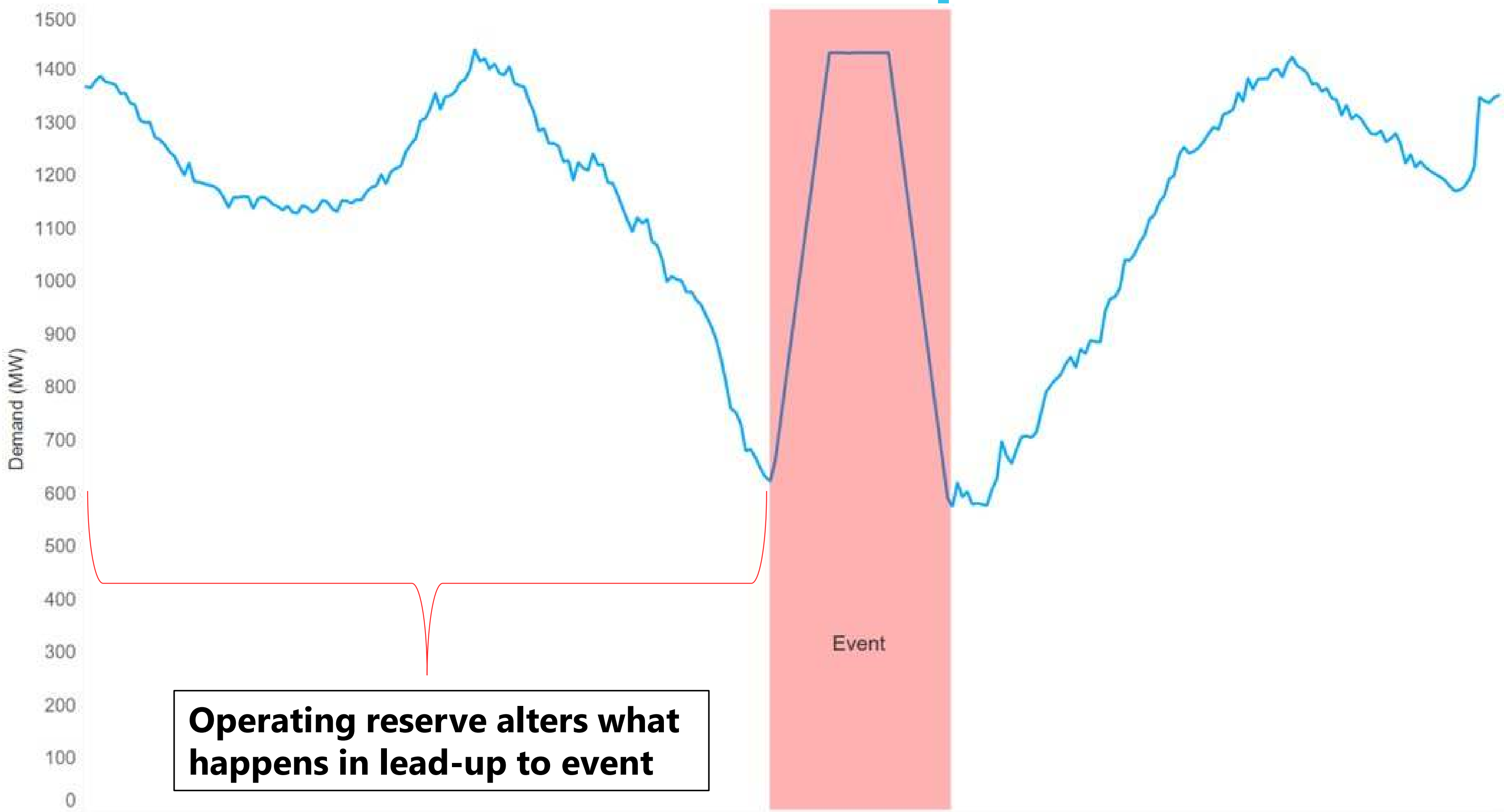
# Demonstration of basic concept



# Demonstration of basic concept



# Demonstration of basic concept



# Principal assumptions

# Input assumptions (1)

## Ramp up rate (MW/min)

- The rate at which the plant can increase output over time
- Data from: Provided by AEMO but subject to change in the next iteration of modelling – these ramp rates may be too high.

## Ramp down rate (MW/min)

- The rate at which the plant can decrease output over time
- Data from: Provided by AEMO

| Generator | Ramp Up Rate (MW/min) | Ramp Down Rate (MW/min) |
|---|---|---|
| LOYYB1 | 10 | 10 |
| LOYYB2 | 10 | 10 |
| LYA1 | 5 | 5 |
| LYA2 | 5 | 5 |
| LYA3 | 5 | 5 |
| LYA4 | 5 | 5 |
| YWPS1 | 3 | 3 |
| YWPS2 | 3 | 3 |
| YWPS3 | 3 | 3 |
| YWPS4 | 3 | 3 |
| MURRAY | 100 | 100 |
| AGLSOM01 | 8 | 8 |
| AGLSOM02 | 8 | 8 |
| AGLSOM03 | 8 | 8 |
| AGLSOM04 | 8 | 8 |
| BDL01 | 4 | 3 |
| BDL02 | 4 | 3 |
| JLA01 | 9 | 9 |
| JLA02 | 9 | 9 |
| JLA03 | 9 | 9 |
| JLA04 | 9 | 9 |
| JLB01 | 6 | 6 |
| JLB02 | 6 | 6 |
| JLB03 | 6 | 6 |

# Input assumptions (2)

Start-up time (Intervals)

- The time it takes for the plant to be fully operational
- Data from: Provided by AEMO

Start-up cost ($)

- The cost of turning the plant on
- Data from: GHD via AEMO

Auxiliary load (% of output)

- The percentage of electricity produced required to operate the plant
- Data from: AEMO ISP Assumptions

| Generator | Start-up time | Start-up cost ($) | Auxiliary load (%) |
|---|---|---|---|
| LOYYB1 | 3 hours (assume warm) | 175,000 | 8.3 |
| LYA1 | 3 hours (assume warm) | 175,000 | 8.3 |
| MURRAY | 10 mins | 7,500 | 0.3 |
| Laverton North 1 | 15 mins | 15,000 | 0.7 |

# Input assumptions (3)

## Round trip efficiency (%)

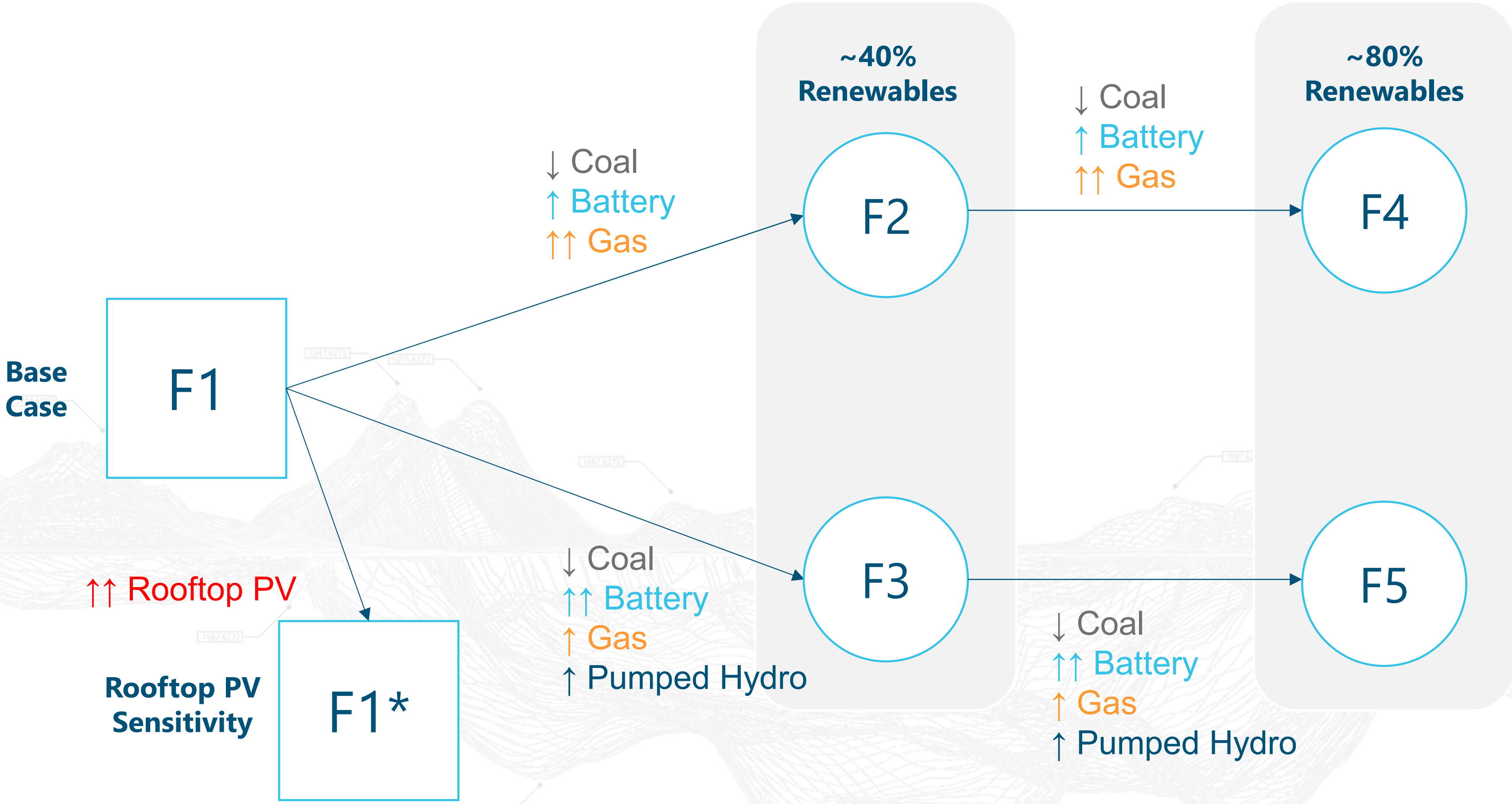
- The ratio of energy put in to energy retrieved from storage
- Data from: AEMO 2020 ISP

## Duration of storage (Hours)

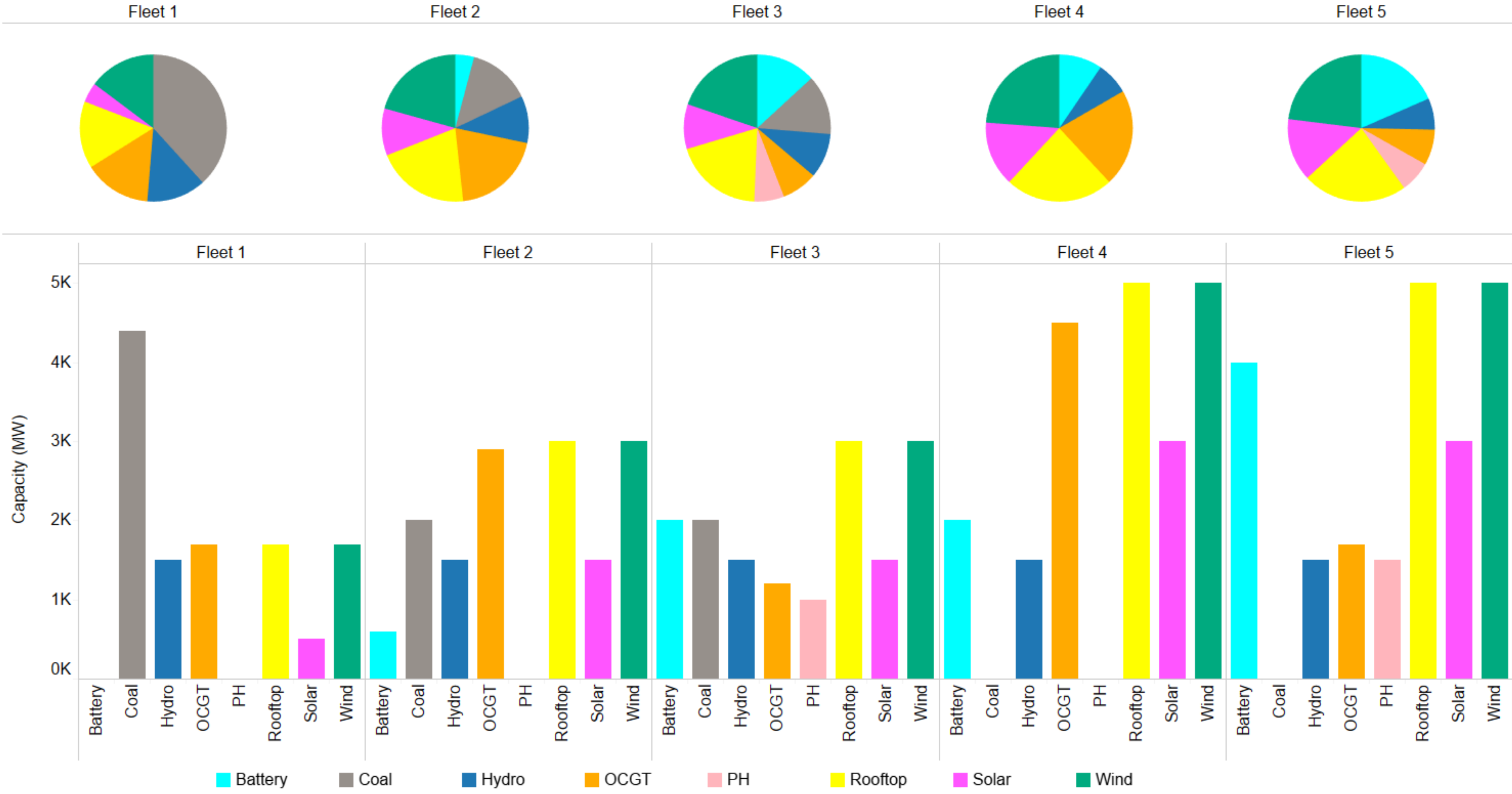
- The amount of usable energy stored in the battery
- Data from: *Variable depending on scenario
- **Note: Assume zero charge in storage at start of the day.**

| Generator | Round trip efficiency (%) | Storage capacity (hours) |
|---|---|---|
| Batteries | 81 | Typically 2* |
| Pumped Hydro | 80 | Typically 8* |

# Generation fleet assumptions



# Composition of generation fleet by scenario



# Illustrative days or ‘case studies’

1. Loss of wind occurring during the evening net demand ramp

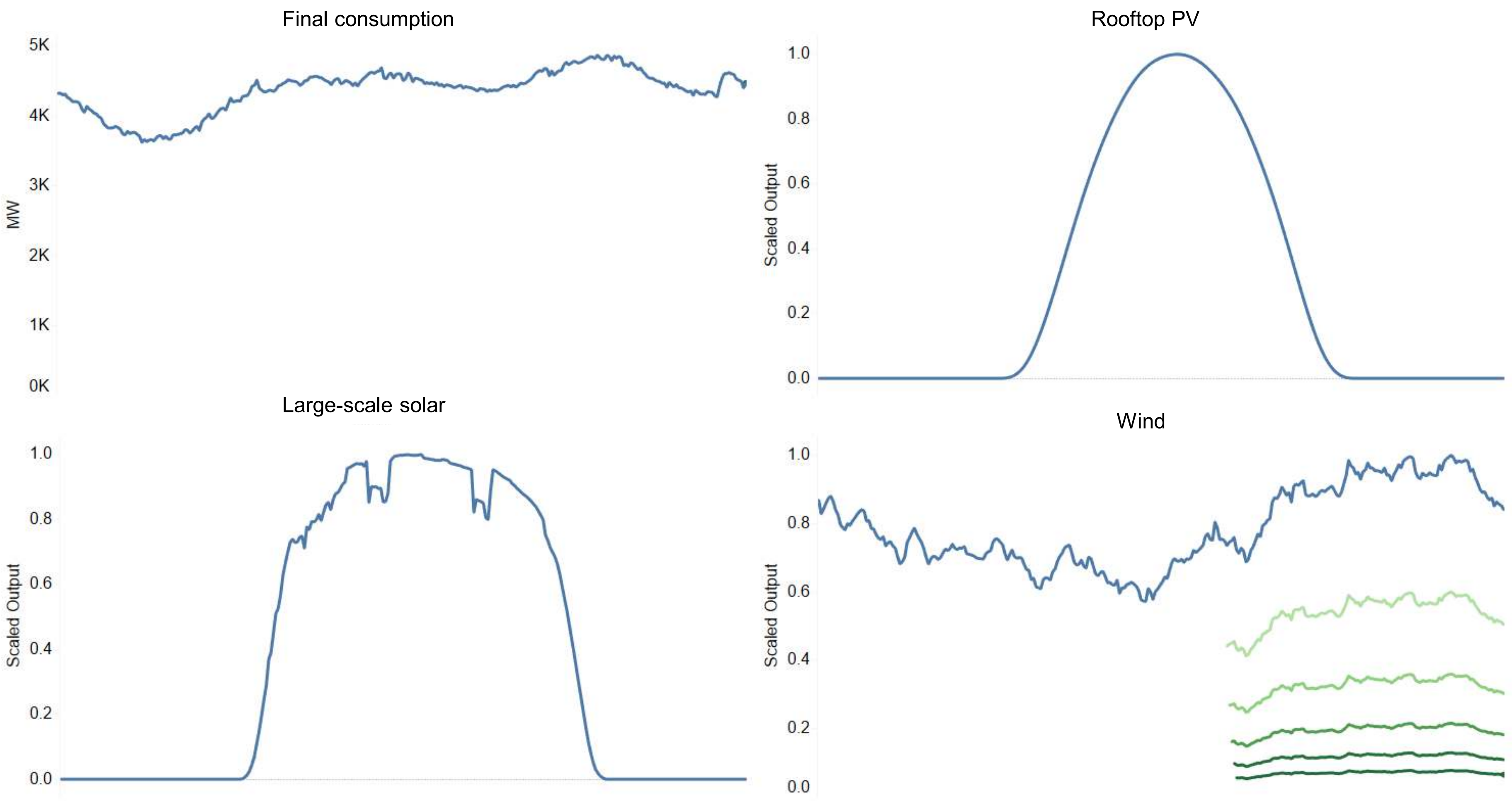
5. Unexpected loss of all rooftop solar in a region occurring over <15 minutes


2. Unexpected loss of a significant amount of VRE in the middle of the day, sustained for some time

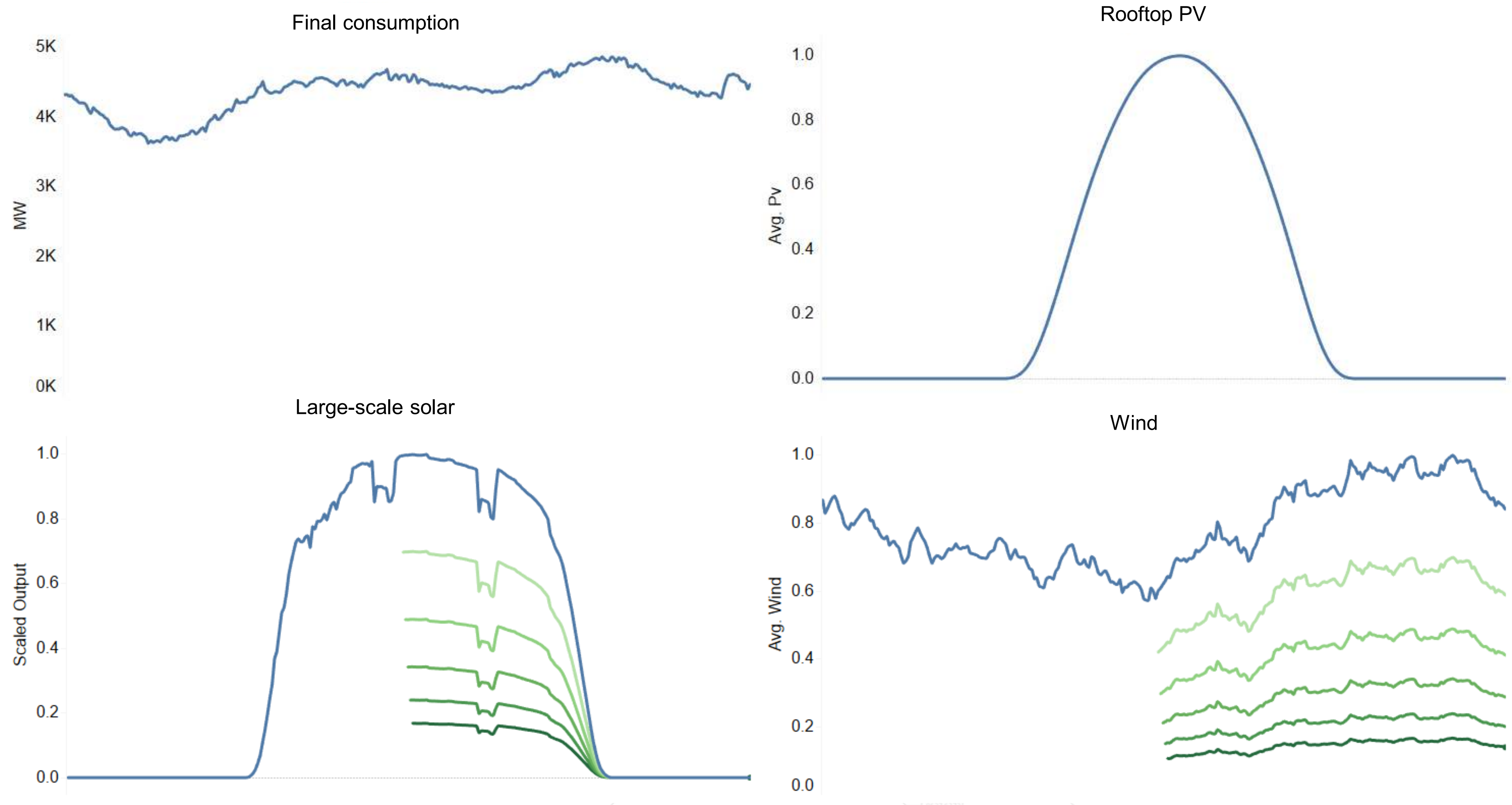
4. Wind never comes despite being expected during the evening

3. Loss of all rooftop solar on low demand sunny day.

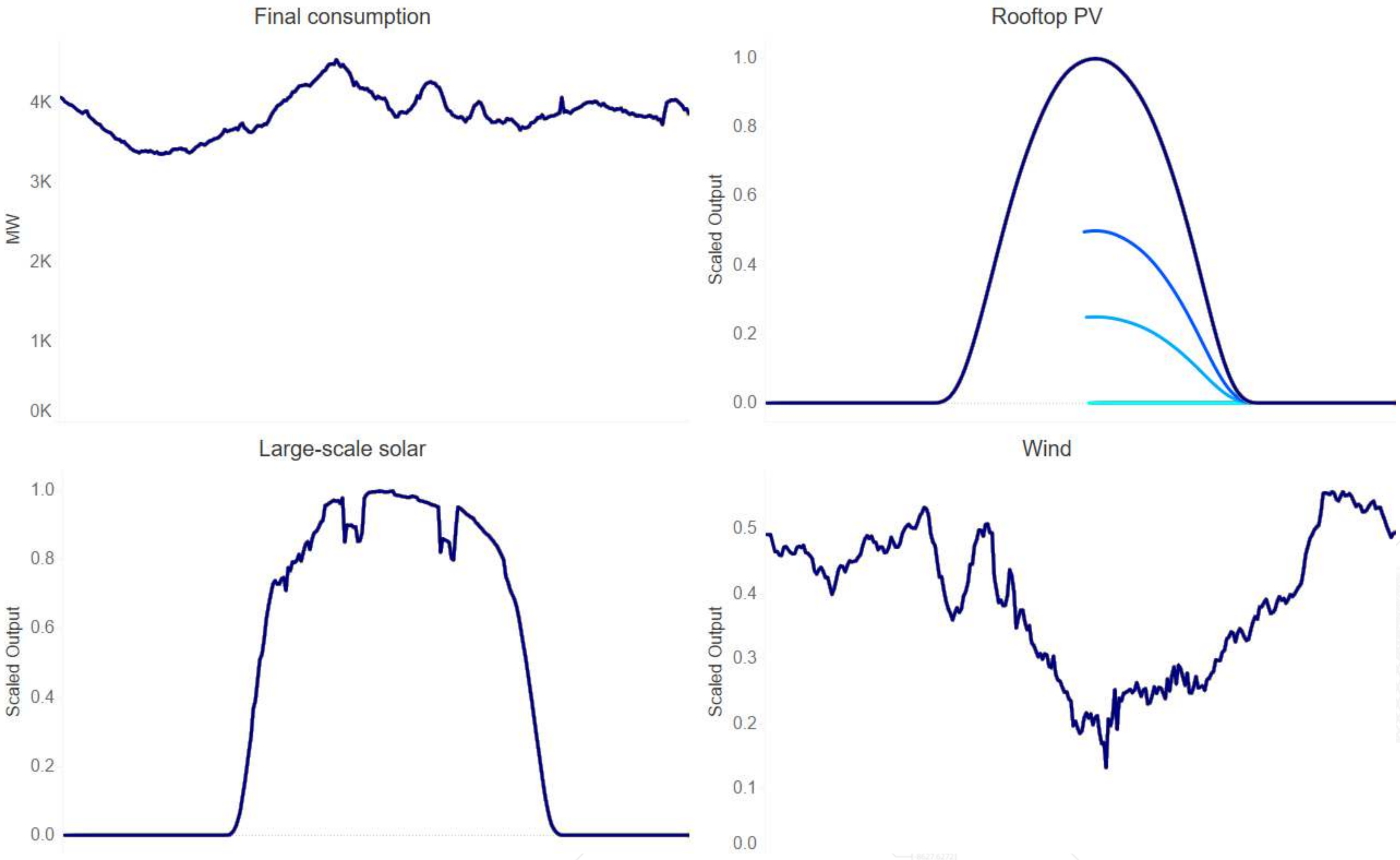
# Case 1: Wind falls off during evening ramp



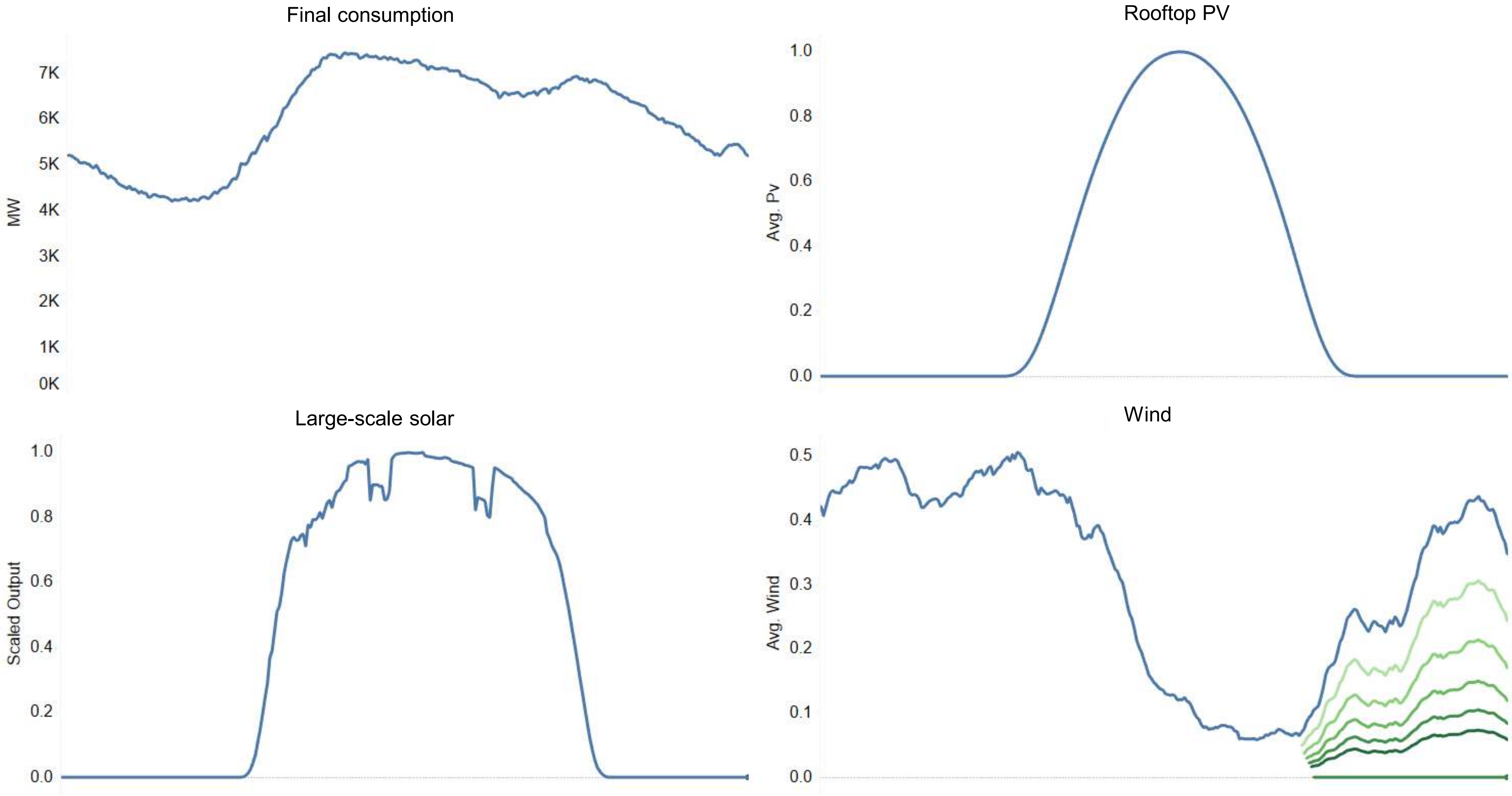
# Case 2: Loss of REZ during middle of the day



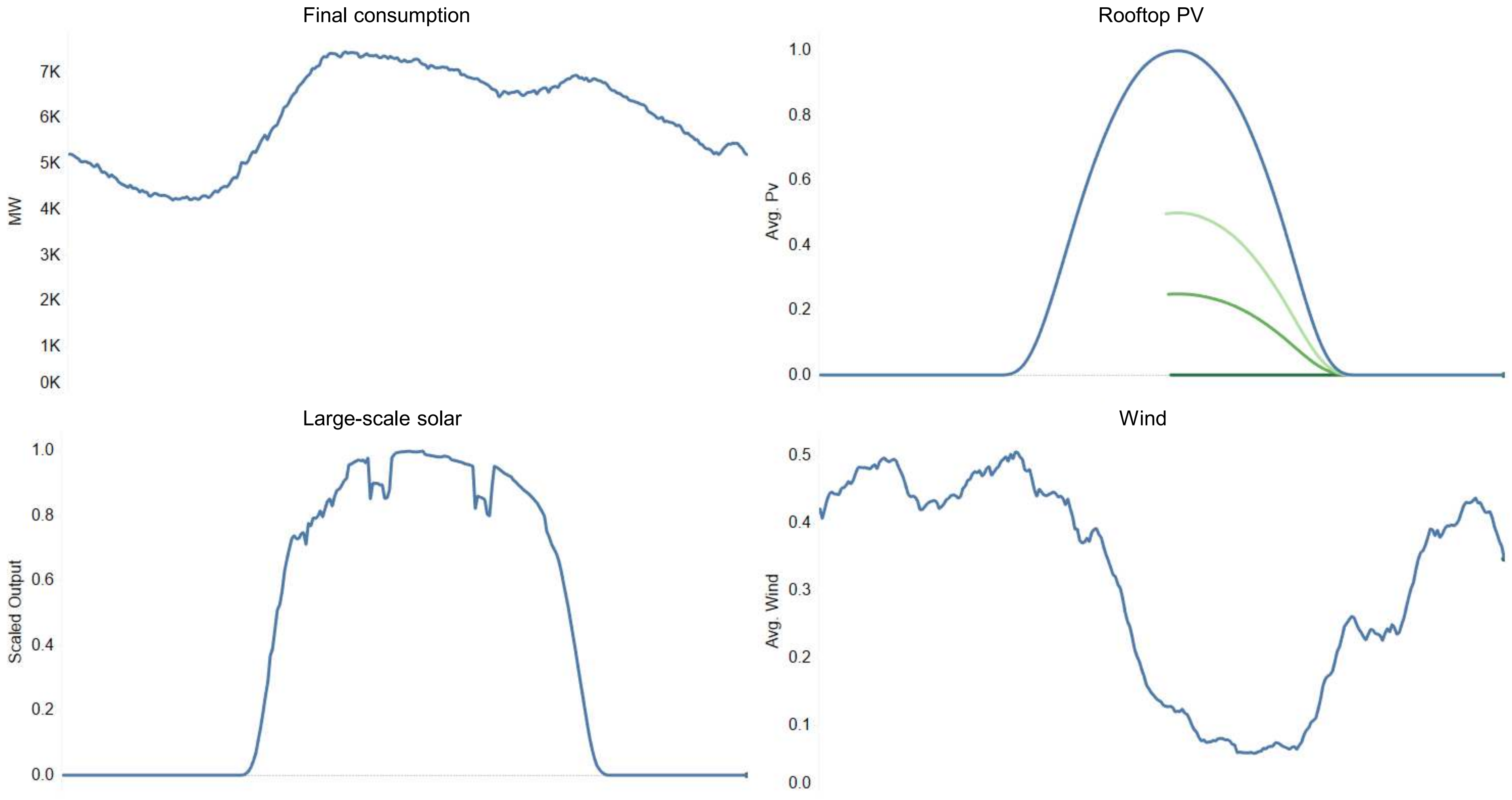
# Case 3: Loss of PV on sunny, low demand day



# Case 4: Wind never comes



# Case 5: Loss of PV on moderate-high demand day



# Limitations

01 **Cost-based modelling:** Exercise focusses on costs, and so cannot capture the role of prices in driving different behaviours from participants.

02 **Events are synthetic:** evolution of days is driven by confected events, that while they change over time are inherently deterministic – real events are different and *stochastic* and so are more uncertain, and may not follow the patterns we have assumed.

03 **Behaviour is assumed to be perfect:** Even though we capture imperfect foresight, decisions at each point are optimised – real world will be noisier, and participant decisions will be influenced by a range of factors.

04 **Model is a simplification:** model is doing something more complex than traditional market models, and so we have simplified other aspects. These simplifications must be recognised.

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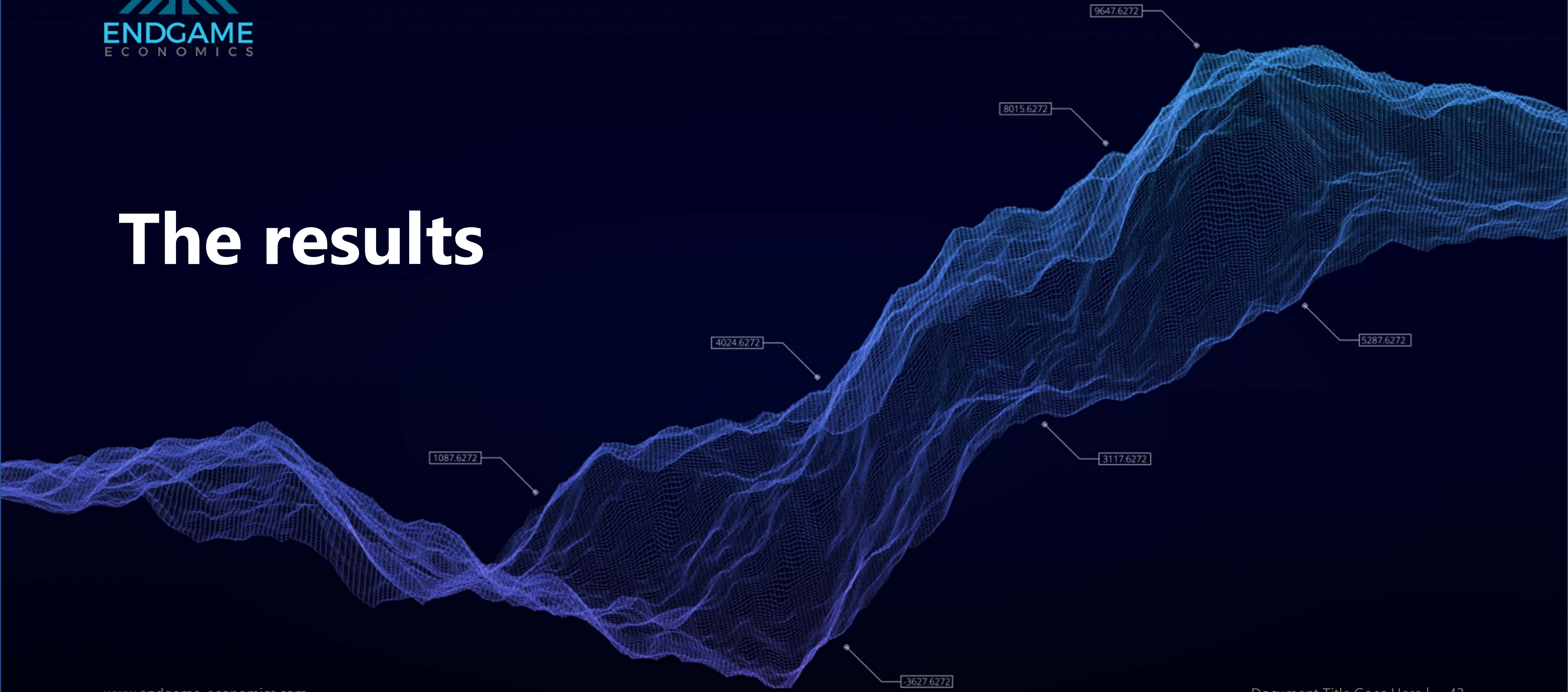
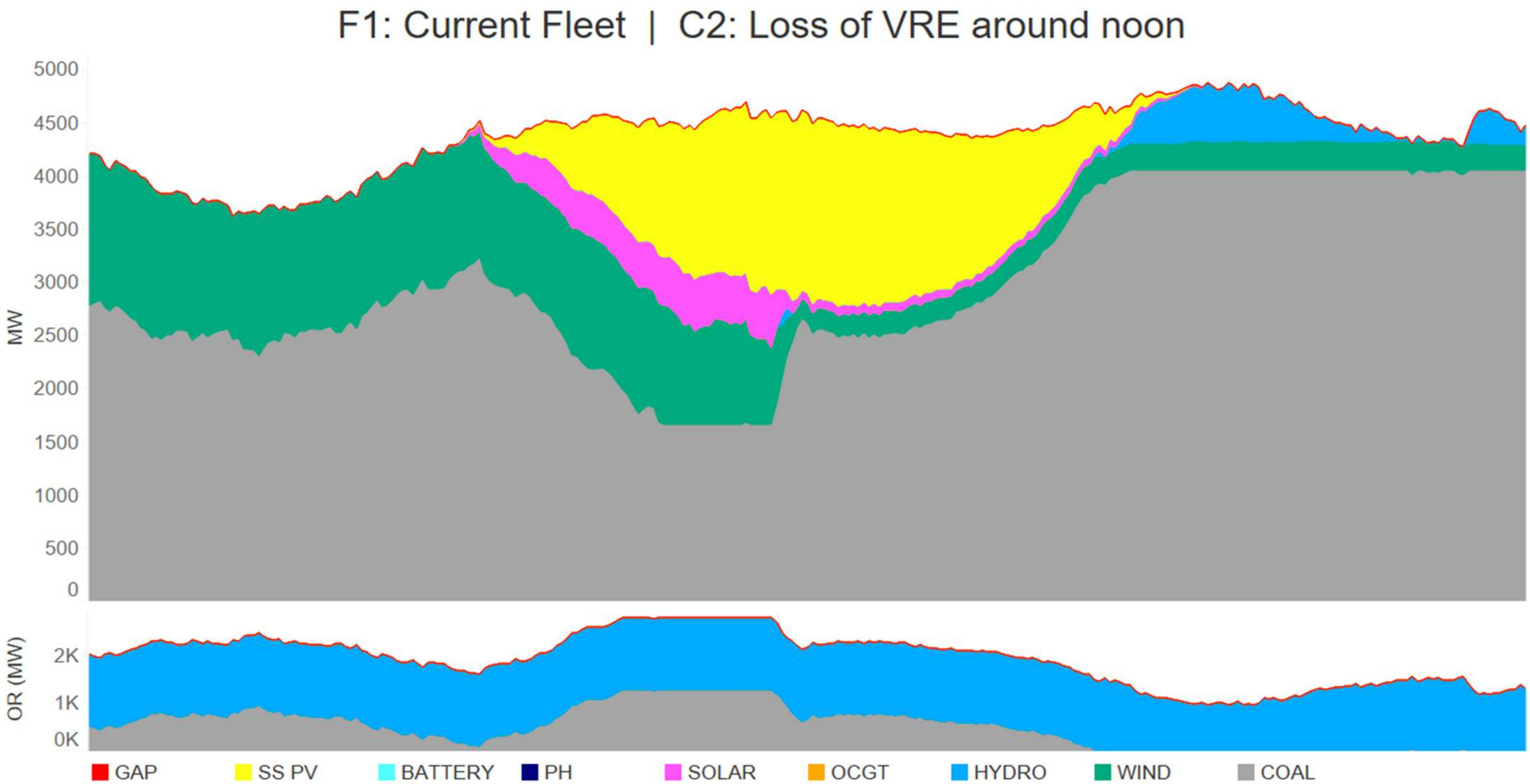
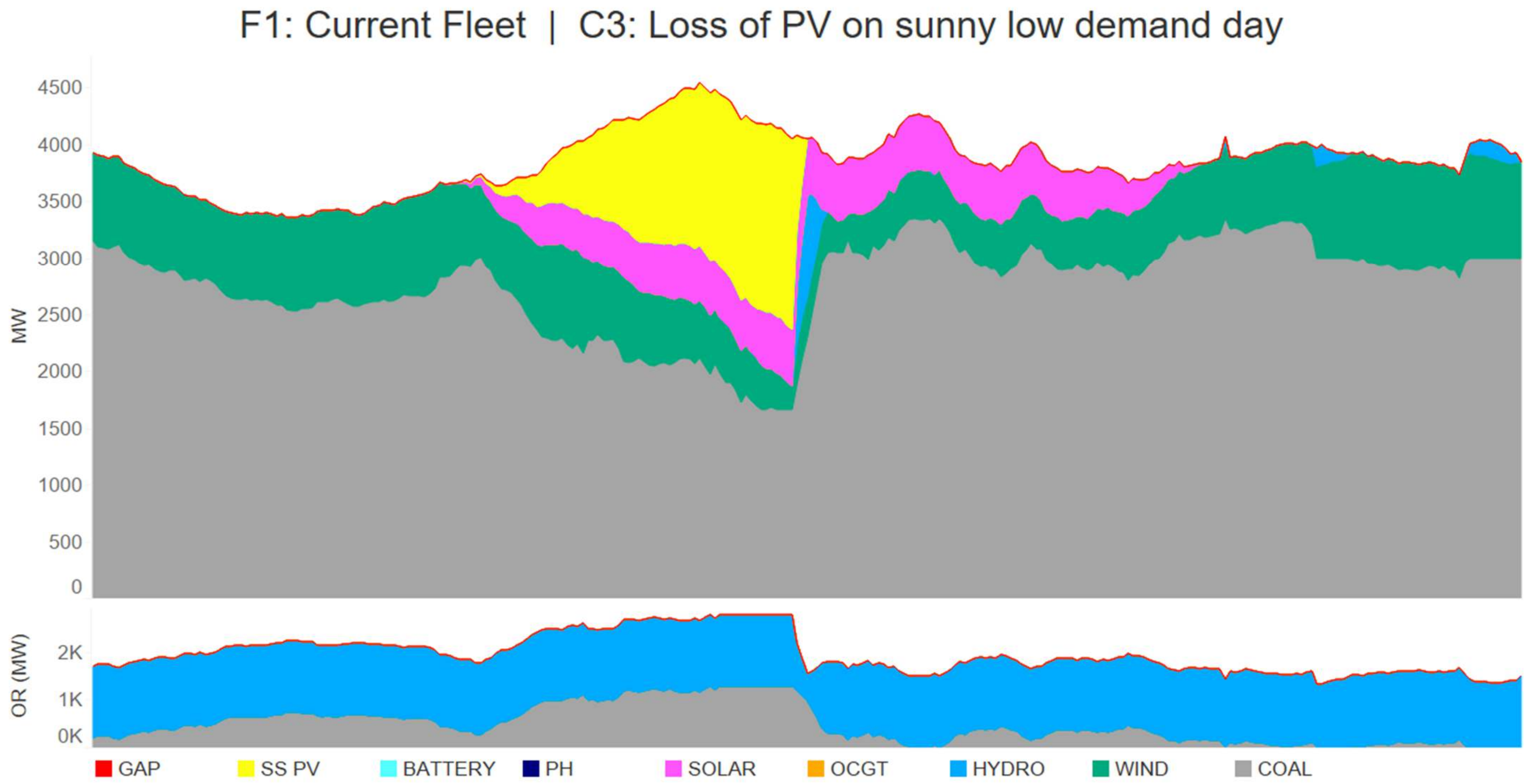
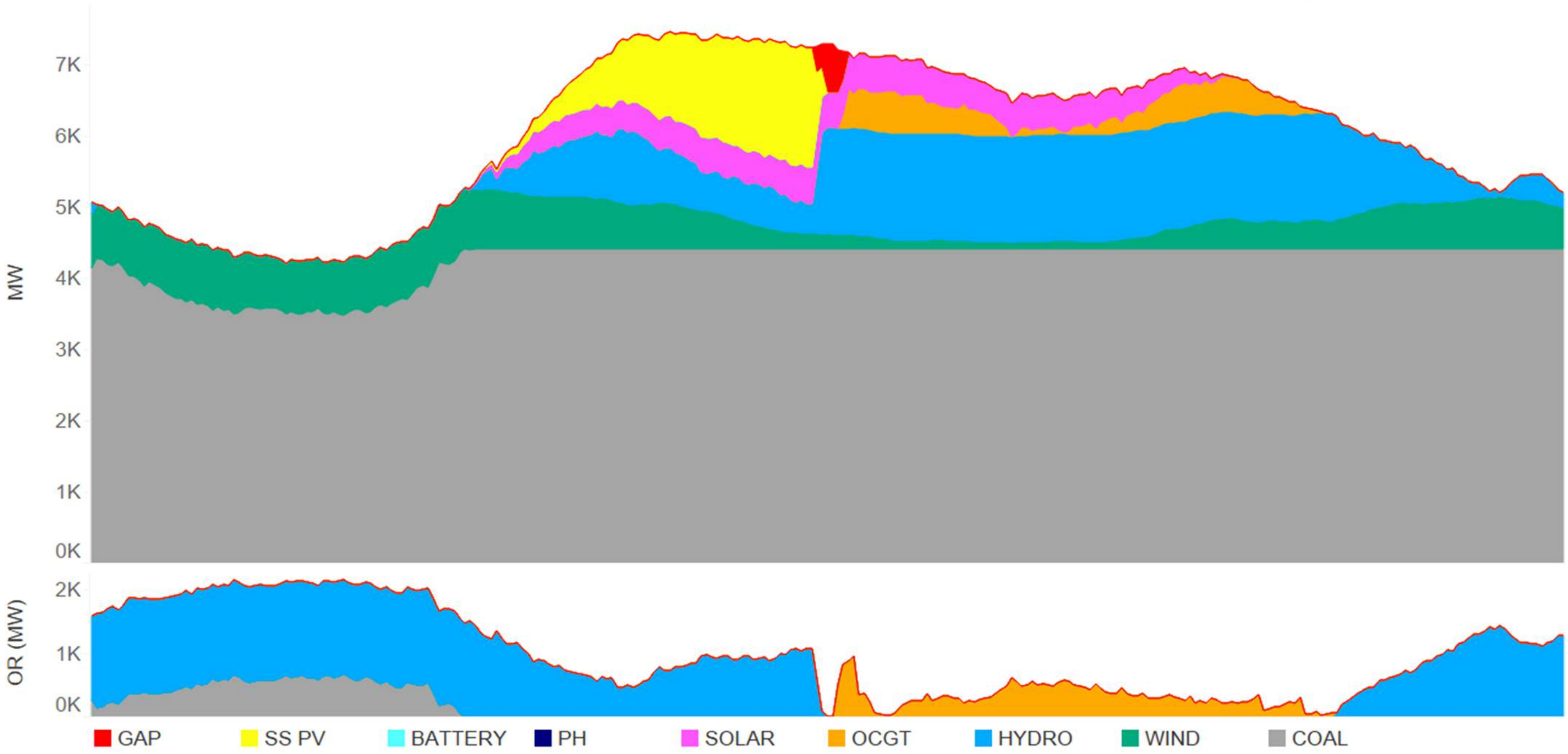
# The results




F1: Current Fleet | C2: Loss of VRE around noon
MW
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
OR (MW)
2K
1K
0K
GAP
SS PV
BATTERY
PH
SOLAR
OCGT
HYDRO
WIND
COAL

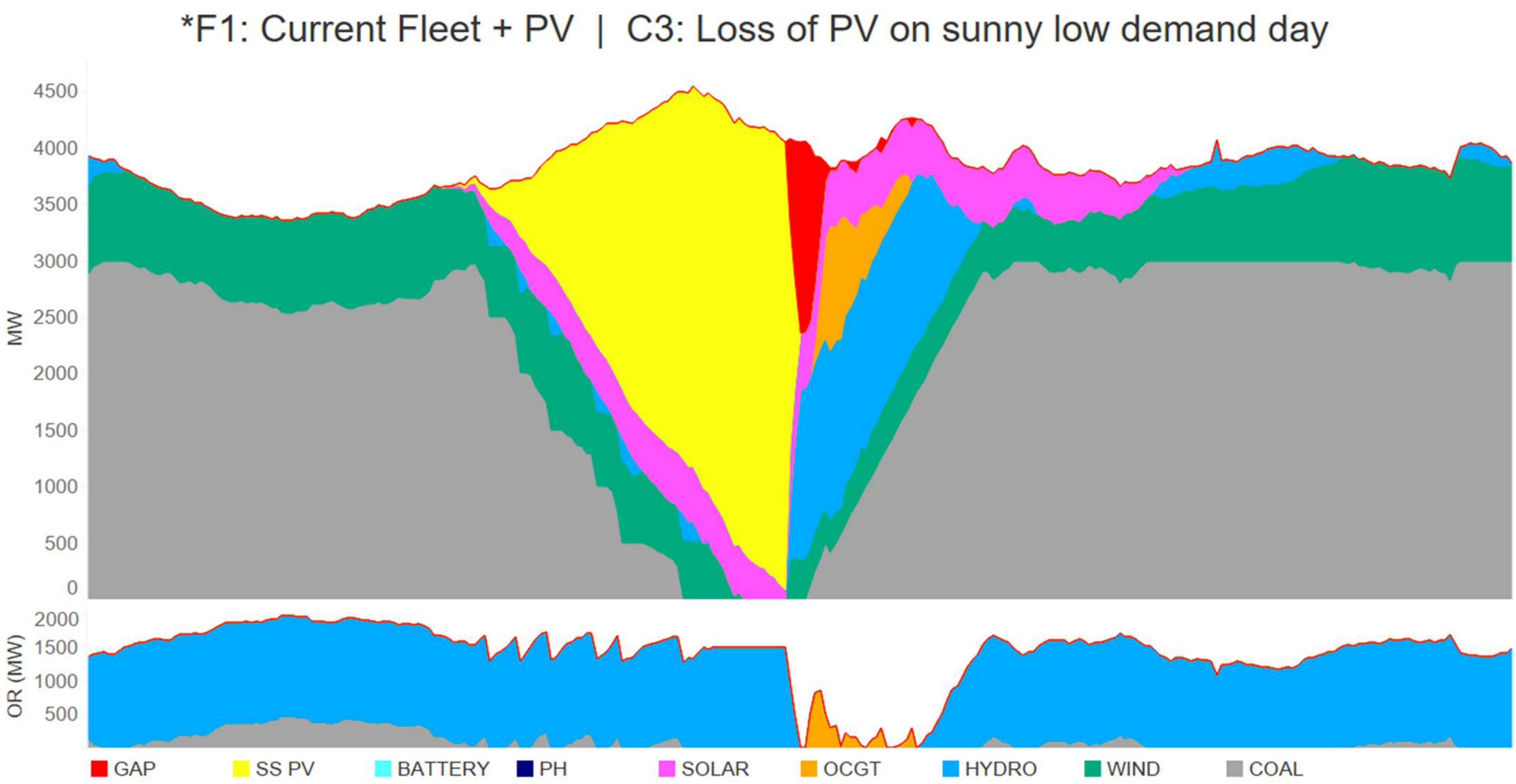

F1: Current Fleet | C3: Loss of PV on sunny low demand day
MW
4500
4000
3500
3000
2500
2000
1500
1000
500
0
OR (MW)
2K
1K
0K
GAP
SS PV
BATTERY
PH
SOLAR
OCGT
HYDRO
WIND
COAL

# F1: Current Fleet | C5: Loss of PV on moderate demand day



# Observations from modelling – current fleet

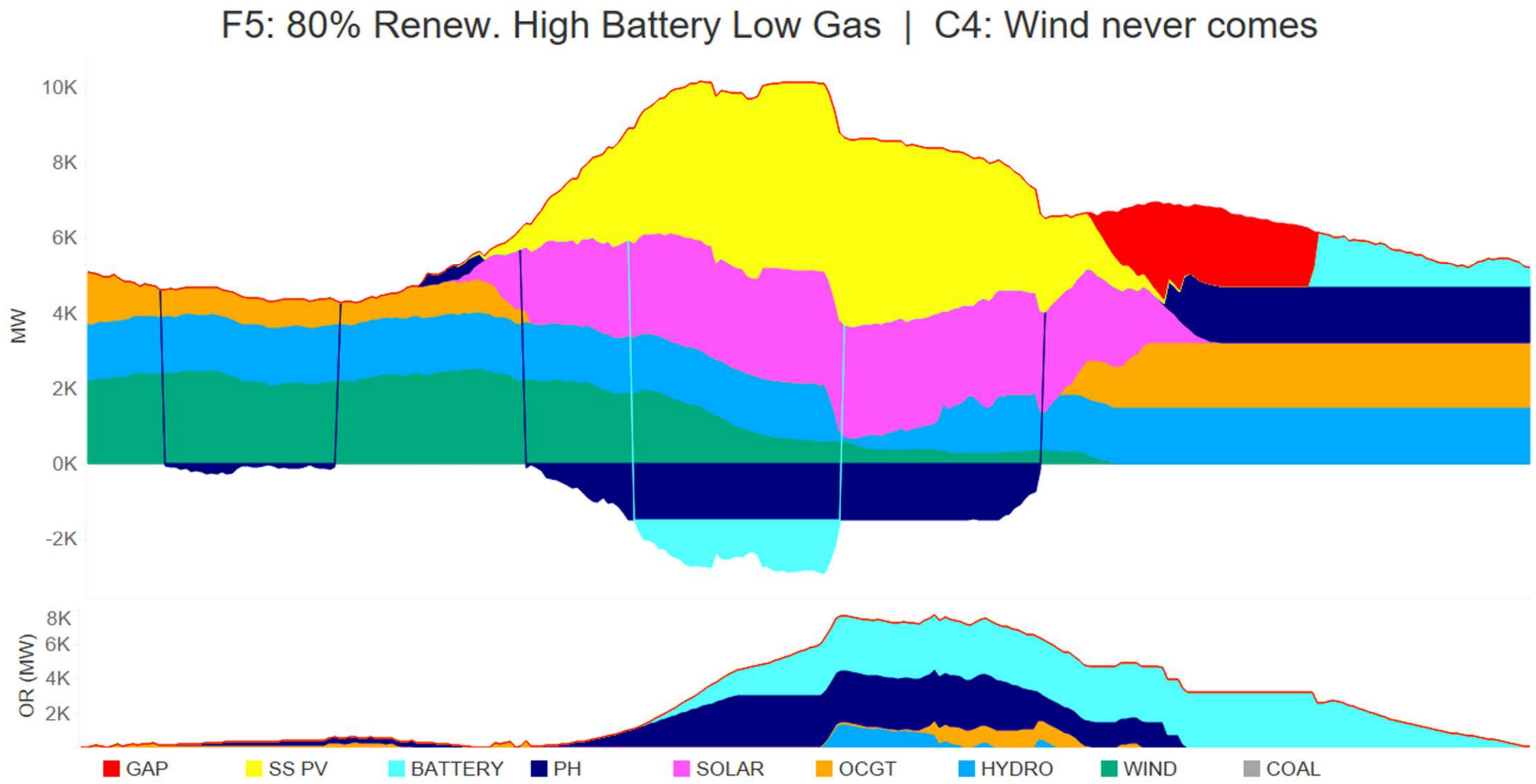
- **System responds in time when …** shock to the system occurs when coal is online and has headroom. Shocks are managed by a combination of ramping of coal and spare hydro capacity.
- **Energy gap occurs when** … shock to the system occurs when coal is already at its capacity. This is due to the shortage of ramping capacity (ie, without coal headroom, ramping is limited to gas and hydro).
- **Important parameters:** in this modelling the ramp rates, start-up costs, and no-load costs are important because they affect how coal plant functions during the middle of the day. These parameters become more and more important as we see increasing penetration of solar PV – see the next fleet scenario for an illustration.
- **Outside of the model:** note that we have not included the role of interconnection or FCAS response in our modelling.



*F1: Current Fleet + PV | C3: Loss of PV on sunny low demand day
MW
4500
4000
3500
3000
2500
2000
1500
1000
500
0
OR (MW)
2000
1500
1000
500
GAP
SS PV
BATTERY
PH
SOLAR
OCGT
HYDRO
WIND
COAL

# Observations from modelling – current fleet + PV

- **Model shows ramps are manageable when …** shock occurs to renewables that are already constrained off at time of shock. This gives more time for system to respond to effects that only matter later in the day.
- **Role of curtailment:** so much depends on how we manage renewables – will we see rooftop PV preferred over constraining large-scale renewables generation, which can then respond? Effectively these large-scale renewables are providing an operating reserve.
- **Energy gap occurs when …** shock to the system occurs when nothing else is online. This is a challenging situation to address, although we note that synchronous generation requirements are unlikely to allow this to occur at the moment.



F5: 80% Renew. High Battery Low Gas | C4: Wind never comes
10K
8K
6K
4K
2K
0K
-2K
MW
8K
6K
4K
2K
OR (MW)
GAP
SS PV
BATTERY
PH
SOLAR
OCGT
HYDRO
WIND
COAL

# Observations from modelling
# 80 % Renewables + High Storage Low Gas

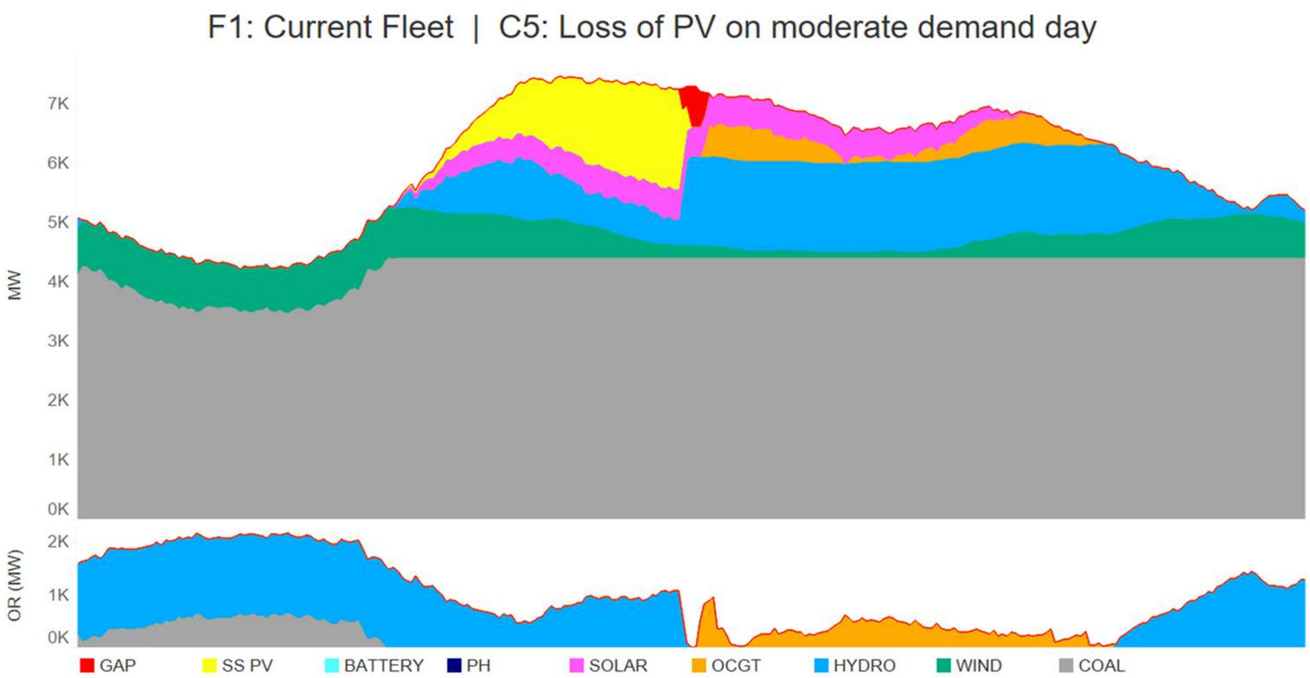
- **No shortage of flexibility:** modelling shows that the capacity that replaces coal adds flexibility to the system, making it able to respond quickly. None of the energy gaps appear to be due to lack of ramping or fast-starting plant.
- **State of charge assumptions are critical:** the energy gaps that occur are due to lack of energy in storage. Our assumptions on this front have been very aggressive – different assumptions about starting storage would remove energy gaps.
- **Importance of energy in storage to the system:** an important question arising from this modelling is how we manage energy in storage to support a robust system.

# 2.

# FLEXIBILITY ISSUES IN THE MODELLED WORLD

# 2.1 Is the current fleet flexible enough?

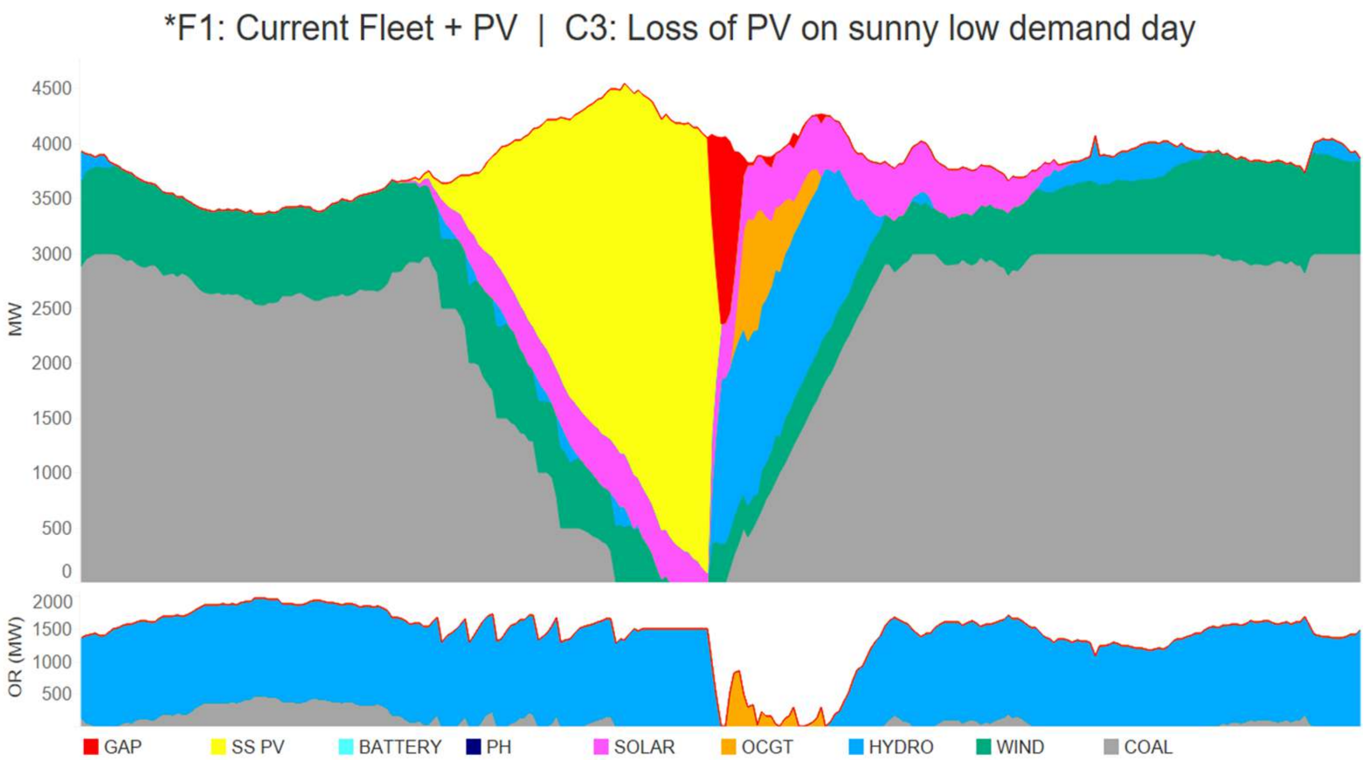
- This scenario is the current fleet exposed to the loss of all rooftop solar PV over 15 minutes
- The modelled fleet here may require additional flexibility to address this event without the loss of load
- Some limitations of the model :
    - assumes participants are dispatched based on their efficient costs
    - events may not reflect what can be expected in the real world
    - does not capture interconnection or FCAS from adjacent regions
    - artificial nature of foresight




- **Would this event result in lost load in the relevant region in the real world?**
- **Are there real world circumstances where the current fleet has been or could be too inflexible to meet uncertain changes in net demand?**

# 2.2 How would the current fleet respond with the addition of significant PV?

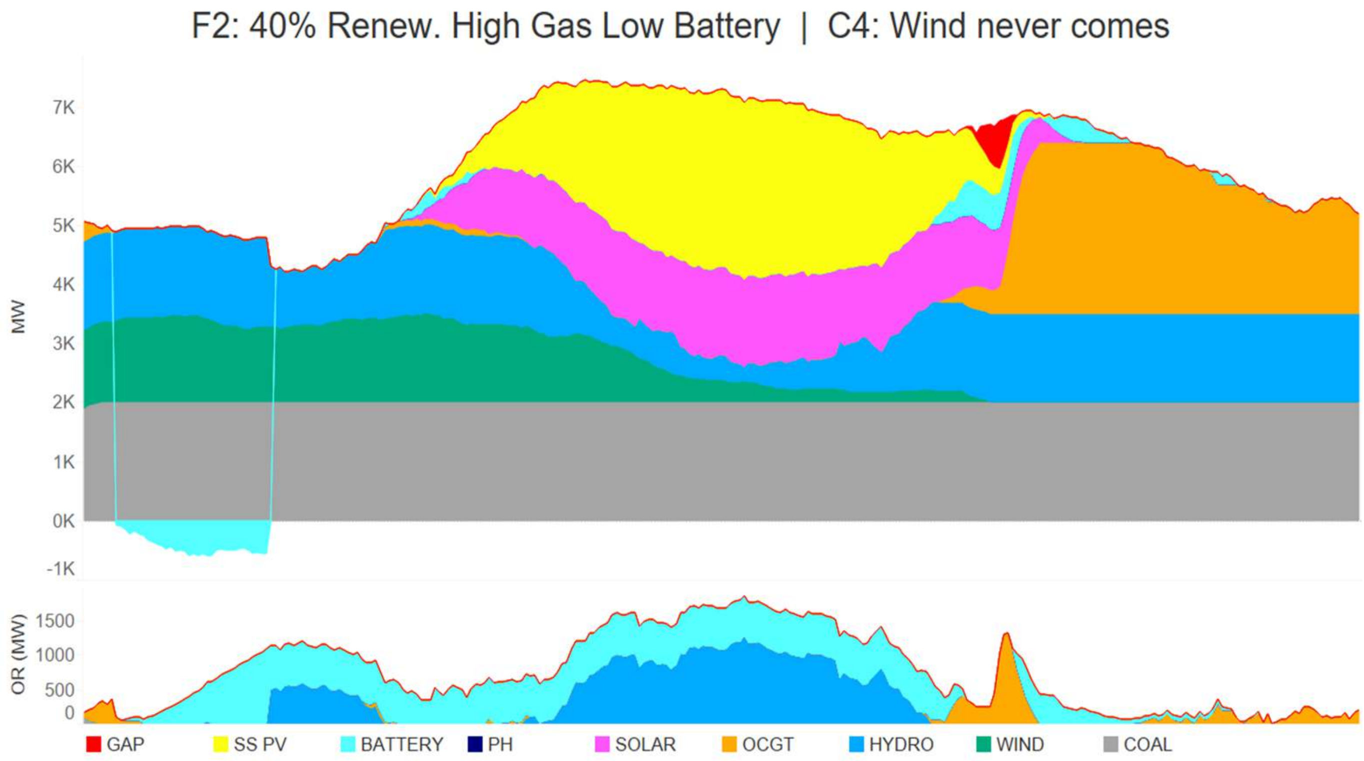
- This scenario is the current fleet + PV, exposed to the loss of all rooftop solar PV over 15 minutes on a particularly sunny day
- The modelled fleet here may require additional flexibility to address this event without the loss of load
- The same limitations apply to this scenario as on the previous slide
- **Is this scenario a realistic risk for the NEM?**
- **Is there a risk of synchronous plant not operating during the day?**
- **How fast will coal ramp?**




- **Is there a risk of increased VRE and rooftop PV without an increase in flexible firming capacity?**
- **Should a reserve service (designed to increase the flexibility of supply to deal with such uncertain events) be designed/implemented to address risks like these for consumers**?

## 2.3 Are there risks for fleet flexibility with a transition to firming with gas?

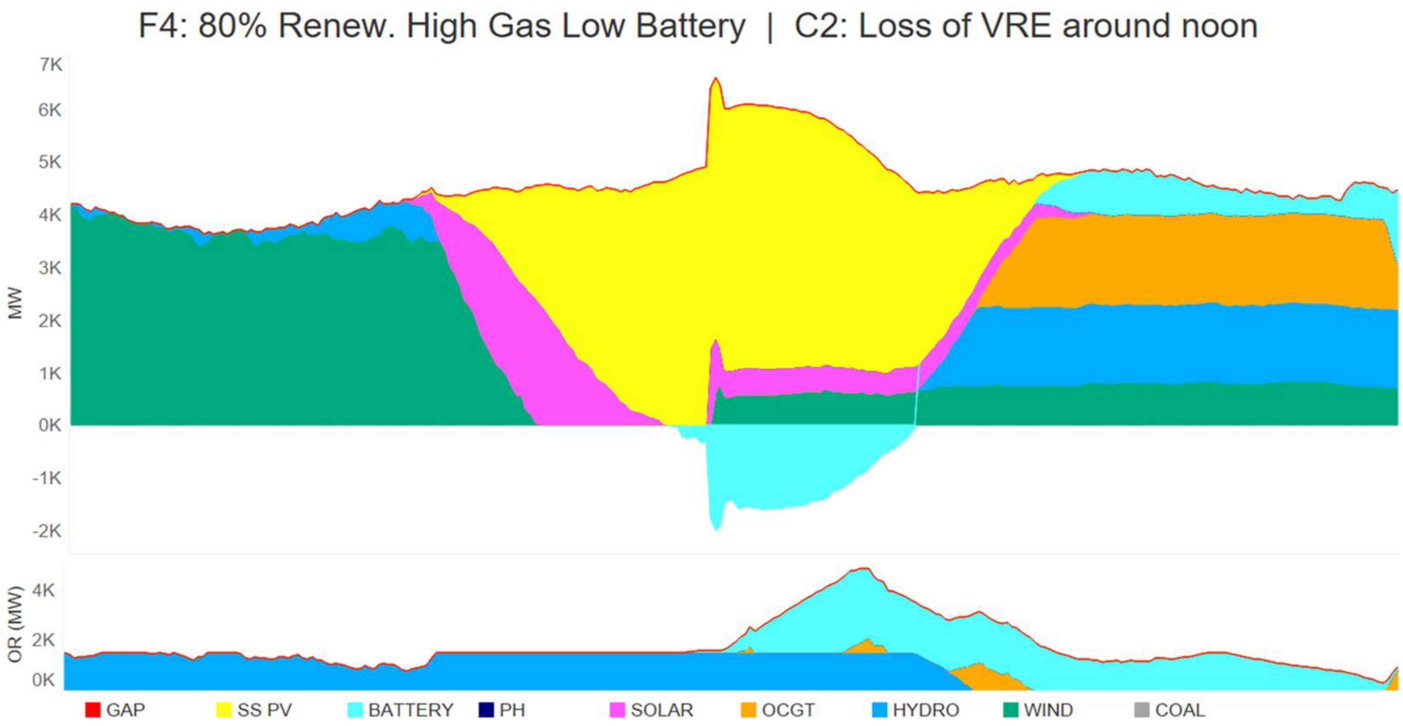
- This scenario is the fleet with 40% renewables that has managed firming needs with additional gas, exposed to the event where a predicted increase in wind output during the evening peak does not eventuate
- The modelled fleet here may require additional flexibility to address this event without the loss of load
- The same limitations apply to this scenario as previous slides
- **Is it realistic or appropriate to expect that the fleet would transition with this level of (in)flexibility?**




- **How would changing assumptions around new gas performance affect outcomes?**
- **Are there risks that participants could dispatch out of merit order, reducing the flexibility of the fleet at times (e.g. could gas or hydro displace coal at times)?**

## 2.4 Can VRE provide reserves if constrained off?

- This scenario is the fleet with 80% renewables that has managed firming with additional gas and some batteries, exposed to the event where most large scale solar and wind in the region is lost around mid-day (e.g. the loss of multiple REZs)
- The modelled fleet here appears to have sufficient flexibility to address this event without the loss of load
- The same limitations apply to this scenario as previous slides

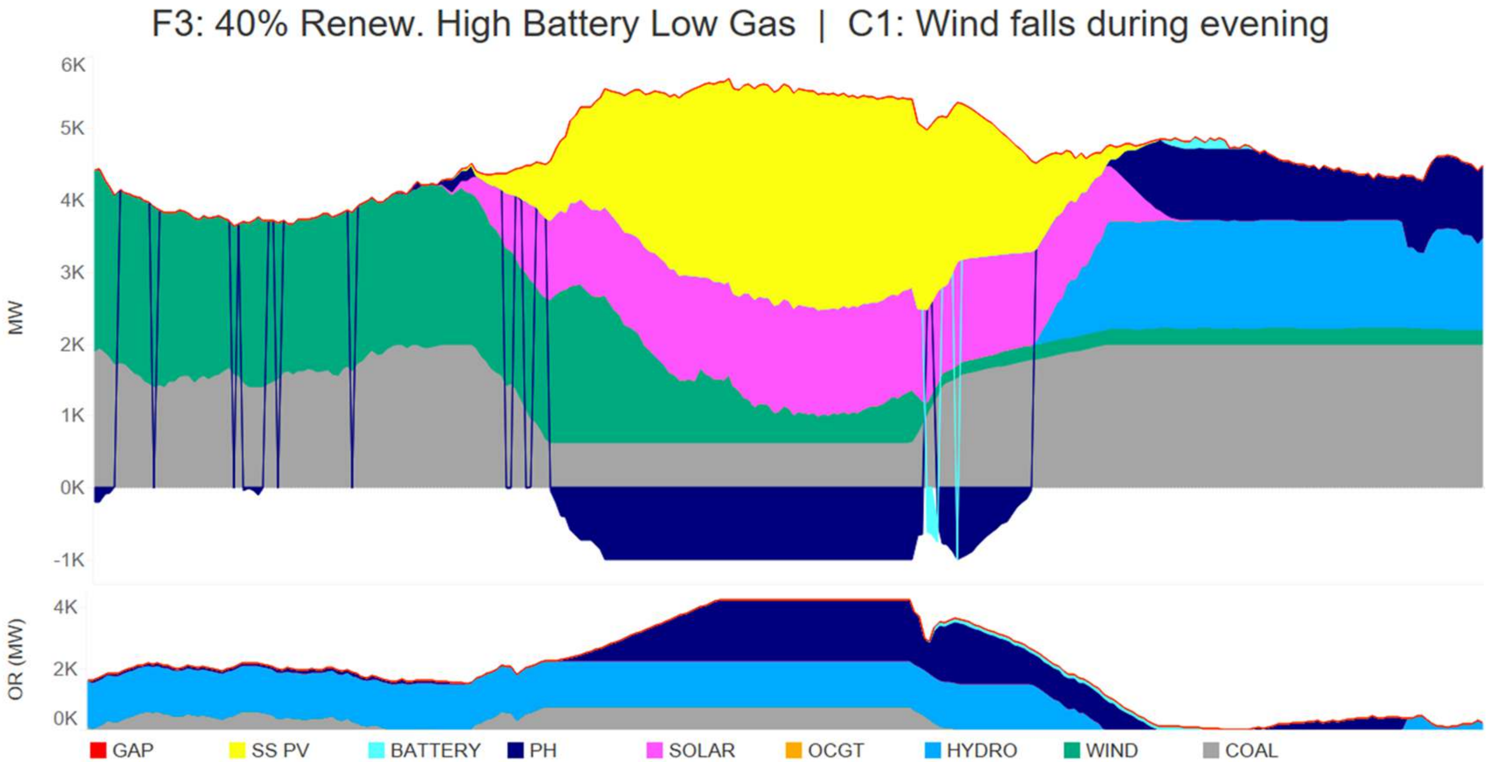



- **In this model, the loss of a significant amount of VRE is not a significant problem because it is lost while it is constrained off. Is this a likely outcome in the real world?**

# 3.
# ENERGY ADEQUACY ISSUES IN THE MODELLED WORLD

# 3.1 How do different technologies in a battery/PH future provide reserves?

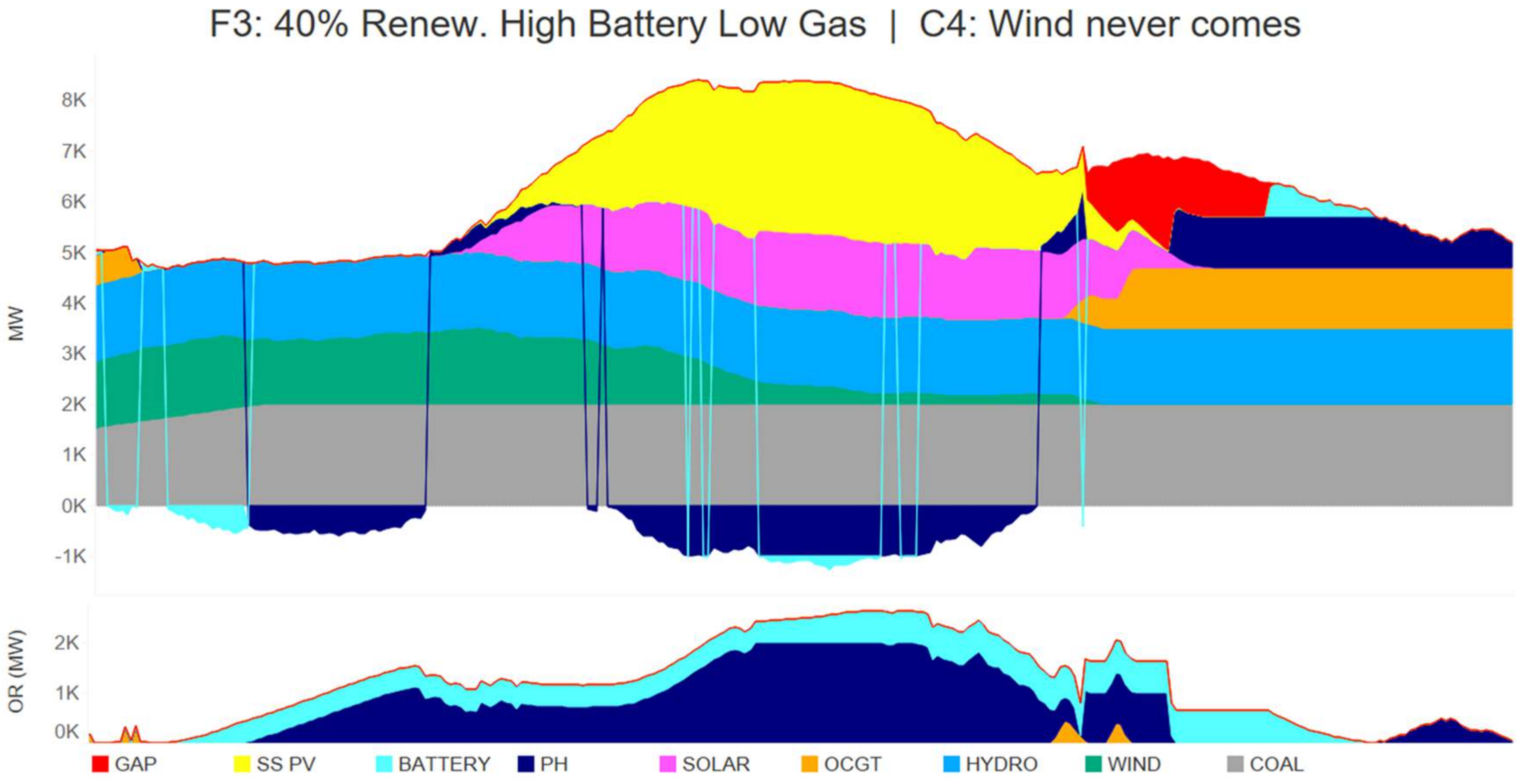
- This scenario is the fleet with 40% renewables that has managed firming largely with batteries and pumped hydro, exposed to the event where wind output falls during the early evening peak
- The modelled fleet here appears to have sufficient flexibility to address this event without the loss of load, but limited capacity in reserve for the rest of the day
- The same limitations apply to this scenario as previous slides




- **The level of reserve in this model is very low during the evening peak to respond to an additional event. Is this likely in the real world given the model assumes batteries decided not to charge?**
- **Could we expect more reserves to be provided by batteries and pumped hydro on a daily basis than is shown here? Is this an investment or operational issue?**

# 3.2 Are there energy adequacy risks around battery charging and duration?

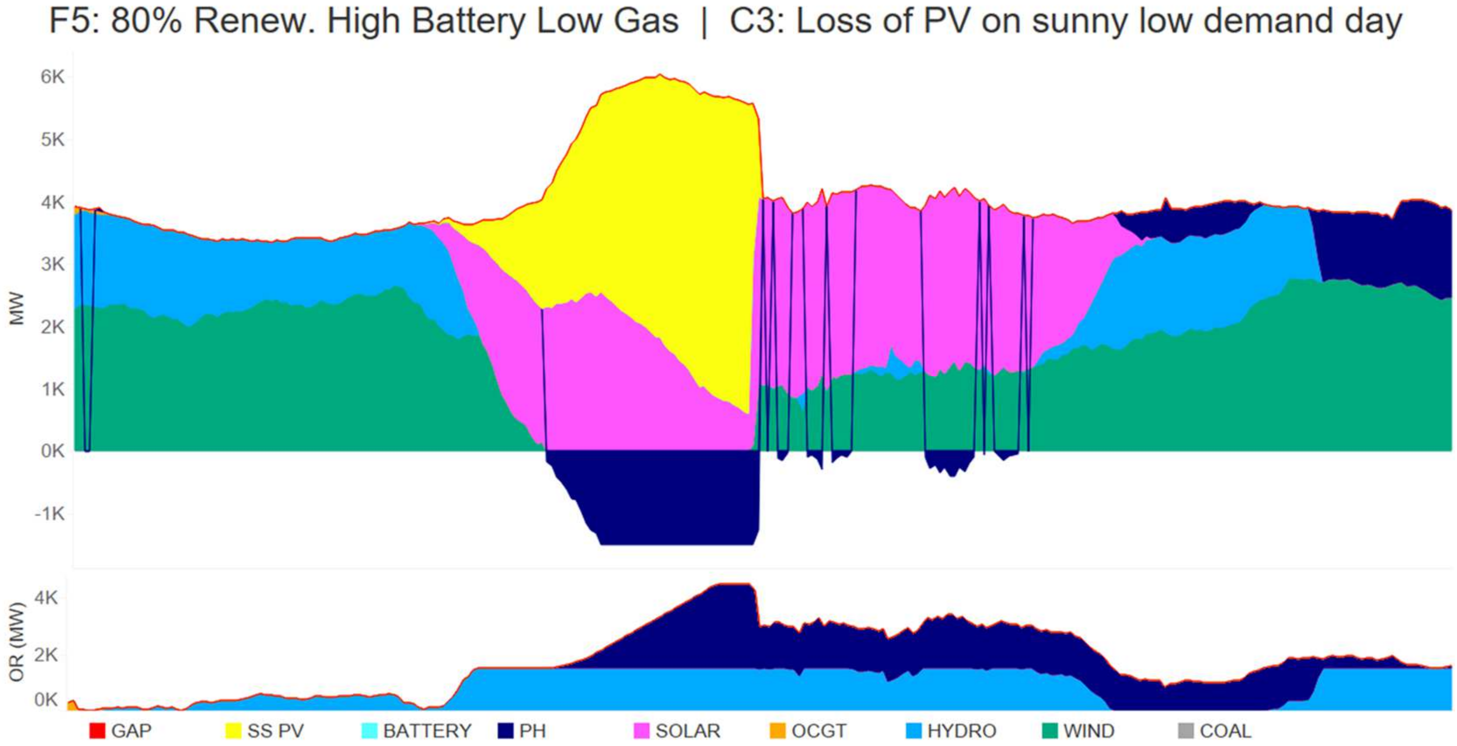
- This scenario is the fleet with 40% renewables that has managed firming largely with batteries and pumped hydro, exposed to the event where wind fails to turn up when expected to ramp up
- The modelled fleet here appears to have sufficient flexibility to address this event without the loss of load, but batteries and pumped hydro do not have sufficient energy in storage for longer duration needs
- The same limitations apply to this scenario as previous slides




- **This scenario is heavily dependant on the behaviour of batteries. Is it reasonable to assume they start the day with no charge?**
- **Would we expect this energy adequacy need to be met by participant behaviour in the real world?**

# 3.3 When might a high batteries/PH future be most vulnerable to a shock?

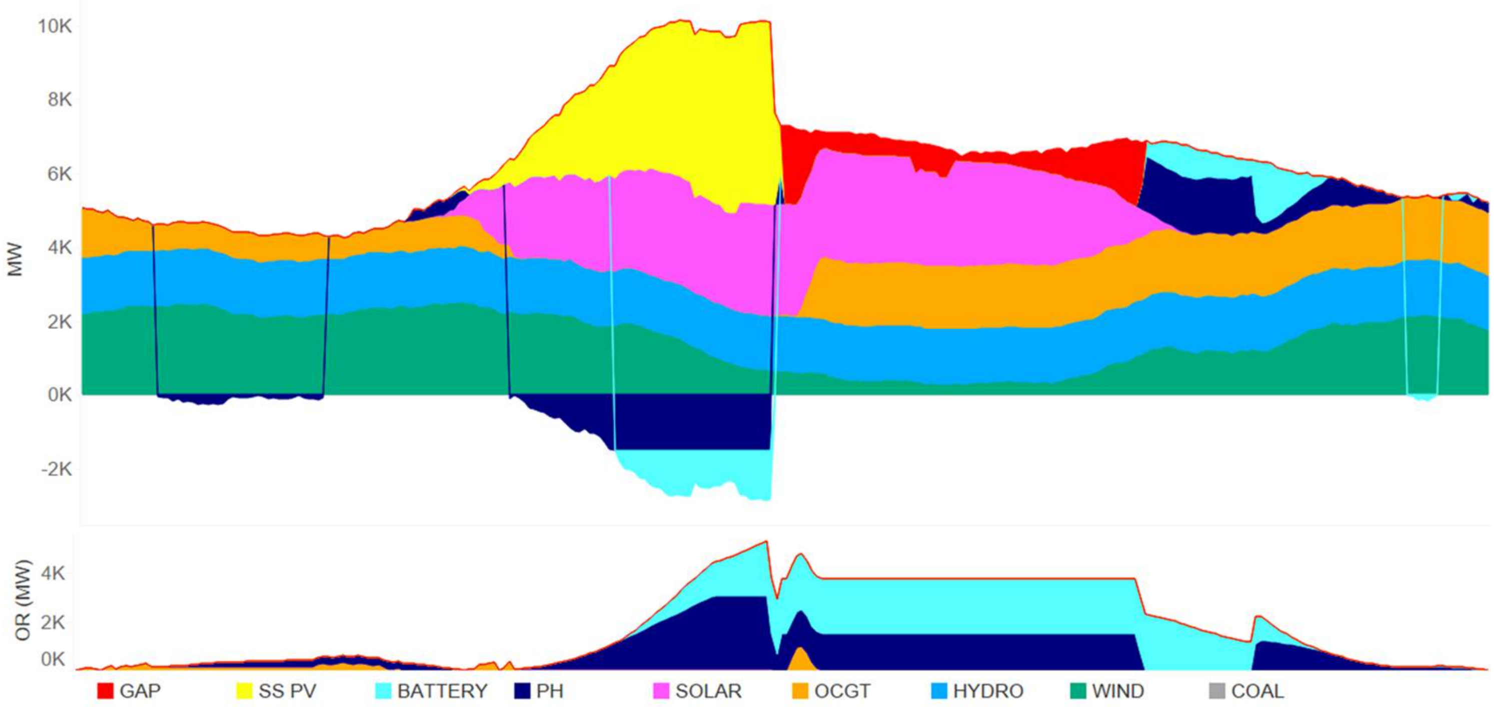
- This scenario is the fleet with 80% renewables that has managed firming largely with batteries and pumped hydro, exposed to the loss of all rooftop solar PV over 15 minutes on a particularly sunny day
- The modelled fleet here appears to have sufficient flexibility to address this event without the loss of load
- The same limitations apply to this scenario as previous slides




- **Why are batteries and gas not participating on this day?**
- **Capacity that was constrained is able to replace solar. If an event were to occur at another time, would there be problems?**
- **Would the fleet adapt to dealing with uncertainty throughout the diurnal pattern?**

# 3.4 What is the worst-case scenario in a battery/PH future?

F5: 80% Renew. High Battery Low Gas | C5: Loss of PV on moderate demand day




- This scenario is the fleet with 80% renewables that has managed firming largely with batteries and pumped hydro, exposed to the loss of all rooftop solar PV over 15 minutes on a moderate demand day
- The modelled fleet here appears to have sufficient flexibility to address this event without the loss of load, but batteries and pumped hydro do not have sufficient energy in storage for longer duration needs
- The same limitations apply to this scenario as previous slides
- **Could we expect participants to behave differently on a day like this?**
- **At what point in the transition to a battery and pumped hydro future might energy adequacy issues arise?**
- **Should we be concerned about events emerging over multiple days (cloudy, muggy, still, high demand weather patterns)?**

# 4.
# WHAT DOES THIS MODELLING MEAN FOR THE NEM?

# 4.1 Does the modelling support the implementation of a reserve service?

- Stakeholder views were mixed on the value of a reserve service in the deep dive in February
- Has this modelling and the discussion around how it relates to the real world changed any stakeholder positions on whether a reserve service is needed for the NEM? How and why?
- What do participants see as the main risks for the system going forward:
  - Flexibility of supply to meet uncertain events when they occur?
  - Energy adequacy over longer durations?
  - Both?
  - Something else?
- What signposts might we see that would suggest a flexibility or energy adequacy issue may or may not arise?
- **Mural session to capture views**

# 5.
# NEXT STEPS

## 5.1 Next steps

- ESB consultation paper on post-2025 market design expected soon
- AEMC to form views on the “spectrum” of options for the draft determination
- Possible deep dive with this stakeholder group in mid-May to consult on options and/or direction for the draft determination
- AEMC draft determination due 24 June 2021

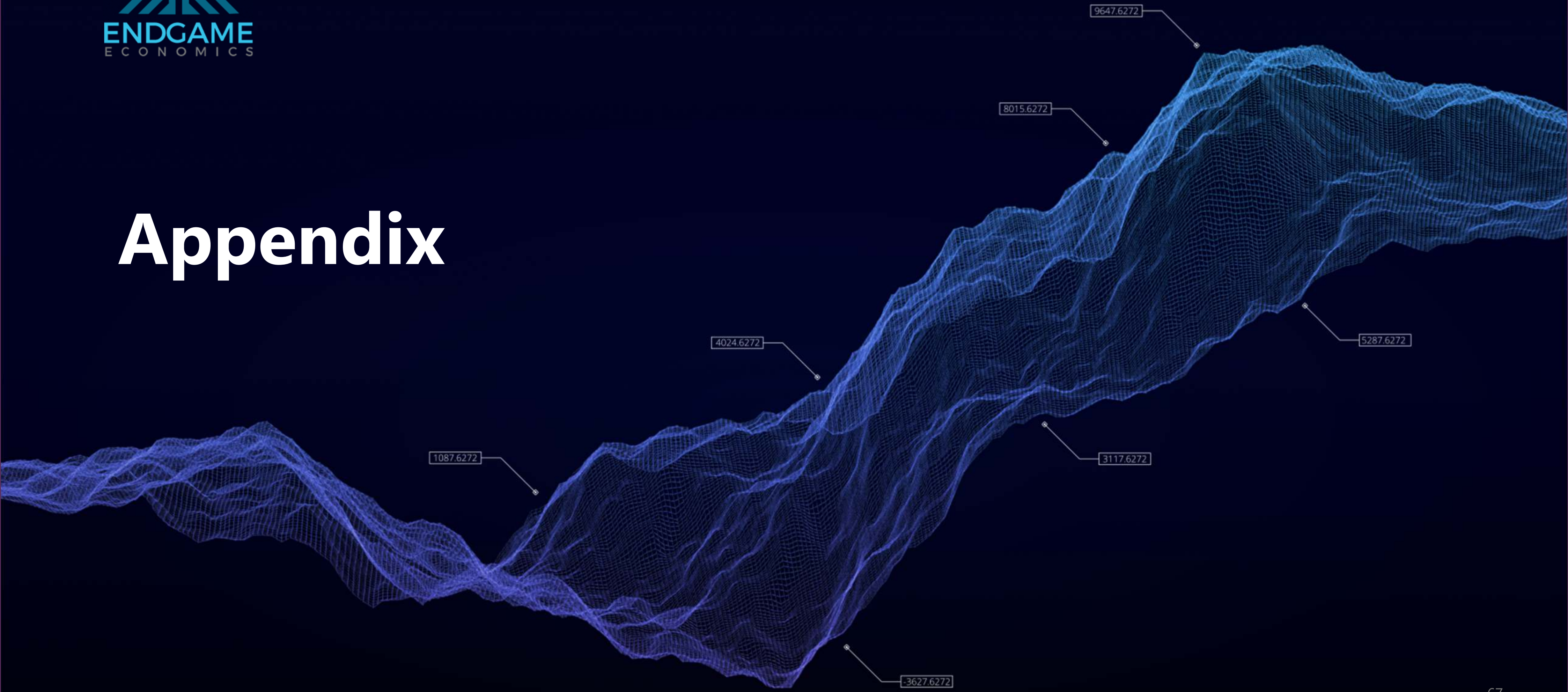
**Office address**
Level 15/60 Castlereagh St,
Sydney NSW 2000

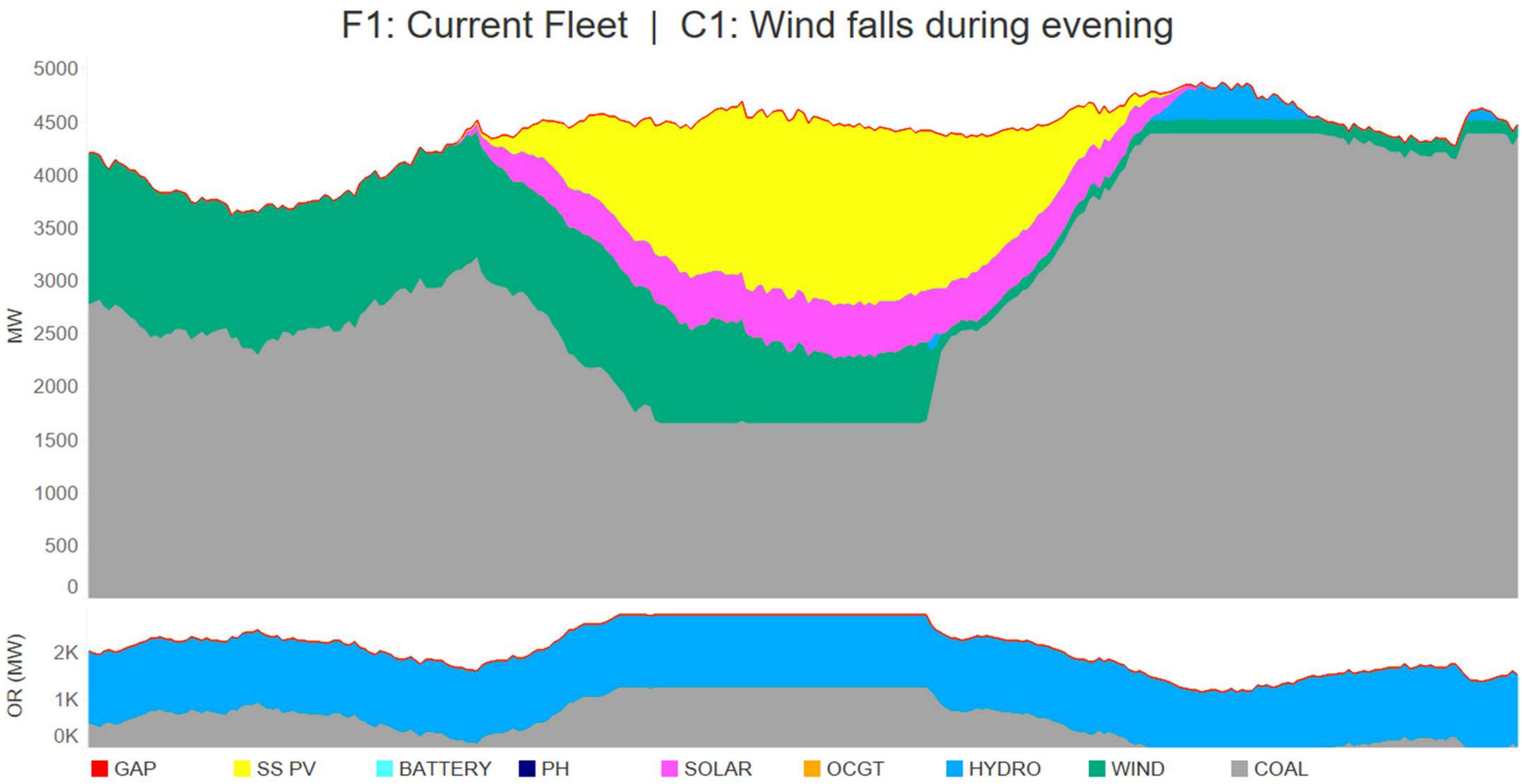
**Postal address**
GPO Box 2603
Sydney 2001

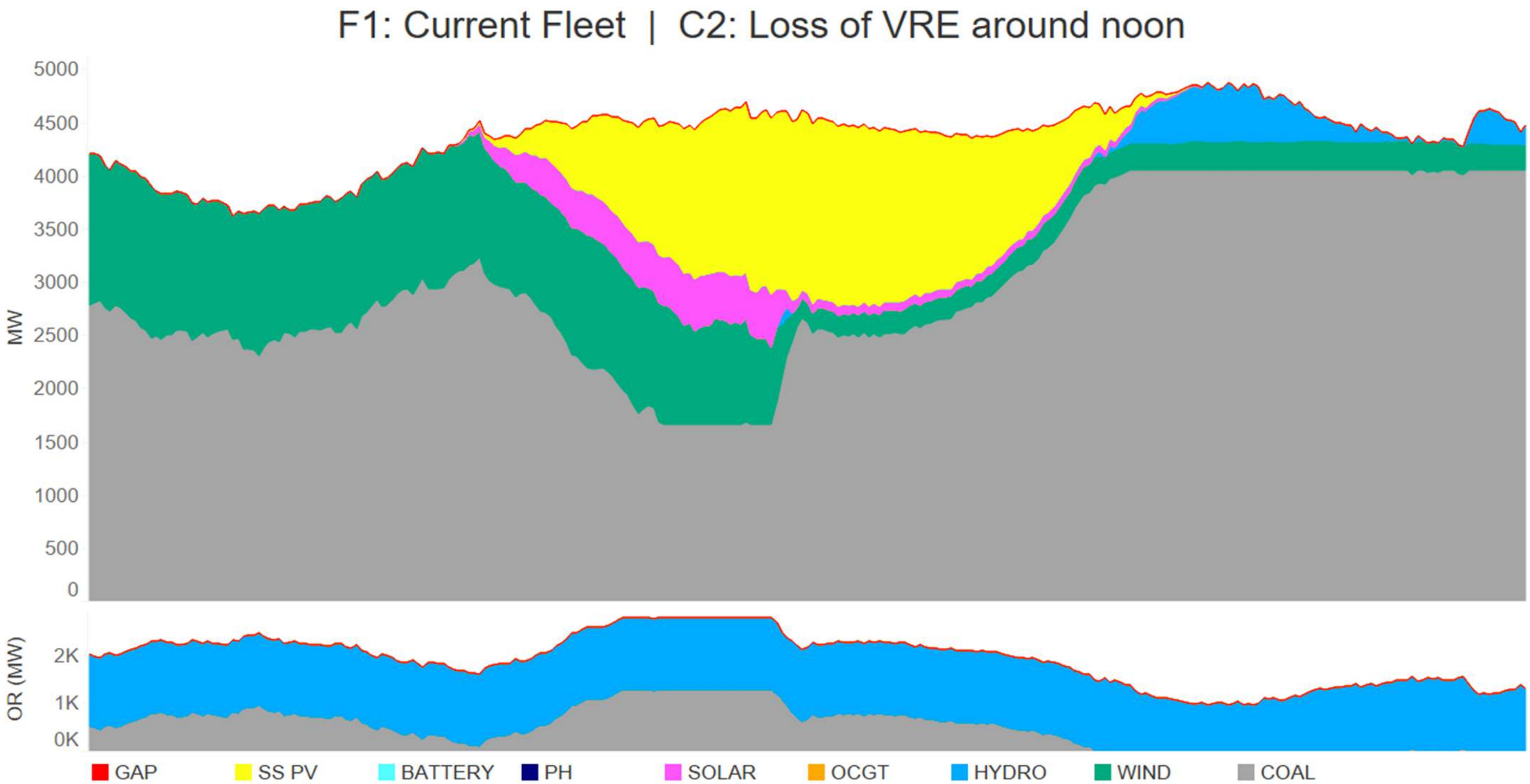
**T** (02) 8296 7800
**F** (02 8296 7899

ENDGAME ECONOMICS

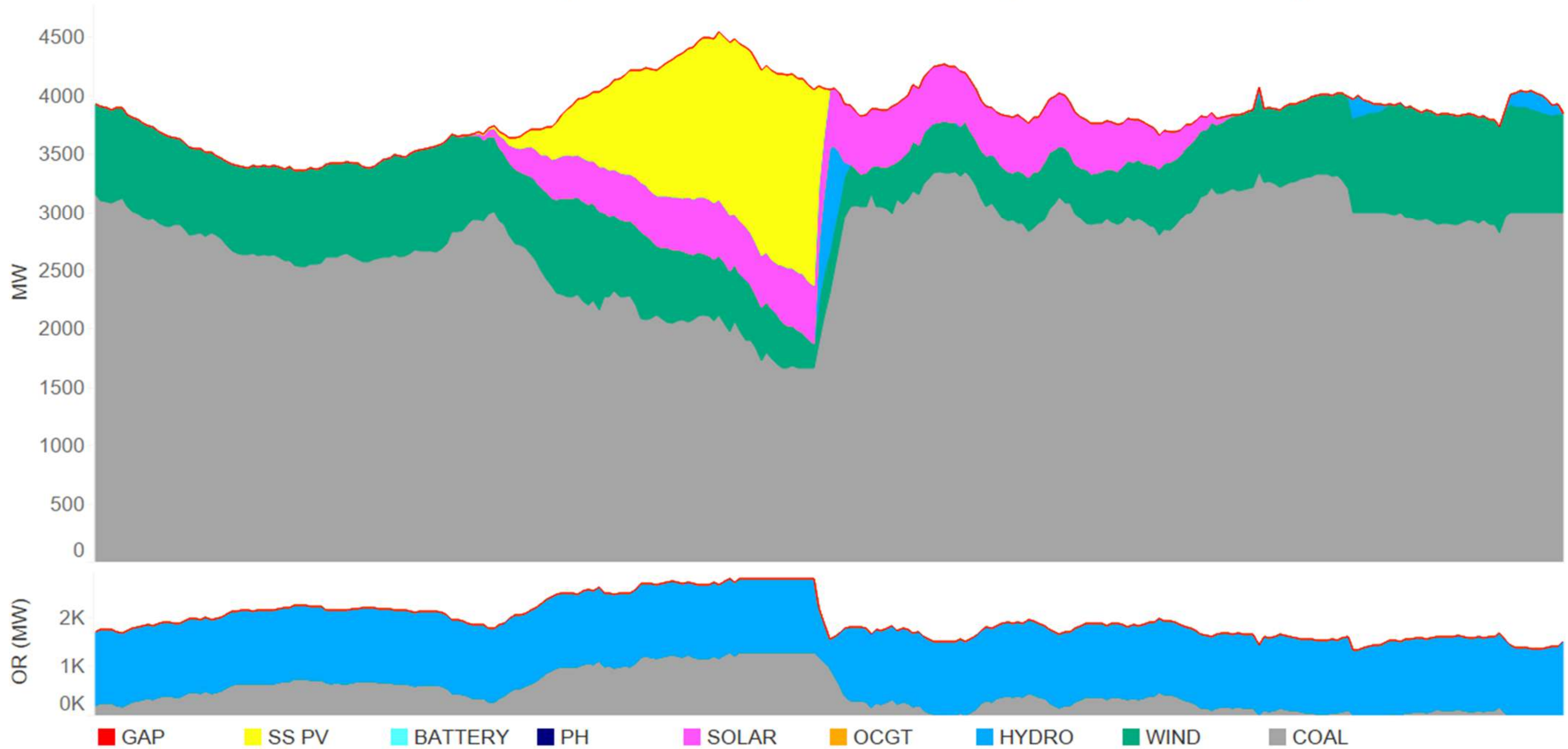
# Appendix

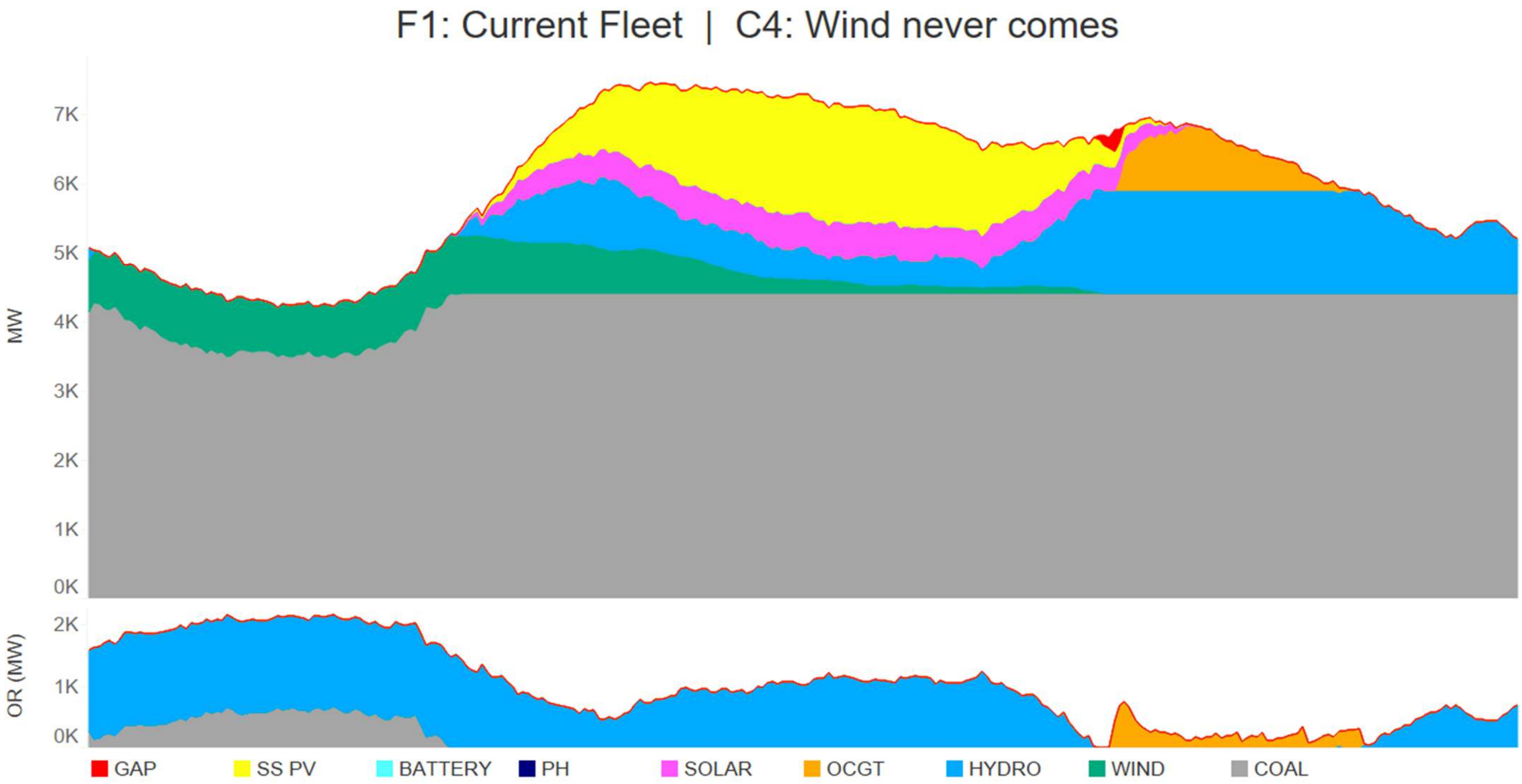



F1: Current Fleet | C1: Wind falls during evening
MW
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
OR (MW)
2K
1K
0K
GAP
SS PV
BATTERY
PH
SOLAR
OCGT
HYDRO
WIND
COAL


F1: Current Fleet | C2: Loss of VRE around noon
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
MW
2K
1K
0K
OR (MW)
GAP
SS PV
BATTERY
PH
SOLAR
OCGT
HYDRO
WIND
COAL

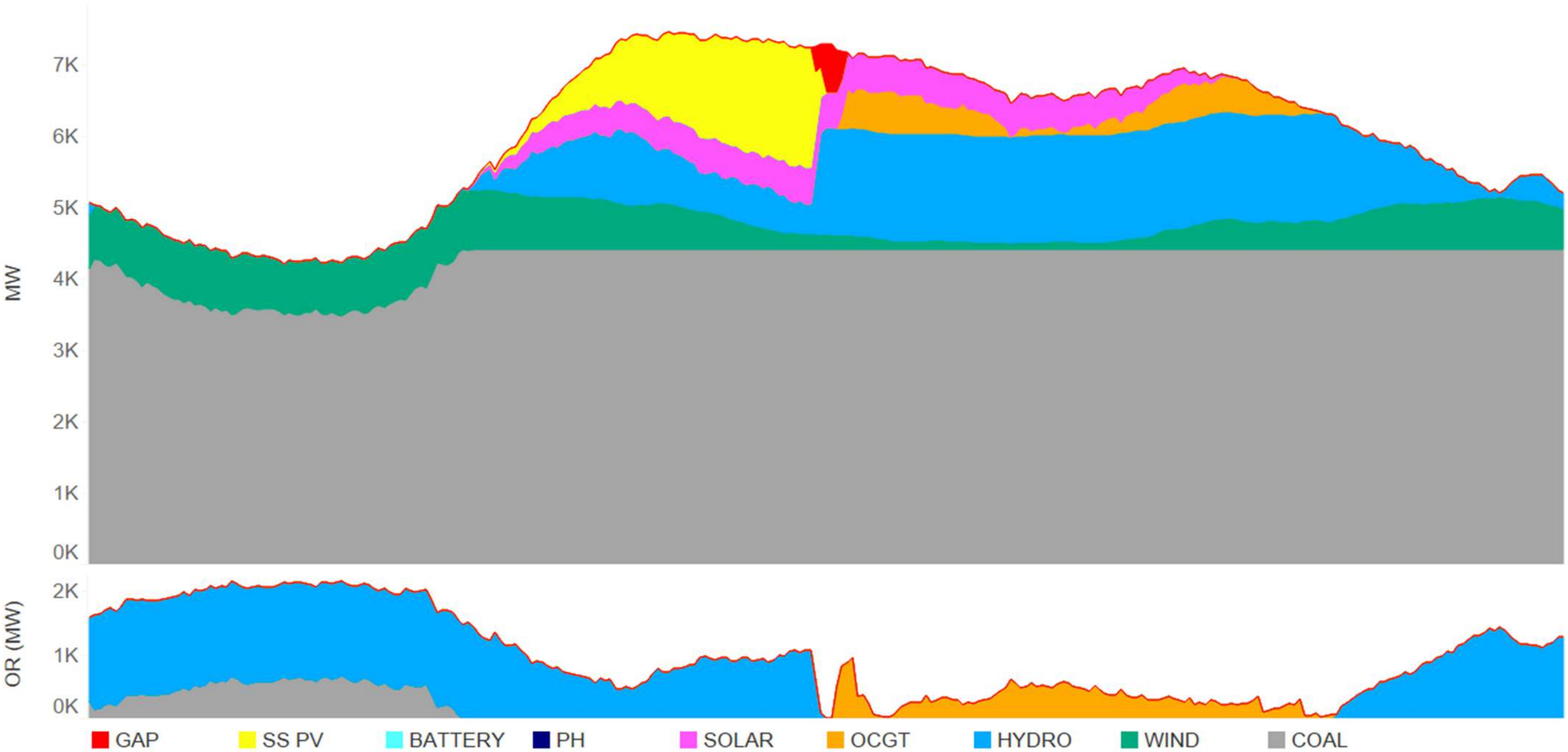
# F1: Current Fleet | C3: Loss of PV on sunny low demand day





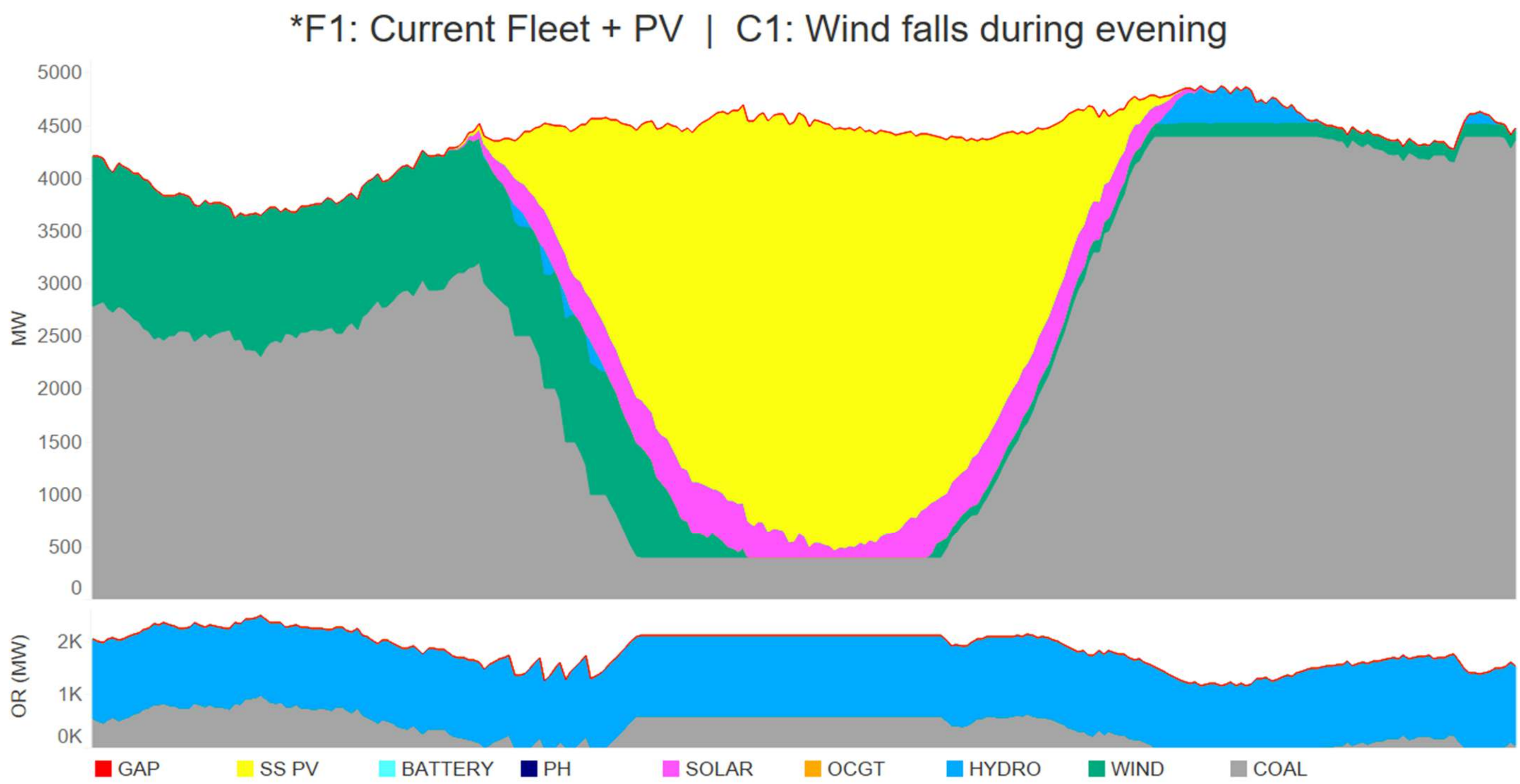
F1: Current Fleet | C4: Wind never comes
MW
7K
6K
5K
4K
3K
2K
1K
0K
OR (MW)
2K
1K
0K
GAP
SS PV
BATTERY
PH
SOLAR
OCGT
HYDRO
WIND
COAL

# F1: Current Fleet | C5: Loss of PV on moderate demand day

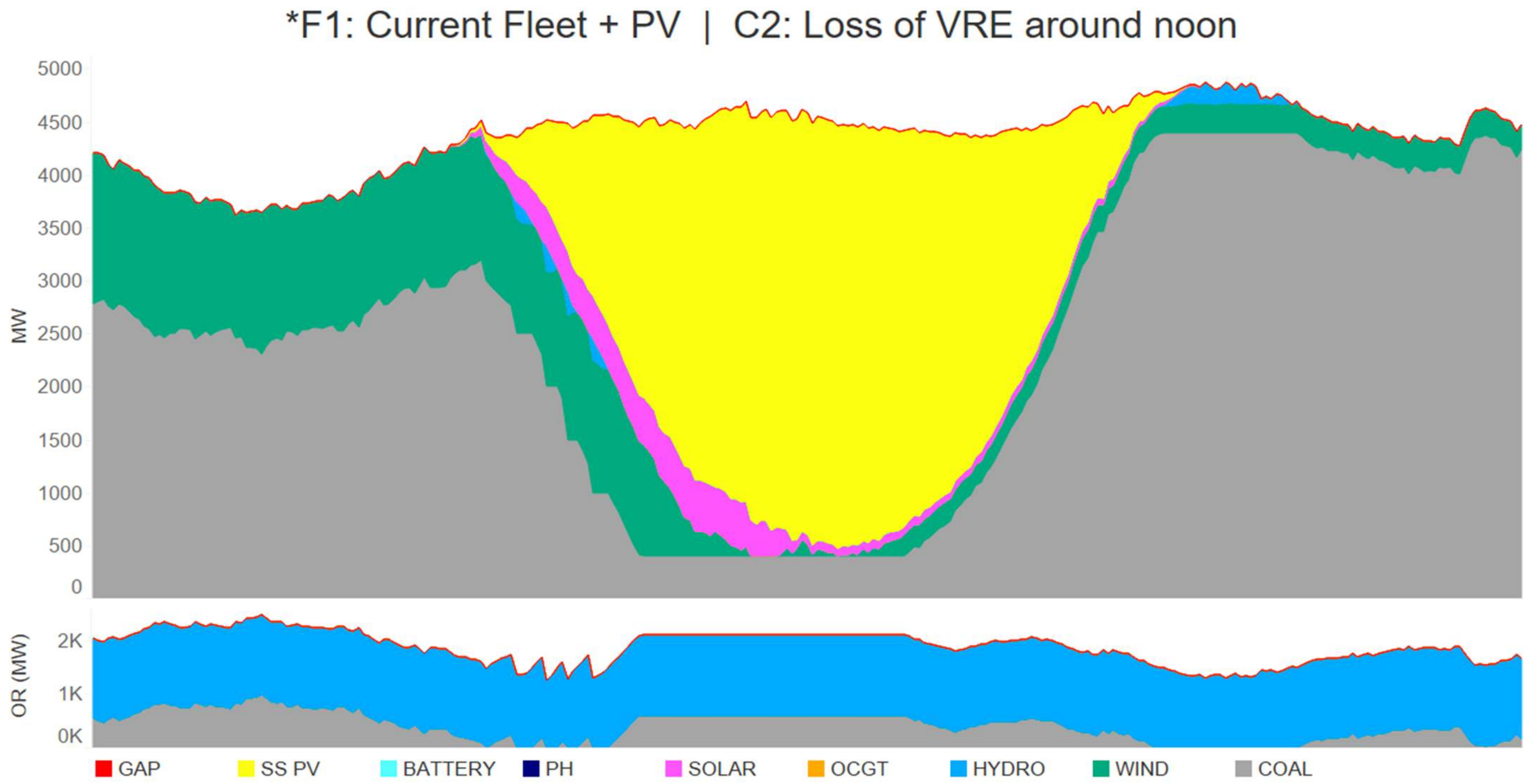


# Observations from modelling – current fleet

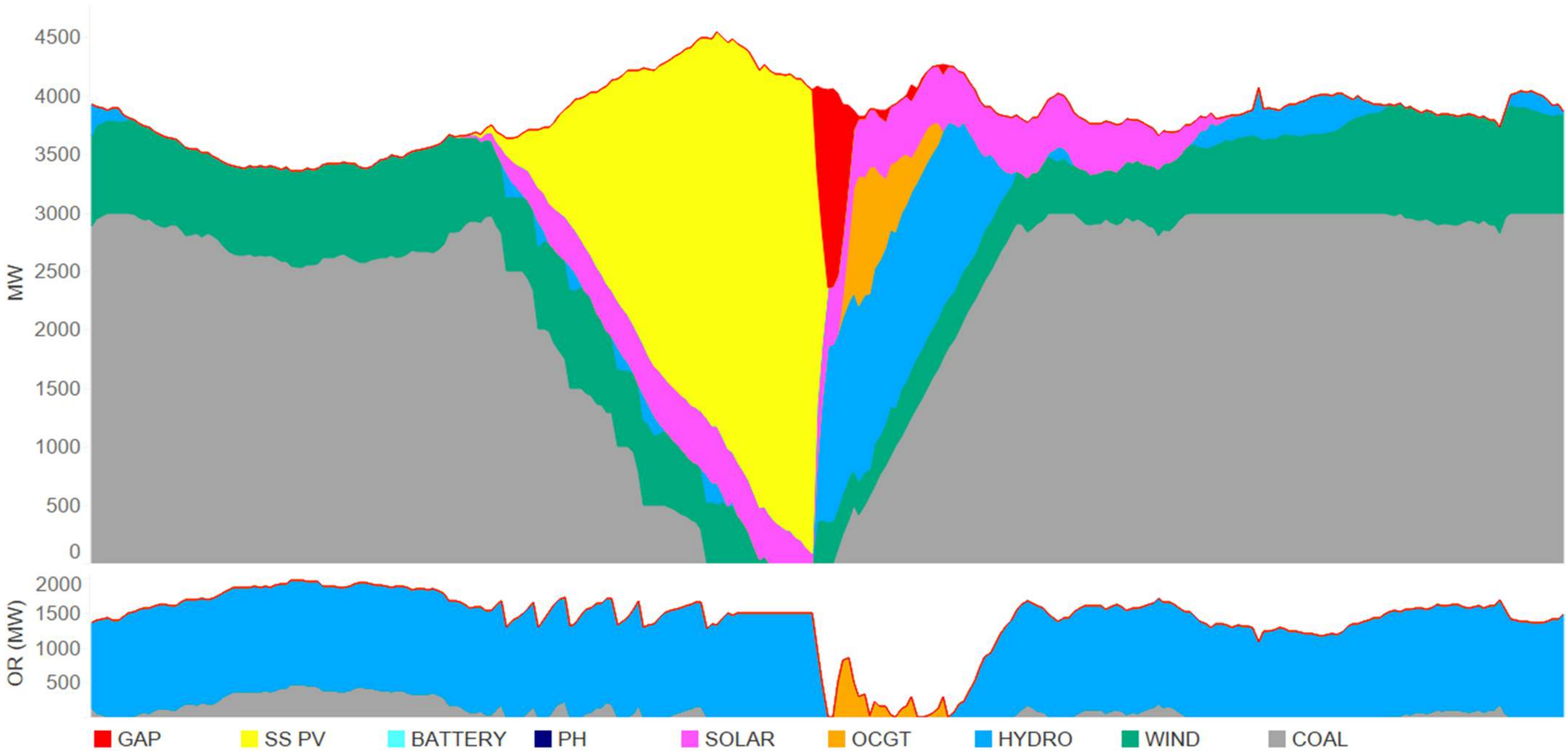
- **System responds in time when ...** shock to the system occurs when coal is online and has headroom. Shocks are managed by a combination of ramping of coal and spare hydro capacity.
- **Energy gap occurs when** ... shock to the system occurs when coal is already at its capacity. This is due to the shortage of ramping capacity (ie, without coal headroom, ramping is limited to gas and hydro).
- **Important parameters:** in this modelling the ramp rates, start-up costs, and no-load costs are important because they affect how coal plant functions during the middle of the day. These parameters become more and more important as we see increasing penetration of solar PV – see the next fleet scenario for an illustration.
- **Outside of the model:** note that we have not included the role of interconnection or FCAS response in our modelling.

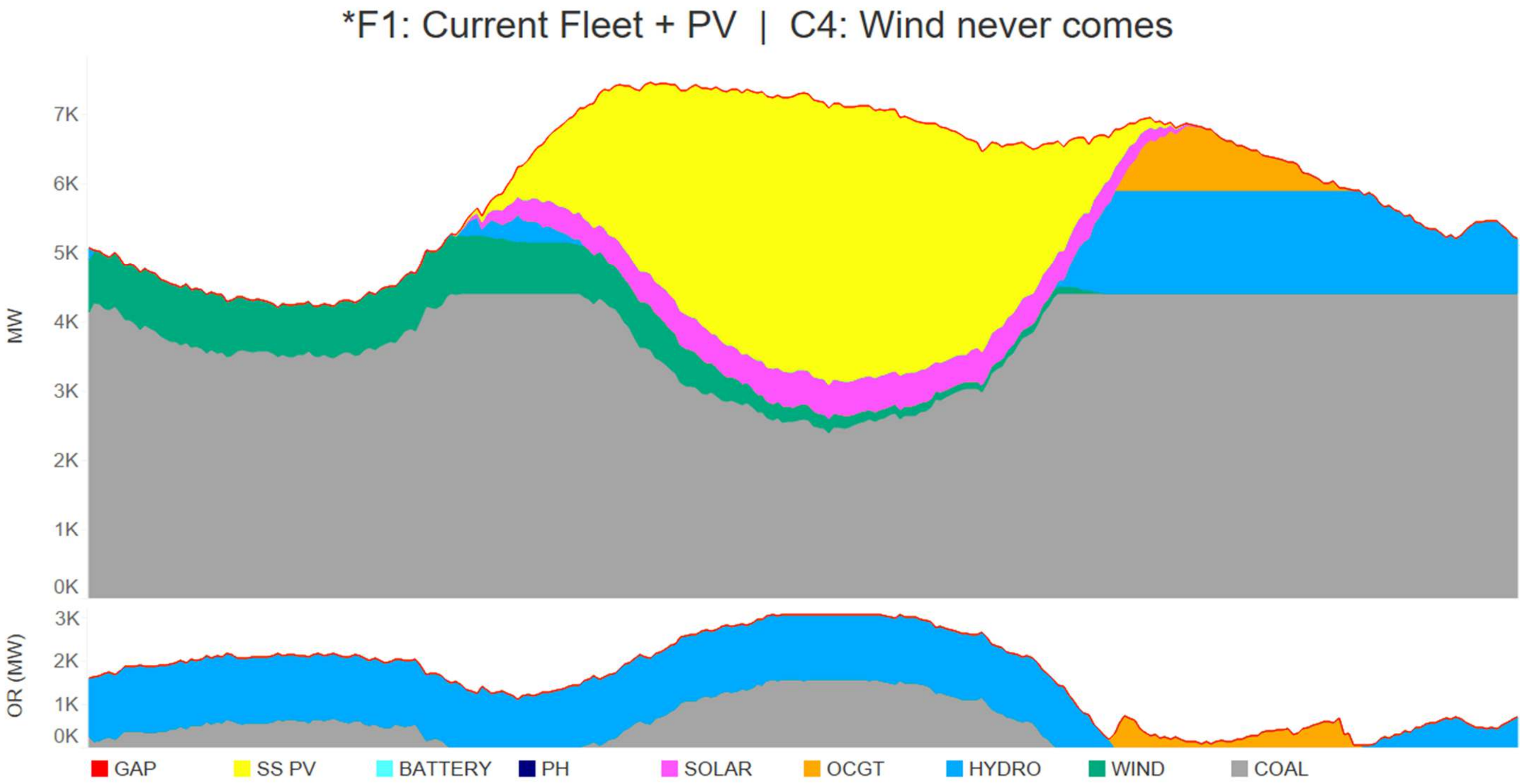


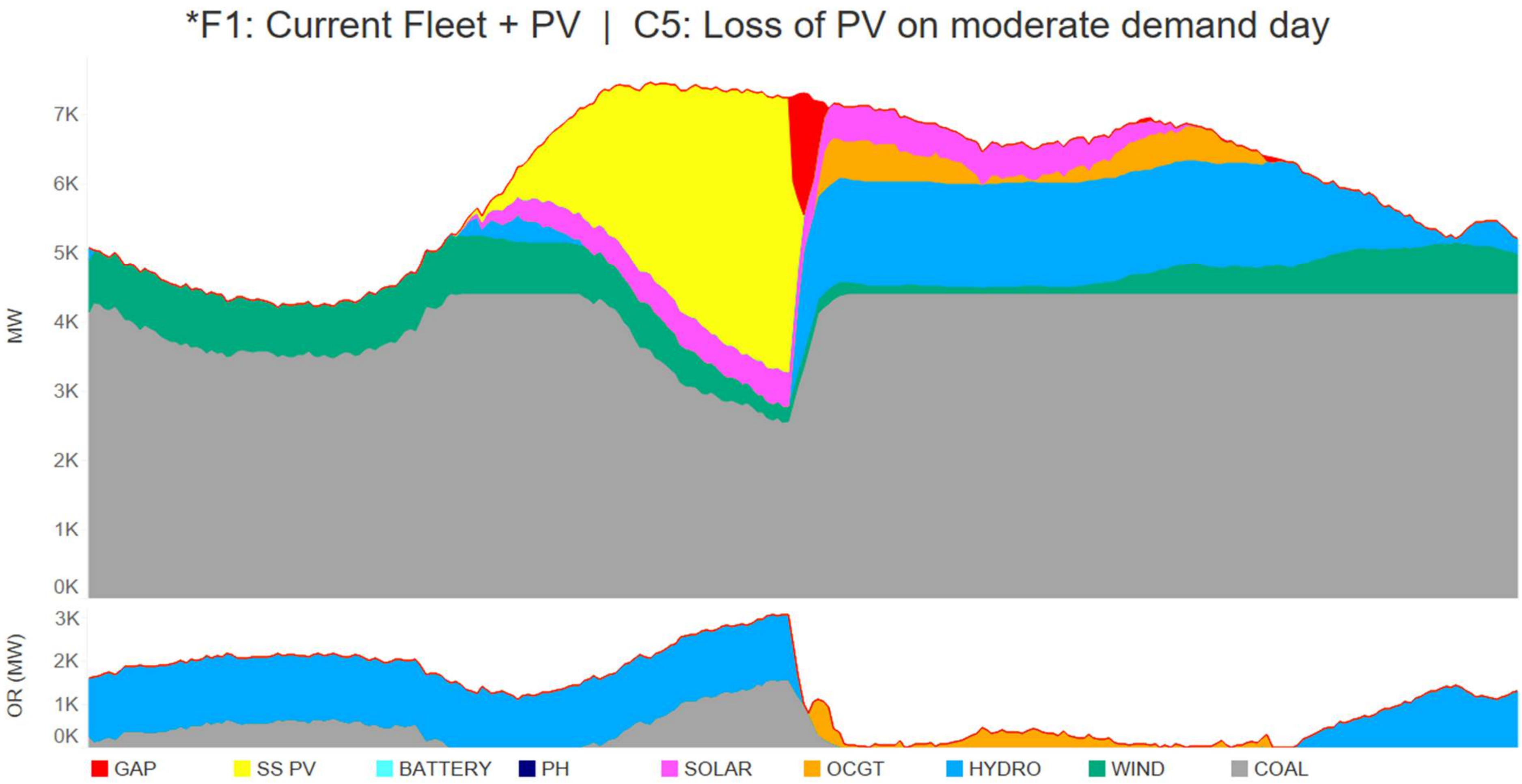
*F1: Current Fleet + PV | C1: Wind falls during evening
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
MW
2K
1K
0K
OR (MW)
GAP
SS PV
BATTERY
PH
SOLAR
OCGT
HYDRO
WIND
COAL


*F1: Current Fleet + PV | C2: Loss of VRE around noon
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
MW
2K
1K
0K
OR (MW)
GAP
SS PV
BATTERY
PH
SOLAR
OCGT
HYDRO
WIND
COAL

# *F1: Current Fleet + PV | C3: Loss of PV on sunny low demand day




*F1: Current Fleet + PV | C4: Wind never comes
MW
7K
6K
5K
4K
3K
2K
1K
0K
OR (MW)
3K
2K
1K
0K
GAP
SS PV
BATTERY
PH
SOLAR
OCGT
HYDRO
WIND
COAL

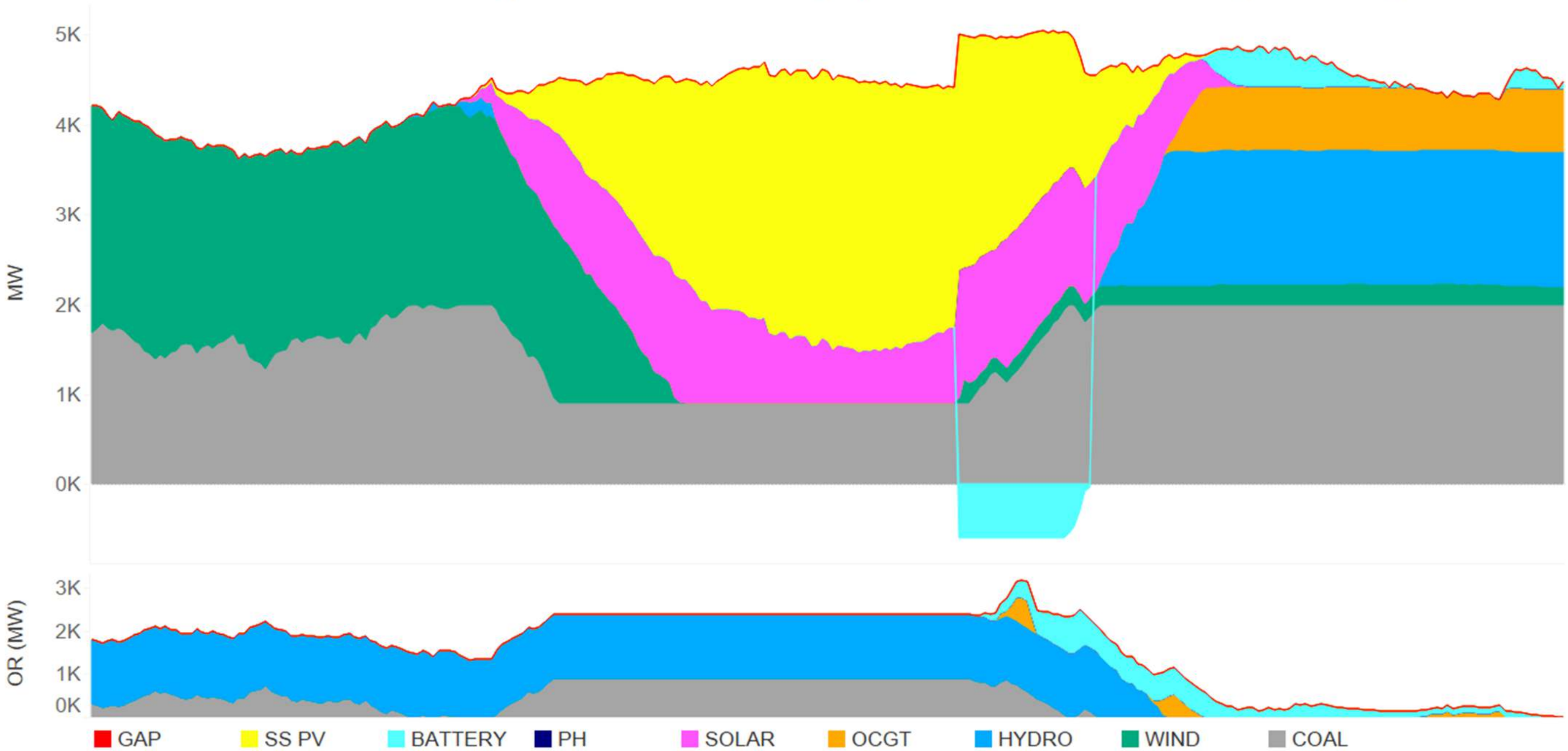

*F1: Current Fleet + PV | C5: Loss of PV on moderate demand day
MW
7K
6K
5K
4K
3K
2K
1K
0K
OR (MW)
3K
2K
1K
0K
GAP
SS PV
BATTERY
PH
SOLAR
OCGT
HYDRO
WIND
COAL

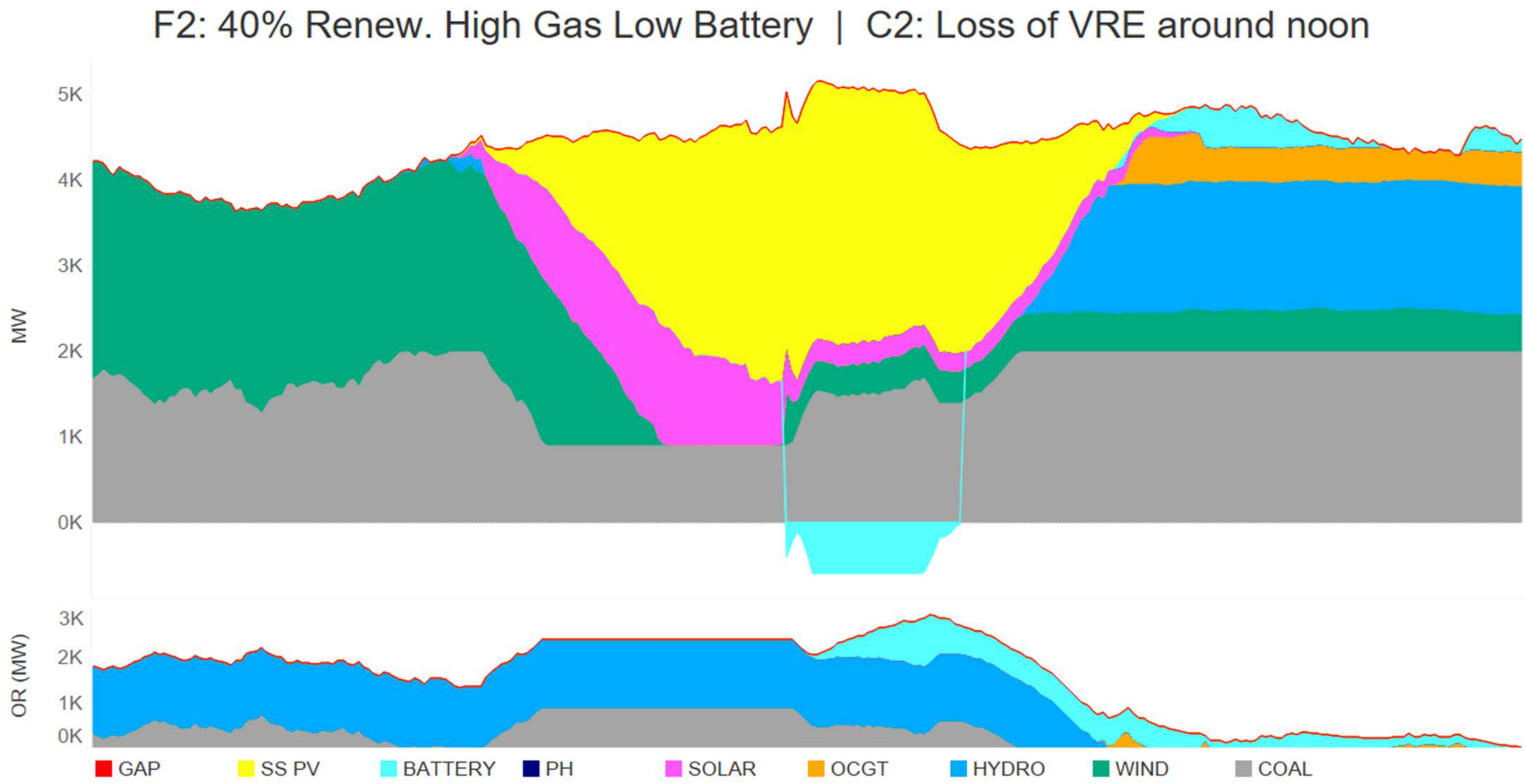
# Observations from modelling – current fleet + PV

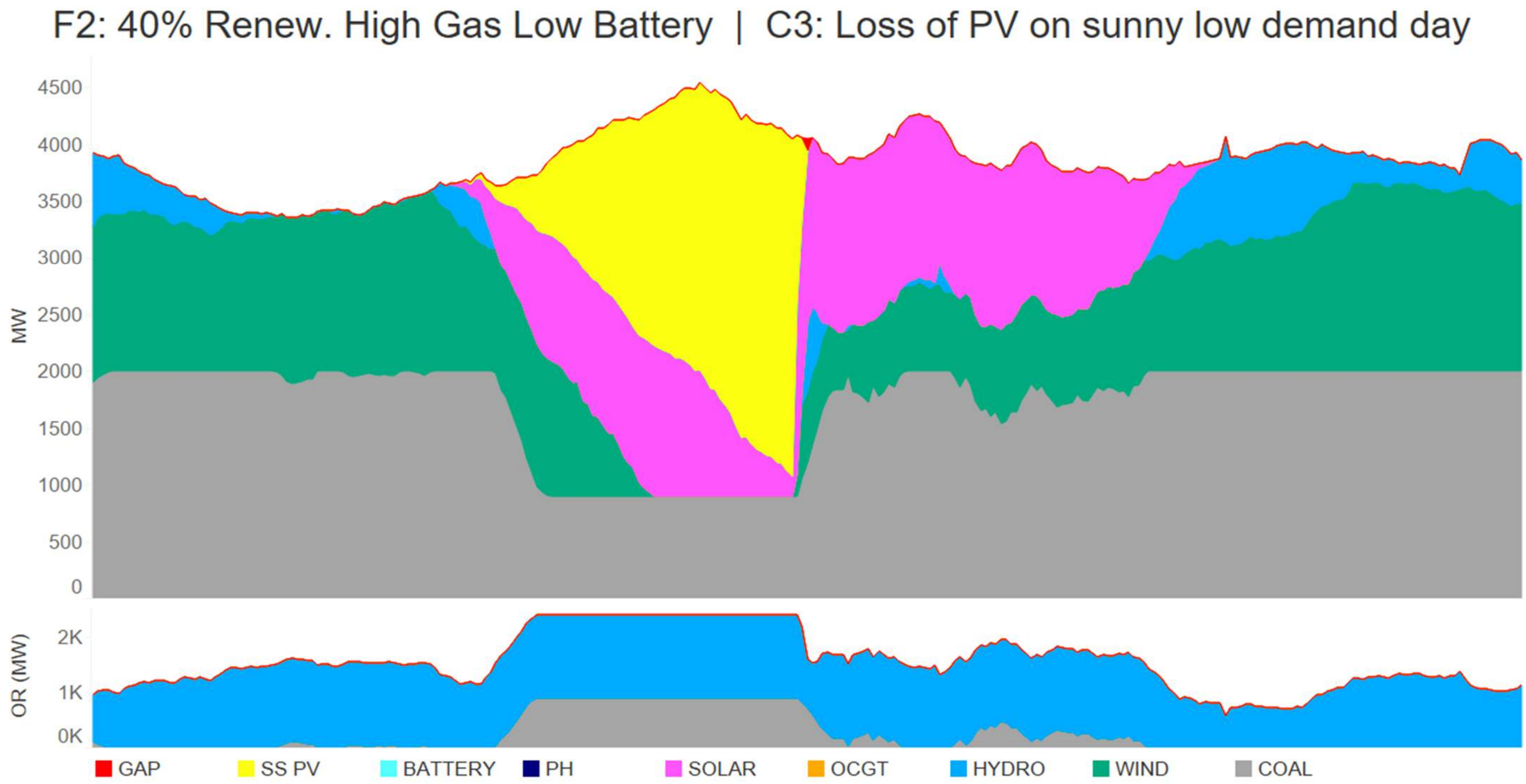
ENDGAME ECONOMICS

- **Model shows ramps are manageable when … ** shock occurs to renewables that are already constrained off at time of shock. This gives more time for system to respond to effects that only matter later in the day.
- **Role of curtailment:** so much depends on how we manage renewables – will we see rooftop PV preferred over constraining large-scale renewables generation, which can then respond? Effectively these large-scale renewables are providing an operating reserve.
- **Energy gap occurs when … ** shock to the system occurs when nothing else is online. This is a challenging situation to address, although we note that synchronous generation requirements are unlikely to allow this to occur at the moment.

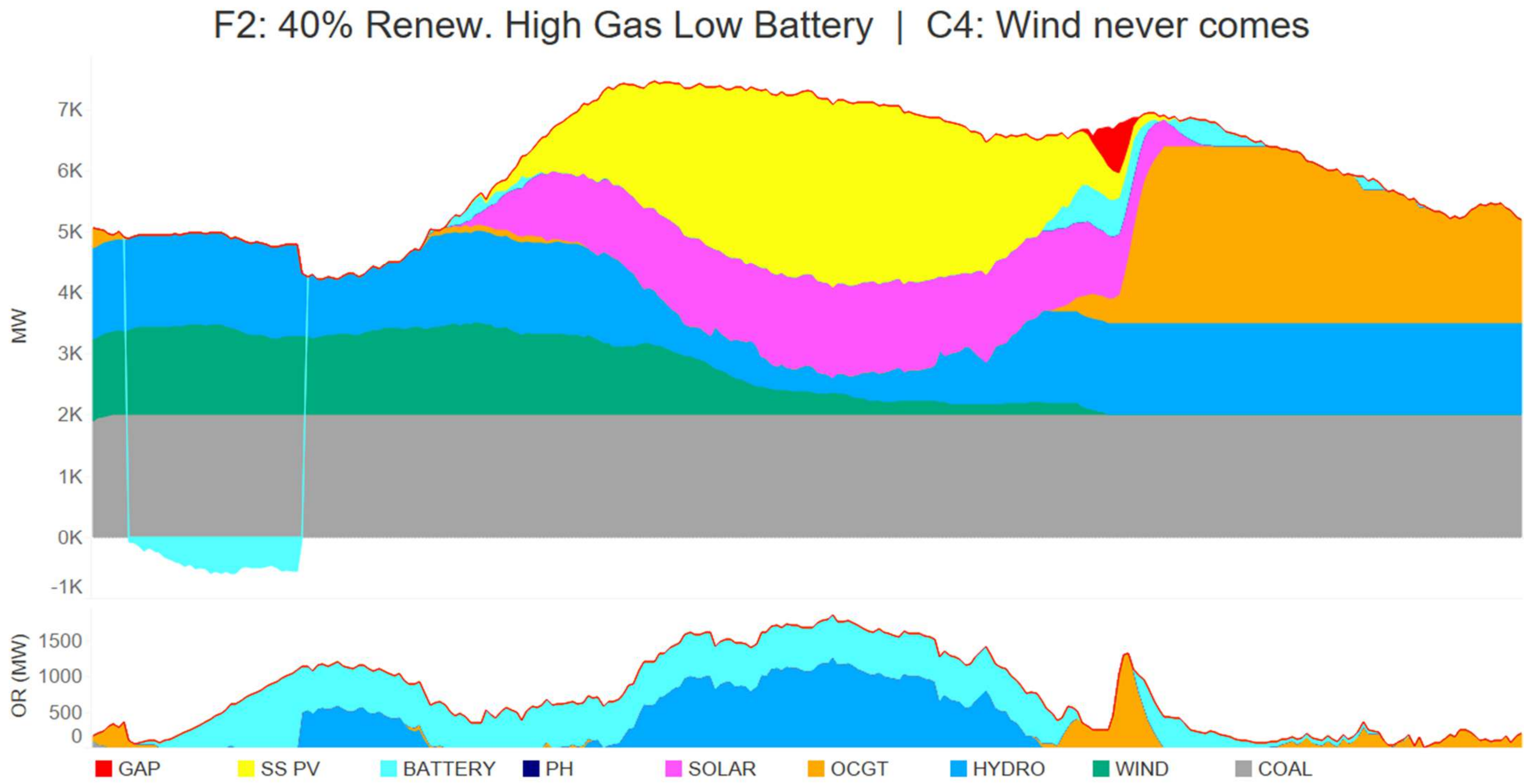
# F2: 40% Renew. High Gas Low Battery | C1: Wind falls during evening




F2: 40% Renew. High Gas Low Battery | C2: Loss of VRE around noon
5K
4K
3K
2K
1K
0K
MW
3K
2K
1K
0K
OR (MW)
GAP
SS PV
BATTERY
PH
SOLAR
OCGT
HYDRO
WIND
COAL

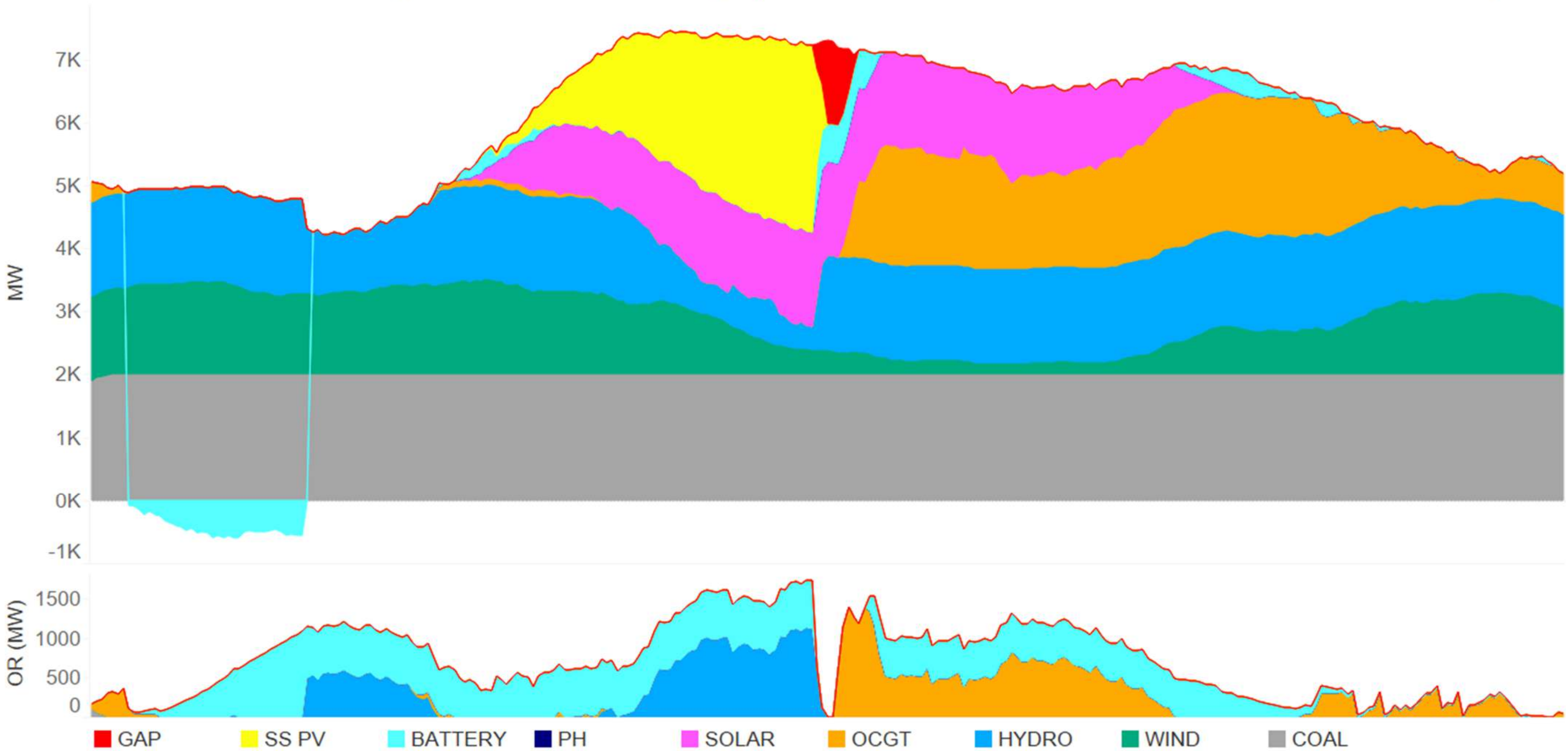


F2: 40% Renew. High Gas Low Battery | C3: Loss of PV on sunny low demand day
4500
4000
3500
3000
2500
2000
1500
1000
500
0
MW
2K
1K
0K
OR (MW)
GAP
SS PV
BATTERY
PH
SOLAR
OCGT
HYDRO
WIND
COAL



F2: 40% Renew. High Gas Low Battery | C4: Wind never comes
MW
7K
6K
5K
4K
3K
2K
1K
0K
-1K
OR (MW)
1500
1000
500
0
GAP
SS PV
BATTERY
PH
SOLAR
OCGT
HYDRO
WIND
COAL

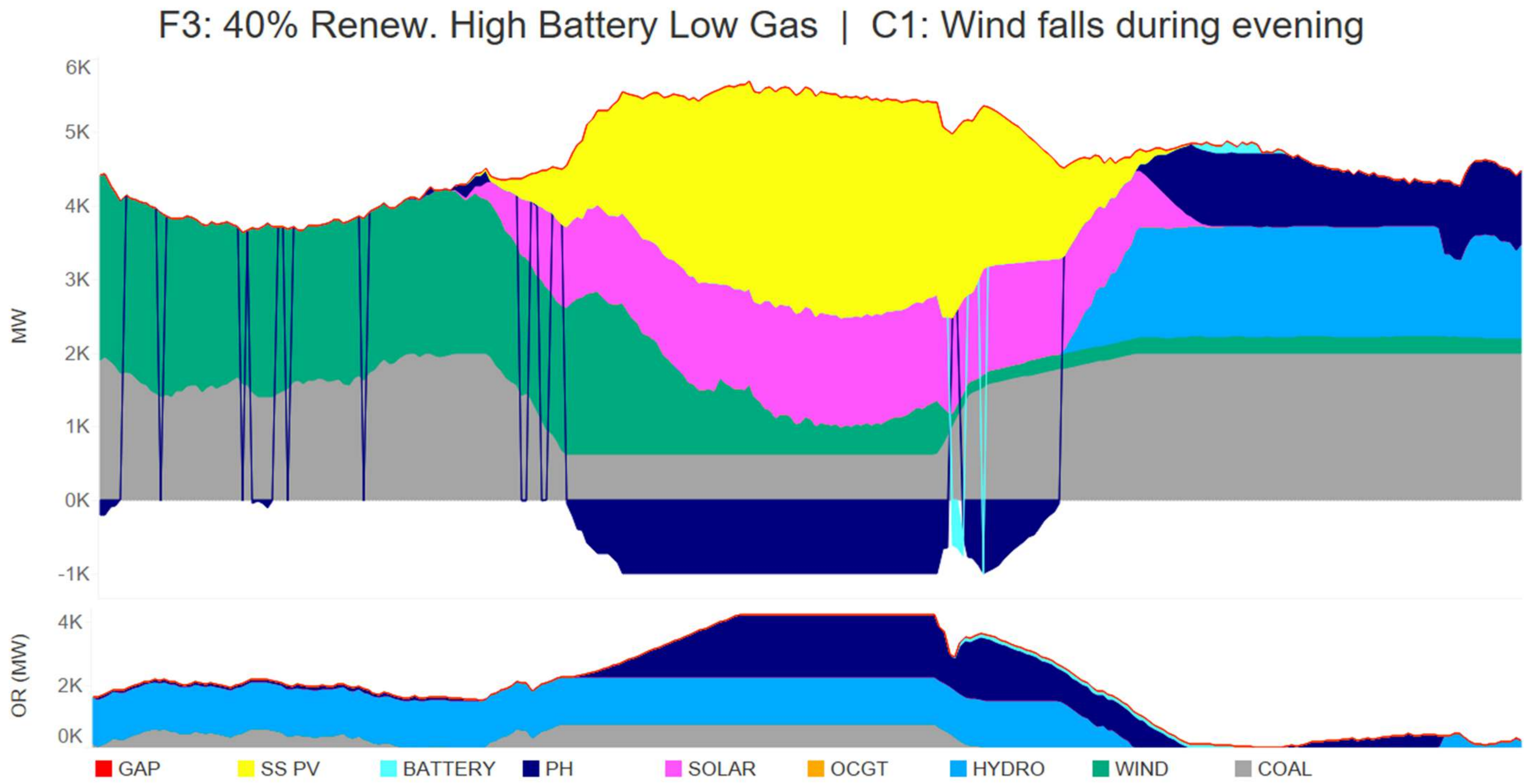
# F2: 40% Renew. High Gas Low Battery | C5: Loss of PV on moderate demand day



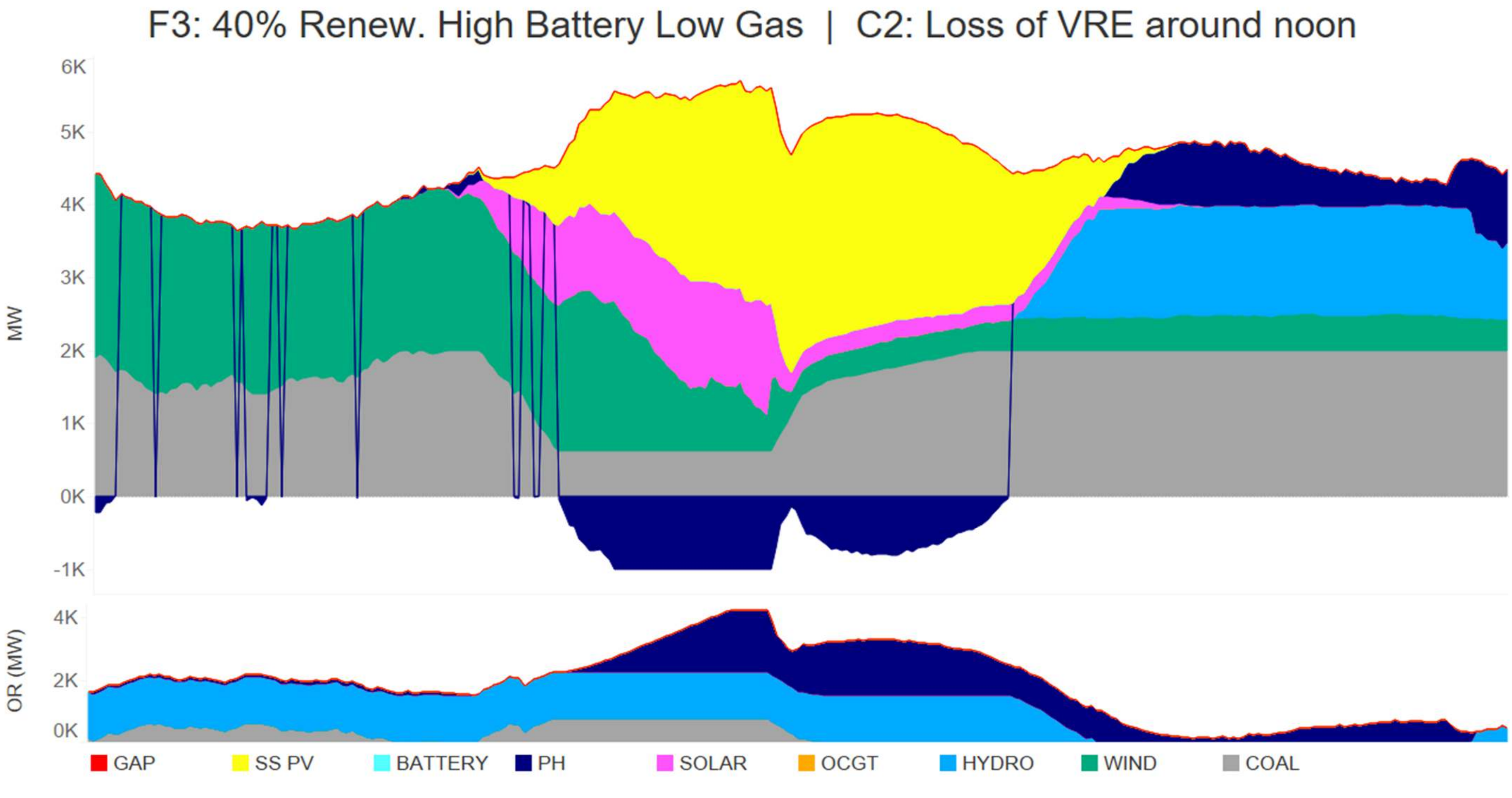
# Observations from modelling
# 40 % Renewables + High Gas Low Battery

ENDGAME ECONOMICS

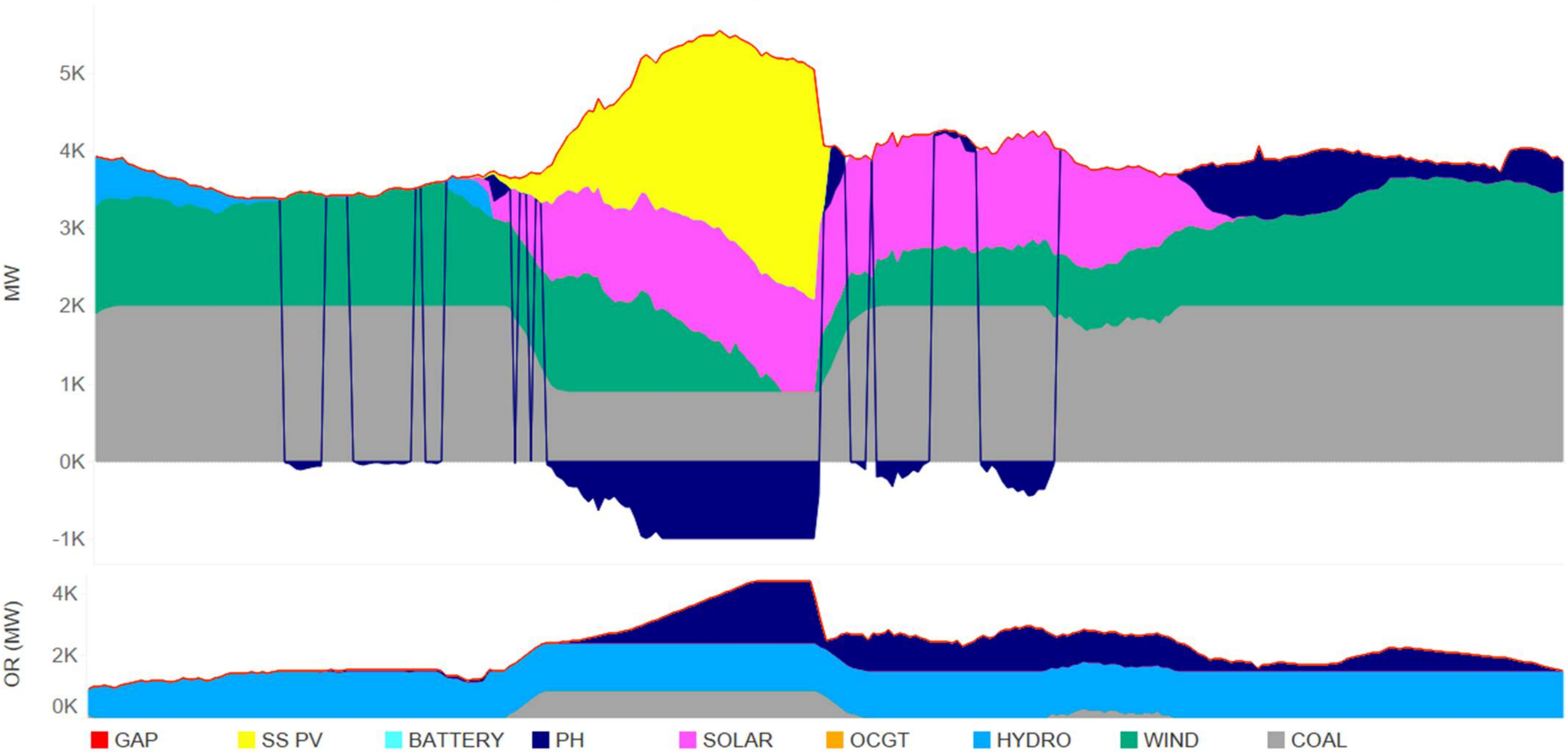
- **Without OR gas not flexible enough to avoid energy gap:** the gas scenario shows a greater energy gap because ramping is not quite fast enough. We suspect that an OR would alter this outcome, making it possible for gas to meet the ramps by changing their behaviour in advance of an event. Is this efficient?
- **No extended energy gap events:** as we will see, high storage scenarios may suffer from risks of under-supply of *energy duration*. This does not appear to be a problem in the high gas scenarios as there are large quantities of energy, albeit less flexible capacity.
- **State of charge is critical:** modelling shows that the state of charge of batteries is very important. Sometimes batteries charge *after* an event begins to provide more flexibility later in the day. Availability of charge can make the difference between an energy gap and meeting demand.



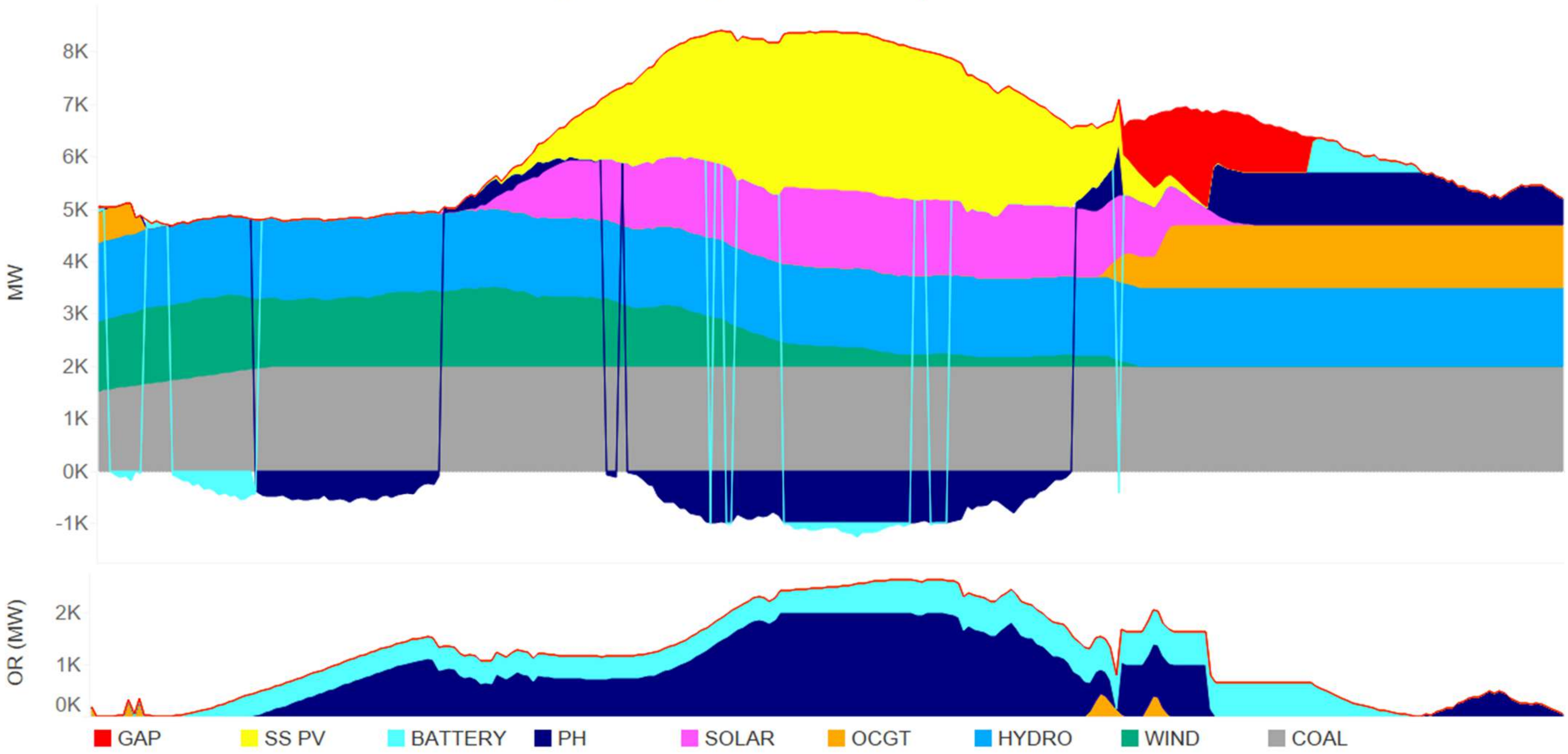
F3: 40% Renew. High Battery Low Gas | C1: Wind falls during evening
6K
5K
4K
3K
2K
1K
0K
-1K
MW
4K
2K
0K
OR (MW)
GAP
SS PV
BATTERY
PH
SOLAR
OCGT
HYDRO
WIND
COAL

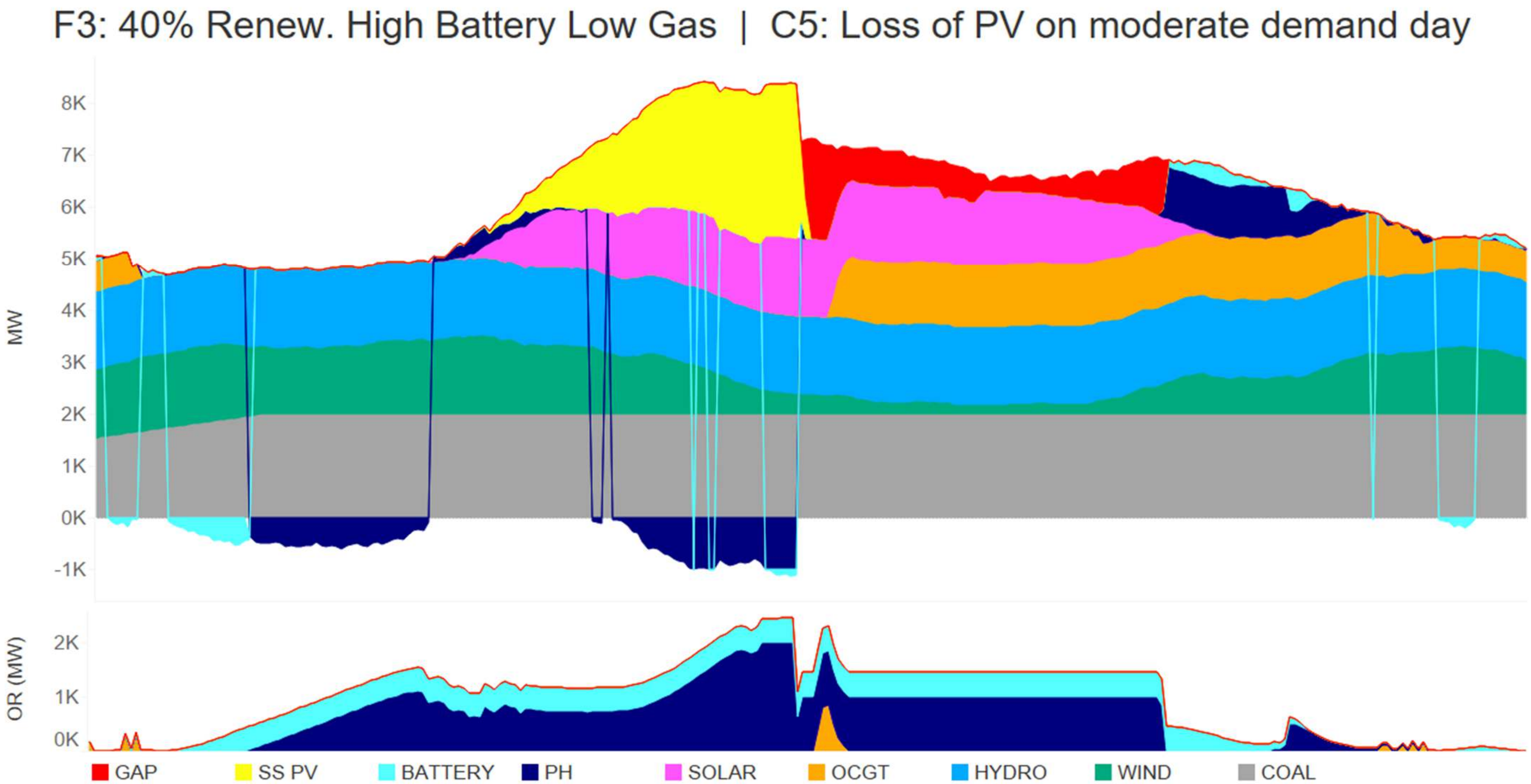

F3: 40% Renew. High Battery Low Gas | C2: Loss of VRE around noon
6K
5K
4K
3K
2K
1K
0K
-1K
MW
4K
2K
0K
OR (MW)
GAP
SS PV
BATTERY
PH
SOLAR
OCGT
HYDRO
WIND
COAL

# F3: 40% Renew. High Battery Low Gas | C3: Loss of PV on sunny low demand day



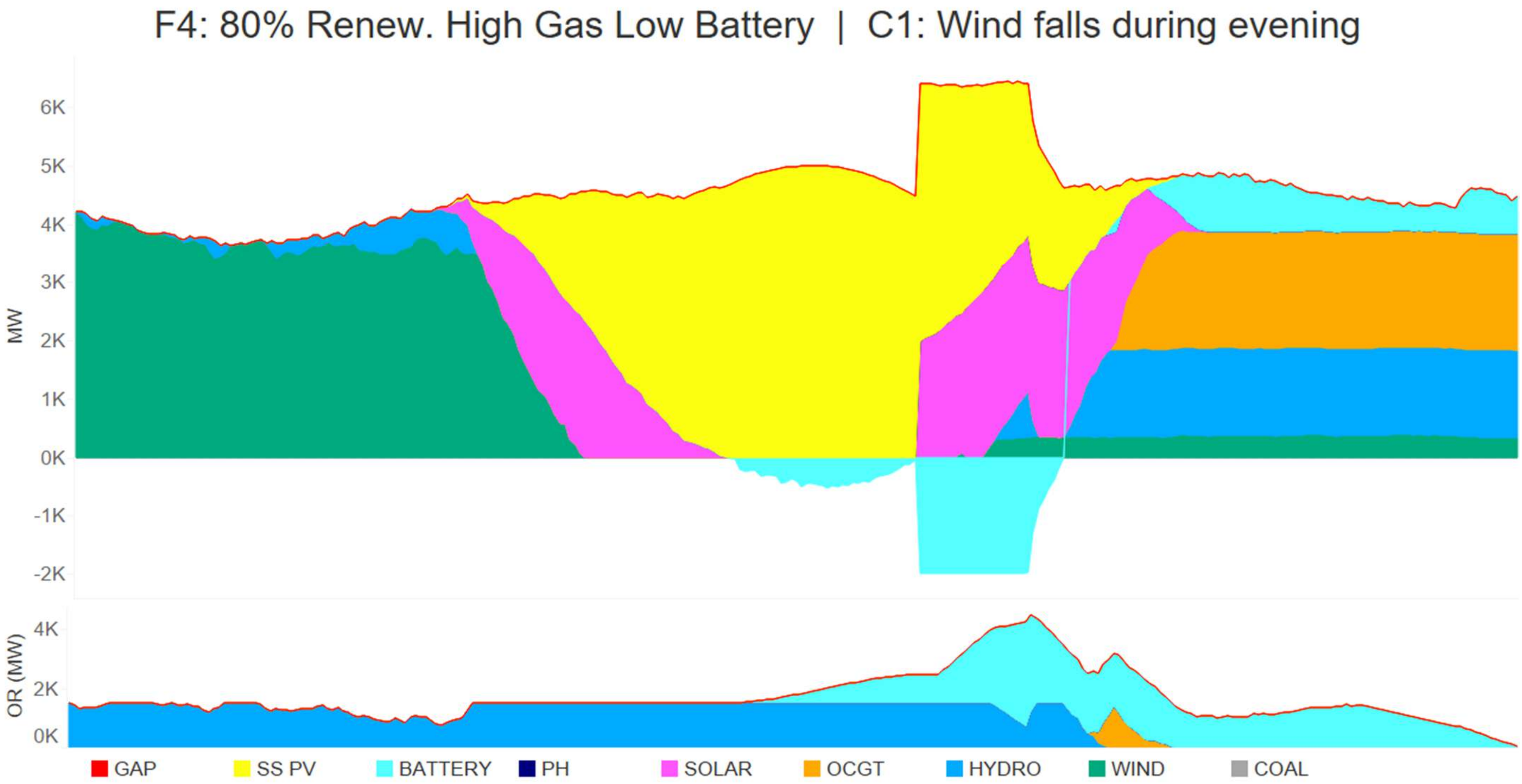
# F3: 40% Renew. High Battery Low Gas | C4: Wind never comes



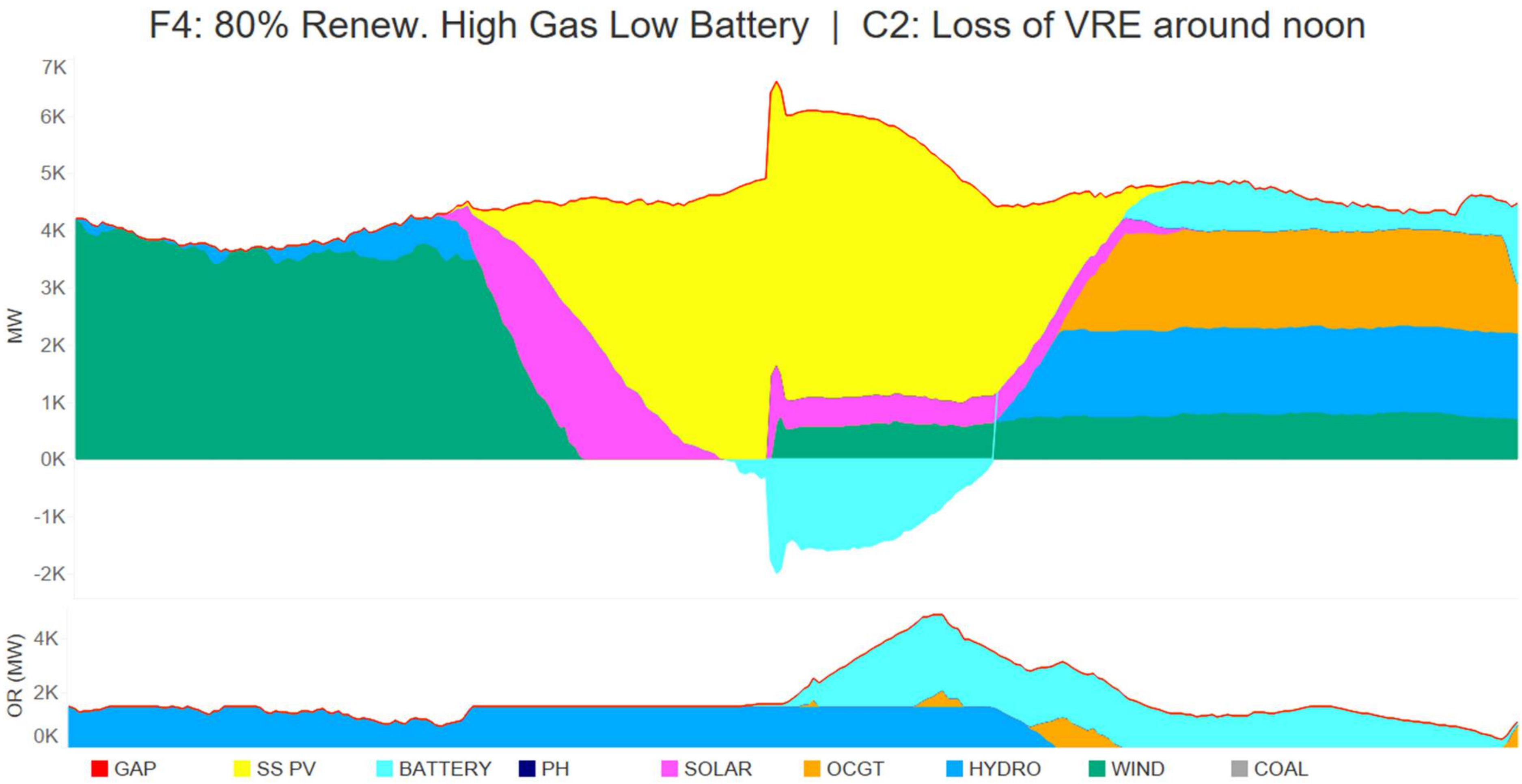

F3: 40% Renew. High Battery Low Gas | C5: Loss of PV on moderate demand day
MW
8K
7K
6K
5K
4K
3K
2K
1K
0K
-1K
OR (MW)
2K
1K
0K
GAP
SS PV
BATTERY
PH
SOLAR
OCGT
HYDRO
WIND
COAL

# Observations from modelling
# 40 % Renewables + High Battery Low Gas

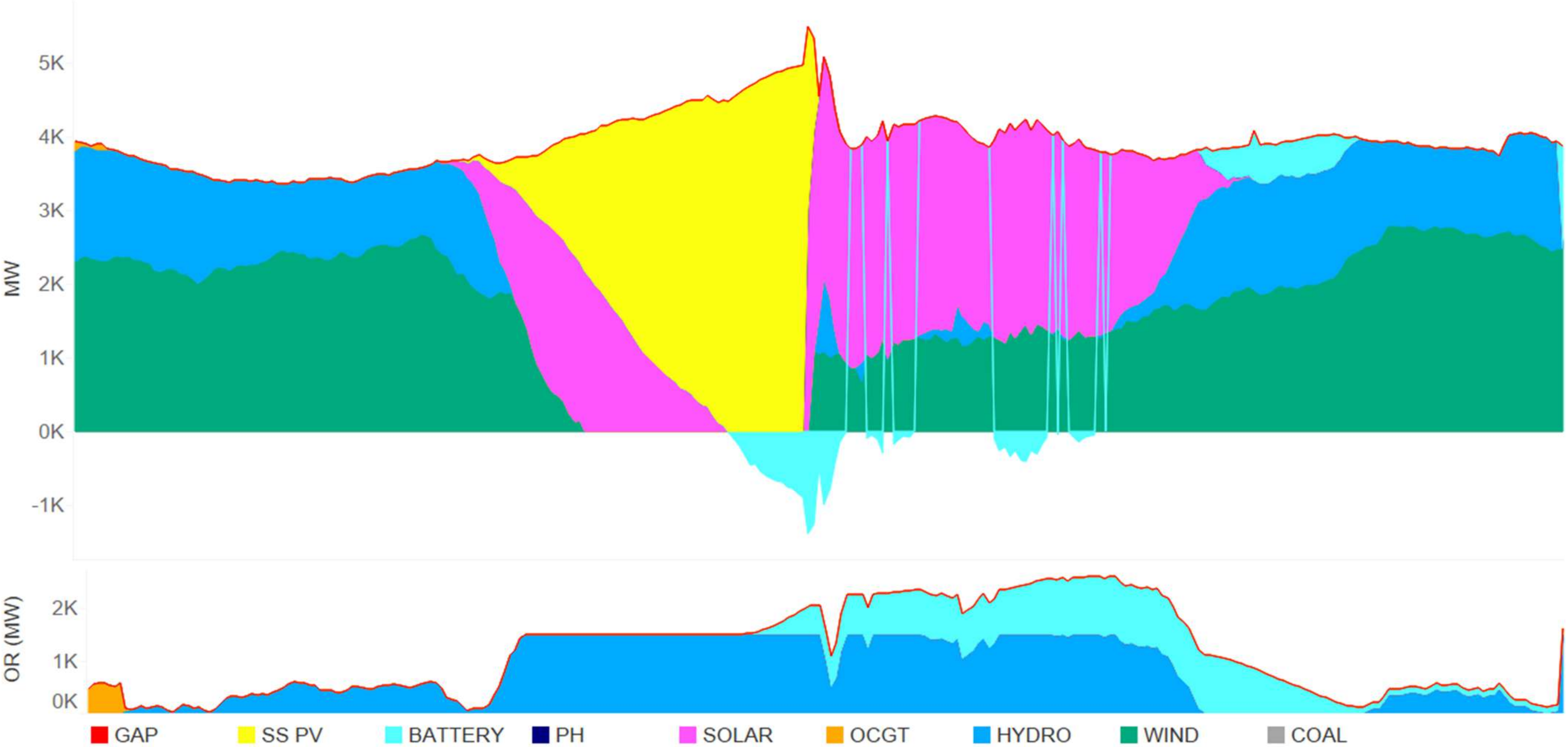
- **State of charge is critical:** modelling shows that the state of charge of batteries is very important. Sometimes batteries charge *after* an event begins to provide more flexibility later in the day. Availability of charge is often enough the major driver of energy gaps.
- **Storage is flexible enough to avoid energy gaps:** the high storage scenario shows no energy gap because of lack of ramping capacity.
- **Energy gap events stem from lack of energy duration:** high storage scenarios suffer from risk of under-supply of *energy duration*. Note we have used an aggressive assumption that no energy is in storage at the start of the day. This may not be realistic, but begs the question of whether we need to change settings to support a high storage system.

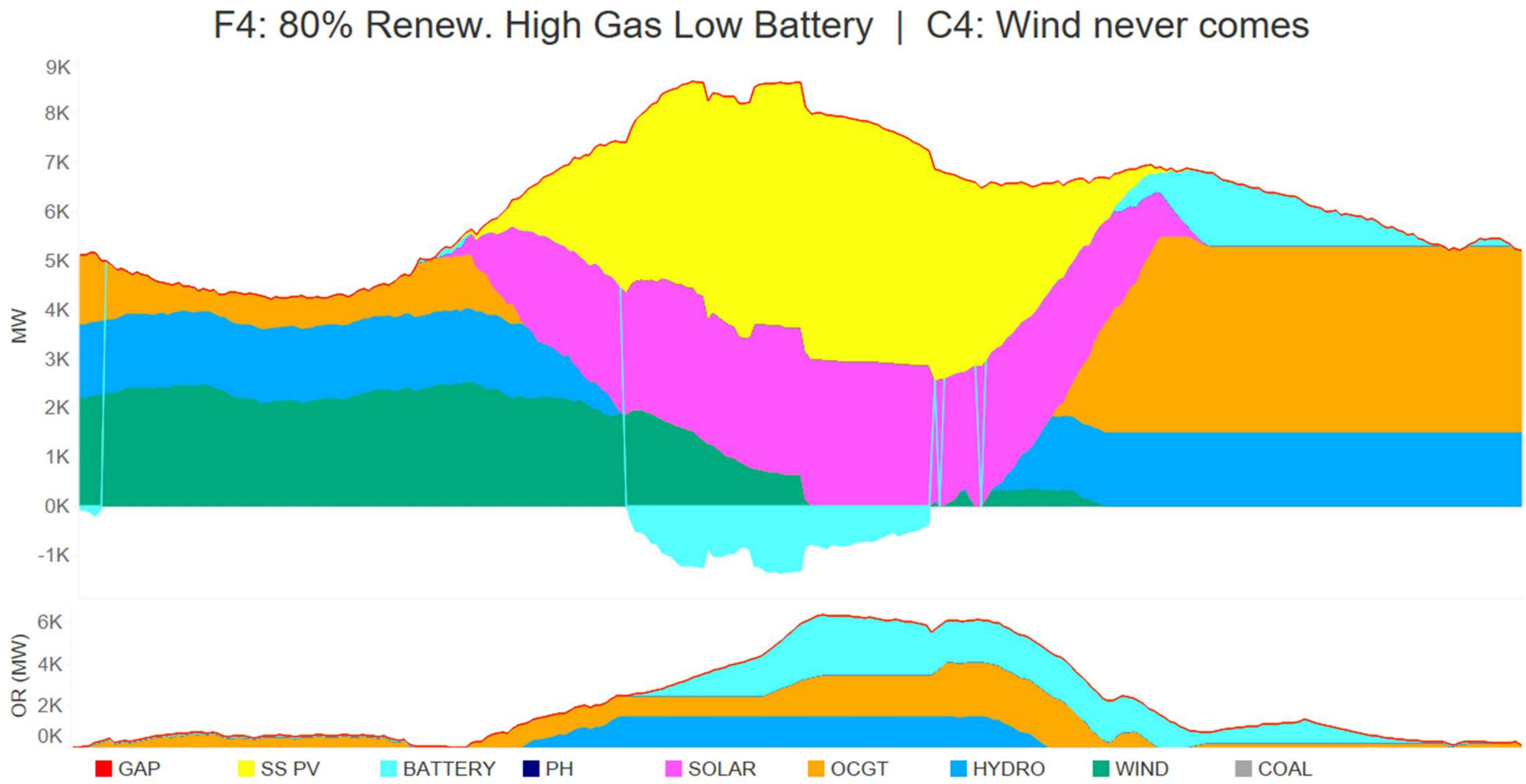


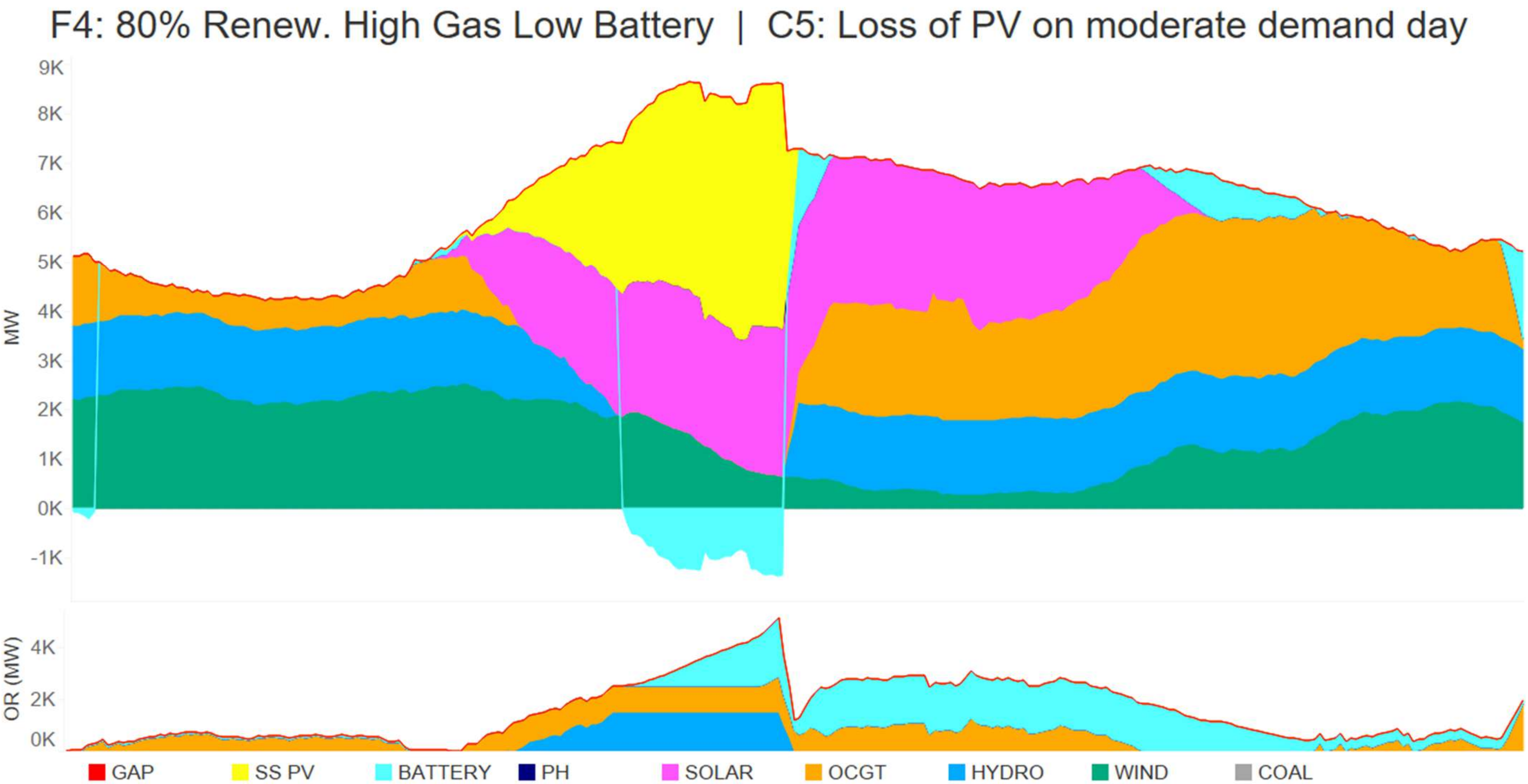
F4: 80% Renew. High Gas Low Battery | C1: Wind falls during evening
MW
6K
5K
4K
3K
2K
1K
0K
-1K
-2K
OR (MW)
4K
2K
0K
GAP
SS PV
BATTERY
PH
SOLAR
OCGT
HYDRO
WIND
COAL


F4: 80% Renew. High Gas Low Battery | C2: Loss of VRE around noon
7K
6K
5K
4K
3K
2K
1K
0K
-1K
-2K
MW
4K
2K
0K
OR (MW)
GAP
SS PV
BATTERY
PH
SOLAR
OCGT
HYDRO
WIND
COAL

# F4: 80% Renew. High Gas Low Battery | C3: Loss of PV on sunny low demand day

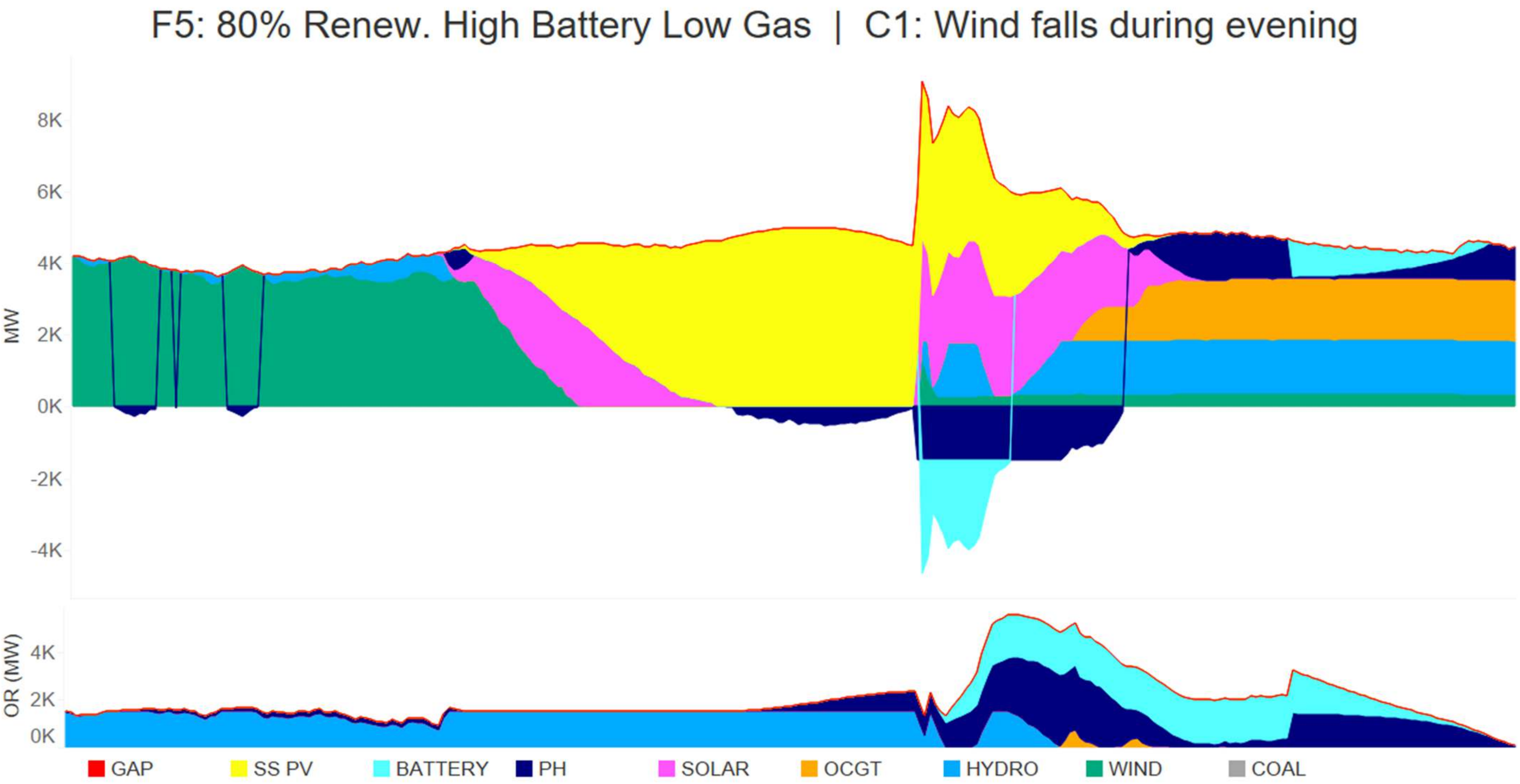


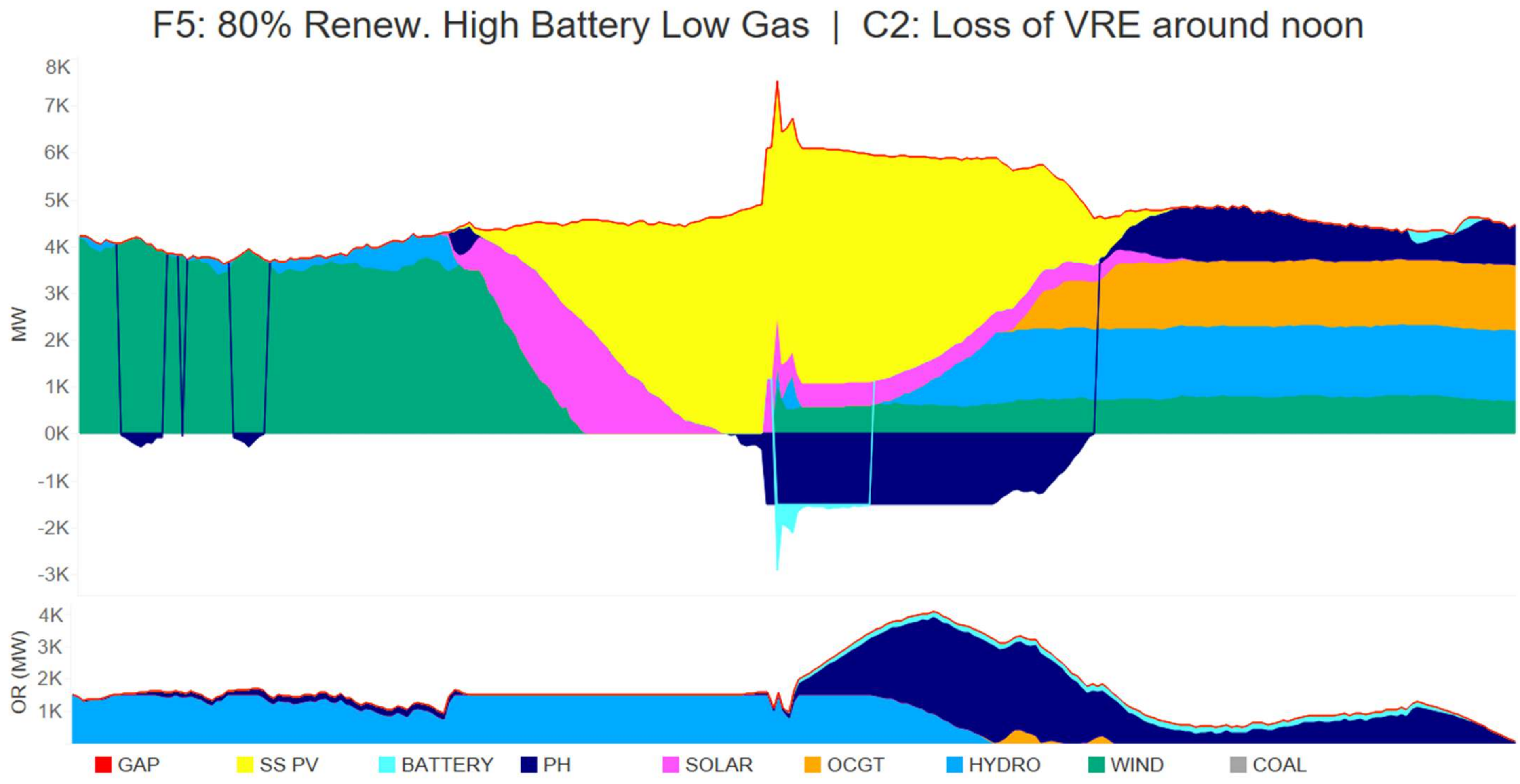

F4: 80% Renew. High Gas Low Battery | C4: Wind never comes
9K
8K
7K
6K
5K
4K
3K
2K
1K
0K
-1K
MW
6K
4K
2K
0K
OR (MW)
GAP
SS PV
BATTERY
PH
SOLAR
OCGT
HYDRO
WIND
COAL


F4: 80% Renew. High Gas Low Battery | C5: Loss of PV on moderate demand day
9K
8K
7K
6K
5K
4K
3K
2K
1K
0K
-1K
MW
4K
2K
0K
OR (MW)
GAP
SS PV
BATTERY
PH
SOLAR
OCGT
HYDRO
WIND
COAL

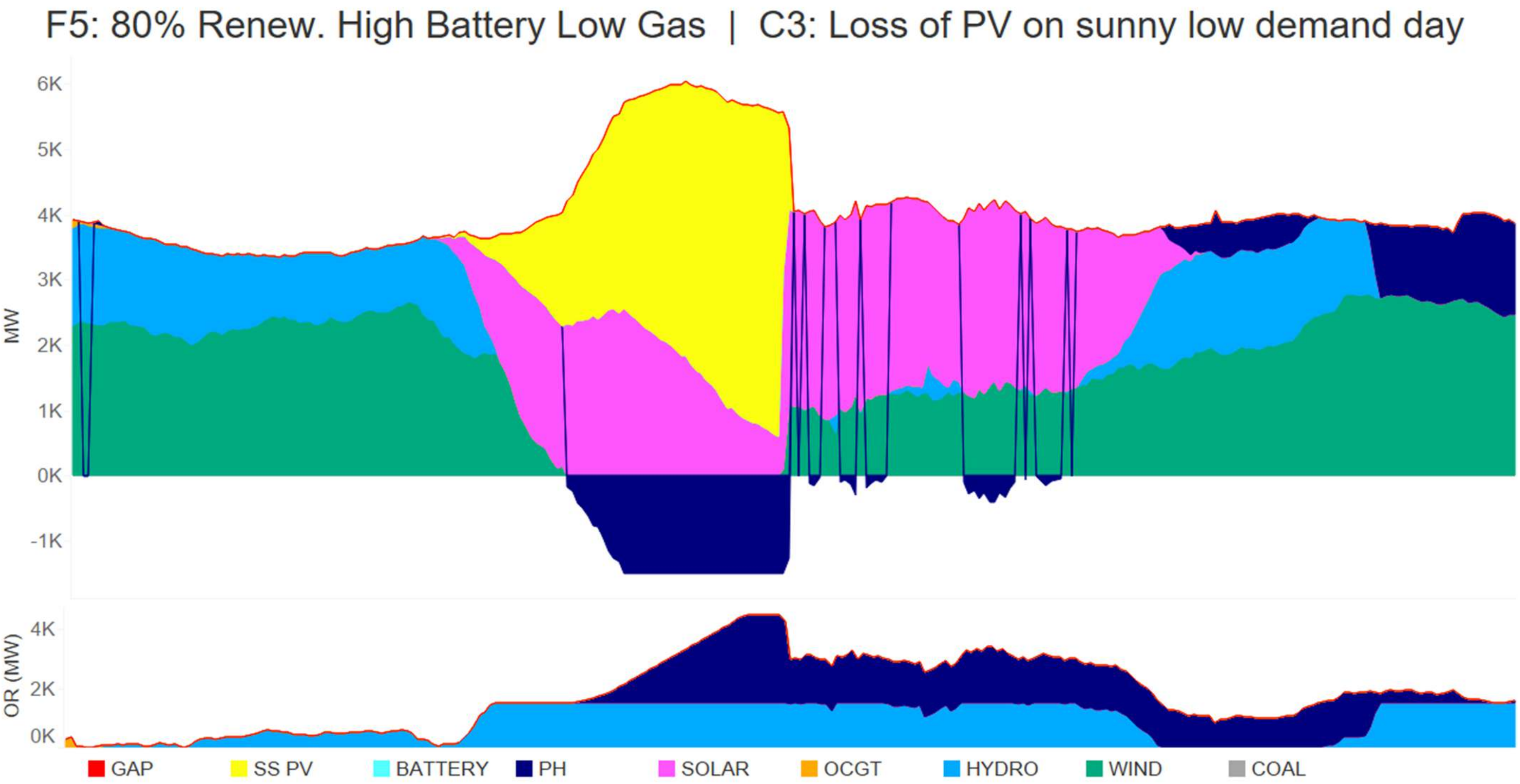
# Observations from modelling
# 80 % Renewables + High Gas Low Storage

- **New capacity strengthens the system:** modelling shows that the capacity that replaces coal adds flexibility to the system, making it more robust to the shocks we have considered. Combination of gas with some rapid starting storage makes the system very robust to the events we have considered.
- **Storage and gas are complementary:** storage responds quickly, gas responds over longer periods. *Based on the modelling* the two technologies together seem to suggest that the system can withstand such a shock.
- **Not a recommendation of fuel mix:** we are not suggesting that this is the 'right' generation mix – we are merely noting that if the system evolves with a combination of gas and storage, there seems to be no need for an OR to address shortages associated with loss of renewables.

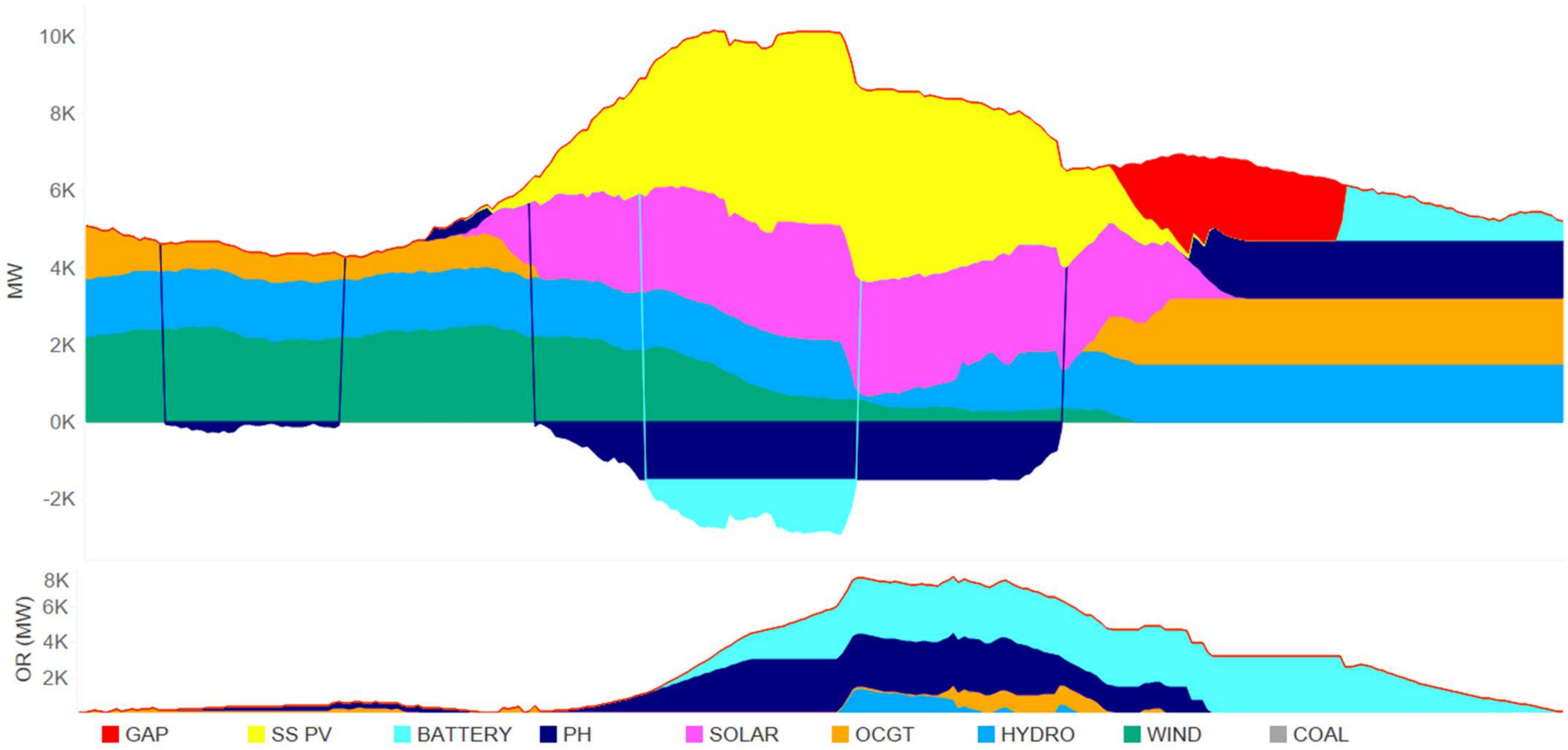

F5: 80% Renew. High Battery Low Gas | C1: Wind falls during evening
MW
8K
6K
4K
2K
0K
-2K
-4K
OR (MW)
4K
2K
0K
GAP
SS PV
BATTERY
PH
SOLAR
OCGT
HYDRO
WIND
COAL

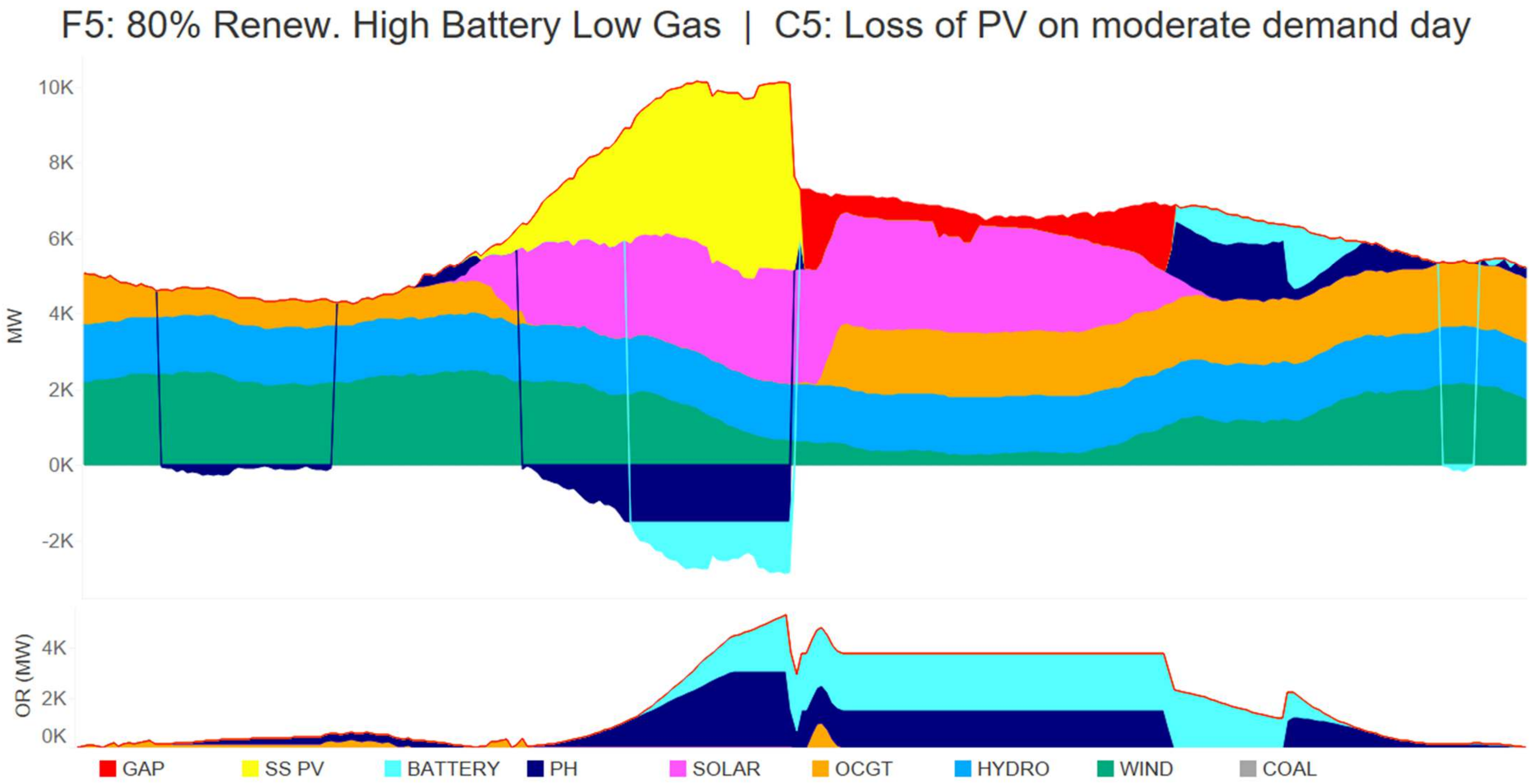


F5: 80% Renew. High Battery Low Gas | C2: Loss of VRE around noon
8K
7K
6K
5K
4K
3K
2K
1K
0K
-1K
-2K
-3K
MW
4K
3K
2K
1K
OR (MW)
GAP
SS PV
BATTERY
PH
SOLAR
OCGT
HYDRO
WIND
COAL


F5: 80% Renew. High Battery Low Gas | C3: Loss of PV on sunny low demand day
6K
5K
4K
3K
2K
1K
0K
-1K
MW
4K
2K
0K
OR (MW)
GAP
SS PV
BATTERY
PH
SOLAR
OCGT
HYDRO
WIND
COAL

## F5: 80% Renew. High Battery Low Gas | C4: Wind never comes




F5: 80% Renew. High Battery Low Gas | C5: Loss of PV on moderate demand day
10K
8K
6K
4K
2K
0K
-2K
MW
OR (MW)
4K
2K
0K
GAP
SS PV
BATTERY
PH
SOLAR
OCGT
HYDRO
WIND
COAL

# Observations from modelling
# 80 % Renewables + High Storage Low Gas

- **No shortage of flexibility:** modelling shows that the capacity that replaces coal adds flexibility to the system, making it able to respond quickly. None of the energy gaps appear to be due to lack of ramping or fast-starting plant.
- **State of charge assumptions are critical:** the energy gaps that occur are due to lack of energy in storage. Our assumptions on this front have been very aggressive – different assumptions about starting storage would remove energy gaps.
- **Importance of energy in storage to the system:** an important question arising from this modelling is how we manage energy in storage to support a robust system.

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T: +61 2 8218 2174
M: +61 425 204 793

Upper Ground 55 Brisbane Street, Surry Hills

oliver.nunn@endgame-economics.com