

Electricity Storage for Renewable Power

Development of a Global Valuation Framework



Emanuele Taibi

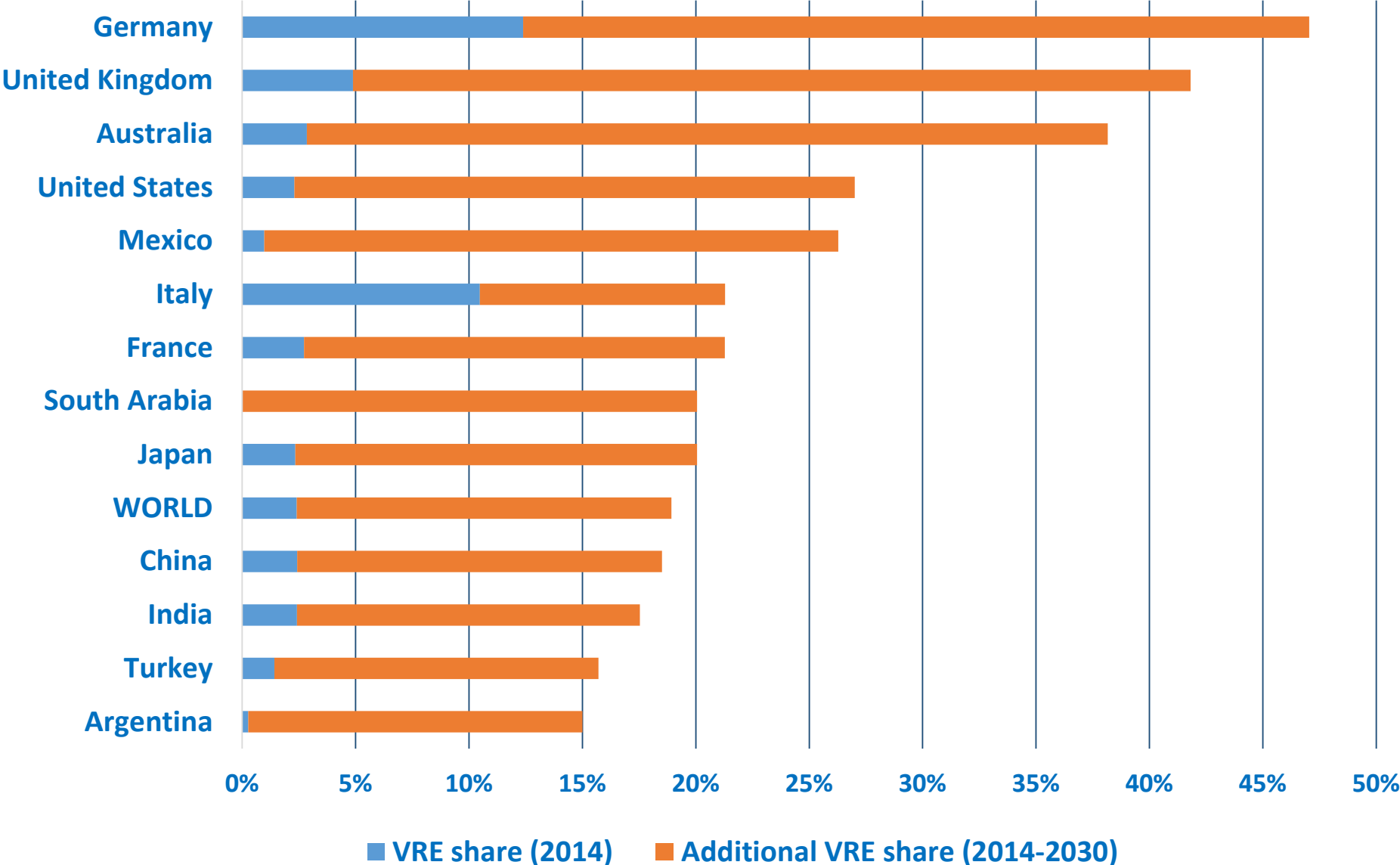
Power Sector Transformation Strategies

Intersolar, Munich, 1 June 2017

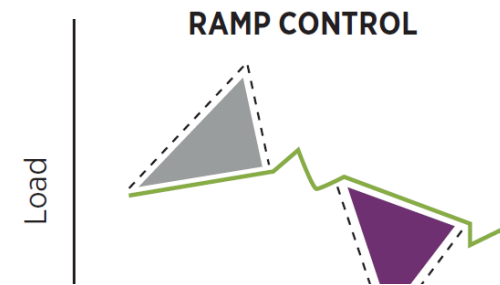
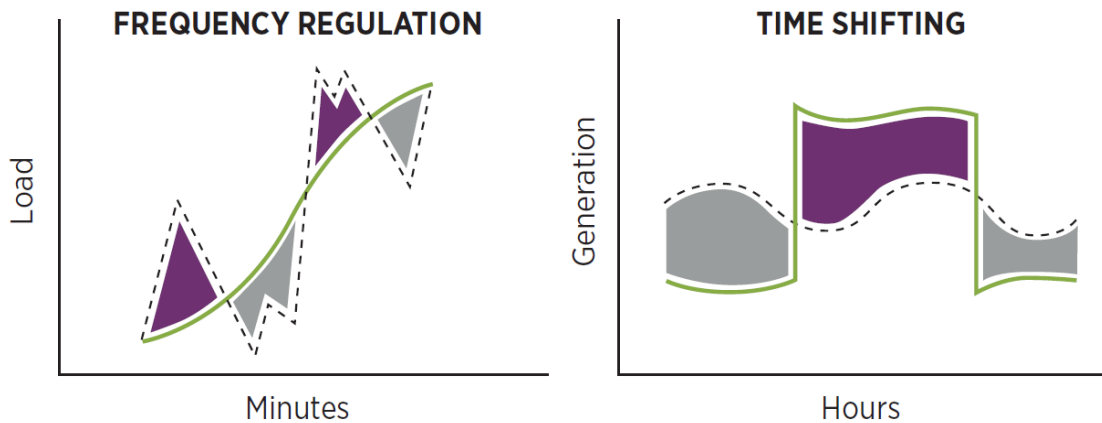
BACKGROUND

- VRE deployment and planned deployment as key driver
- Stronger business case for storage to replace services currently provided by thermal generators
- Ancillary market design evolving to allow storage to provide more than just energy (arbitrage?)
- Value of storage recognized: stacking multiple revenue streams is key for deployment of projects
- System level needs, linked to project viability assessment and simulation of operations is needed
- IRENA is developing a framework and a tool to answer policy makers' questions on storage value

Rapid growth of variable renewables

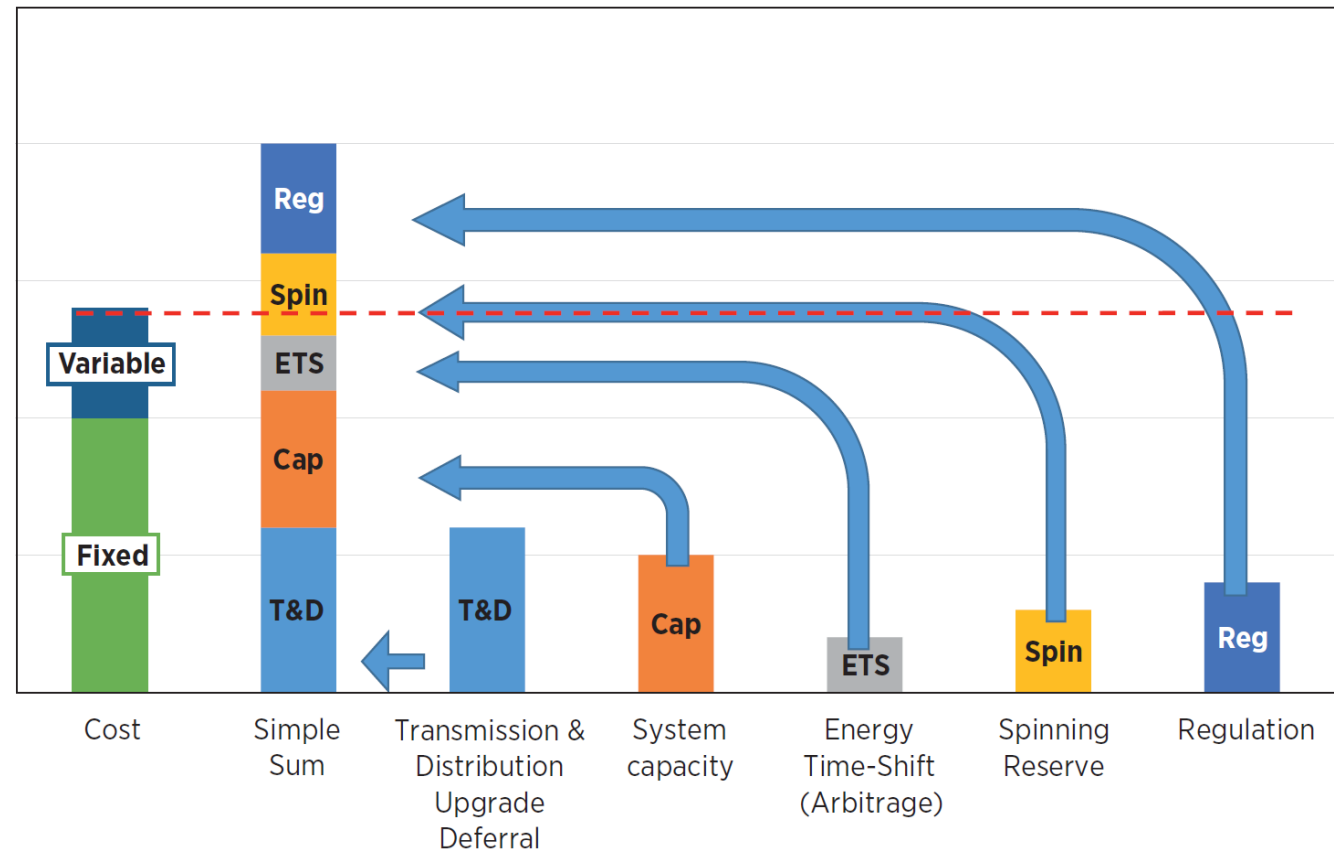


Multiple applications and associated revenue streams for storage

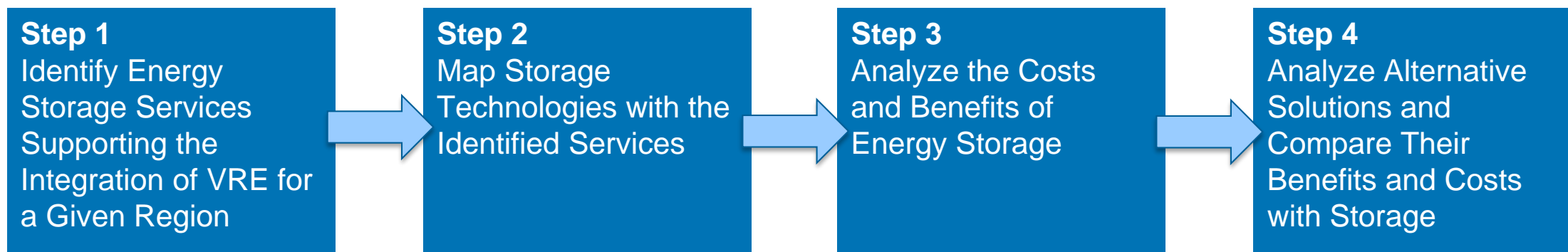
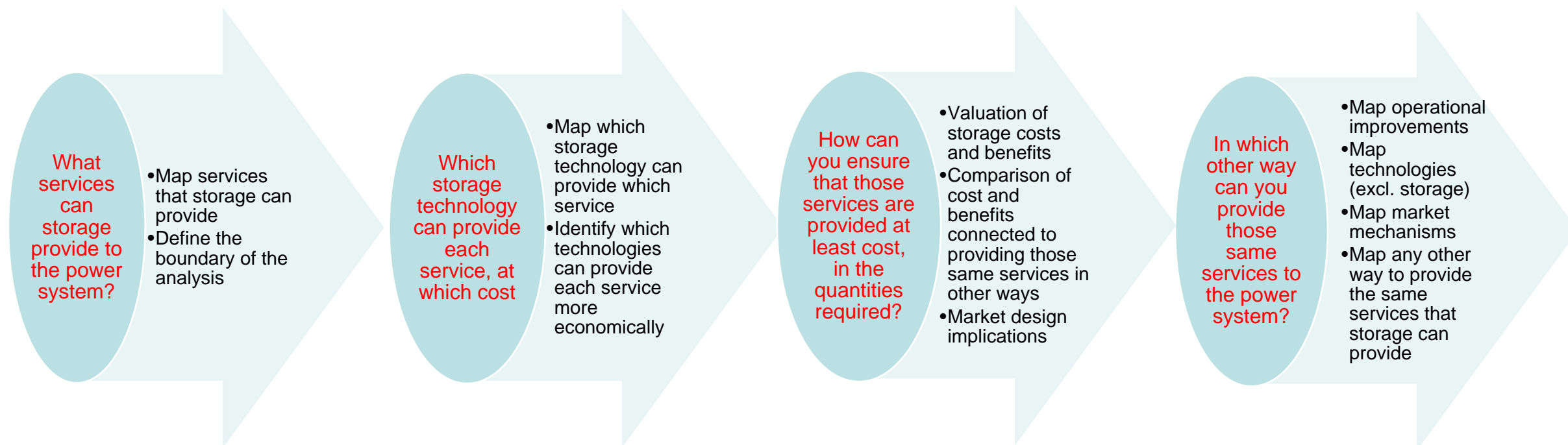


More VRE in the power system increases the need for flexibility and grid services

Storage can provide multiple services, at different cost, therefore a solid quantitative framework is required to appreciate the value proposition of storage in multiple applications



The Framework



WEB-BASED ANALYTICAL TOOL

Web-based tool

IRENA Input Interface

System Level Inputs:

Generators

Nodes

Transmission Lines

Load

Fuel Prices

Renewables

Project Level Inputs:

Load

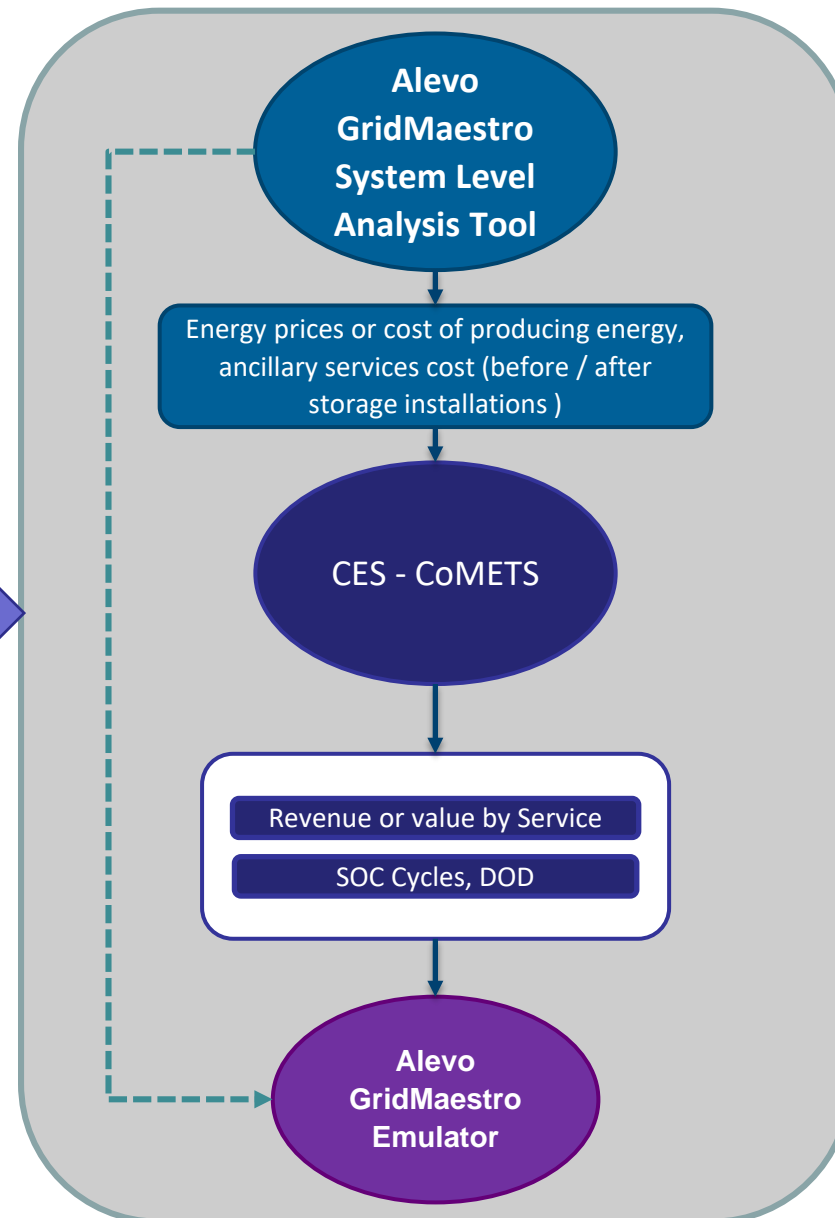
Solar/Wind
Production

Utility Rates

Market
Participation

Storage
MW/MWh, cost,
SOC

Life, O&M,
Depreciation



IRENA Output Interface

System Level Outputs

Storage
MW/MWh

Benefit Category
Summary

Share per Use
Case

Revenue Category
Summary

Project Level Outputs

Use Case Outputs:

Benefit per Use Case

Revenue per Use Case

Cost to Benefit Ratios

Storage Opportunity Analysis:

Benefits Specific
to Storage

Solution Comparison

Mapping of storage
technologies

Alternative Solutions





Dispatch

Minute-by-Minute Energy Storage
Service Simulation

Welcome Page

Username	Welcome Page
Mapping of Storage Technologies	<p>+ Start A New Analysis</p>
System Analysis	
Project Analysis	
Emulator	
Alternative technology Solutions	

Saved Analysis

No	Name	Action
1	Analysis 1	 
2	Analysis 2	 

This will start a new Analysis

This section will display previous saved Analysis for a particular user

Mapping of Storage Technologies

Tables in this section serve as input for generation of ranking matrix. The inputs in some of the tables are editable by the User

Username																																																																																																	
Mapping of Storage Technologies	Comparative Scores																																																																																																
System Analysis	<p><i>Score: 0 Worst, 5 Best</i></p> <table border="1"> <thead> <tr> <th></th> <th>ESS Tech 1</th> <th>ESS Tech 2</th> <th>ESS Tech 3</th> <th>ESS Tech 4</th> <th>ESS Tech 5</th> <th>ESS Tech 6</th> <th>ESS Tech 7</th> </tr> </thead> <tbody> <tr> <td>Technical</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>Efficiency</td> <td>4</td> <td>5</td> <td>4</td> <td>3</td> <td>4</td> <td>2</td> <td>2</td> </tr> <tr> <td>C-rate</td> <td>4</td> <td>5</td> <td>3</td> <td>3</td> <td>3</td> <td>3.5</td> <td>3.5</td> </tr> <tr> <td>Usable SOC</td> <td>3</td> <td>4</td> <td>1</td> <td>4</td> <td>4</td> <td>5</td> <td>5</td> </tr> <tr> <td>Commercial</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>Initial Capital Cost</td> <td>5</td> <td>3.5</td> <td>4</td> <td>4</td> <td>2</td> <td>3</td> <td>3</td> </tr> <tr> <td>Development & Construction Period</td> <td>5</td> <td>5</td> <td>5</td> <td>4</td> <td>4</td> <td>4</td> <td>4</td> </tr> <tr> <td>Operating Cost</td> <td>2</td> <td>5</td> <td>3</td> <td>4</td> <td>3</td> <td>3</td> <td>4</td> </tr> <tr> <td>Space Required</td> <td>1</td> <td>5</td> <td>1</td> <td>4</td> <td>4</td> <td>5</td> <td>2</td> </tr> <tr> <td>Life</td> <td>2</td> <td>4</td> <td>3</td> <td>4</td> <td>4</td> <td>4</td> <td>5</td> </tr> <tr> <td>Maturity of Technology</td> <td>3</td> <td>4</td> <td>2</td> <td>4</td> <td>1</td> <td>1</td> <td>3</td> </tr> </tbody> </table>		ESS Tech 1	ESS Tech 2	ESS Tech 3	ESS Tech 4	ESS Tech 5	ESS Tech 6	ESS Tech 7	Technical								Efficiency	4	5	4	3	4	2	2	C-rate	4	5	3	3	3	3.5	3.5	Usable SOC	3	4	1	4	4	5	5	Commercial								Initial Capital Cost	5	3.5	4	4	2	3	3	Development & Construction Period	5	5	5	4	4	4	4	Operating Cost	2	5	3	4	3	3	4	Space Required	1	5	1	4	4	5	2	Life	2	4	3	4	4	4	5	Maturity of Technology	3	4	2	4	1	1	3
	ESS Tech 1	ESS Tech 2	ESS Tech 3	ESS Tech 4	ESS Tech 5	ESS Tech 6	ESS Tech 7																																																																																										
Technical																																																																																																	
Efficiency	4	5	4	3	4	2	2																																																																																										
C-rate	4	5	3	3	3	3.5	3.5																																																																																										
Usable SOC	3	4	1	4	4	5	5																																																																																										
Commercial																																																																																																	
Initial Capital Cost	5	3.5	4	4	2	3	3																																																																																										
Development & Construction Period	5	5	5	4	4	4	4																																																																																										
Operating Cost	2	5	3	4	3	3	4																																																																																										
Space Required	1	5	1	4	4	5	2																																																																																										
Life	2	4	3	4	4	4	5																																																																																										
Maturity of Technology	3	4	2	4	1	1	3																																																																																										
Project Analysis																																																																																																	
Emulator																																																																																																	
Alternative Technology Solutions	Application Weightage																																																																																																
	<table border="1"> <thead> <tr> <th></th> <th>Application 1</th> <th>Application 2</th> <th>Application 3</th> <th>Application 4</th> <th>Application 5</th> <th>Application 6</th> <th>Application 7</th> <th>Application 8</th> <th>Application 9</th> </tr> </thead> <tbody> <tr> <td>Technical</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>Efficiency</td> <td>15%</td> <td>20%</td> <td>10%</td> <td>10%</td> <td>10%</td> <td>10%</td> <td>20%</td> <td>5%</td> <td>15%</td> </tr> <tr> <td>C-Rate</td> <td>5%</td> <td>5%</td> <td>5%</td> <td>5%</td> <td>15%</td> <td>0%</td> <td>5%</td> <td>5%</td> <td>5%</td> </tr> <tr> <td>Usable SOC</td> <td>10%</td> <td>10%</td> <td>10%</td> <td>10%</td> <td>10%</td> <td>10%</td> <td>10%</td> <td>5%</td> <td>10%</td> </tr> <tr> <td>Commercial</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>Initial Capital Cost</td> <td>30%</td> <td>30%</td> <td>30%</td> <td>30%</td> <td>30%</td> <td>30%</td> <td>30%</td> <td>30%</td> <td>20%</td> </tr> </tbody> </table>		Application 1	Application 2	Application 3	Application 4	Application 5	Application 6	Application 7	Application 8	Application 9	Technical										Efficiency	15%	20%	10%	10%	10%	10%	20%	5%	15%	C-Rate	5%	5%	5%	5%	15%	0%	5%	5%	5%	Usable SOC	10%	10%	10%	10%	10%	10%	10%	5%	10%	Commercial										Initial Capital Cost	30%	30%	30%	30%	30%	30%	30%	30%	20%																										
	Application 1	Application 2	Application 3	Application 4	Application 5	Application 6	Application 7	Application 8	Application 9																																																																																								
Technical																																																																																																	
Efficiency	15%	20%	10%	10%	10%	10%	20%	5%	15%																																																																																								
C-Rate	5%	5%	5%	5%	15%	0%	5%	5%	5%																																																																																								
Usable SOC	10%	10%	10%	10%	10%	10%	10%	5%	10%																																																																																								
Commercial																																																																																																	
Initial Capital Cost	30%	30%	30%	30%	30%	30%	30%	30%	20%																																																																																								
	Calculate																																																																																																

Mapping of Storage Technologies

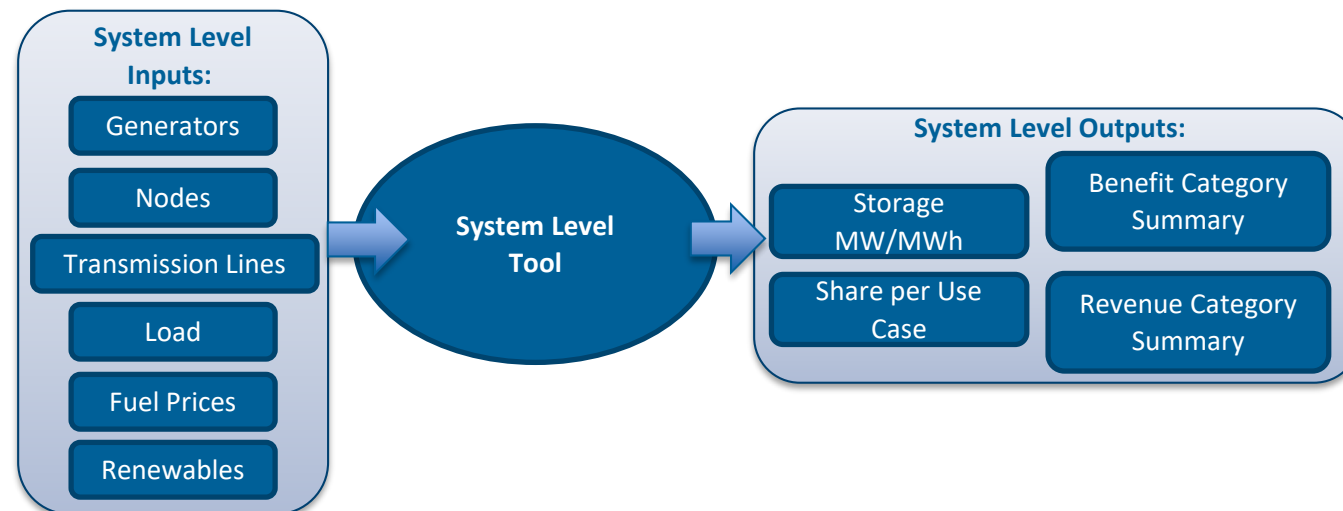
<p>Username</p>								
<p>Mapping of Storage Technologies</p>	<p>Ranking Matrix</p>							
<p>System Analysis</p>	<p>Ranking by Applications</p>	<p>ESS Tech 1</p>	<p>ESS Tech 2</p>	<p>ESS Tech 3</p>	<p>ESS Tech 4</p>	<p>ESS Tech 5</p>	<p>ESS Tech 6</p>	<p>ESS Tech 7</p>
<p>Project Analysis</p>	<p>Application 1</p>	<p>3</p>	<p>1</p>	<p>2</p>	<p>4</p>	<p>7</p>	<p>6</p>	<p>5</p>
<p>Emulator</p>	<p>Application 2</p>	<p>3</p>	<p>1</p>	<p>5</p>	<p>2</p>	<p>7</p>	<p>6</p>	<p>4</p>
<p>Alternative technology Solutions</p>	<p>Application 3</p>	<p>7</p>	<p>1</p>	<p>6</p>	<p>2</p>	<p>5</p>	<p>3</p>	<p>4</p>
	<p>Application 4</p>	<p>3</p>	<p>1</p>	<p>7</p>	<p>2</p>	<p>6</p>	<p>4</p>	<p>5</p>
	<p>Application 5</p>	<p>3</p>	<p>1</p>	<p>2</p>	<p>4</p>	<p>7</p>	<p>6</p>	<p>5</p>
	<p>Application 6</p>	<p>2</p>	<p>1</p>	<p>3</p>	<p>4</p>	<p>7</p>	<p>6</p>	<p>5</p>
	<p>Application 7</p>	<p>3</p>	<p>1</p>	<p>7</p>	<p>2</p>	<p>6</p>	<p>5</p>	<p>4</p>
	<p>Application 8</p>	<p>3</p>	<p>1</p>	<p>7</p>	<p>2</p>	<p>6</p>	<p>5</p>	<p>4</p>
	<p>Application 9</p>	<p>4</p>	<p>1</p>	<p>7</p>	<p>5</p>	<p>6</p>	<p>3</p>	<p>2</p>

Ranking Matrix for Storage vs Applications will be generated based on tables from the left section

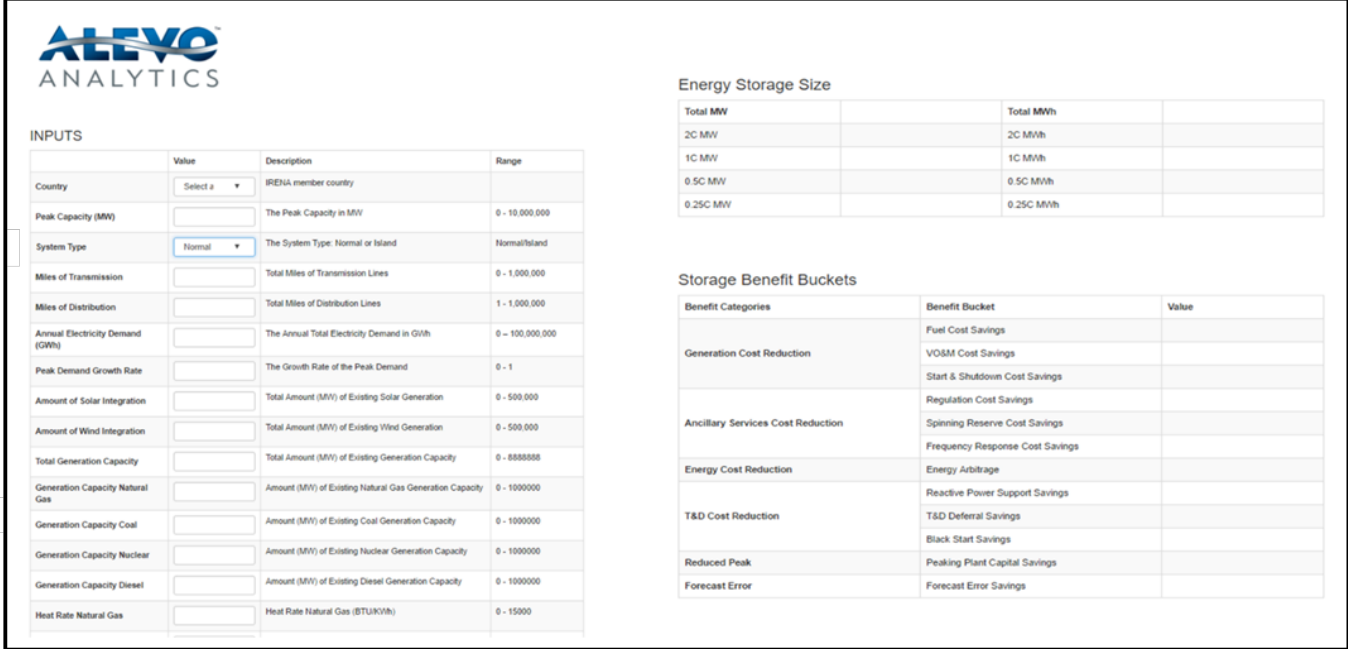
MODULE 1: SYSTEM LEVEL TOOL

GridMaestro System Level Tool

- The tool determines the locations and sizes of energy storage technologies that minimize the cost of reliably serving the system demand.
- It takes into consideration system data such as location and capacity of generators, location and capacity of transmission lines and renewables portfolio as well as uncertain factors such as load growth, projection of fuel prices and availability of renewable resources to identify the gaps in energy supply and system needs.
- The tool creates a loop between storage capacity optimization and production cost modeling to find the amount and location of storage that results in the least cost of serving the system demand.



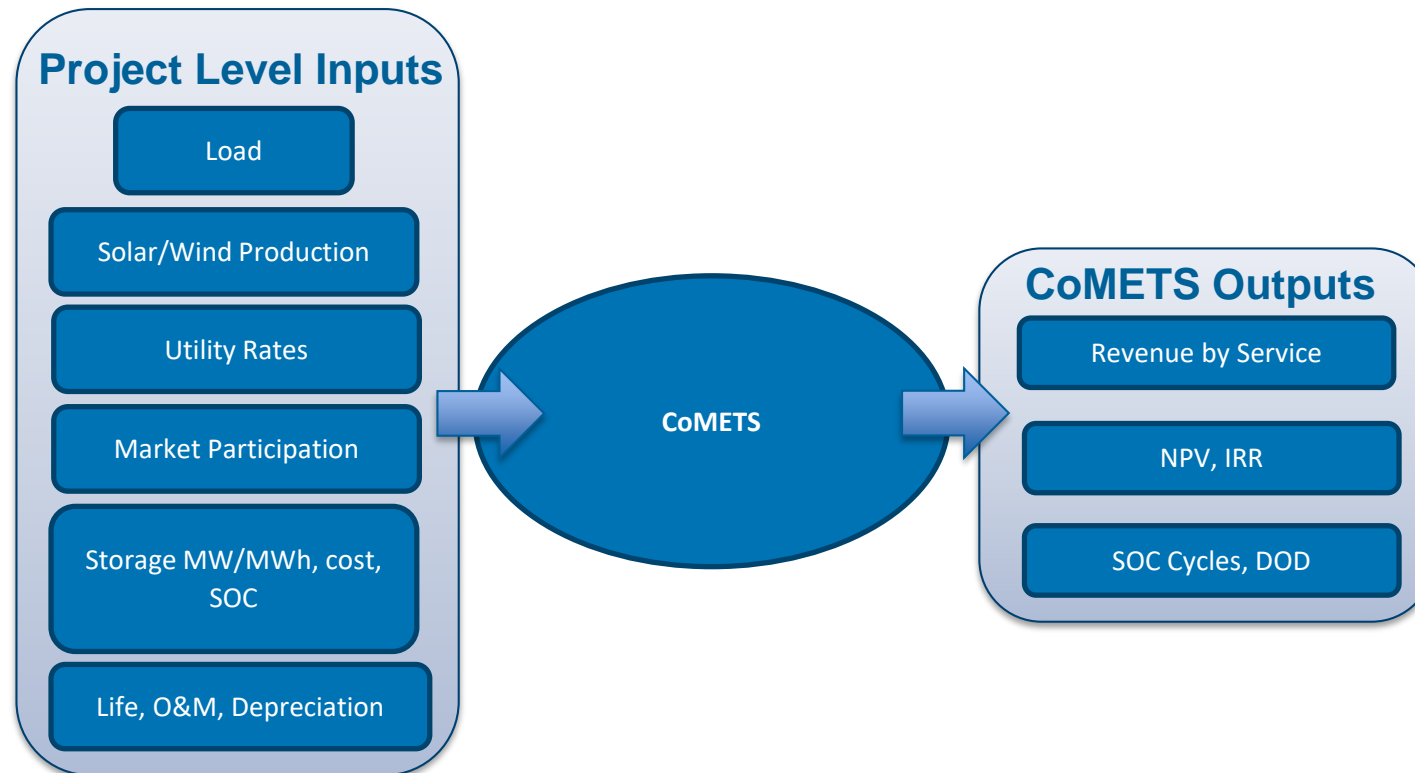
System Analysis

Username	Analysis Name
Headers	
Mapping of Storage Technologies	
System Analysis	
Project Analysis	
Emulator	
Alternative technology Solutions	
	 <p>The screenshot displays the ALEVO ANALYTICS interface. On the left, there is an 'INPUTS' table with columns for 'Value', 'Description', and 'Range'. The inputs include Country (IRENA member country), Peak Capacity (MW), System Type (Normal or Island), Miles of Transmission and Distribution, Annual Electricity Demand (GWh), Peak Demand Growth Rate, Amount of Solar and Wind Integration, and various Generation Capacity (Natural Gas, Coal, Nuclear, Diesel) and Heat Rate Natural Gas parameters.</p> <p>On the right, there are two tables. The first is 'Energy Storage Size', which shows Total MW and Total MWh for different storage sizes (2C, 1C, 0.5C, 0.25C). The second is 'Storage Benefit Buckets', which lists various benefit categories and their corresponding values.</p>

The Interface will provide a link to Alevo System Level Tool. The outputs of the System Level Tool will available for CoMETS.

MODULE 2: PROJECT LEVEL TOOL

- CoMETS is a project level tool that analyzes multiple stacks of revenue / value streams for an energy storage project and provides the cost-benefit analysis.
- CoMETS will receive inputs from GridMaestro System Level Tool and additional user inputs to create Use Cases and optimal dispatch for energy storage



Project Analysis (Inputs)

The project level analysis is based on CES modeling suite CoMETS

- Username
- Mapping of Storage Technologies
- System Analysis
- Project Analysis**
- Emulator
- Alternative technology Solutions

Wholesale Prices

Hour	prices w/o storage	prices with storage
0	2	2
1	24	24
2	62	62
3	32	32
4	4	4
5	23	23
6	26	26
7	26	26
8	27	27
9	27	27
10	28	28

Ancillary Prices
Benefits Stack from SLT

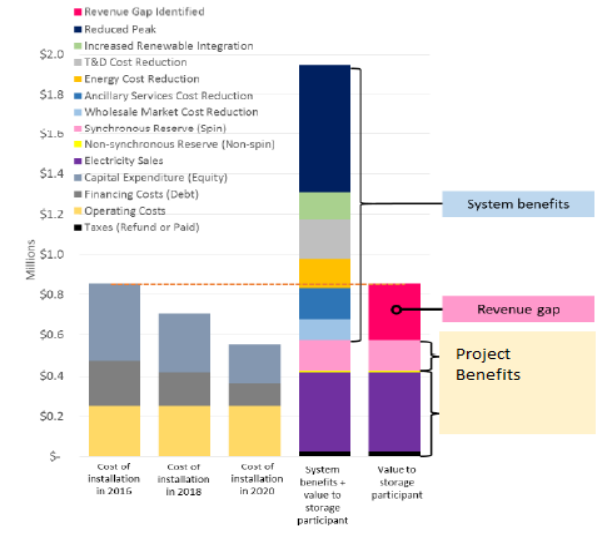
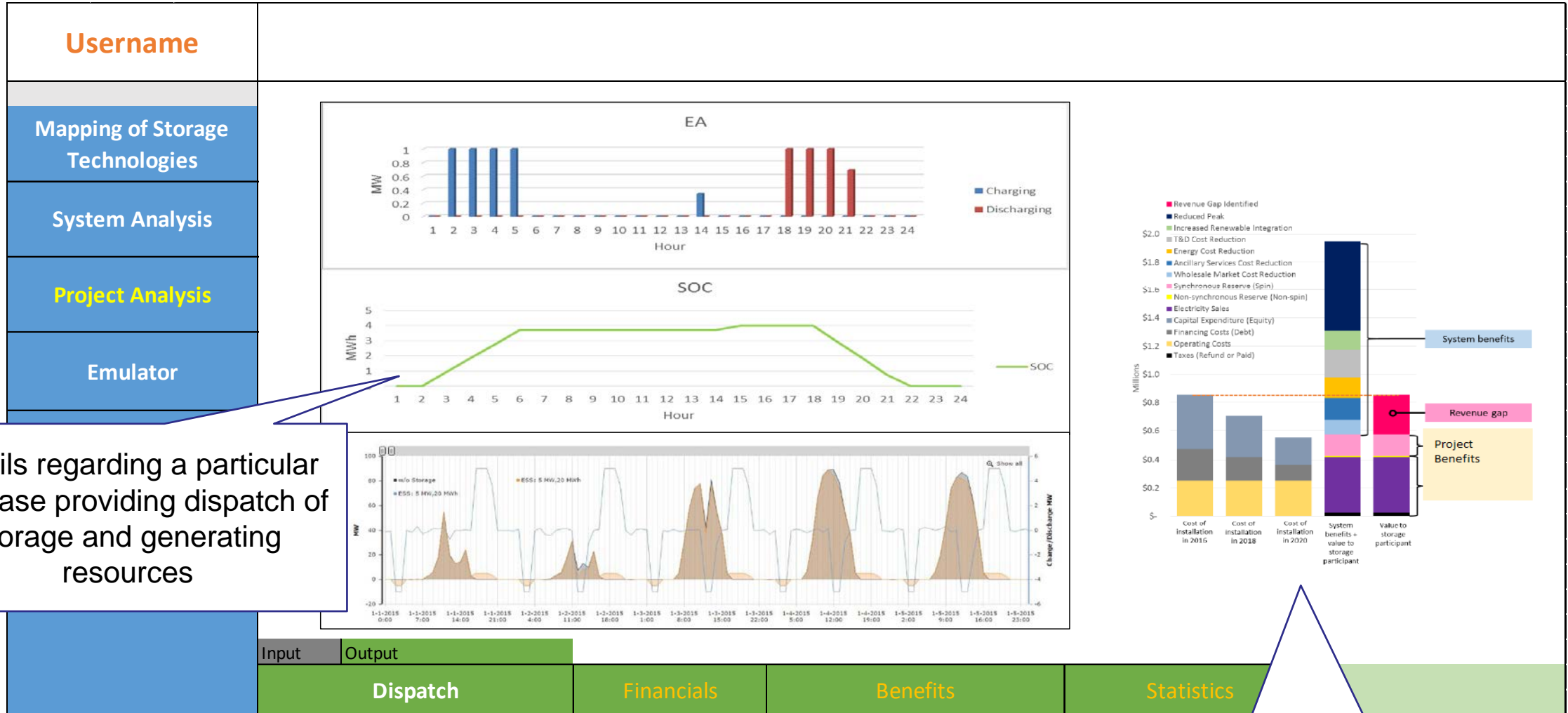
Get Data from SLT Inputs Specific Data

User can import data generated by ALEVO system Level tool

Input Output

System	Renewables	Project	Policy	
---------------	------------	---------	--------	--

Project Analysis (Outputs)

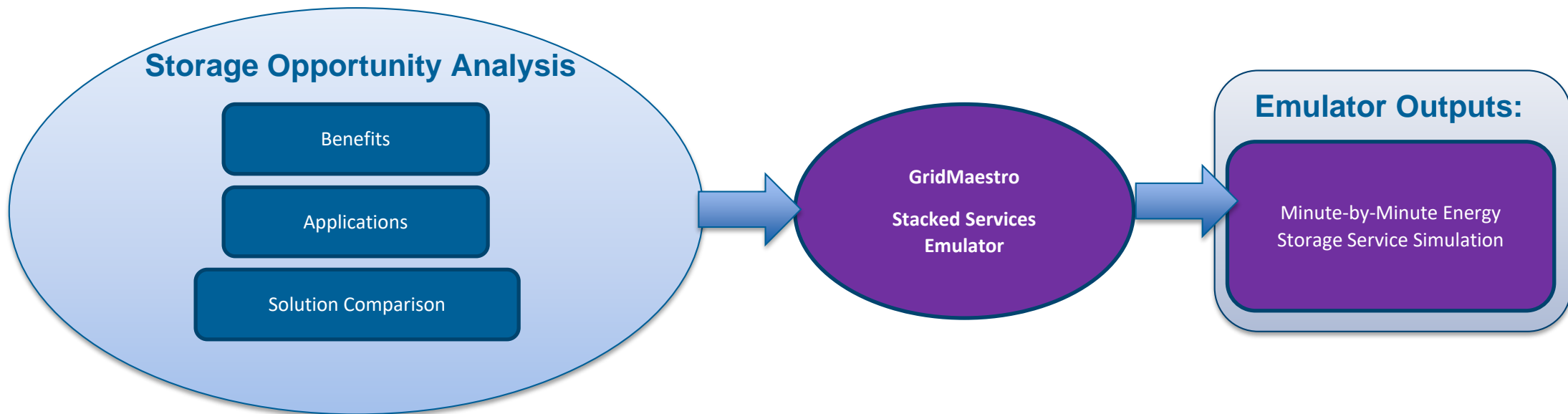


Benefits of a selected Use Case

MODULE 3: SERVICES EMULATOR

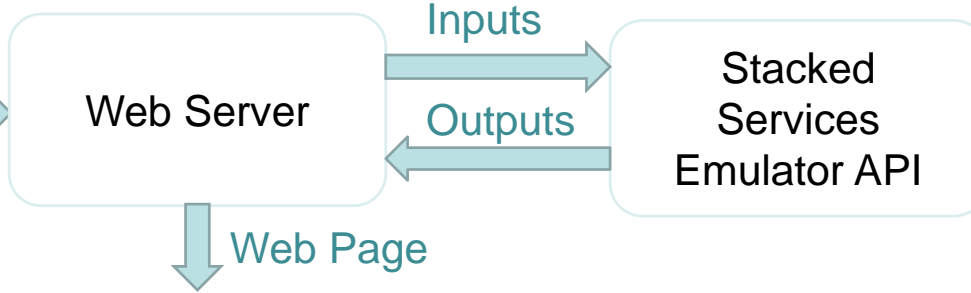
GridMaestro Stacked Services Emulator

- The GridMaestro Stacked Services Emulator integrates the results from the System Level Tool and CoMETS to simulate the minute-to-minute performance of the stacked services provided by the energy storage.
- This simulation allows for the design and optimization of energy storage project sites, as well as renewables sites, by showing the interaction of the energy storage with various grid assets.



GridMaestro Stacked Services Emulator

Inputs
Energy Prices (\$/MWh)
Regulation Reserve Prices (\$/MW)
Spin Reserve Prices (\$/MW)
Original Load (MW)
Provision (MW)
Renewables Generation (MW)



Outputs
SOC(%)
Original Load (MW)
Net Load (MW)
Discharging Power (MW)
Charging Power (MW)
Reg Down Nomination (MW)
Reg Up Nomination (MW)
Spin Nomination (MW)
Spin Energy Allocation (MWh)
Reg UP Energy Allocation (MWh)
Discharging Energy Allocation (MWh)
Provision Energy Allocation (MWh)
Unallocated Energy (MWh)
Profit from energy market (\$)
Profit from providing Spin Reserve (\$)
Profit from providing Regulation (\$)
Nominated Power (MW)
Allocated Energy (MWh)
Cycles
Throughput (MWh)
Total Revenue (\$)
ESS Power (MW)
ESS Energy (MWh)
Hourly Total Revenue (\$)



Alternative Technology Solutions

Username					
Mapping of Storage Technologies		Energy Storage	Interconnectors	Smart Grid Technologies	Demand Response
System Analysis	<i>Capital Cost</i>	Capex, \$/cycle, LOCS	capex, \$/mile	Capex, \$/MWh, LCOE	Capex, \$/MWh, LCOE
Project Analysis	<i>Operational Cost</i>	\$/MWh, annual maintenance	Losses, annual maintenance	\$/MWh, annual maintenance	\$/MWh, annual maintenance
Emulator	<i>Fitness of Technology for the Primary Service</i>	Response time, duration, four quadrant control	Response time, duration, four quadrant control	Response time, duration, four quadrant control	Response time, duration, four quadrant control
Alternative technology Solutions	<i>Example of Other Services</i>	Resiliency, security, reliability	Resiliency, security, reliability	Resiliency, security, reliability	Resiliency, security, reliability

NEXT STEPS

- ~~• Presentation of the framework structure at Africa Utility Week 18 May~~
- Presentation of the tool on 1 June at Intersolar (Munich)
- Final draft of the framework report and draft tool completed by end of July
- External review of report and tool in August (**please approach me if interested to be a reviewer**)
- Final report and live version of the web tool ready in September
- Application of the framework to IRENA Member countries – first one agreed to be South Africa



www.irena.org



www.twitter.com/irena



www.facebook.com/irena.org



www.instagram.com/irenaimages



www.flickr.com/photos/irenaimages



www.youtube.com/user/irenaorg

Emanuele Taibi

Power Sector Transformation Strategies

ETaibi@irena.org