THE ELECTRICITY SYSTEM VALUE CHAIN

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e⁻Lab®
Electricity Innovation Lab
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Authors & Acknowledgements

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What is e-Lab?

The Electricity Innovation Lab (e-Lab) brings together thought leaders and decision makers from across the U.S. electricity sector to address critical institutional, regulatory, business, economic, and technical barriers to the economic deployment of distributed resources. In particular, e-Lab works to answer three key questions:

- How can we understand and effectively communicate the costs and benefits of distributed resources as part of the electricity system and create greater grid flexibility?
- How can we harmonize regulatory frameworks, pricing structures, and business models of utilities and distributed resource developers for greatest benefit to customers and society as a whole?
- How can we accelerate the pace of economic distributed resource adoption?

A multi-year "change lab," e-Lab regularly convenes its members to identify, test, and spread practical solutions to the challenges inherent in these questions. e-Lab has member meetings, coupled with ongoing project work, facilitated and supported by Rocky Mountain Institute.

e-Lab meetings allow members to share learnings, best practices, and analysis results; collaborate around key issues or needs; and conduct deep-dives into research and analysis findings.

For more information about e-Lab, please visit: www.rmi.org/eLab

e-Lab is a joint collaboration, convened by RMI, with participation from stakeholders across the electricity industry. e-Lab is not a consensus organization, and the views expressed in this document are not intended to represent those of any individual e-Lab member or supporting organization.

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INTRODUCTION

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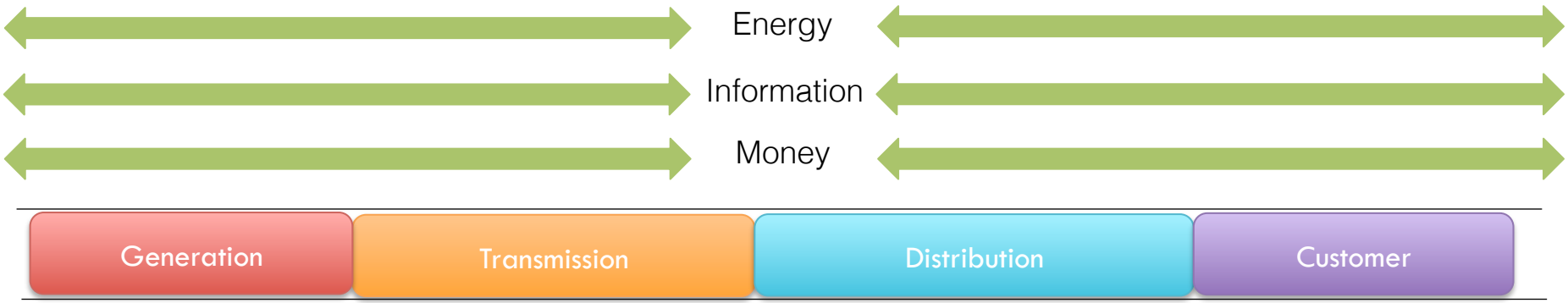
What's wrong with today's electricity system?

A clean, prosperous, and secure electricity system requires rapid, two-way transfer of electrons, information, and money.

Clean, prosperous, and secure energy systems need:



Key tenets of a transformed future:

- Energy services create value
- Bidirectional exchange of this value should be realized
- Monetary transactions should be aligned with the energy values exchanged on the grid
- The more accurately compensation matches value, the better the system will capture that value
- High-quality information is required to match compensation with value

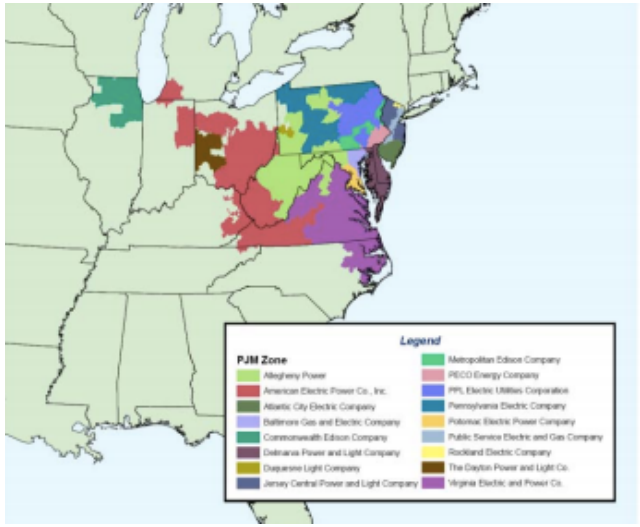
Today's grid doesn't fully support these needs because of historic paradigms:

- Energy flowed in one direction from generators to customers
- Real-time communications across all grid segments were not possible
- Utilities had limited visibility and control over system operations
- Vertically integrated utilities only transacted with customers via meters for simplicity

Why do we need a better system?
The transformation can capture significant value.

For example: In 2012, PJM transformed its system, implementing Order 745 rules that compensate economic demand response (DR) resources directly in wholesale markets as a generating resource (receiving the full wholesale price when the wholesale price exceeds the monthly net benefits threshold).

PJM map



Before:

Demand response was compensated at less than the wholesale rate. This compensation method was not commensurate to the value of DR for keeping the wholesale price low on the grid. Without proper compensation, no more than 2,500 MW would clear the capacity auctions within PJM.

After:

The change of rules provided more opportunity for DR to provide value to the grid, and as a result the latest capacity auction cleared with nearly 11,000 MW of demand response.

In order to capture the full value potential of a technology, compensation must align with the value the marketplace is seeking to capture.

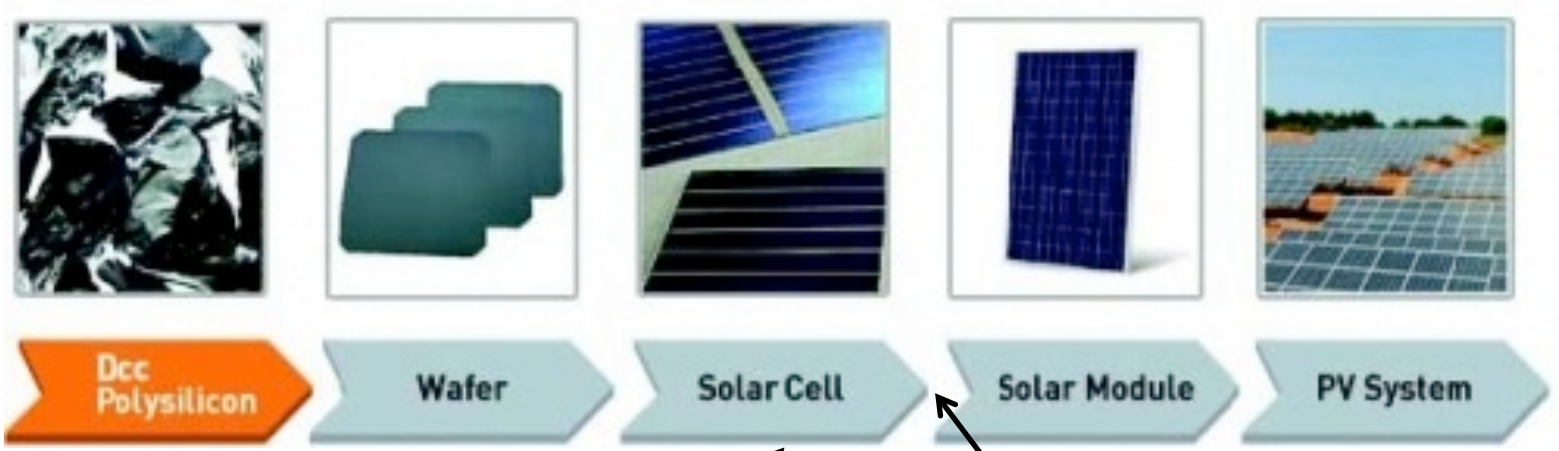
While the grid is getting better at capturing existing value, emerging technologies are bringing new value to the grid.

- In order to integrate an emerging technology with the grid, it must work in harmony with the system objectives.
- In order to work in harmony with system objectives, you must have communication between layers of the grid.
- This results in numerous material and informational connections between technologies.
- Each technology creates a specific set of values, and the connections between technologies exchange that value.
- A system value chain facilitates understanding the flow of informational and material value across the electricity grid to help identify opportunities to capture value.
- **Emerging technology will be developed and deployed depending on its ability to capture value.**

A value chain describes a series of activities that are performed in order to deliver value to a market.

The value chain below describes the solar PV industry in simple terms:

- Value is added in each step
- Value is captured in the interface between steps



Example:

Raw wafers are turned into solar cells to add value

Solar cell manufacturers capture this value by selling cells to solar module manufacturers

Our electricity system is complex, and identifying sources of value and opportunities to capture it needs more than a chain.

The electricity system is not sequential but rather a network of connections—we need a **system value chain** to describe it instead of a linear value chain.

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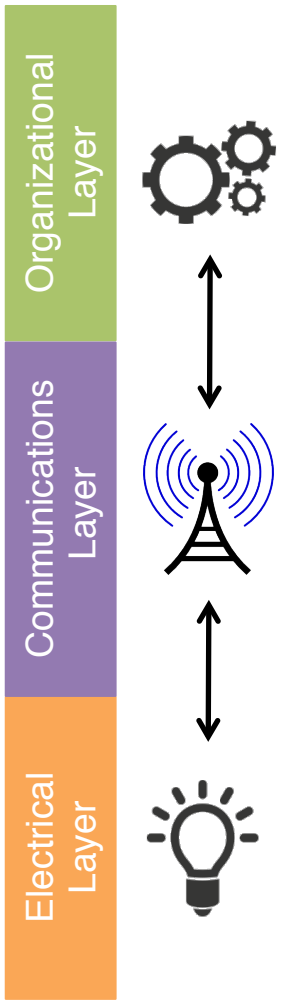
DEVELOPING THE ELECTRICITY SYSTEM VALUE CHAIN

02

Components and interactions in electricity systems

Any electricity system has three fundamental layers.

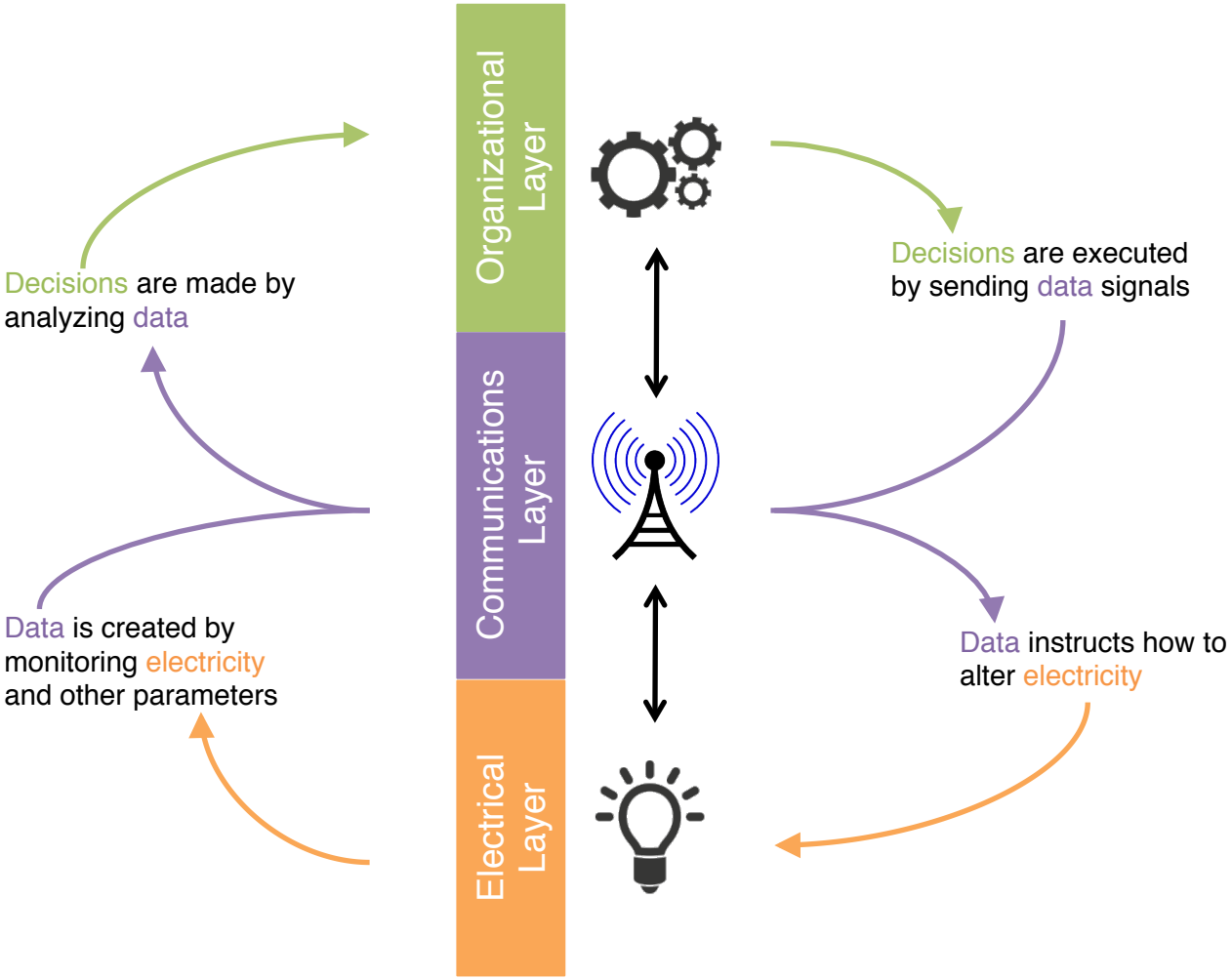


The **organizational layer** is where operational decisions are made to govern an electricity system.

The **communications layer** is the set of communication assets and activities that create and manipulate data to generate useful information for decision making.

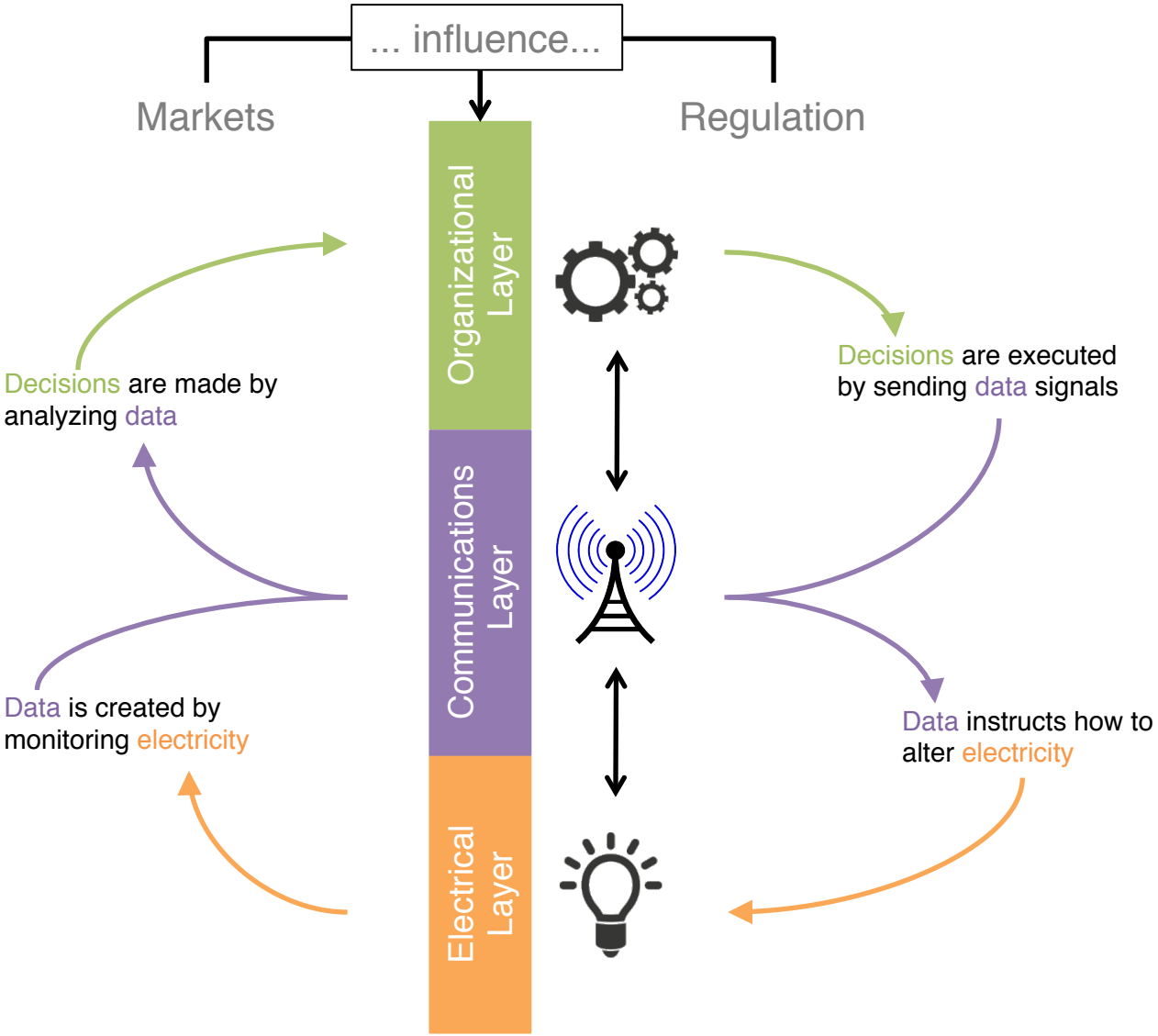
The **electrical layer** is the physical grid—the assets involved in making, modifying, and using electricity.

The three fundamental layers are connected.



- Control theory forms the basis for how value is passed between the electrical and organizational systems on the grid.
- A similar structure for understanding the grid has been developed by many, including the GridWise Architecture Council and in the work of Santiago Grijalva on market technology. The nomenclature selected aims to align with this discourse.

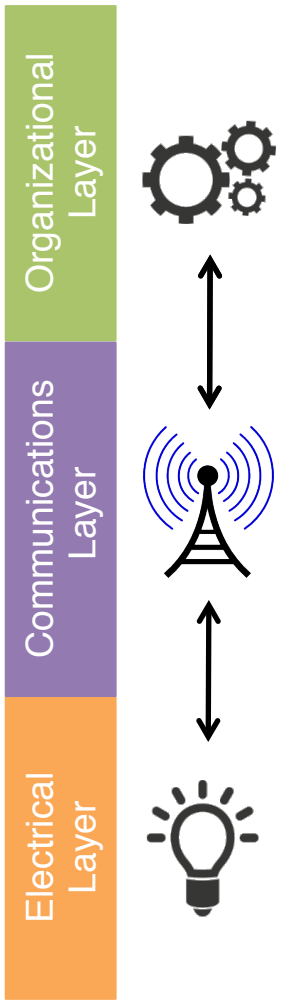
Markets and regulation influence the organizational layer.



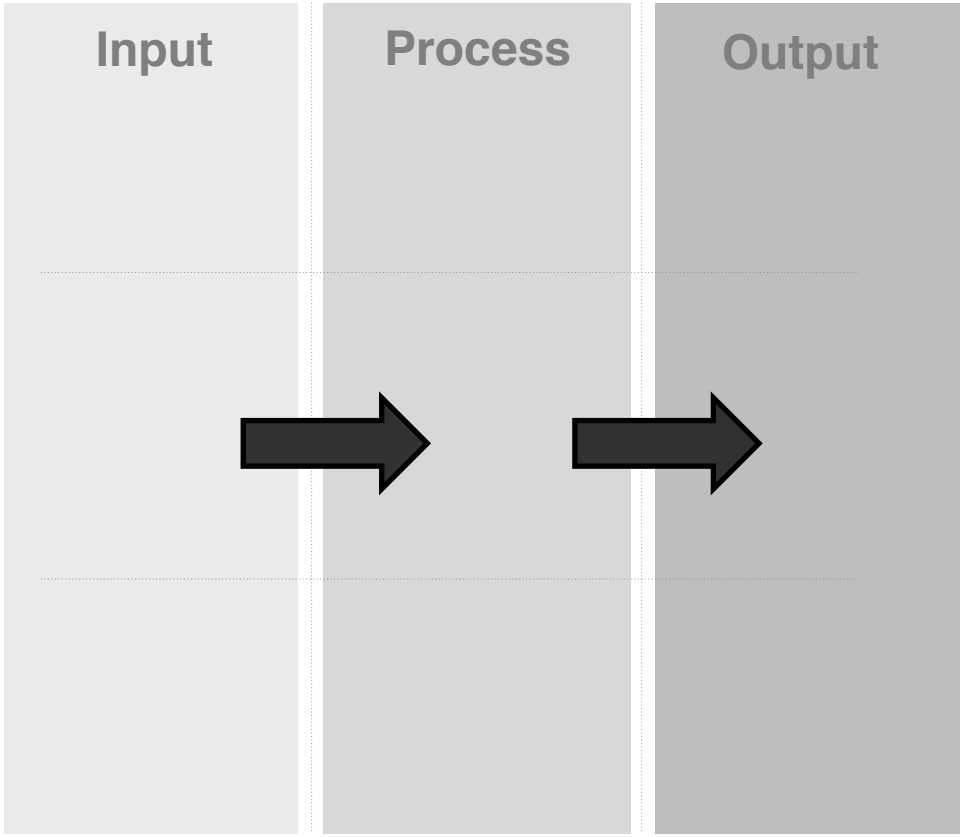
Although **markets** and **regulation** are often expressed as additional layers in electricity system topologies, the system value chain expresses these as "influencers" on the organizational layer. They also express themselves in the way values are exchanged on the system and how they are compensated.

There are three essential function groups in each layer.

Three fundamental layers:

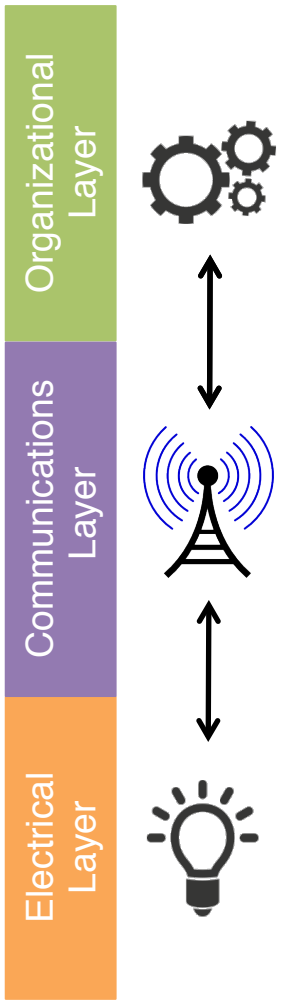


Three essential functions:

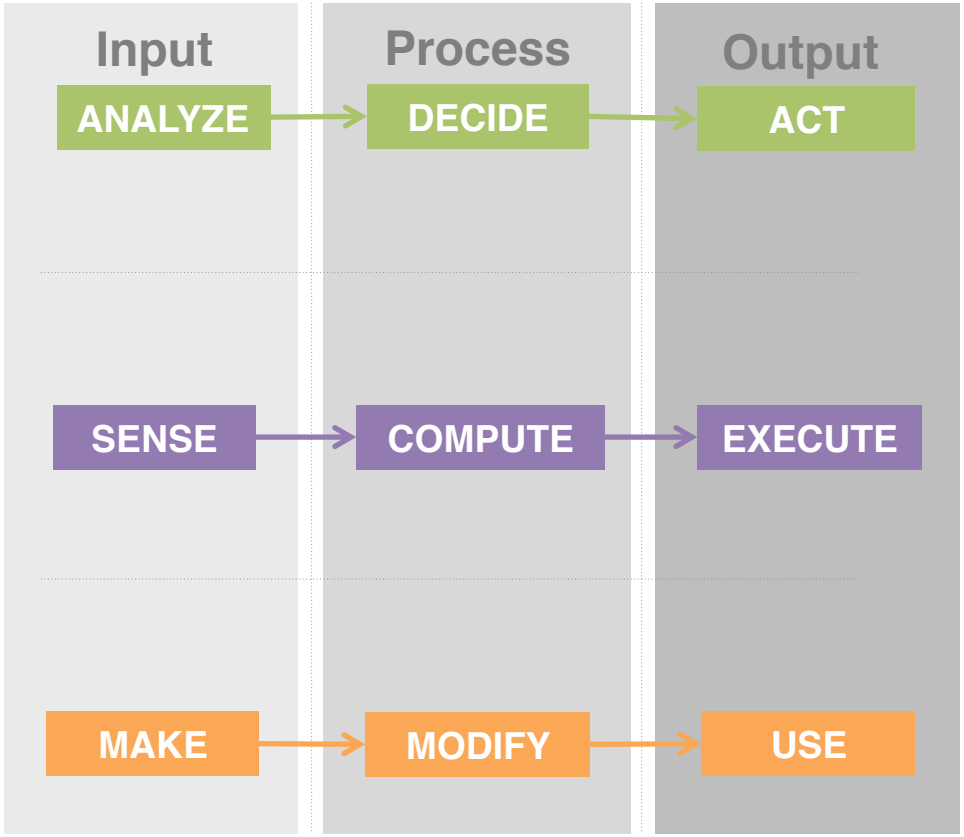


The essential functions take on different forms in specific layers.

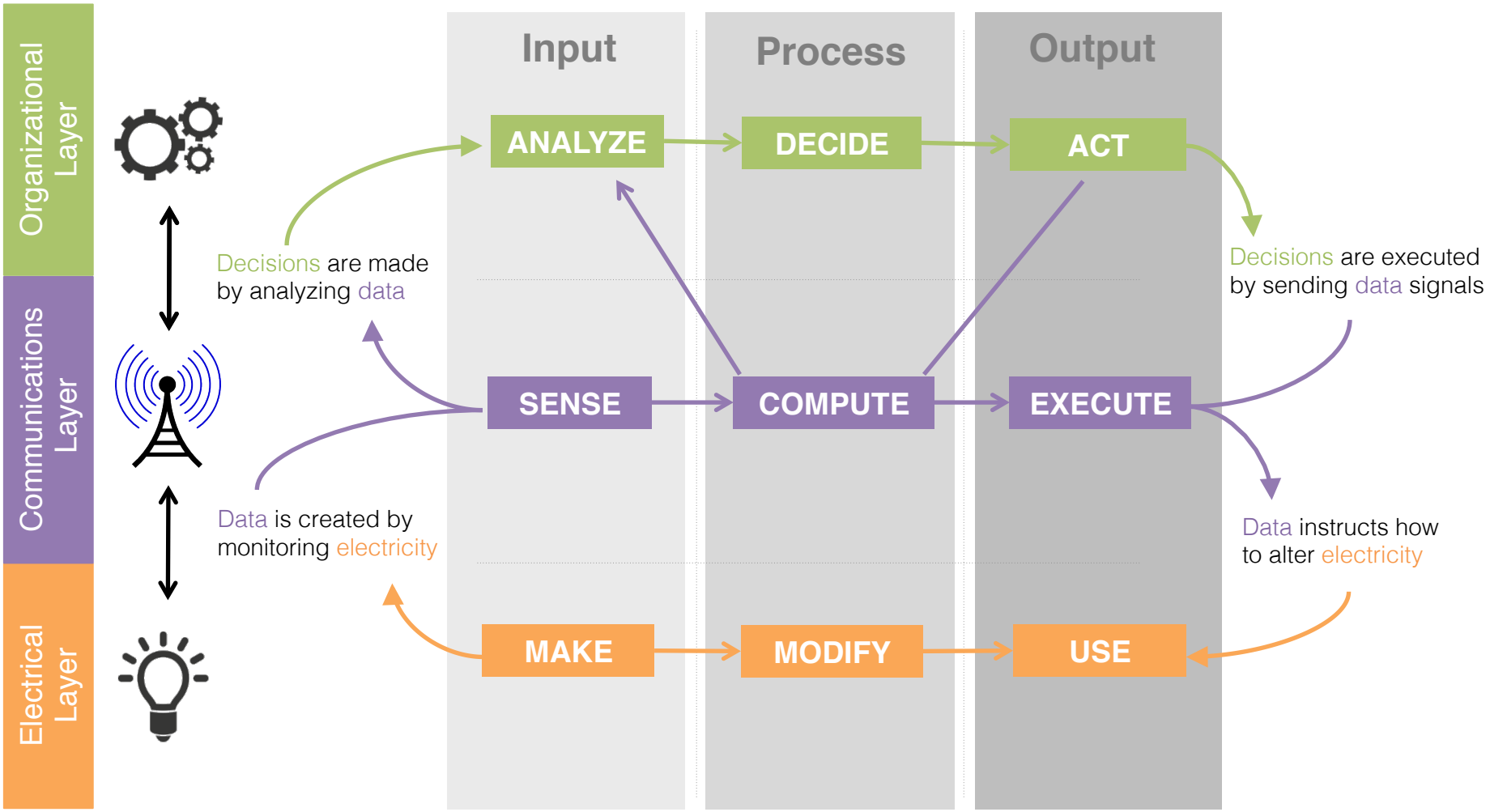
Three fundamental layers:



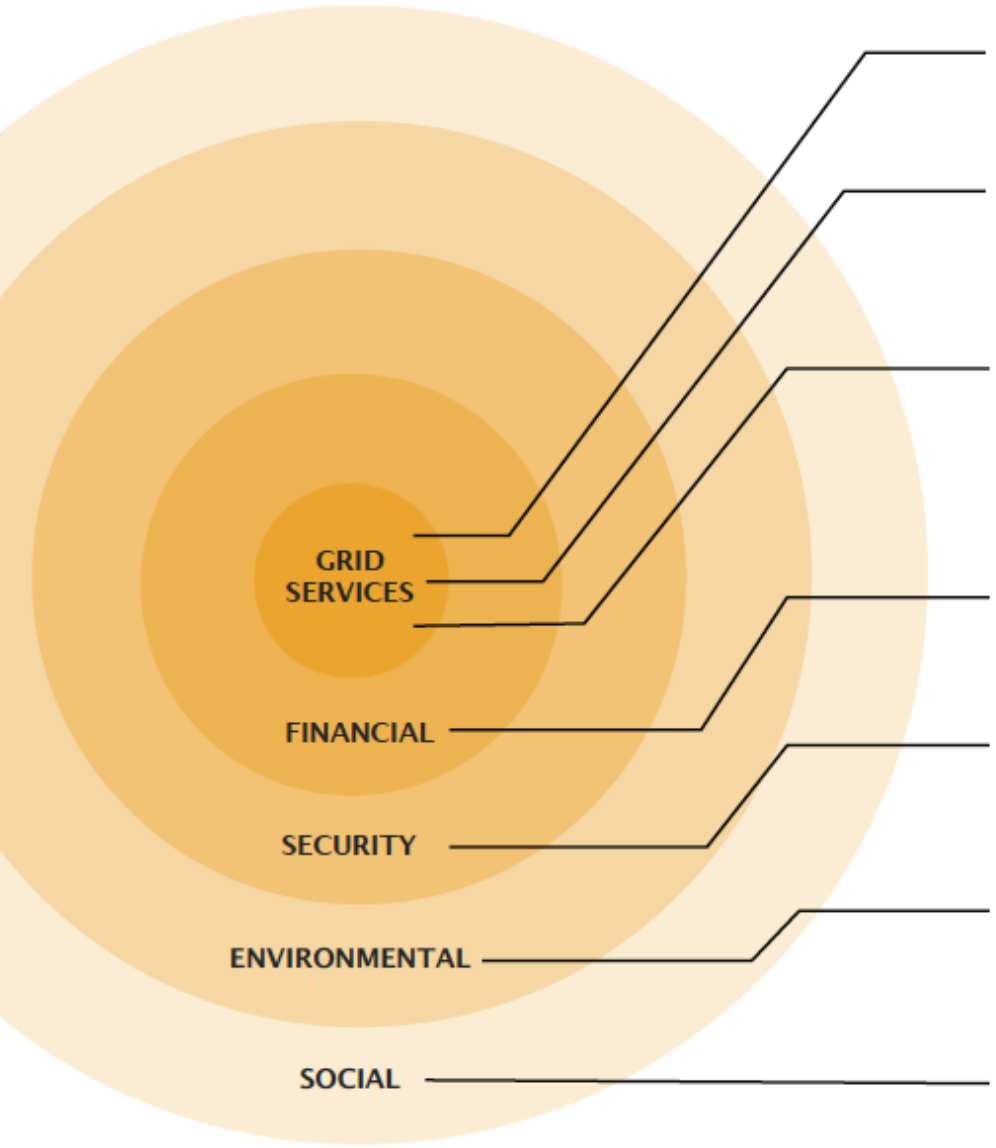
Three essential functions:



Together, the essential functions in the fundamental grid layers, and their connections, are the electricity system value chain.



The electricity system value chain is used to identify opportunities to capture 18 well-established system values.



ENERGY
- energy
- system losses

CAPACITY
- generation capacity
- transmission & distribution capacity
- DPV installed capacity

GRID SUPPORT SERVICES
- reactive supply & voltage control
- regulation & frequency response
- energy & generator imbalance
- synchronized & supplemental operating reserves
- scheduling, forecasting, and system control & dispatch

FINANCIAL RISK
- fuel price hedge
- market price response

SECURITY RISK
- reliability & resilience

ENVIRONMENTAL
- carbon emissions (CO_2)
- criteria air pollutants (SO_2, NO_x, PM)
- water
- land

SOCIAL
- economic development (jobs and tax revenues)

So… what's the point of the electricity system value chain?

The electricity system value chain framework can be used to look at the electricity system from different perspectives, revealing different value for each:

1. **For technology and service providers:** It reveals the connections and components that are needed in order for their *product* to provide one or more of the 18 electricity system values and also identifies pathways and barriers to being compensated for that value.

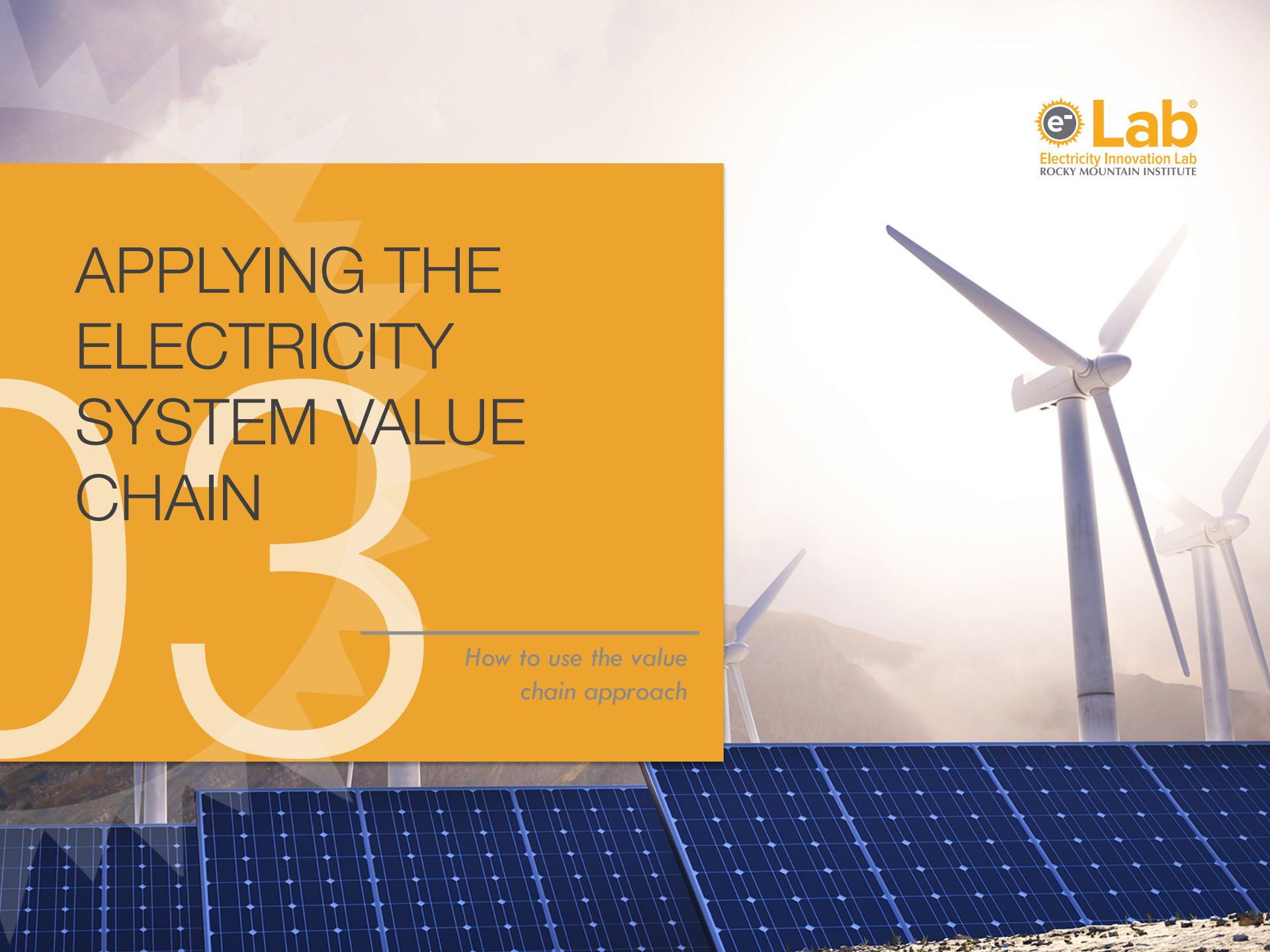
2. **For system designers:** It articulates the required components and connections that enable one or more of the 18 electricity system values to be captured by a *system platform* and informs how system operators go about compensating these values.

How would these stakeholders use the electricity system value chain?

Here are some examples on how the electricity system value chain framework might be used by those two user-groups:

1. **By technology and service providers:** A smart inverter manufacturer might use the framework to understand how they might coordinate their inverters to deliver reactive power control in conjunction with utility signals. By mapping the connections in the system, the value chain will help technology providers visualize how value is shared between stakeholders in the system, allowing them to identify the most probable avenues for compensation in the current paradigm.

2. **By system designers:** A system designer may use the framework to understand the assets required to determine real-time pricing, and the connections in the system necessary to send those signals to customers. System designers can then compare several different technology platforms in order to inform their decision on which is the best technology to achieve the desired market reform.



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APPLYING THE ELECTRICITY SYSTEM VALUE CHAIN

03

How to use the value chain approach

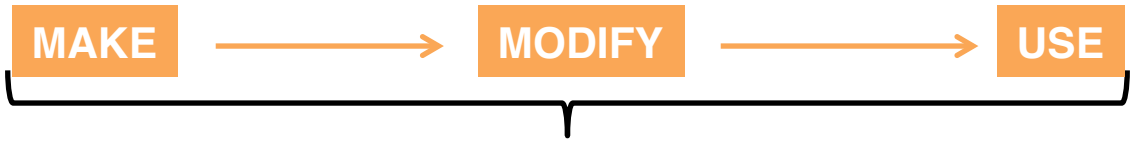
Applying the electricity system value chain

While it is possible to define the system boundary anywhere on the electrical system, for emerging technology at the distribution edge it is often useful to think about value exchange in relation to the customer meter. Two types of boundary conditions arise:

- Behind-the-meter systems (with the boundary being the utility meter to end-use loads)
- Distribution-scale systems that interact with individual customers across the meter (with the boundary being the distribution substation to end-use loads)

Electrical Layer

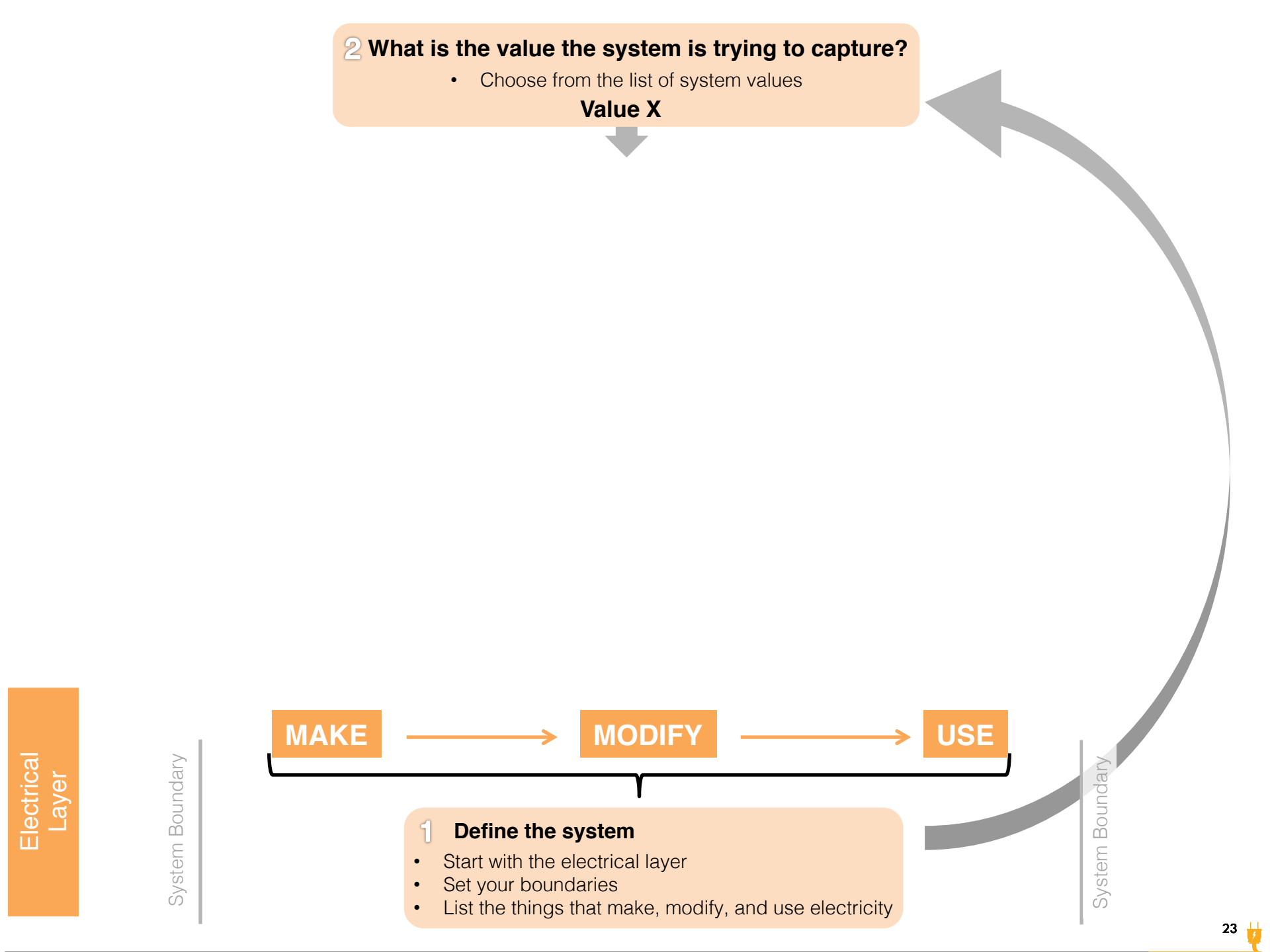
System Boundary

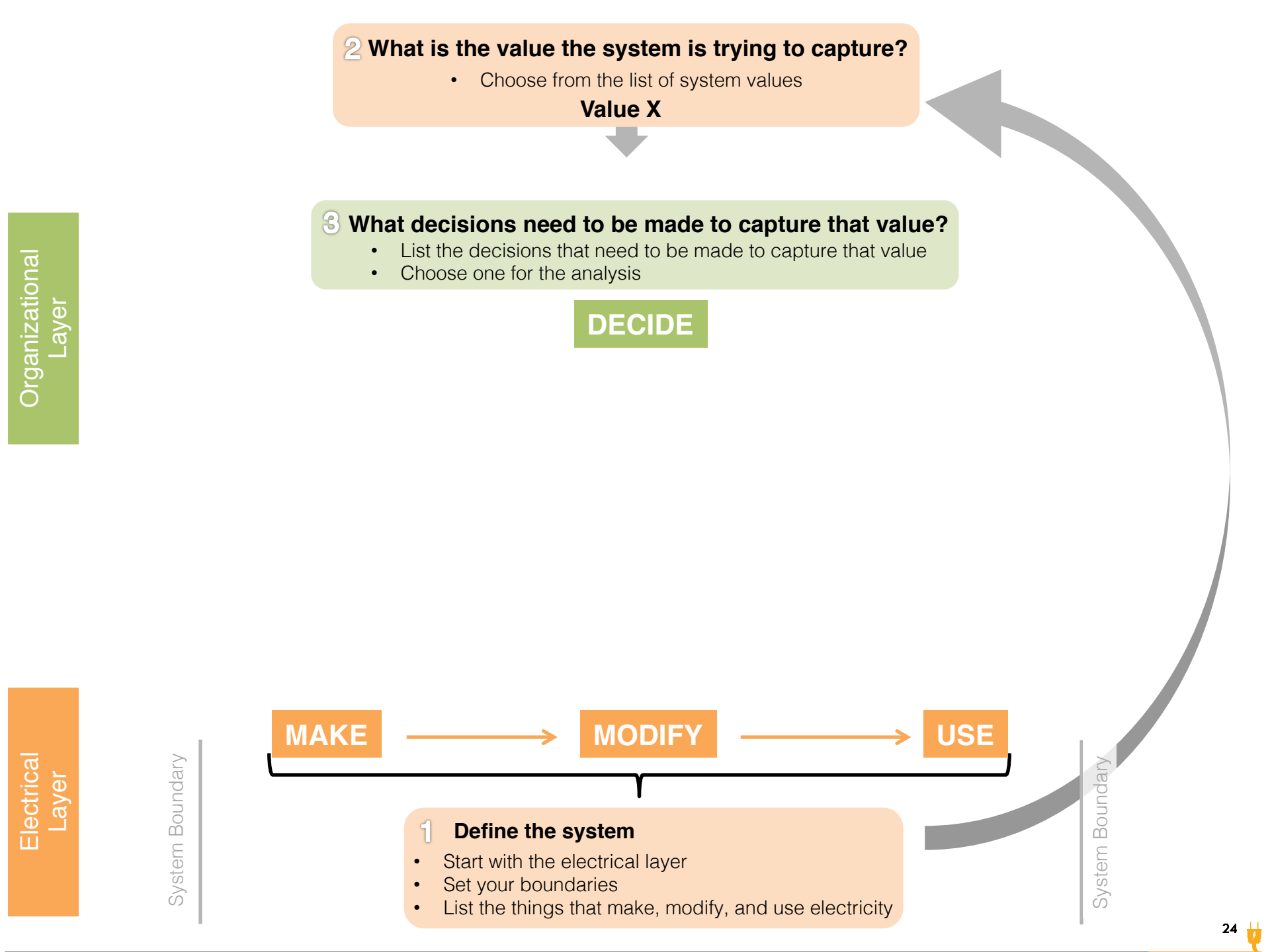


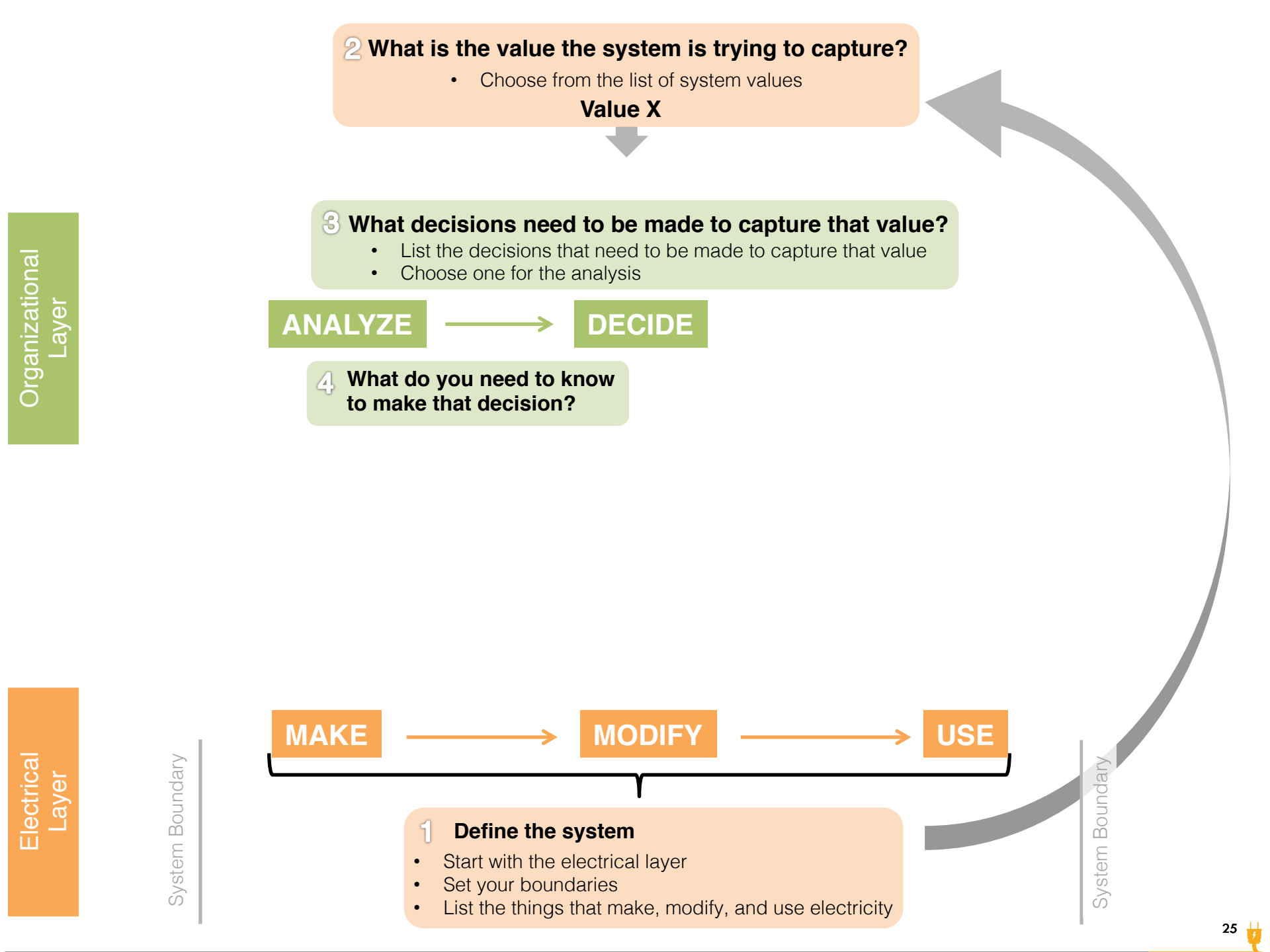
System Boundary

1 Define the system

- Start with the electrical layer
- Set your boundaries
- List the things that make, modify, and use electricity


2 What is the value the system is trying to capture?
• Choose from the list of system values
Value X
Electrical Layer
System Boundary
MAKE
MODIFY
USE
1 Define the system
• Start with the electrical layer
• Set your boundaries
• List the things that make, modify, and use electricity
System Boundary


2 What is the value the system is trying to capture?
• Choose from the list of system values
Value X
3 What decisions need to be made to capture that value?
• List the decisions that need to be made to capture that value
• Choose one for the analysis
DECIDE
Organizational Layer
Electrical Layer
MAKE
MODIFY
USE
System Boundary
System Boundary
1 Define the system
• Start with the electrical layer
• Set your boundaries
• List the things that make, modify, and use electricity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Value X
3 What decisions need to be made to capture that value?
• List the decisions that need to be made to capture that value
• Choose one for the analysis
ANALYZE
DECIDE
4 What do you need to know to make that decision?
Organizational Layer
Electrical Layer
MAKE
MODIFY
USE
System Boundary
System Boundary
1 Define the system
• Start with the electrical layer
• Set your boundaries
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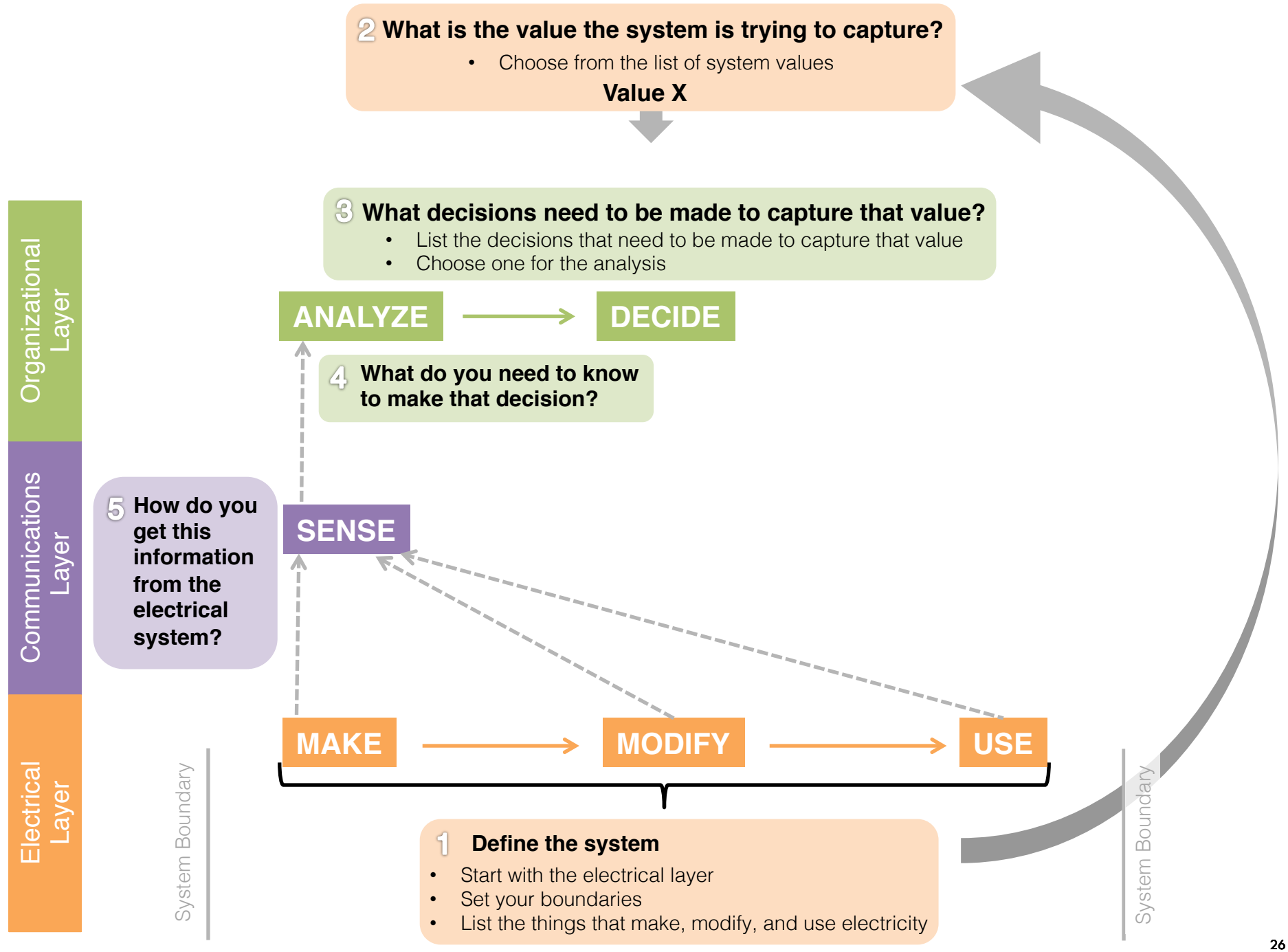
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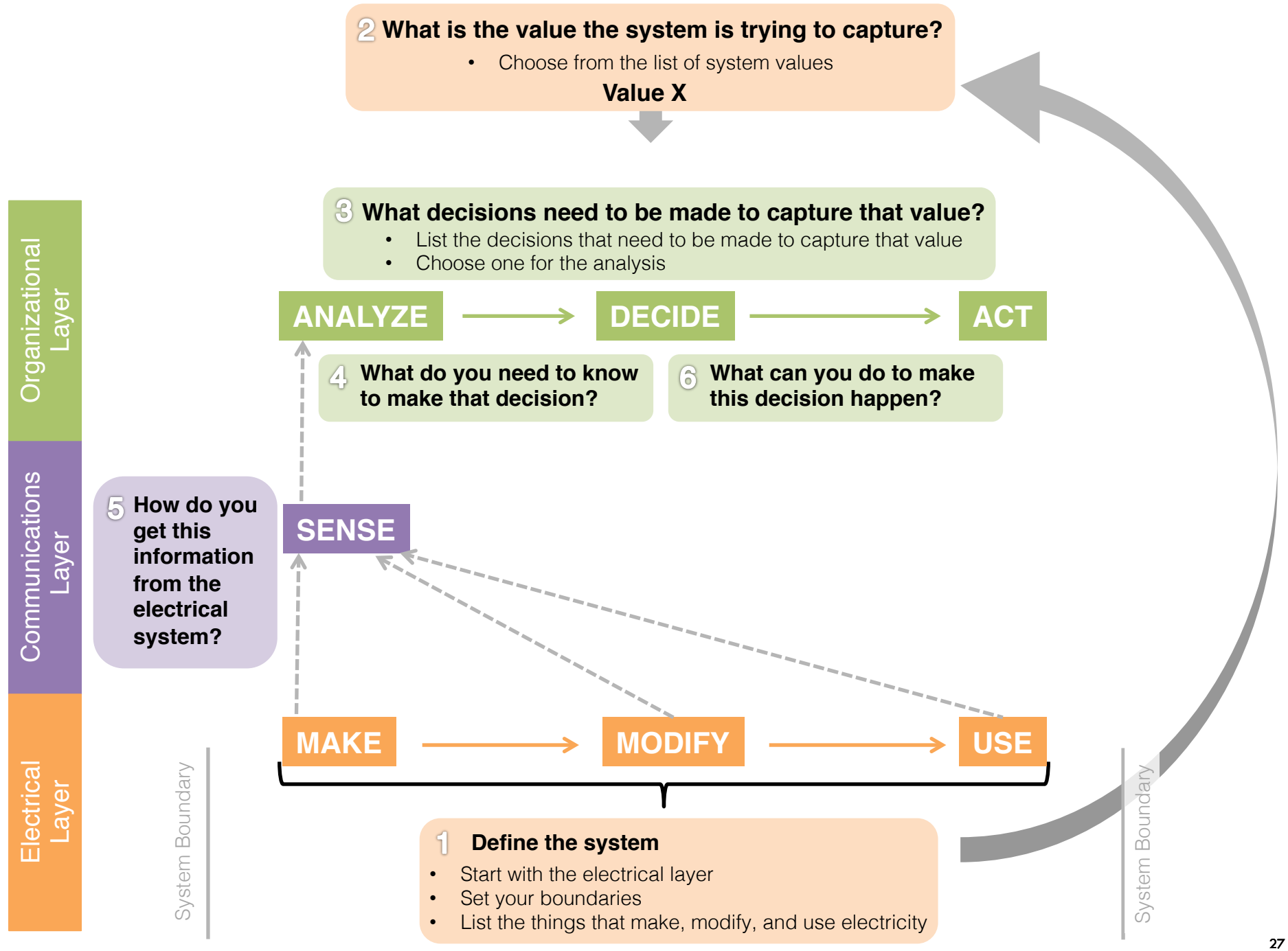
• List the decisions that need to be made to capture that value
• Choose one for the analysis
ANALYZE
DECIDE
4 What do you need to know to make that decision?
5 How do you get this information from the electrical system?
SENSE
MAKE
MODIFY
USE
1 Define the system
• Start with the electrical layer
• Set your boundaries
• List the things that make, modify, and use electricity
Organizational Layer
Communications Layer
Electrical Layer
System Boundary
System Boundary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Value X
3 What decisions need to be made to capture that value?
• List the decisions that need to be made to capture that value
• Choose one for the analysis
ANALYZE
DECIDE
ACT
4 What do you need to know to make that decision?
6 What can you do to make this decision happen?
5 How do you get this information from the electrical system?
SENSE
MAKE
MODIFY
USE
1 Define the system
• Start with the electrical layer
• Set your boundaries
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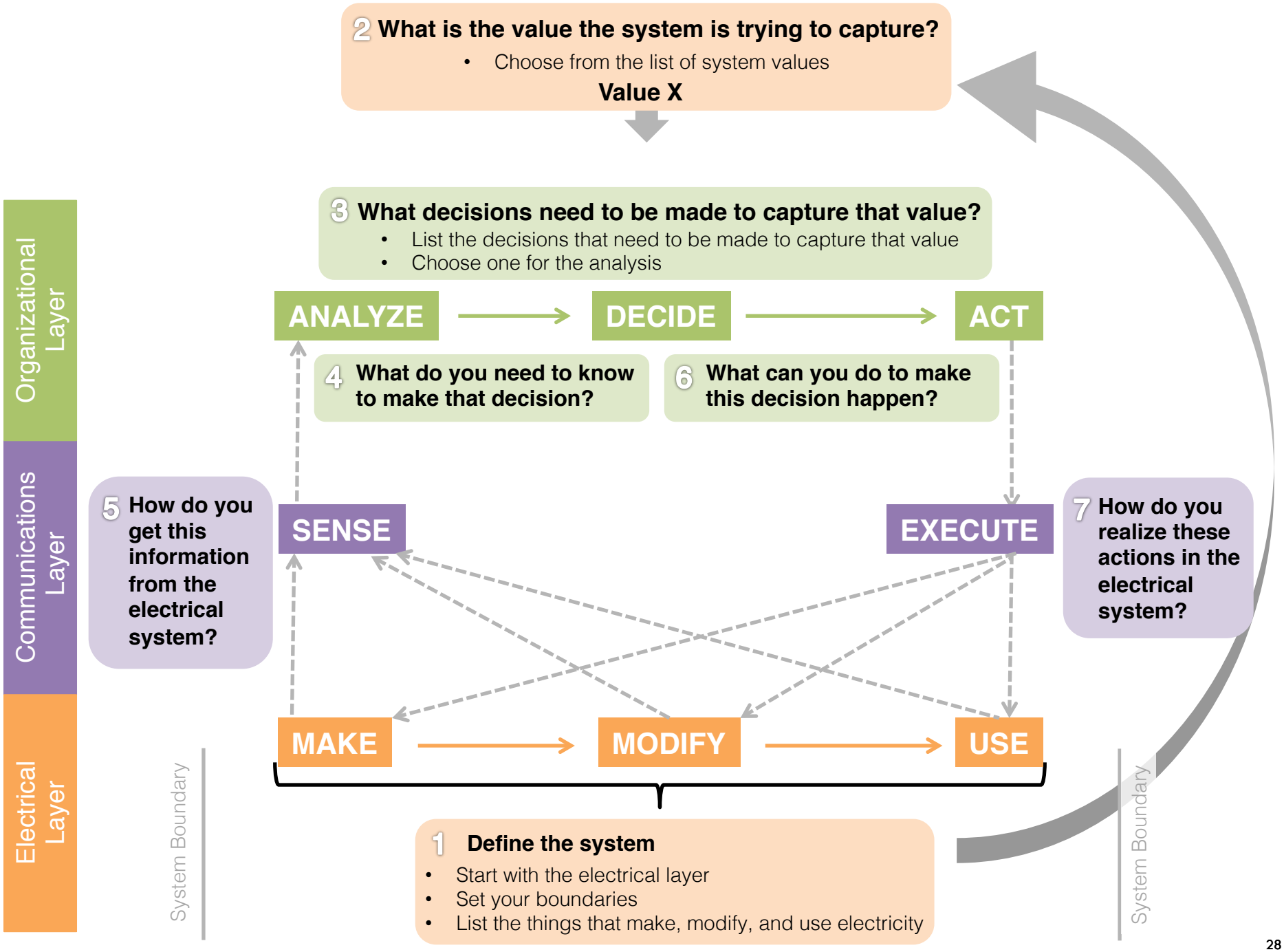
Organizational Layer
Communications Layer
Electrical Layer
System Boundary
System Boundary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• List the decisions that need to be made to capture that value
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DECIDE
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4 What do you need to know to make that decision?
6 What can you do to make this decision happen?
5 How do you get this information from the electrical system?
SENSE
EXECUTE
7 How do you realize these actions in the electrical system?
MAKE
MODIFY
USE
1 Define the system
• Start with the electrical layer
• Set your boundaries
• List the things that make, modify, and use electricity
Organizational Layer
Communications Layer
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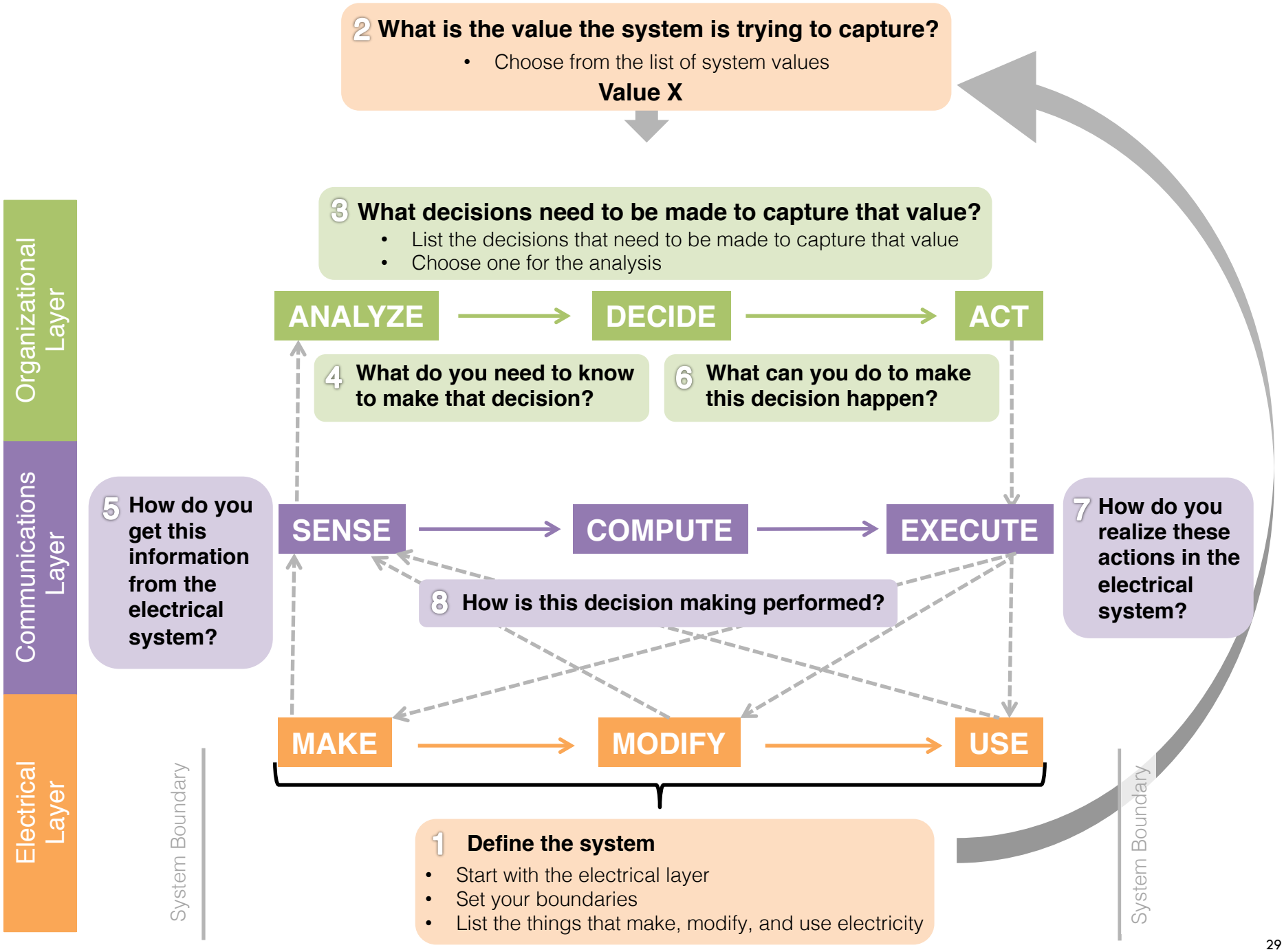
System Boundary
System Boundary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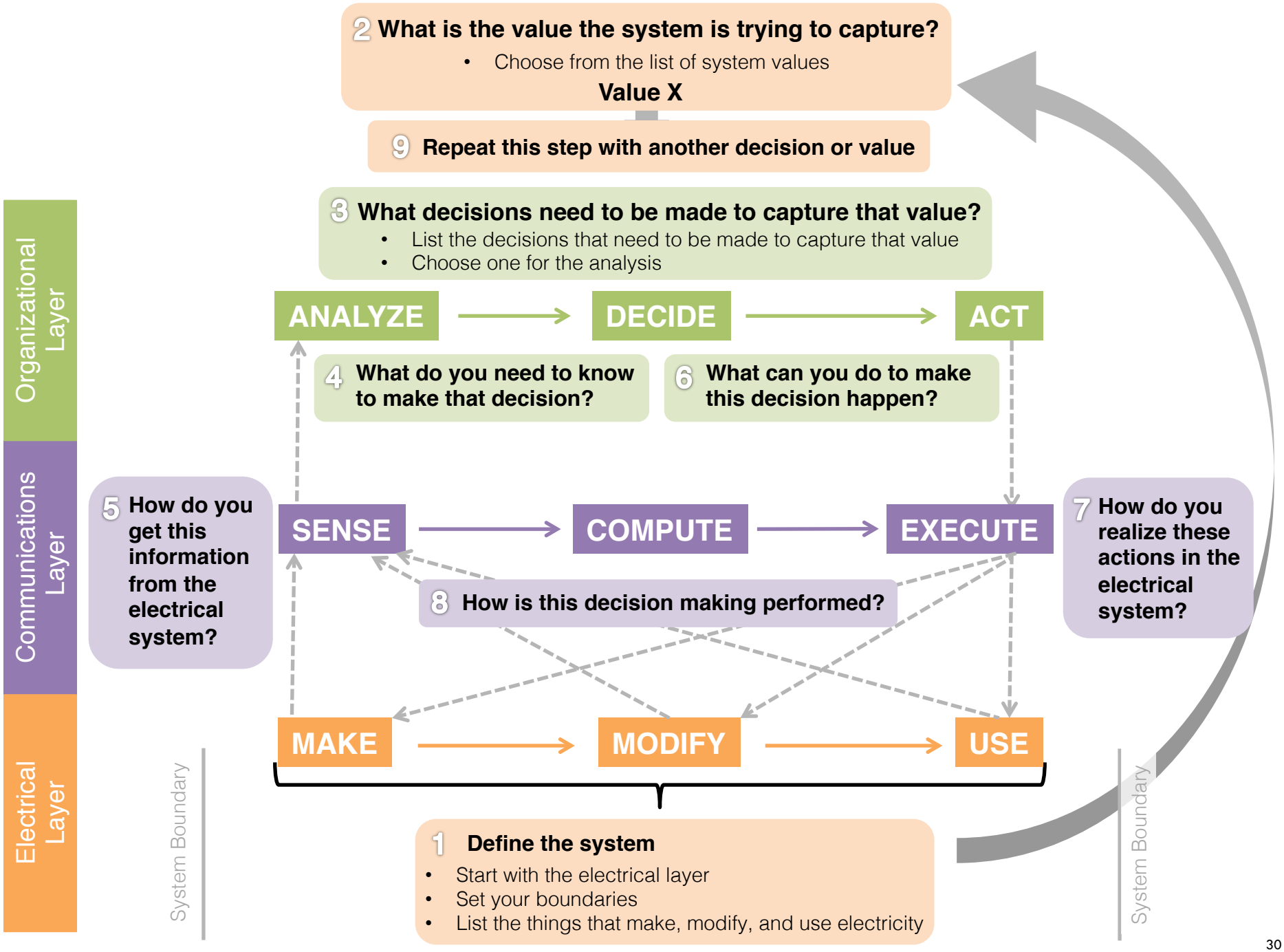
Organizational Layer
Communications Layer
Electrical Layer
ANALYZE
DECIDE
ACT
4 What do you need to know to make that decision?
6 What can you do to make this decision happen?
5 How do you get this information from the electrical system?
SENSE
COMPUTE
EXECUTE
7 How do you realize these actions in the electrical system?
8 How is this decision making performed?
MAKE
MODIFY
USE
System Boundary
System Boundary
1 Define the system
• Start with the electrical layer
• Set your boundaries
• List the things that make, modify, and use electricity


2 What is the value the system is trying to capture?
• Choose from the list of system values
Value X
9 Repeat this step with another decision or value
3 What decisions need to be made to capture that value?
• List the decisions that need to be made to capture that value
• Choose one for the analysis
Organizational Layer
Communications Layer
Electrical Layer
ANALYZE
DECIDE
ACT
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System Boundary
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EXAMPLE APPLICATIONS

04

Four specific examples

Setting context for the following examples

- The following examples give a sense of how the system value chain could be applied to identify additional sources of value in the context of a technology provider.
- While, in reality, the systems described here are more complex, they were simplified to aid in understanding value chain application.
- The full value of applying the system value chain can be realized when it is used as a discussion framework.

Start with a simple example of using the system value chain to look at a solar PV system.

- You are a PV installer looking to understand the amount of “smarts” that need to be designed into your system.
- You use the system value chain to understand how your PV system operates in accordance with a building’s needs.

On the following slides, the notes section in the PowerPoint document offers additional detail and narrative for clarity.

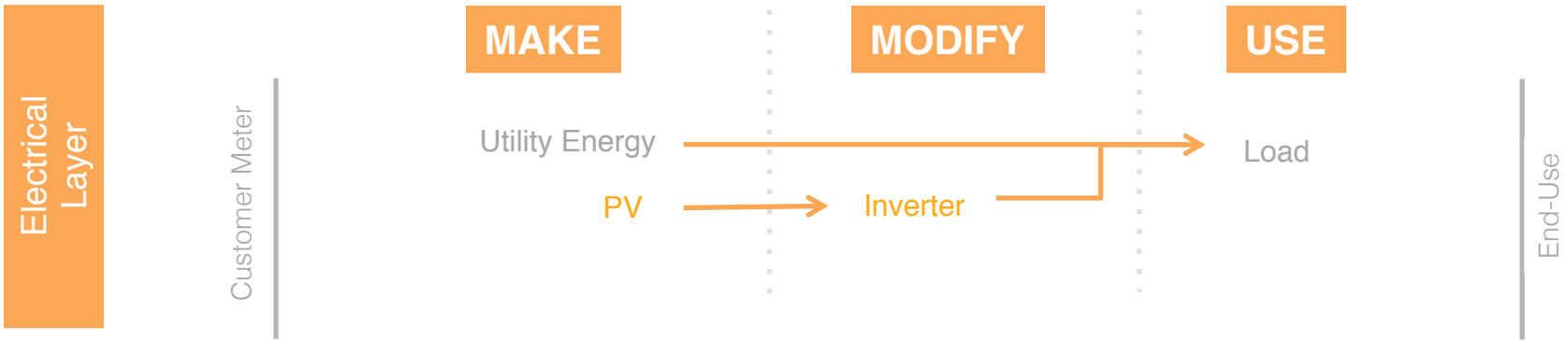
1: Define the system

Behind-the-Meter Environment:

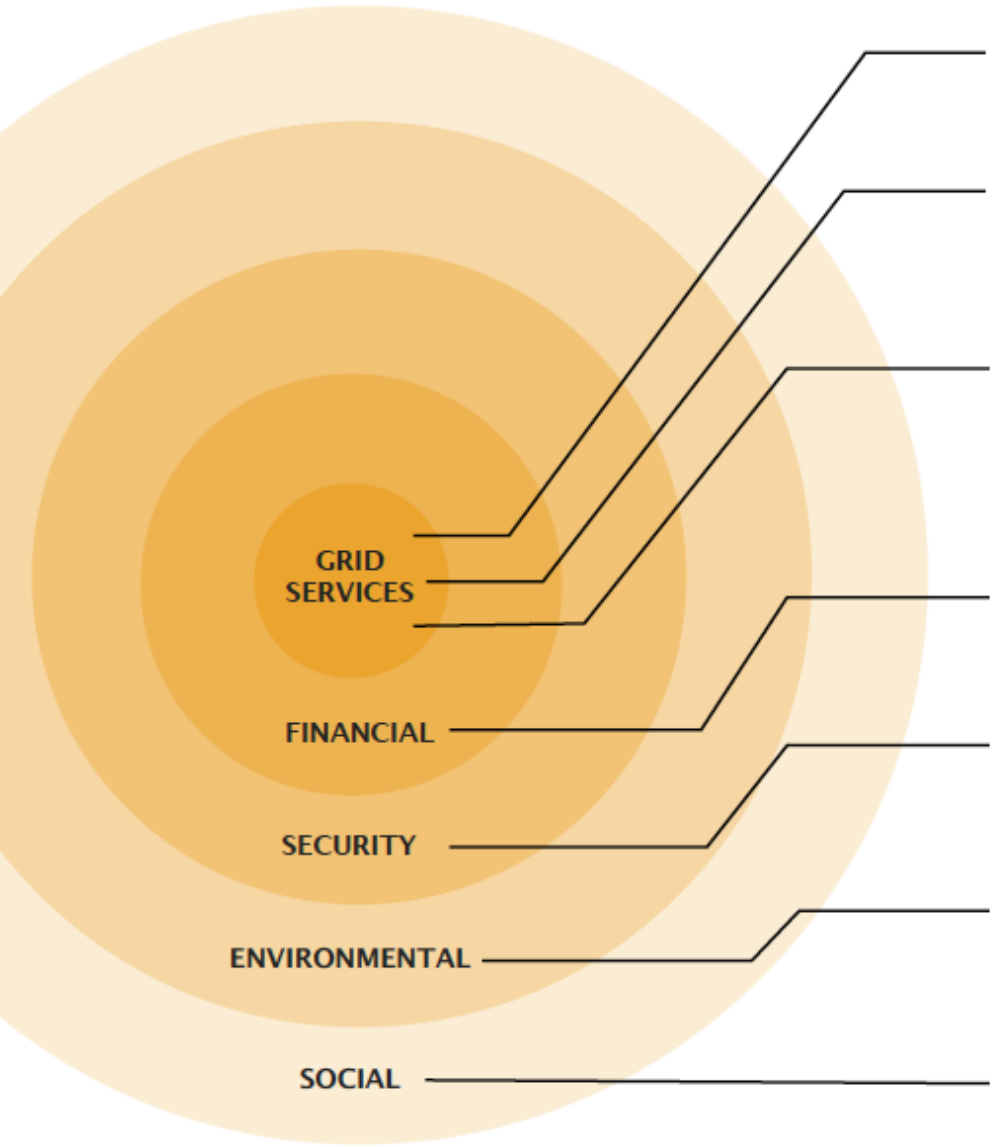
- In this case we're constraining the system to a commercial building with the customer meter being the input and the end-use load being the output

Throughout this process, focus on how the things your company already does and wants to do relate to the broader system to identify needs and sources of value that you can provide.

Colored text:
pieces of the system
directly in your value
chain



2 & 3: Select a value to explore and focus on a single decision that supports that value



ENERGY
- energy
- system losses

CAPACITY
- generation capacity
- transmission & distribution capacity
- DPV installed capacity

GRID SUPPORT SERVICES
- reactive supply & voltage control
- regulation & frequency response
- energy & generator imbalance
- synchronized & supplemental operating reserves
- scheduling, forecasting, and system control & dispatch

FINANCIAL RISK
- fuel price hedge
- market price response

SECURITY RISK
- reliability & resilience

ENVIRONMENTAL
- carbon emissions (CO_2)
- criteria air pollutants (SO_2, NO_x, PM)
- water
- land

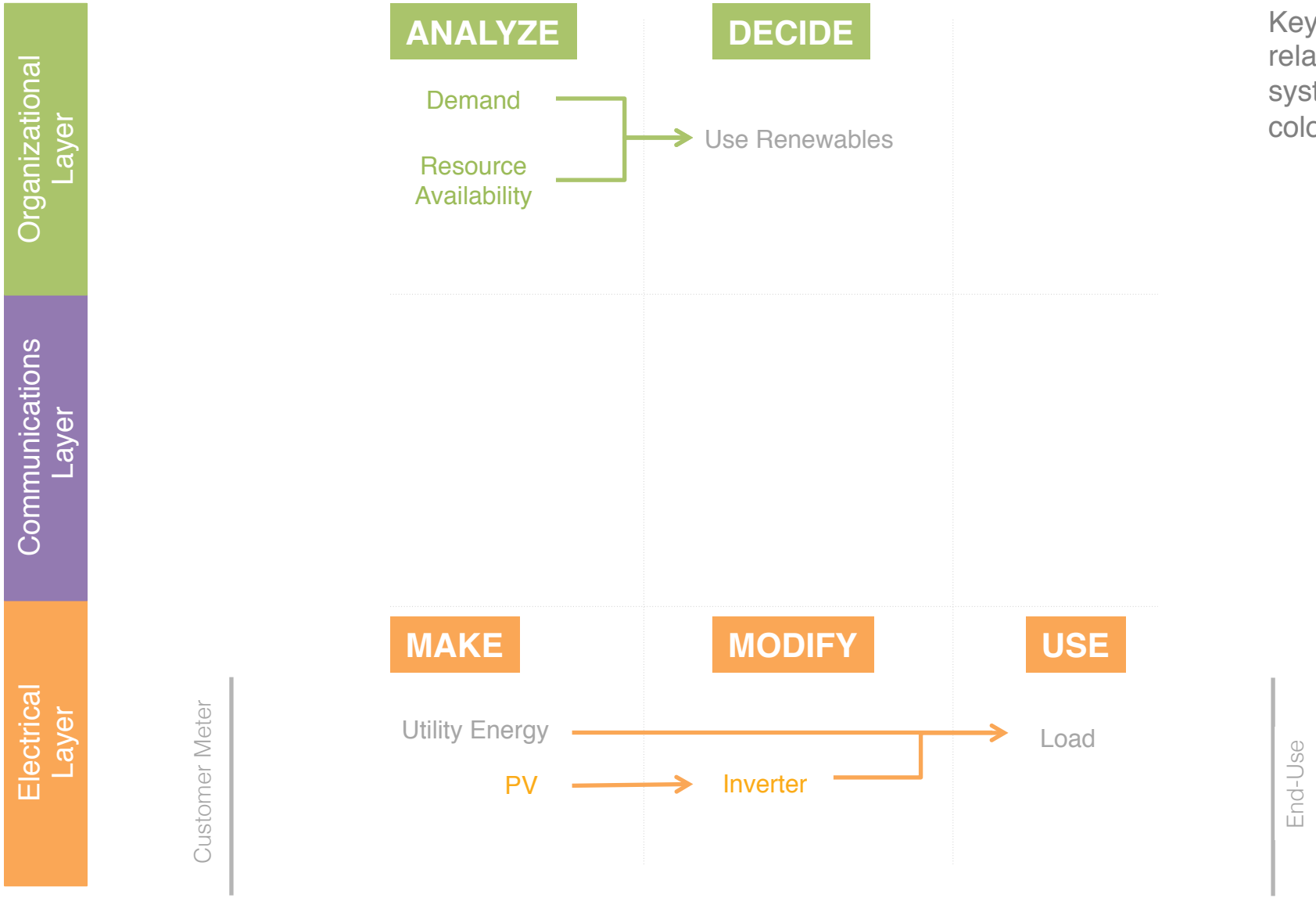
Use less energy

Use higher percentage renewable energy

SOCIAL
- economic development (jobs and tax revenues)

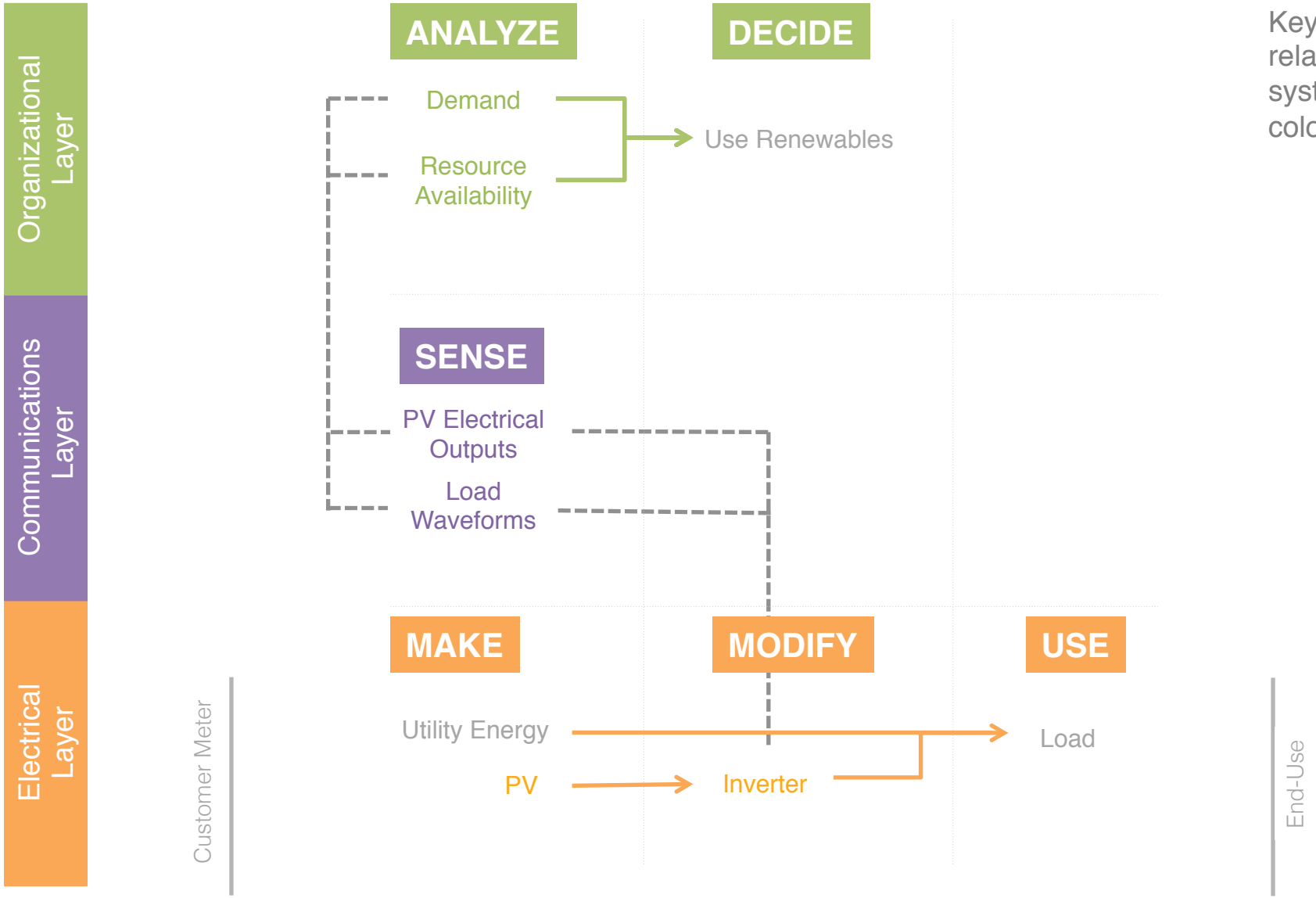
A Review of Solar PV Benefit & Cost Studies, 2nd edition

4: What do you need to know to make the decision?



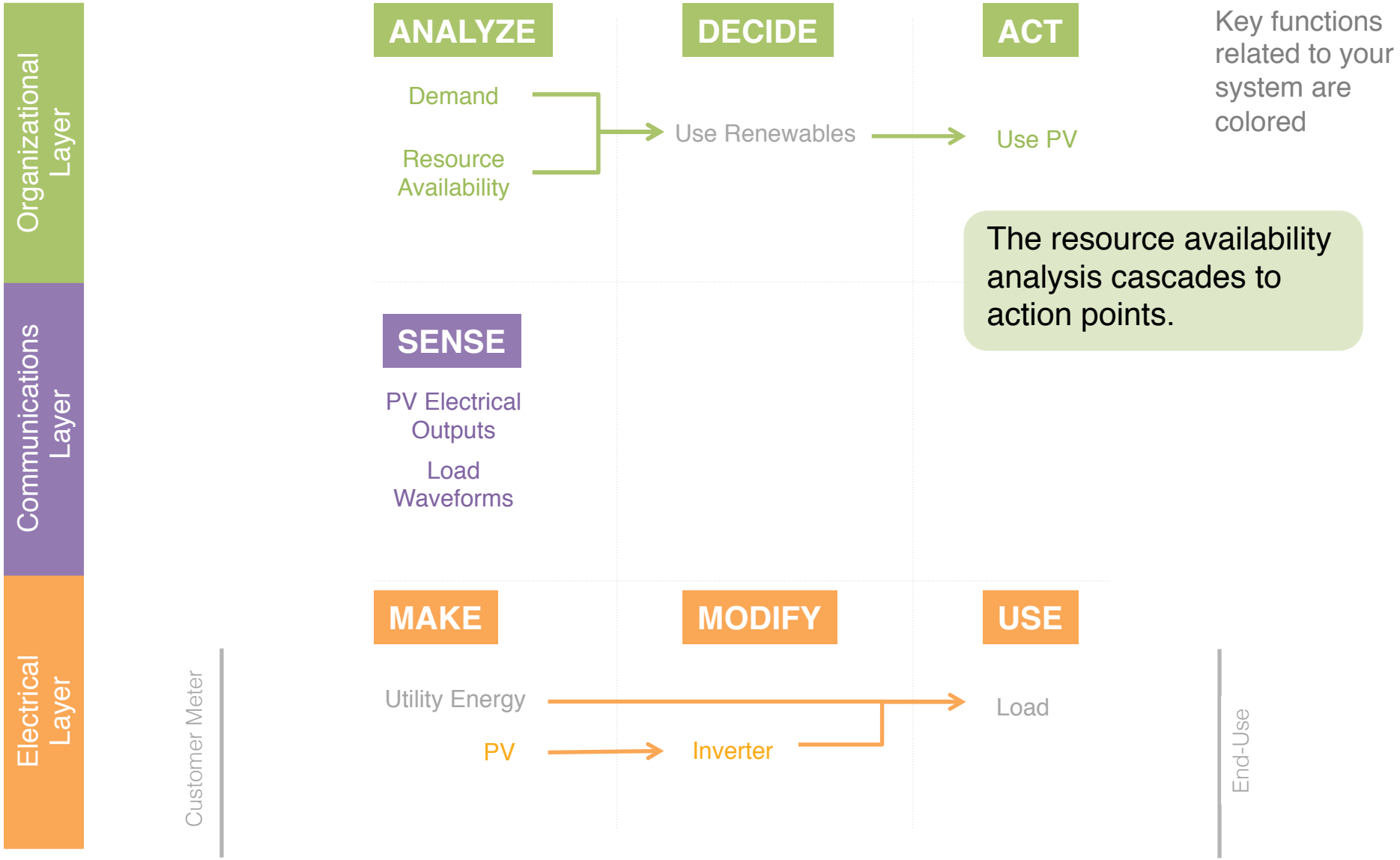
Key functions related to your system are colored

5: How do you get the info you need from the electrical system?

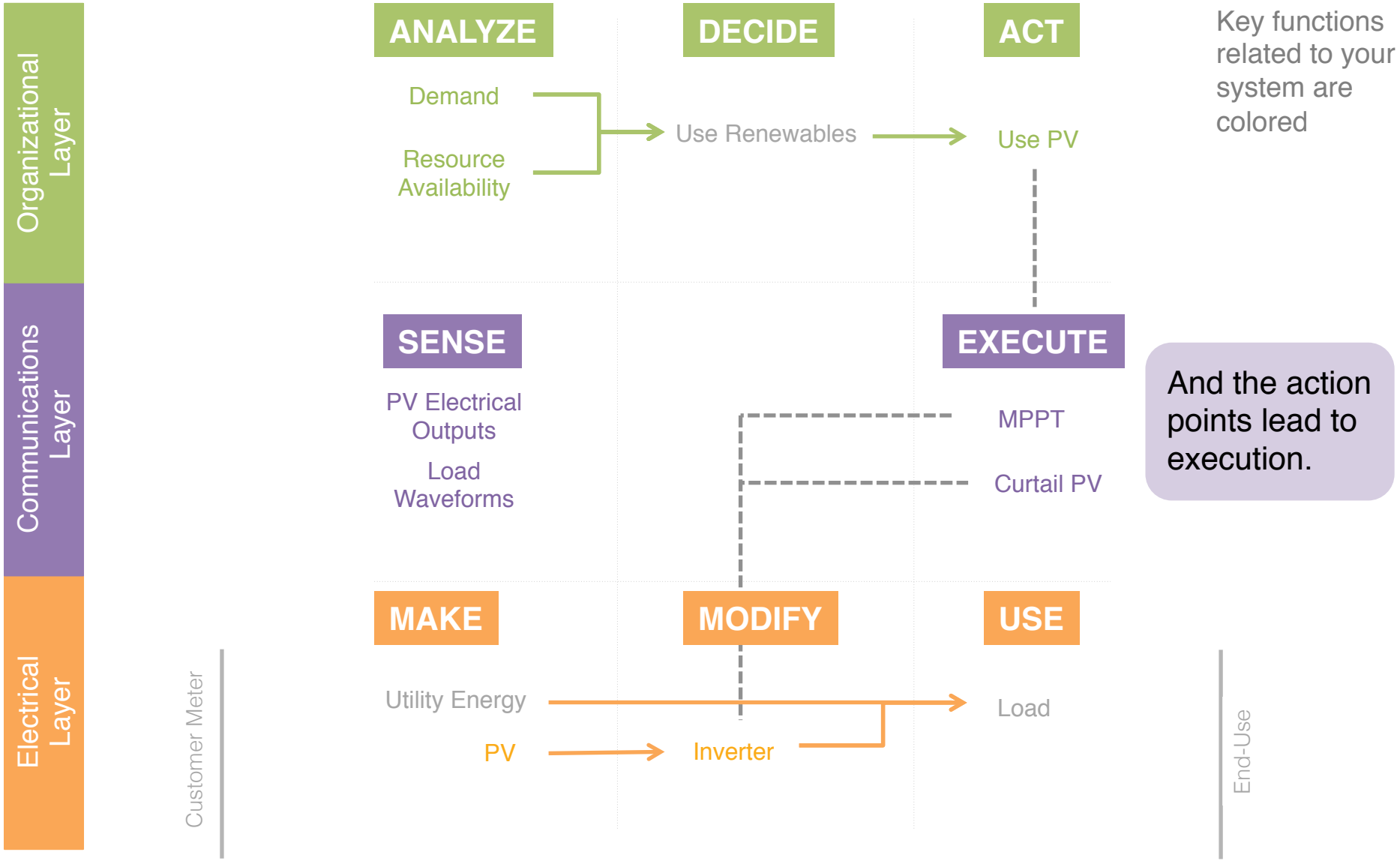


Key functions related to your system are colored

6: What can you do to make the renewables decision happen?



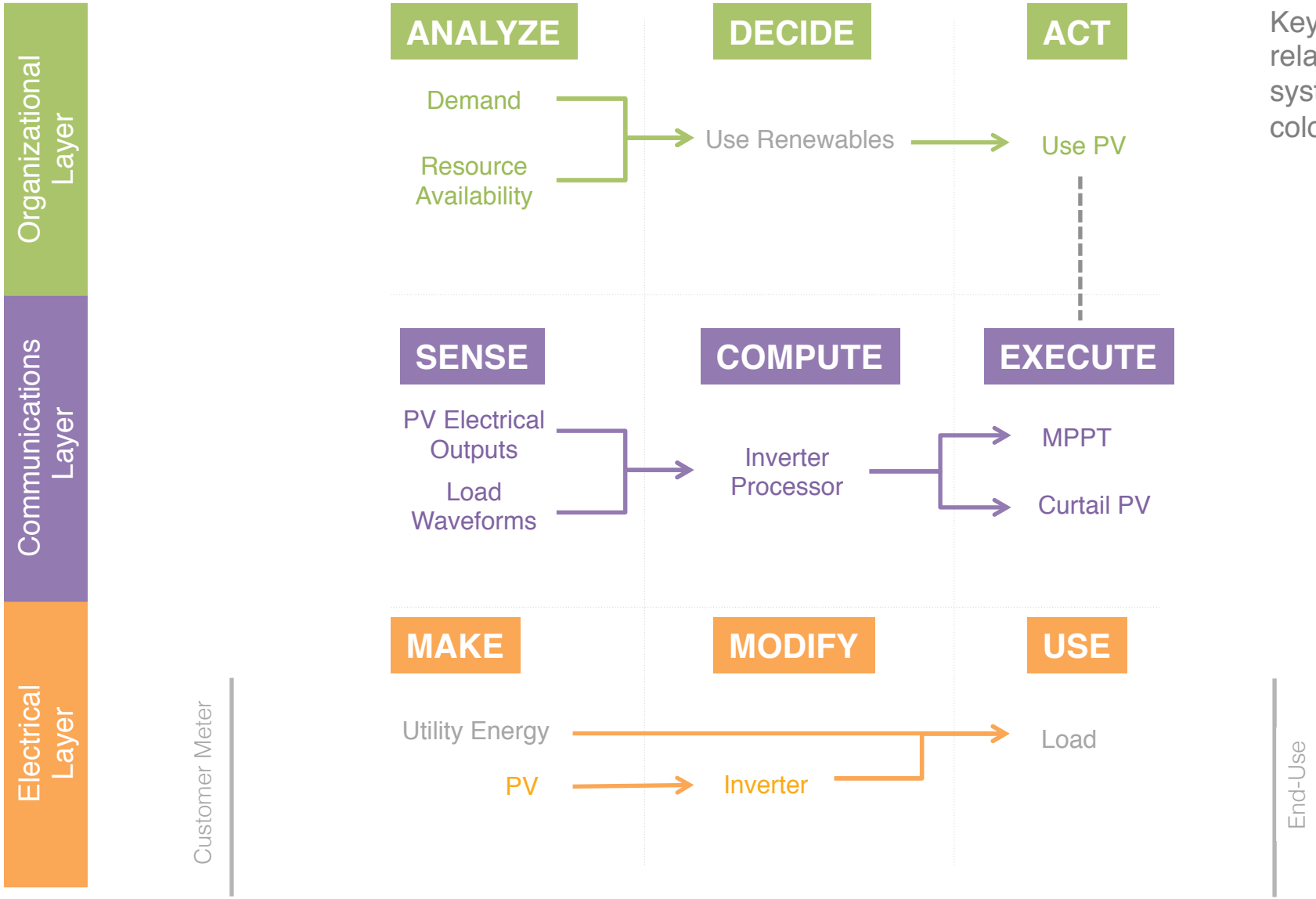
7: How do you execute the desired actions?



Key functions related to your system are colored

And the action points lead to execution.

8: How are the decisions actually made?



Key functions related to your system are colored

Was anything interesting revealed in this process?

- This was a fairly simple example that didn't reveal much that we didn't already know.
- Let's try applying the system value chain to something that's a little more complicated.

Using the system value chain as a solar company that is expanding and integrating its offerings

- You are trying to help a commercial facility reduce its carbon footprint by selling it a PV system.
- Its utility has a 90% fossil generation mix and has a net-metering cap, so it is not able to install as large an array as it would like.
- You just partnered with a battery systems company and are thinking about installing batteries alongside the PV array to help the facility use more renewable energy on site and get around the net-metering cap.
- You apply the system value chain to gain high-level perspective of how you can use batteries to help maximize renewable energy consumption behind the meter at that facility.

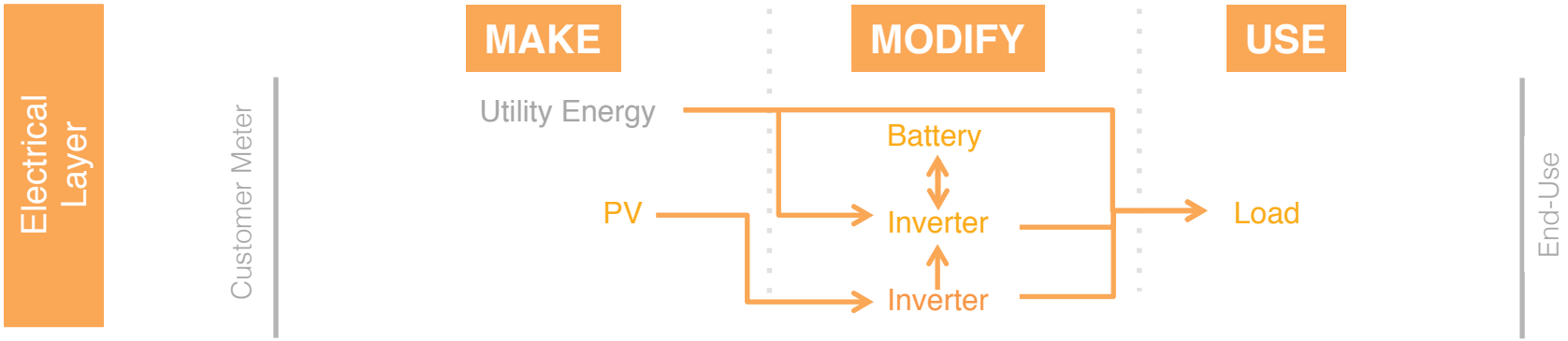
1: Define the system

Behind-the-Meter Environment:

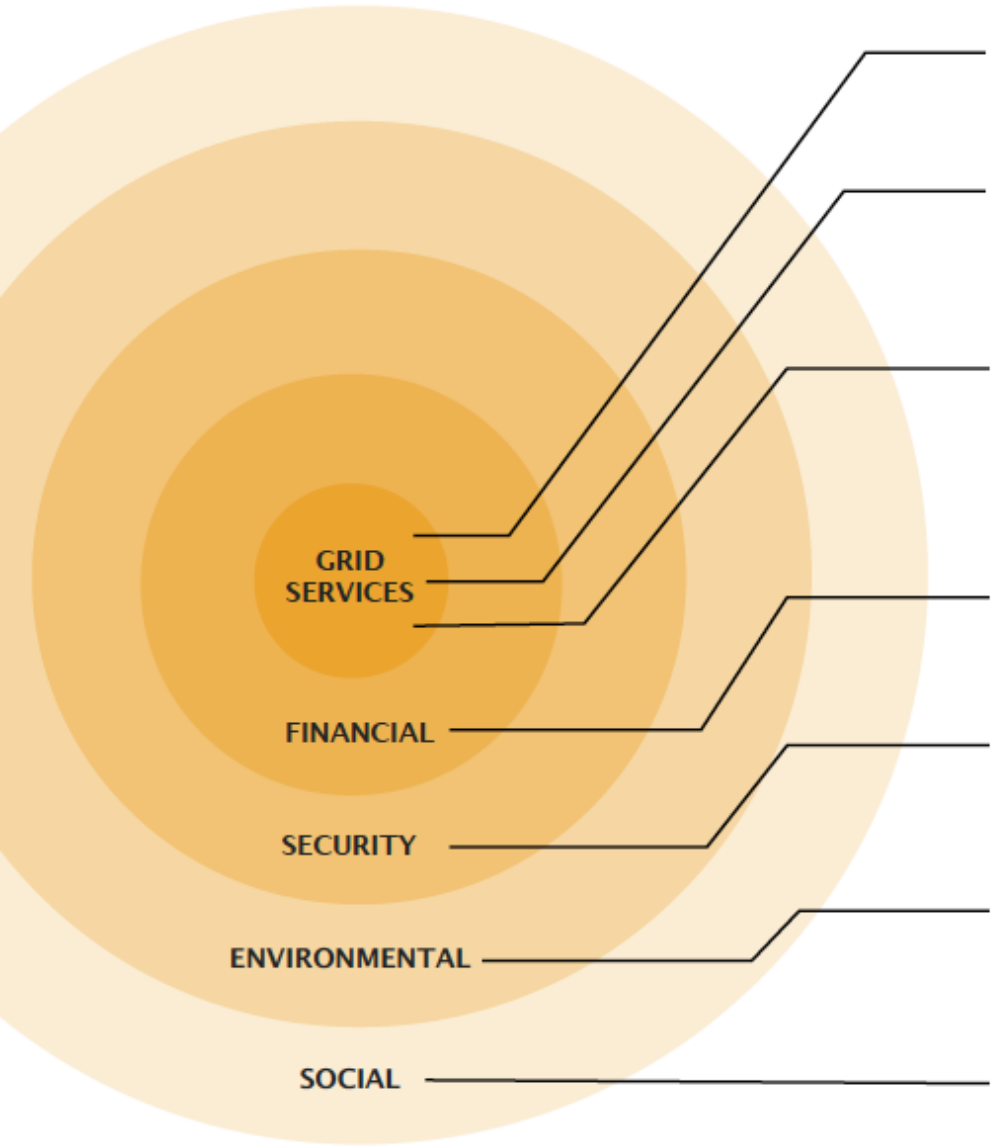
- In this case we're constraining the system to a commercial building with the customer meter being the input and the end-use load being the output

Throughout this process, focus on how the things your company already does and wants to do relate to the broader system to identify needs and sources of value that you can provide.

Colored text:
pieces of technology directly in your value chain



2 & 3: Select a value to explore and focus on a single decision that supports the value



ENERGY
- energy
- system losses

CAPACITY
- generation capacity
- transmission & distribution capacity
- DPV installed capacity

GRID SUPPORT SERVICES
- reactive supply & voltage control
- regulation & frequency response
- energy & generator imbalance
- synchronized & supplemental operating reserves
- scheduling, forecasting, and system control & dispatch

FINANCIAL RISK
- fuel price hedge
- market price response

SECURITY RISK
- reliability & resilience

ENVIRONMENTAL
- carbon emissions (CO_2)
- criteria air pollutants (SO_2, NO_x, PM)
- water
- land

Use less energy

Use higher percentage renewable energy

SOCIAL
- economic development (jobs and tax revenues)

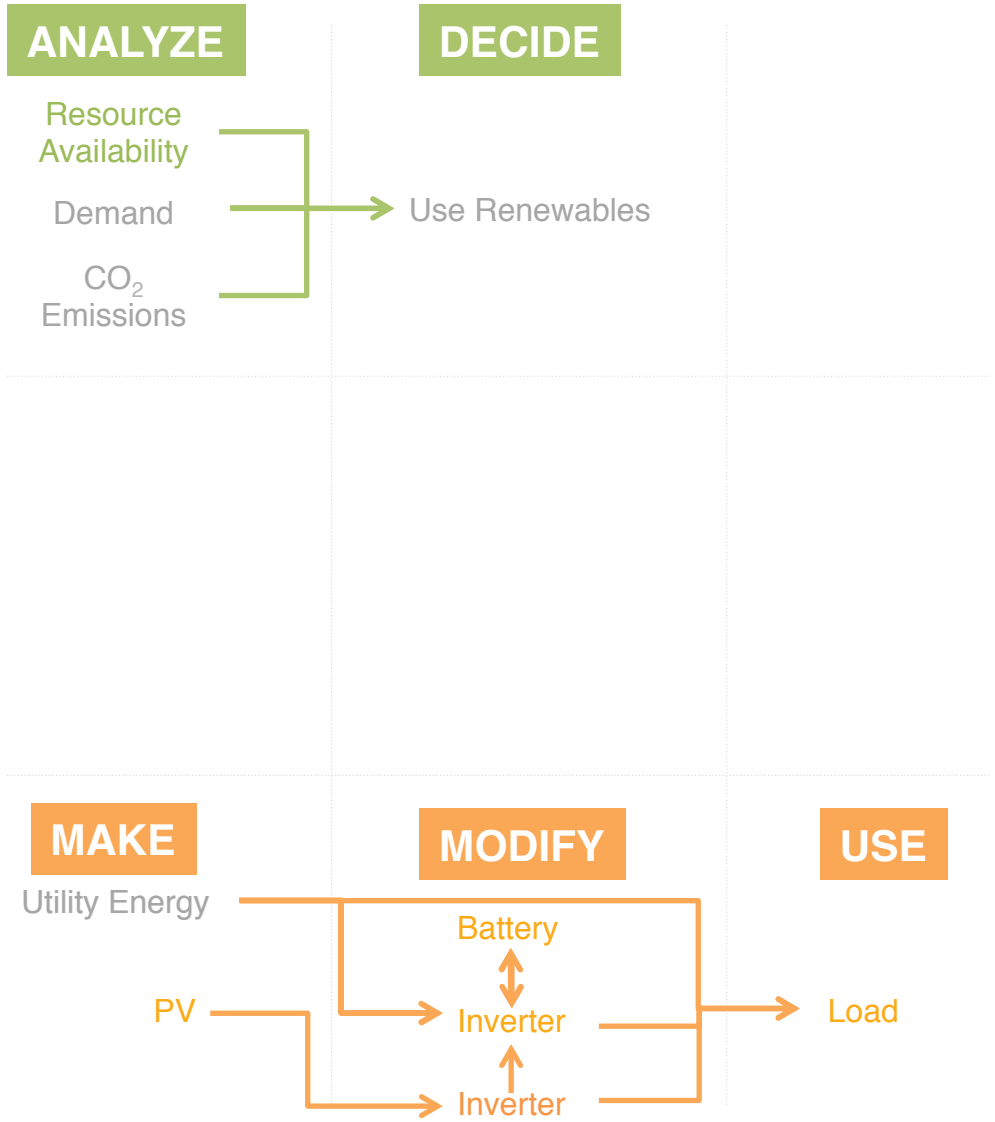
A Review of Solar PV Benefit & Cost Studies, 2nd edition

4: What do you need to know to make the decision?

Organizational Layer

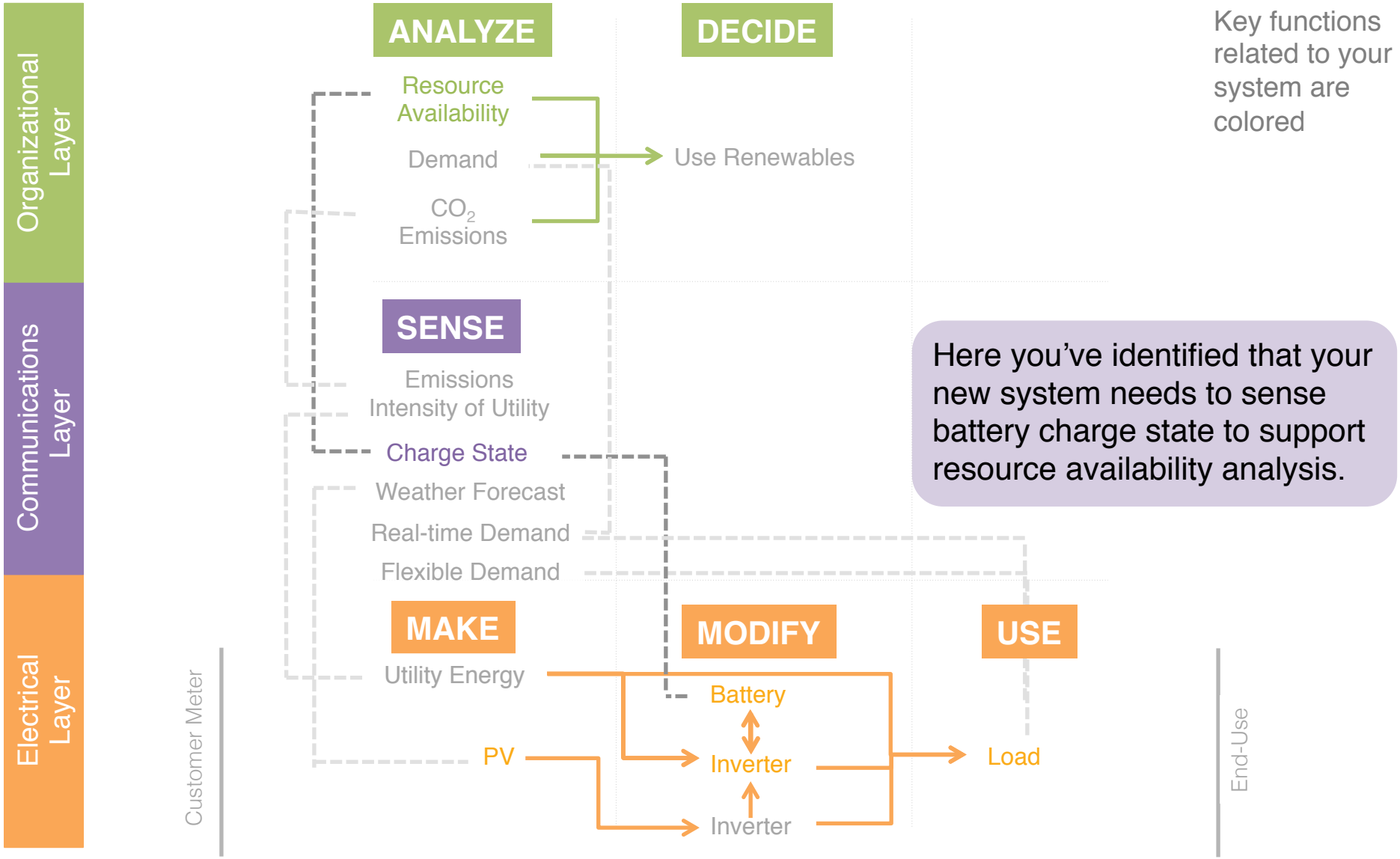
Communications Layer

Electrical Layer



Key functions related to your system are colored

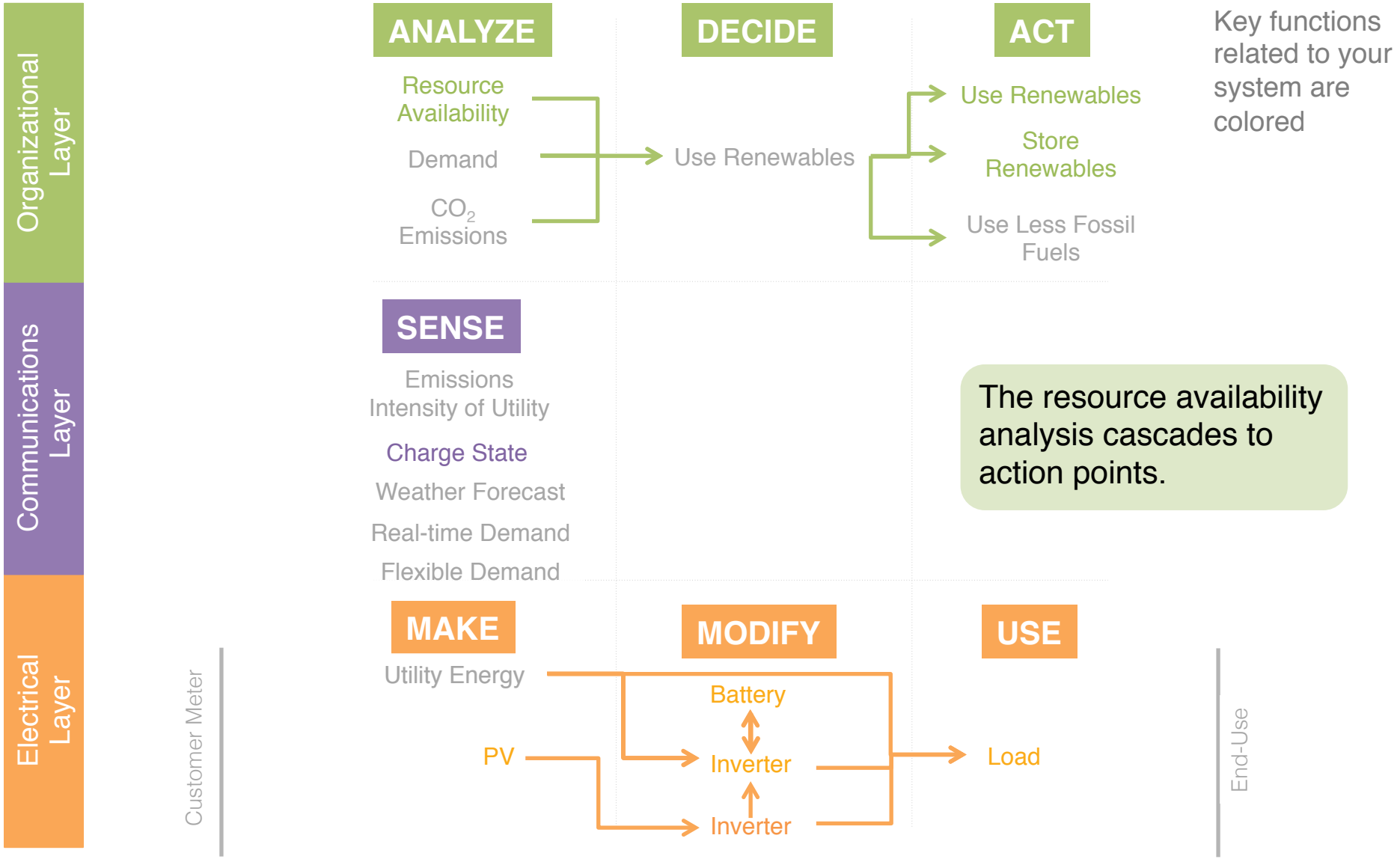
5: How do you get the info you need from the electrical system?



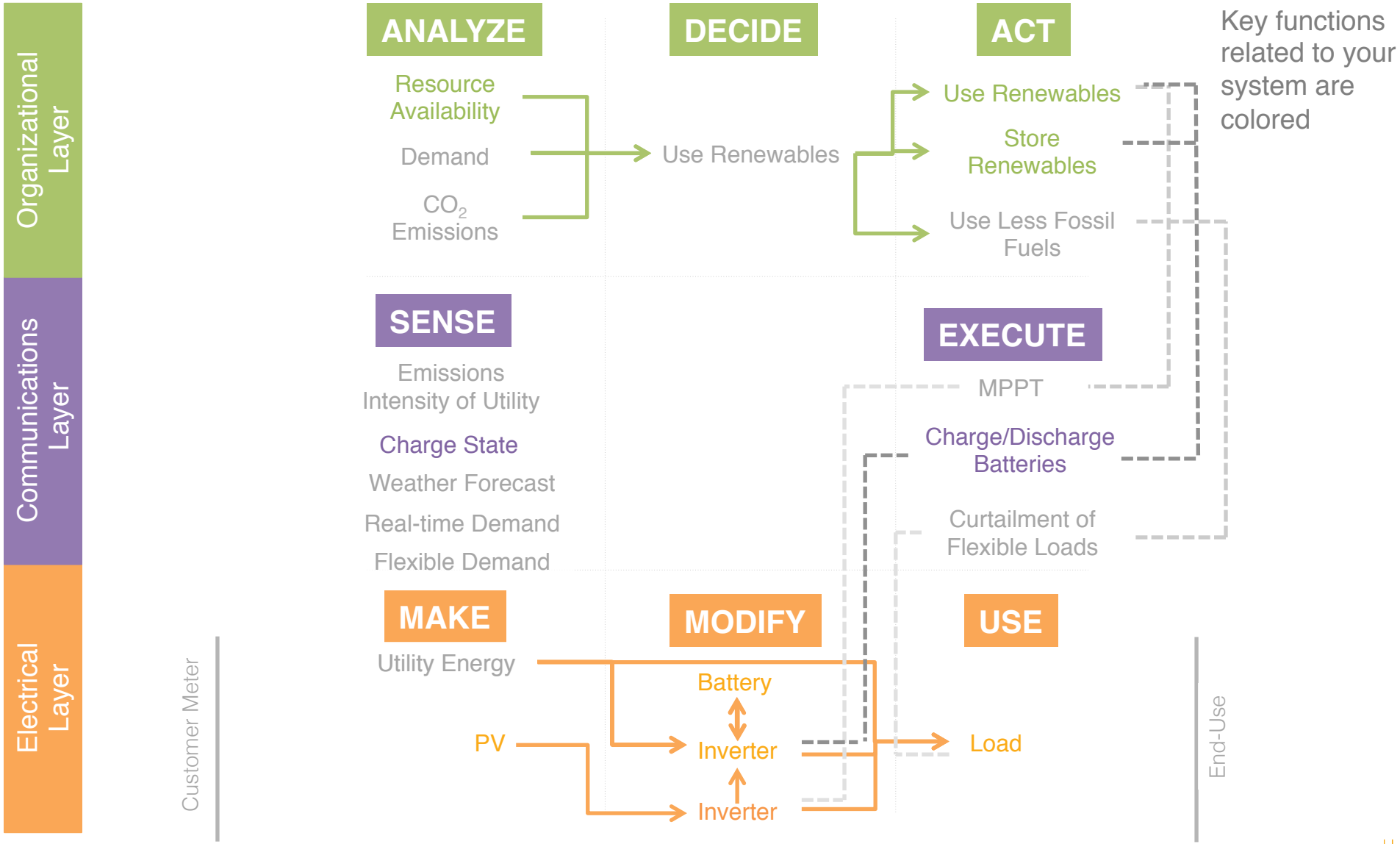
Key functions related to your system are colored

Here you've identified that your new system needs to sense battery charge state to support resource availability analysis.

6: What can you do to make the renewables decision happen?



7: How do you execute the desired actions?

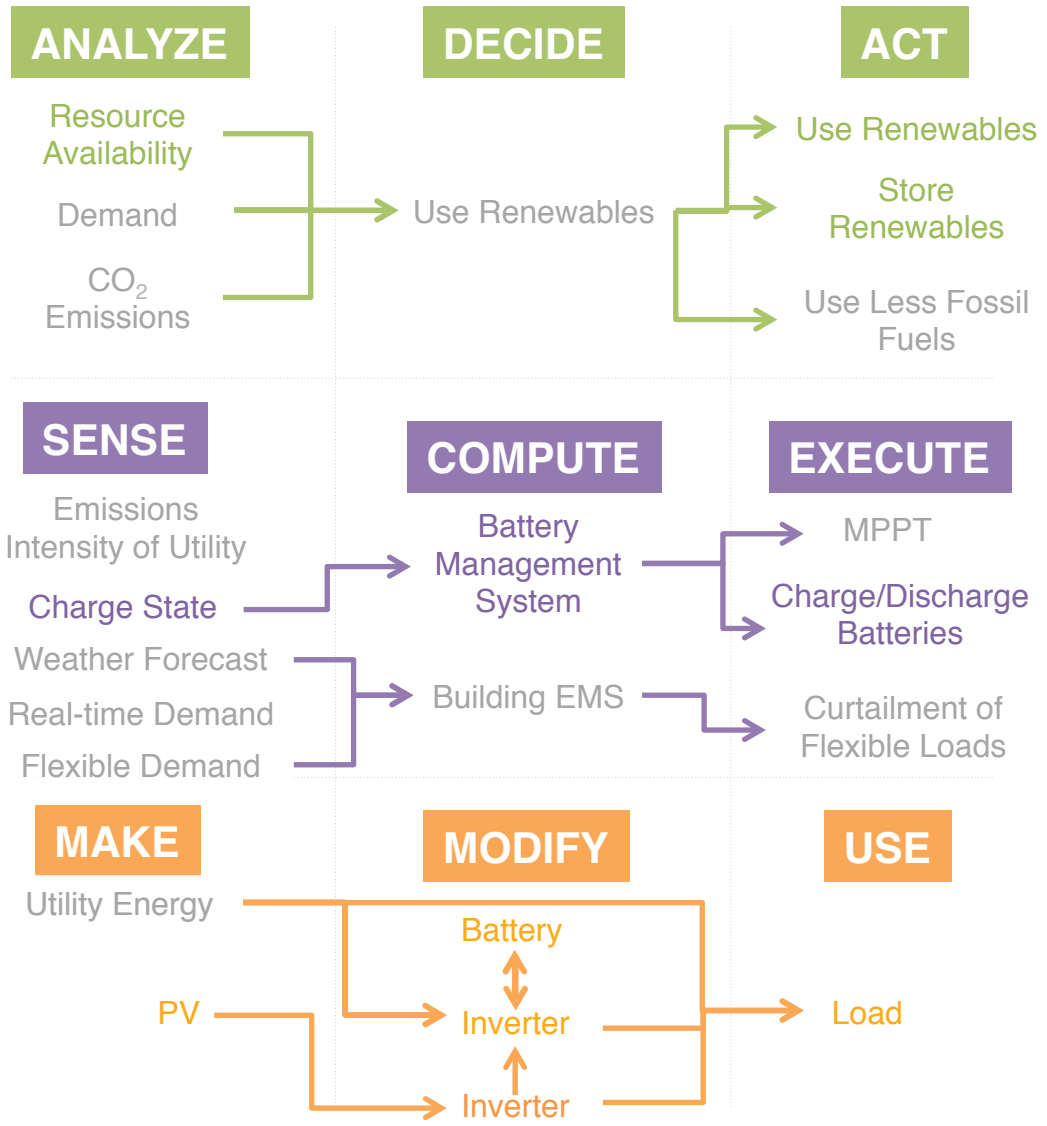


8: How are the decisions actually made?

Organizational Layer

Communications Layer

Electrical Layer

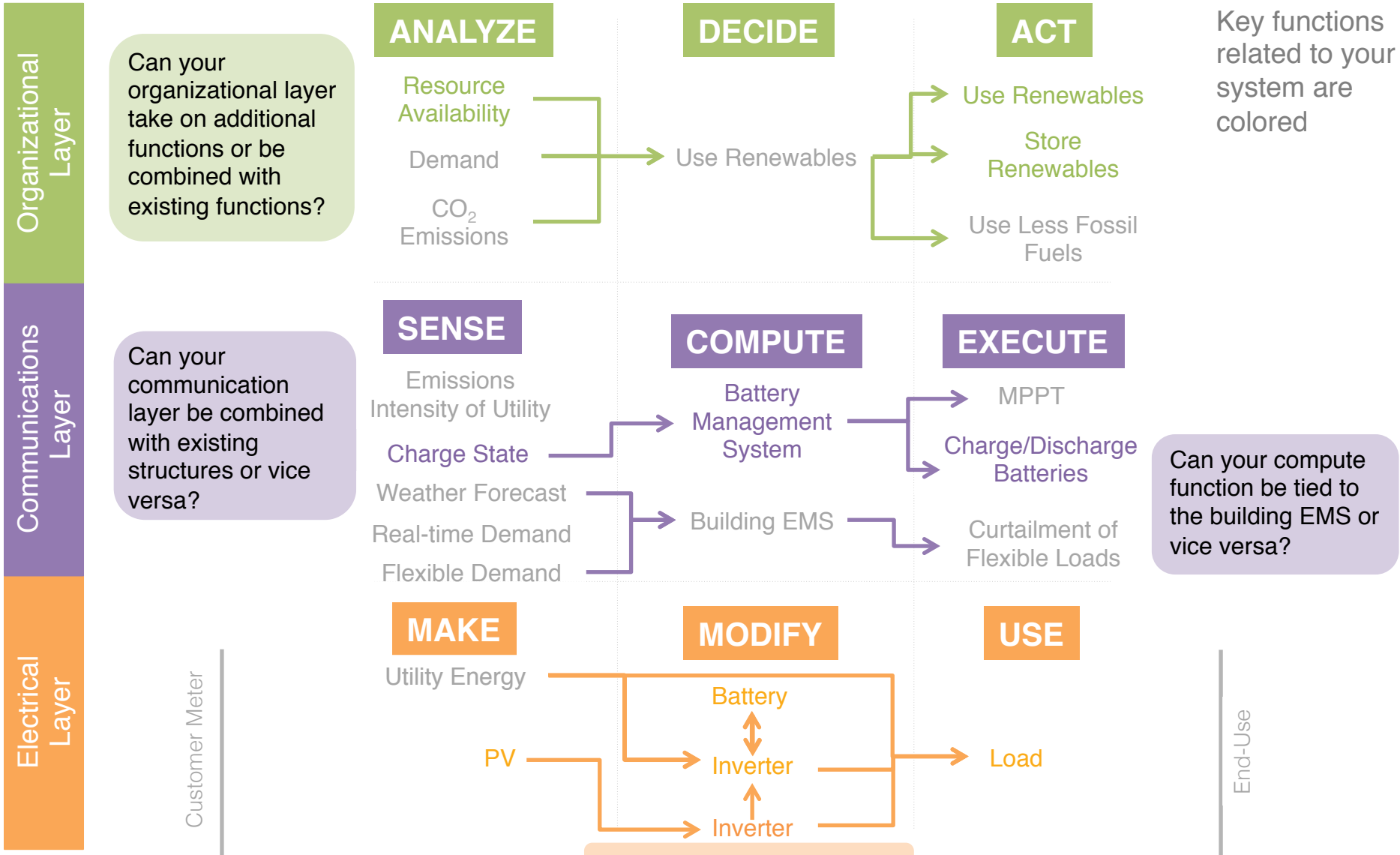


Key functions related to your system are colored

Customer Meter

End-Use

At this point you can also take a step back and evaluate—look for similar functions and redundancy.



Was anything interesting revealed in this process?

- You've learned how your system fits into the broader system and identified some basic things that you already know about—you need a charge state sensor and battery management system.
- You've also gained some insight into areas that you might choose to investigate further as new services (e.g., coordinating your battery management system with the building management system).
- In pitching the battery system to the client it becomes clear that while the client likes the idea, the cost is too much if the value is simply increasing renewable energy consumption.

- In further conversations with the client, it becomes clear that the facility has been having some power quality issues that are affecting certain sensitive loads in their building.
- You go back to the system value chain and think through how your system might be able to provide other values to the customer.

1: Define the system

Behind-the-Meter Environment:

- In this case we're constraining the system to a commercial building with the customer meter being the input and the end-use load being the output

Throughout this process focus on how the things your company already does, and wants to do, relate to the broader system to identify needs and sources of value that you can provide.

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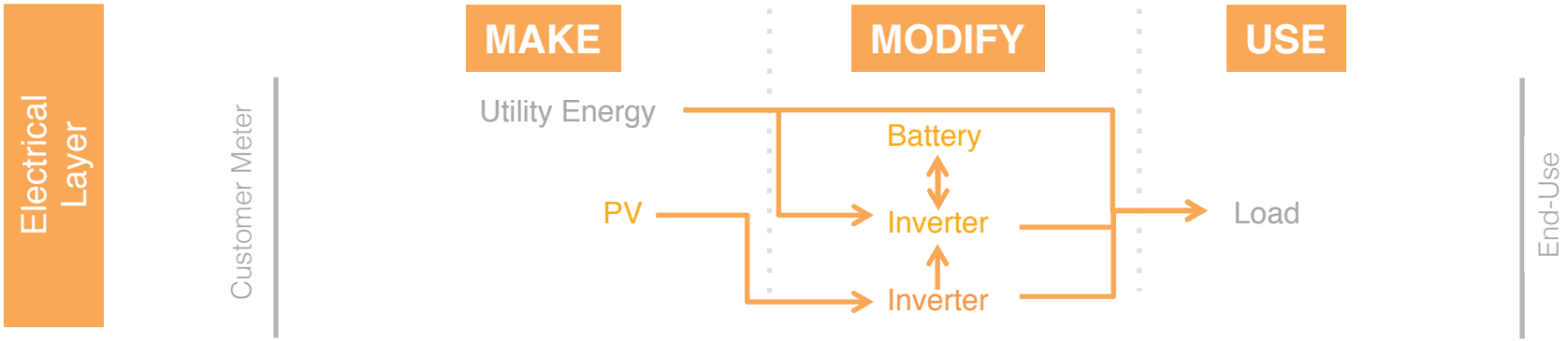

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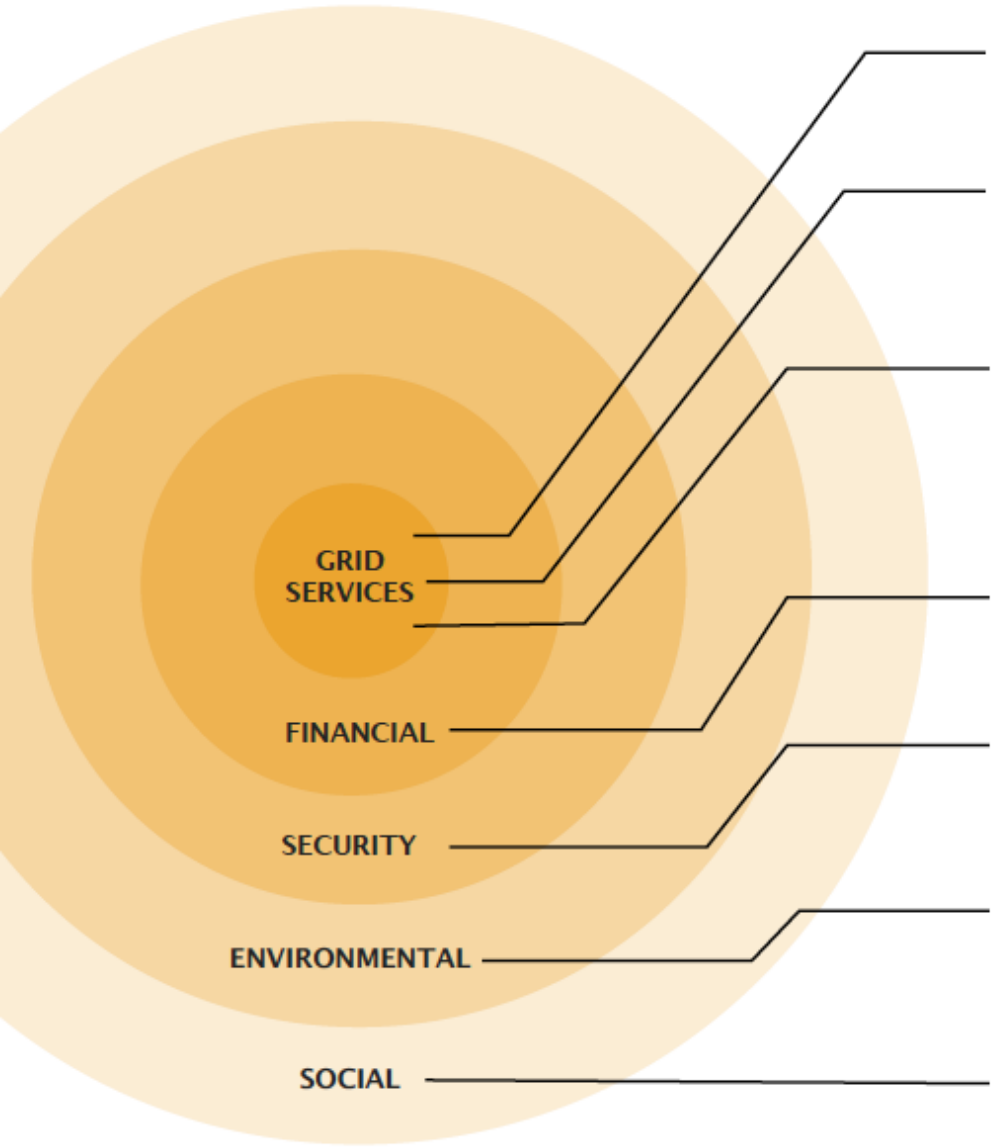

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Frequency regulation

Frequency response

FINANCIAL RISK
- fuel price hedge
- market price response

SECURITY RISK
- reliability & resilience

ENVIRONMENTAL
- carbon emissions (CO_2)
- criteria air pollutants (SO_2, NO_x, PM)
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- economic development (jobs and tax revenues)

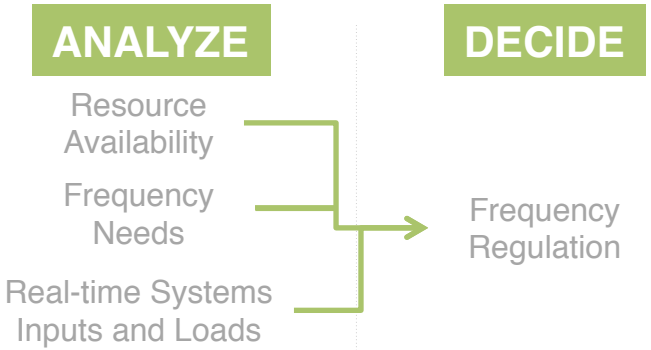
A Review of Solar PV Benefit & Cost Studies, 2nd edition

4: What do you need to know to make the decision?

Organizational Layer

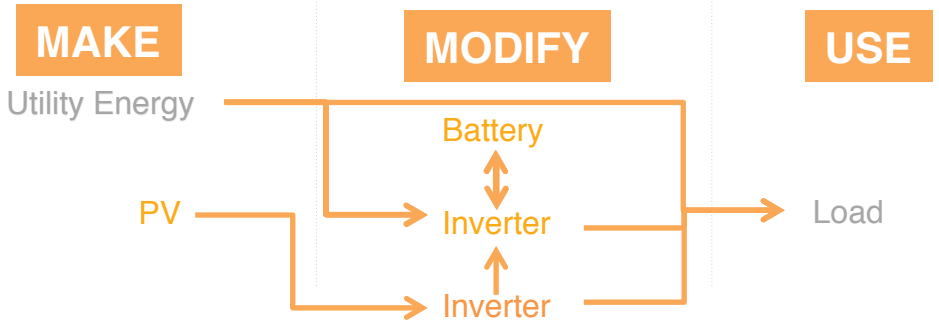
Communications Layer

Electrical Layer



Key functions related to your system are colored

In this step you articulate a different set of analysis needs to make decisions regarding frequency regulation.



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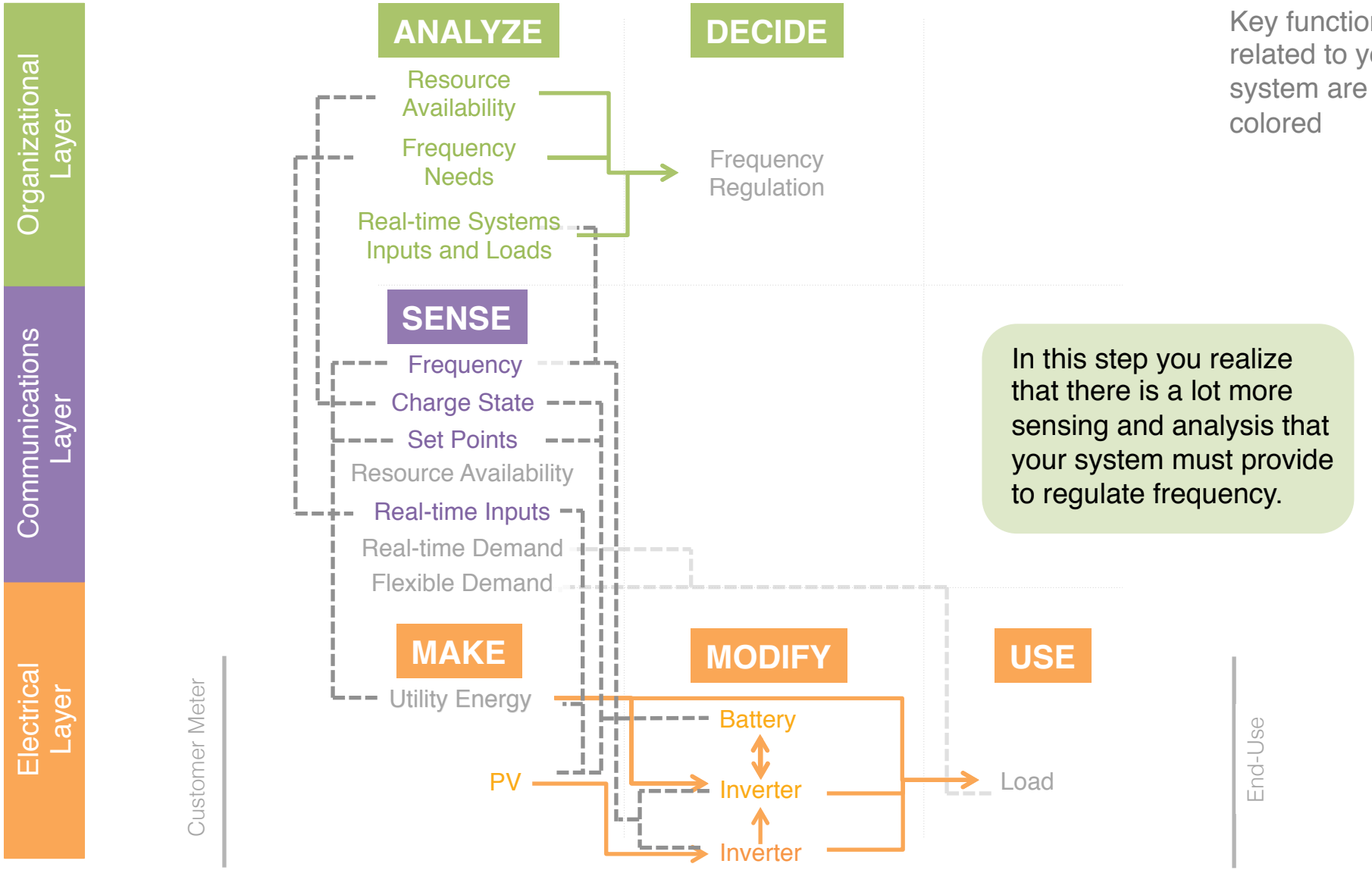


Key functions related to your system are colored

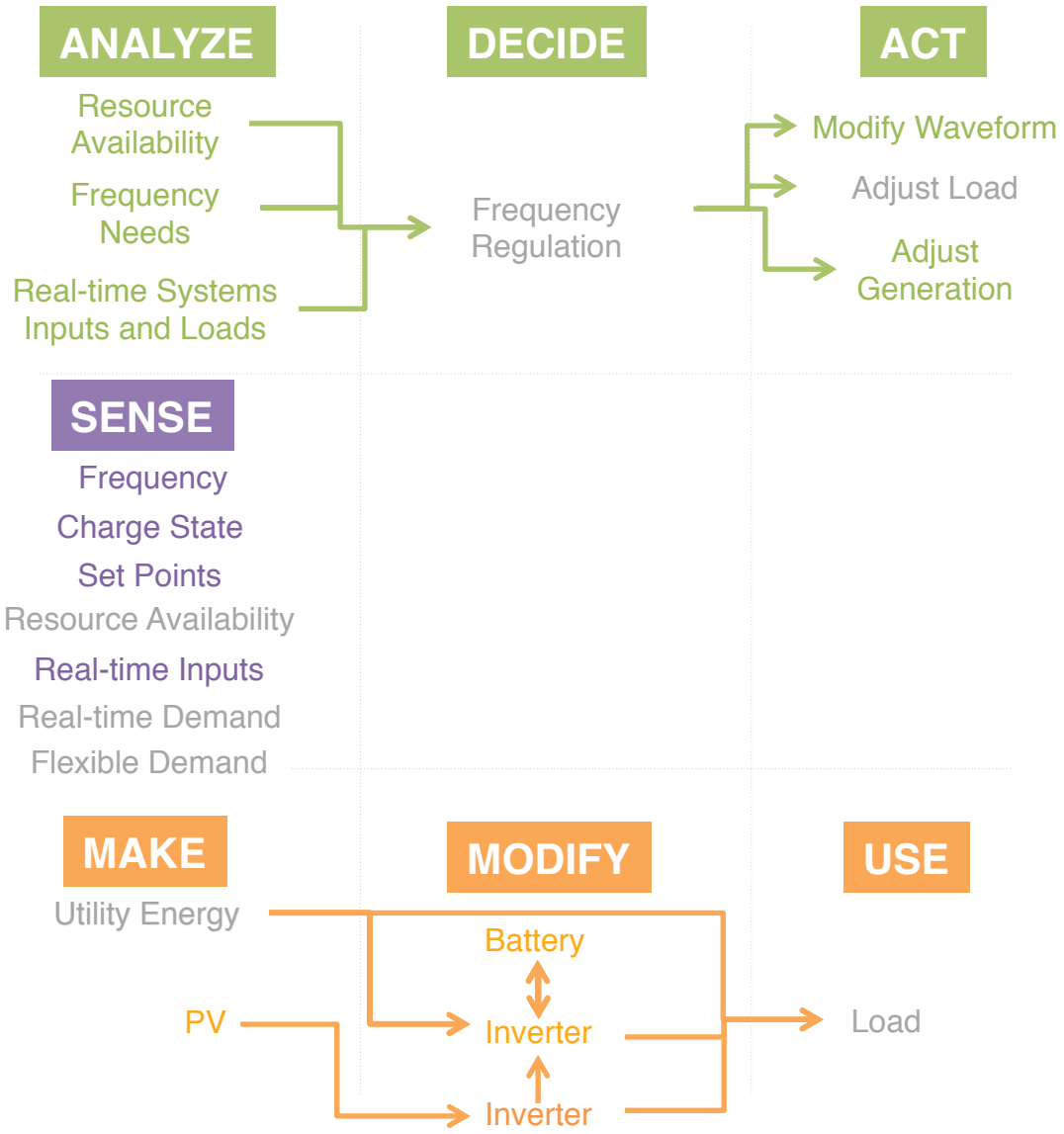
In this step you realize that there is a lot more sensing and analysis that your system must provide to regulate frequency.

6: What can you do to regulate frequency?

Organizational Layer

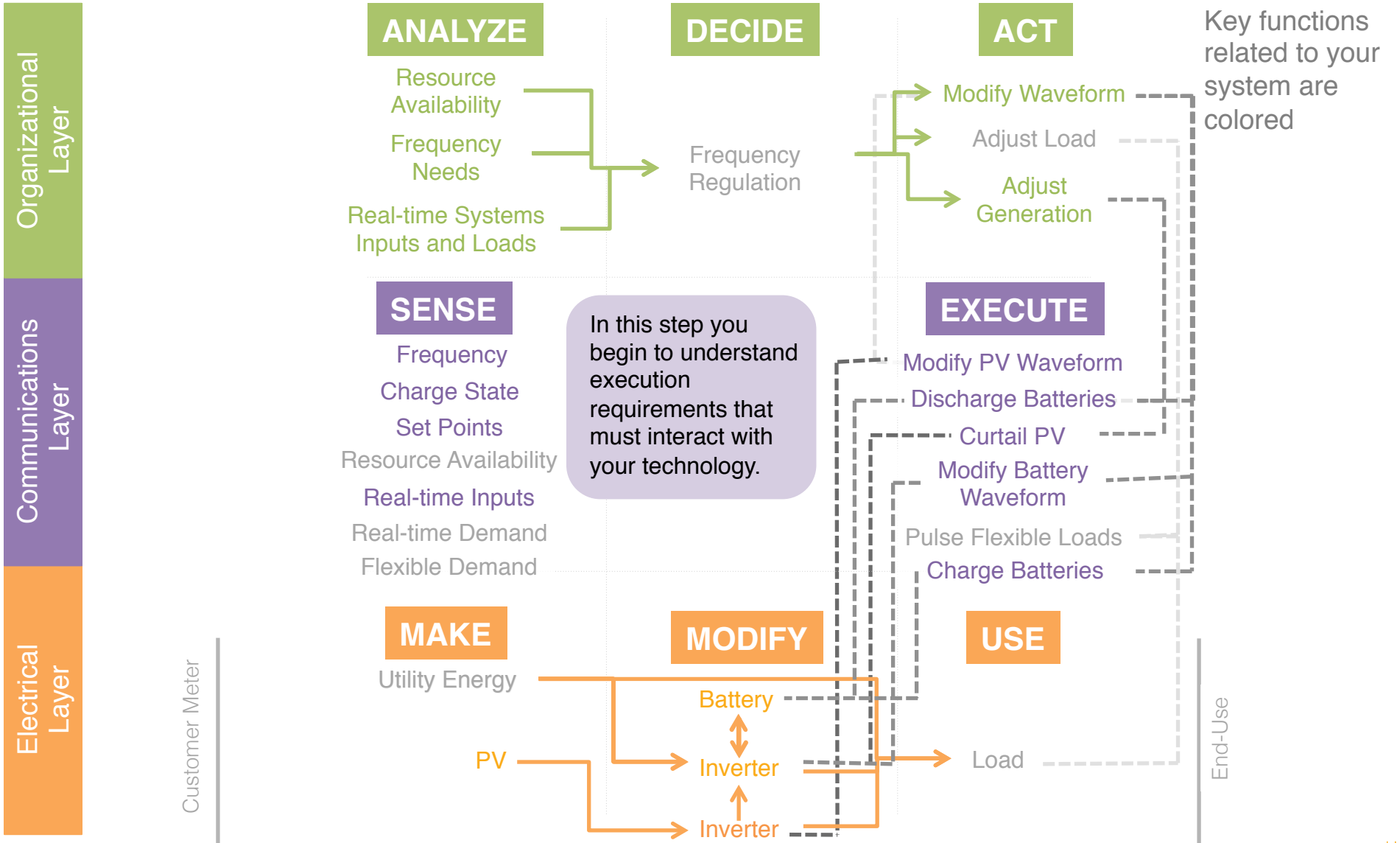
Communications Layer

Electrical Layer



Key functions related to your system are colored

7: How do you execute the desired actions?



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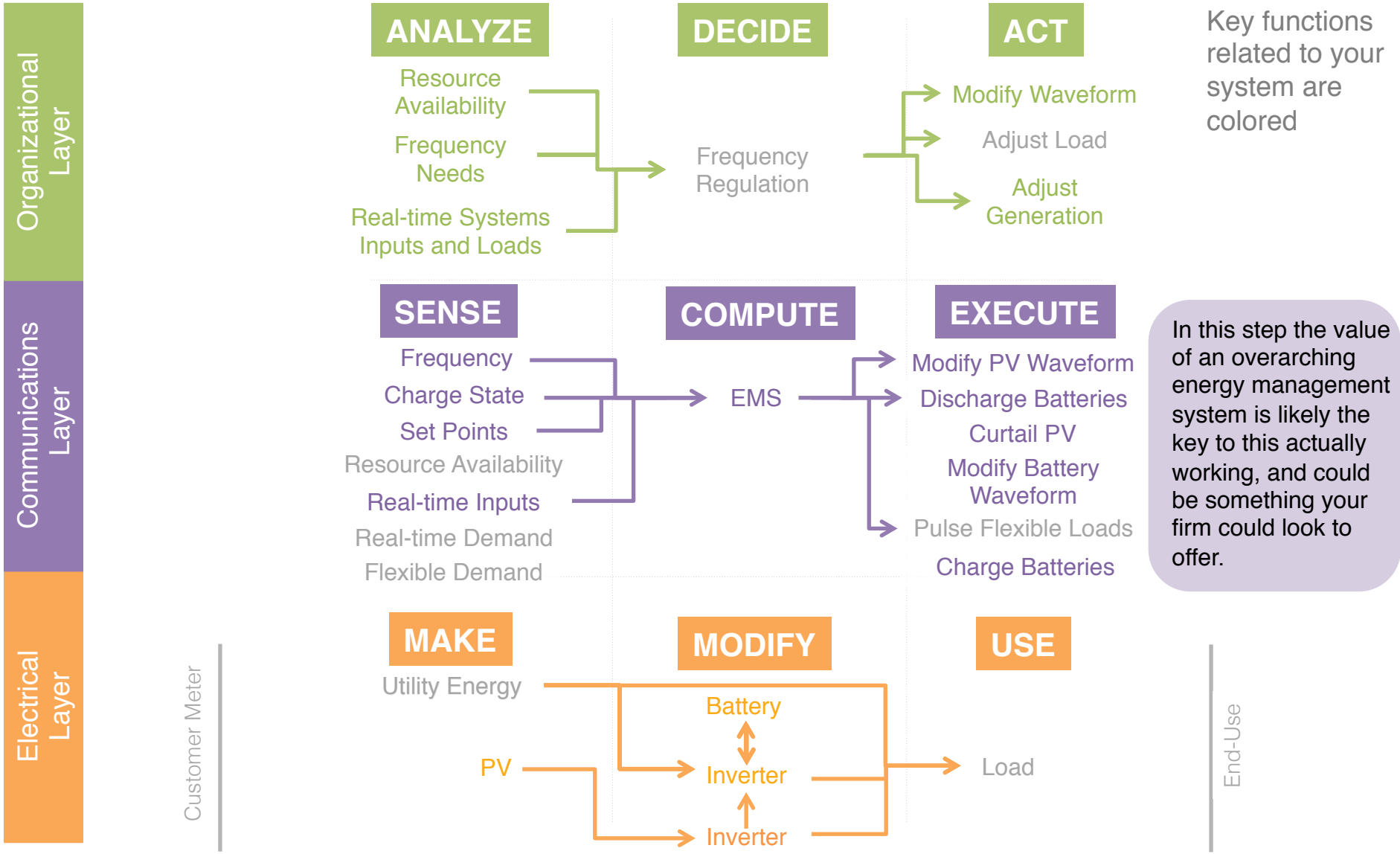


Key functions related to your system are colored

In this step the value of an overarching energy management system is likely the key to this actually working, and could be something your firm could look to offer.

Was anything interesting revealed in this process?

- You've learned that there are a lot more sensors and control functions that must be in place to use your PV-plus-battery system to provide frequency regulation in a commercial building.
- This understanding helps identify areas where your company needs to get smarter or needs to partner with other technology suppliers in order to capture the value associated with frequency regulation.

- In this process, you wonder what it would take to provide frequency regulation to a larger system, beyond your customer's building.
- By expanding the boundary of the electrical layer in the system value chain, you can assess what key connections the battery system would need to have in order to receive revenue from an ISO market.
- Whole-systems approaches can get really complex very quickly, making it important to limit your scope. So when you are looking at how a single asset can provide that value, it is helpful to focus on connections surrounding that asset.

Starting again… 1: Define the system (broadened here)

Organizational Layer

Communications Layer

Electrical Layer

DECIDE

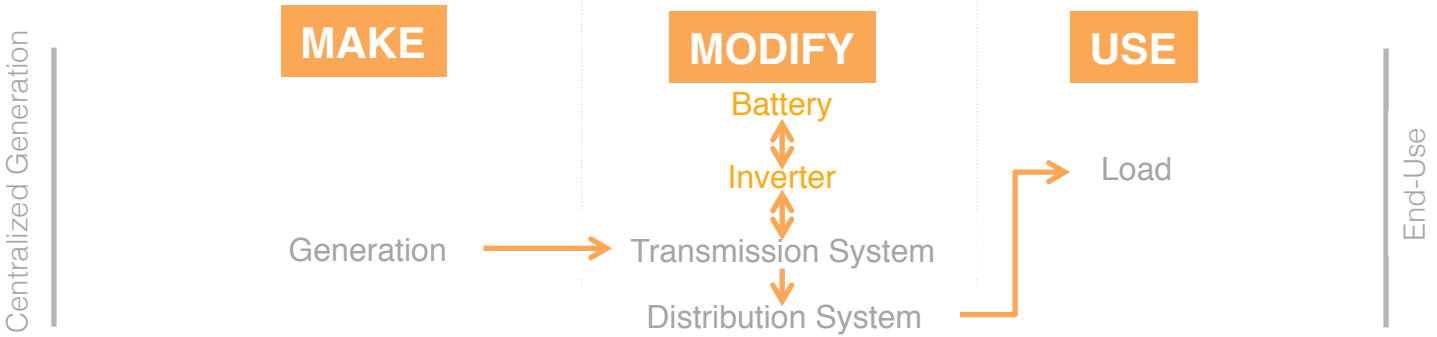
Frequency Regulation

Key functions related to your system are colored

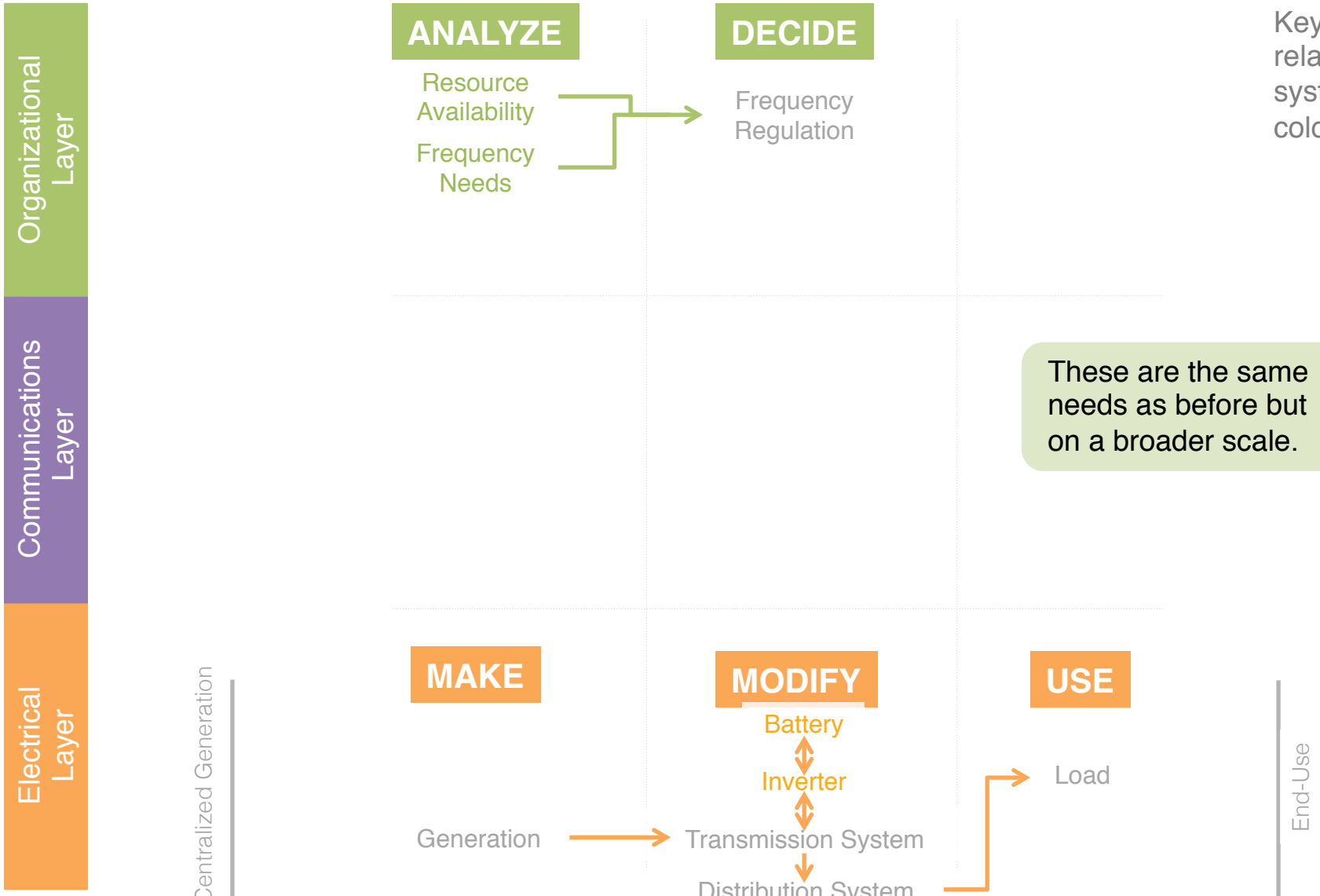
Distribution System Environment:

- In this case we're constraining the system to be the utility substation with electric generation from the wholesale market being the input, and the end-use load being the output.

Step 1 sets the bounds as the entire distribution system. Steps 2 and 3 are the same as last time—frequency regulation.



4: What do you need to know to make the decision?



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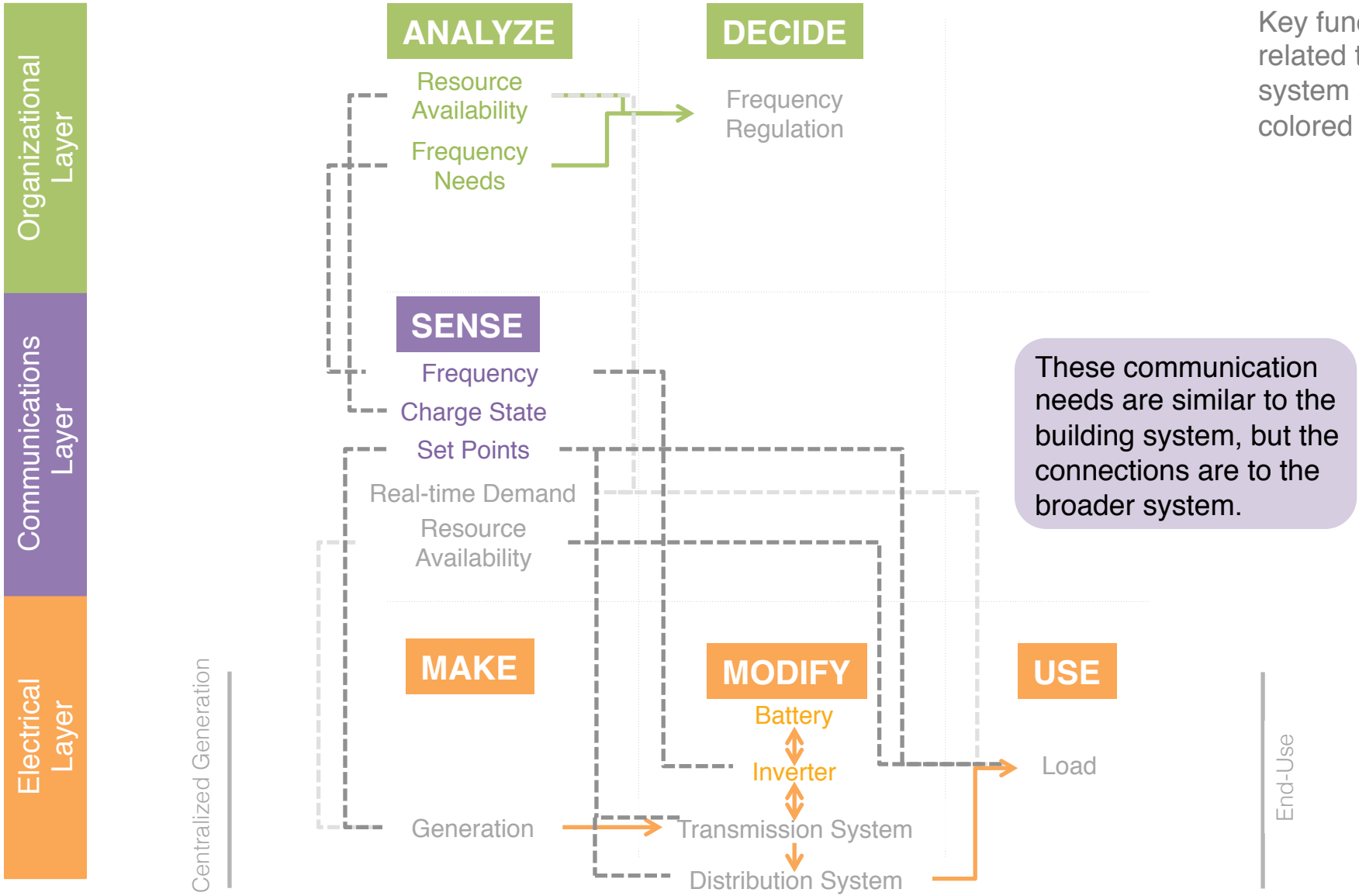
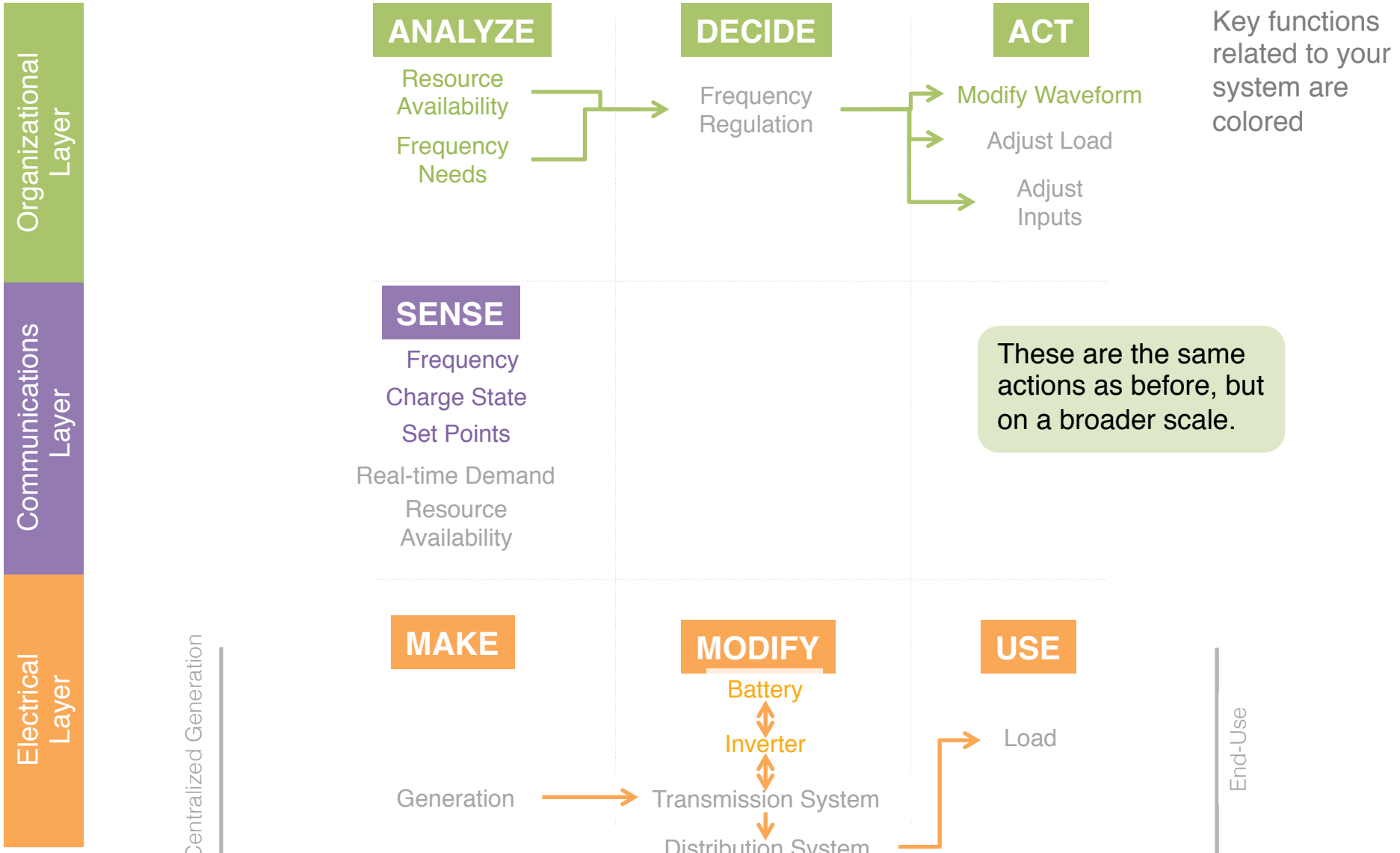


Key functions related to your system are colored

These communication needs are similar to the building system, but the connections are to the broader system.

6: What can you do to regulate frequency?



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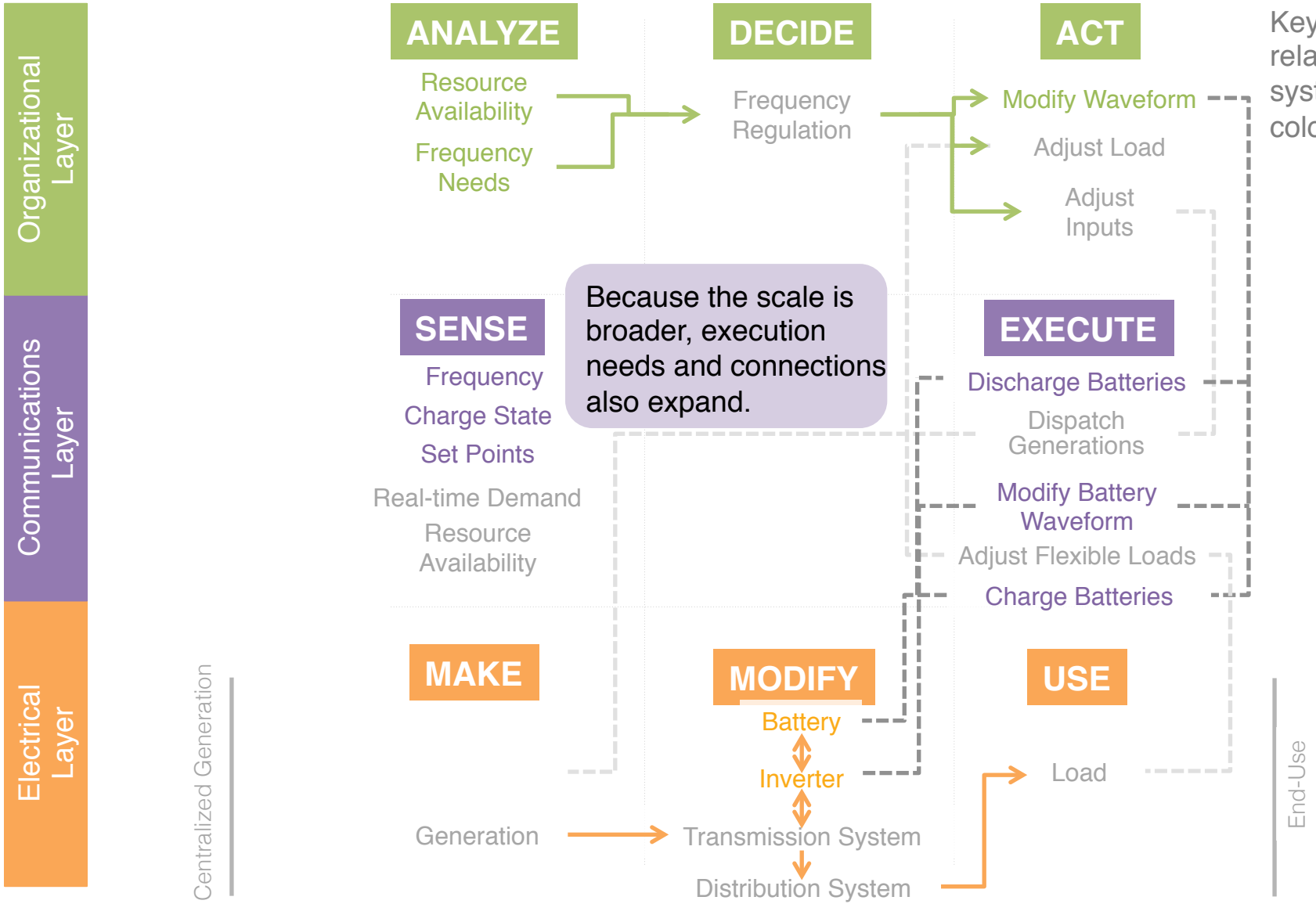

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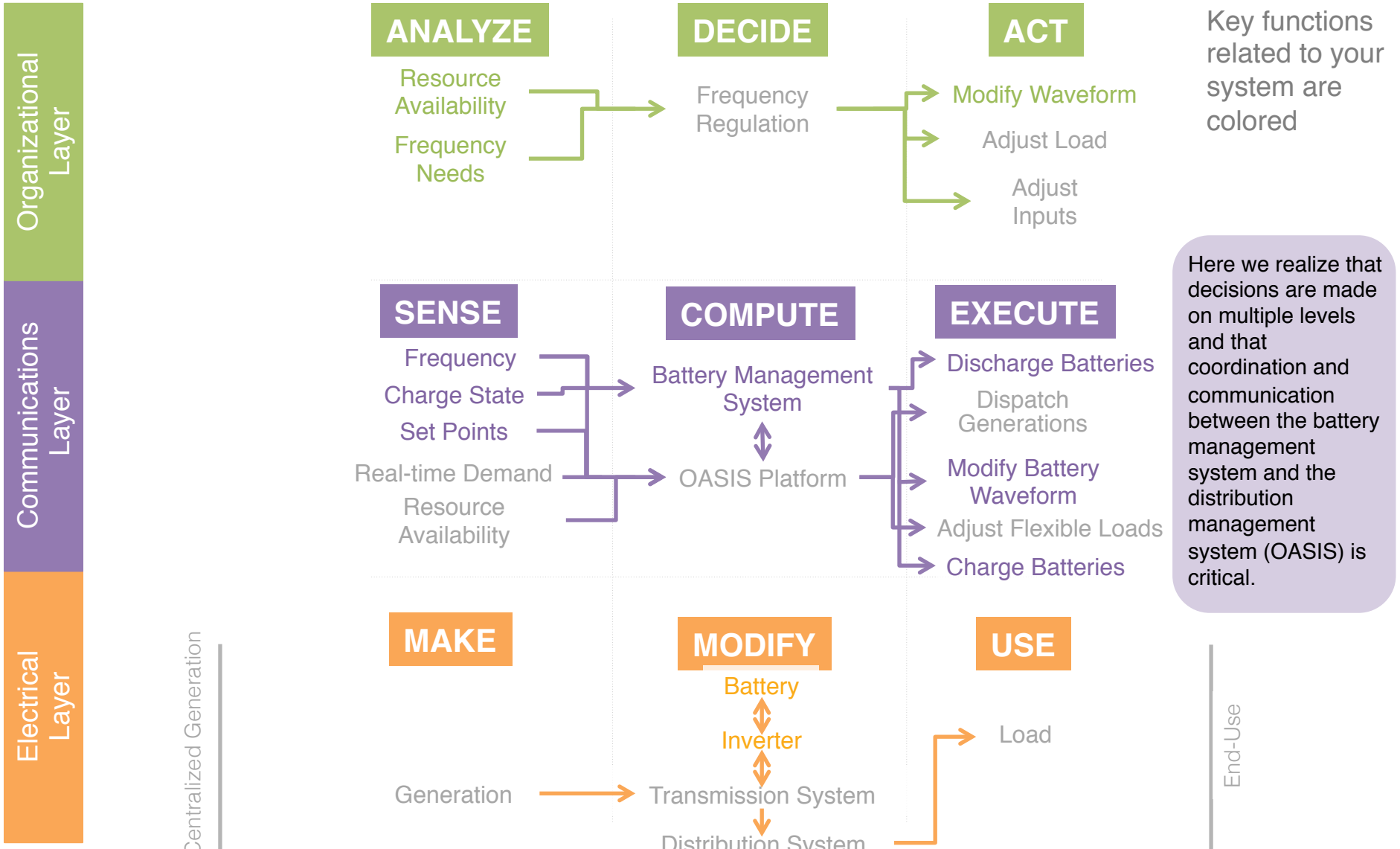
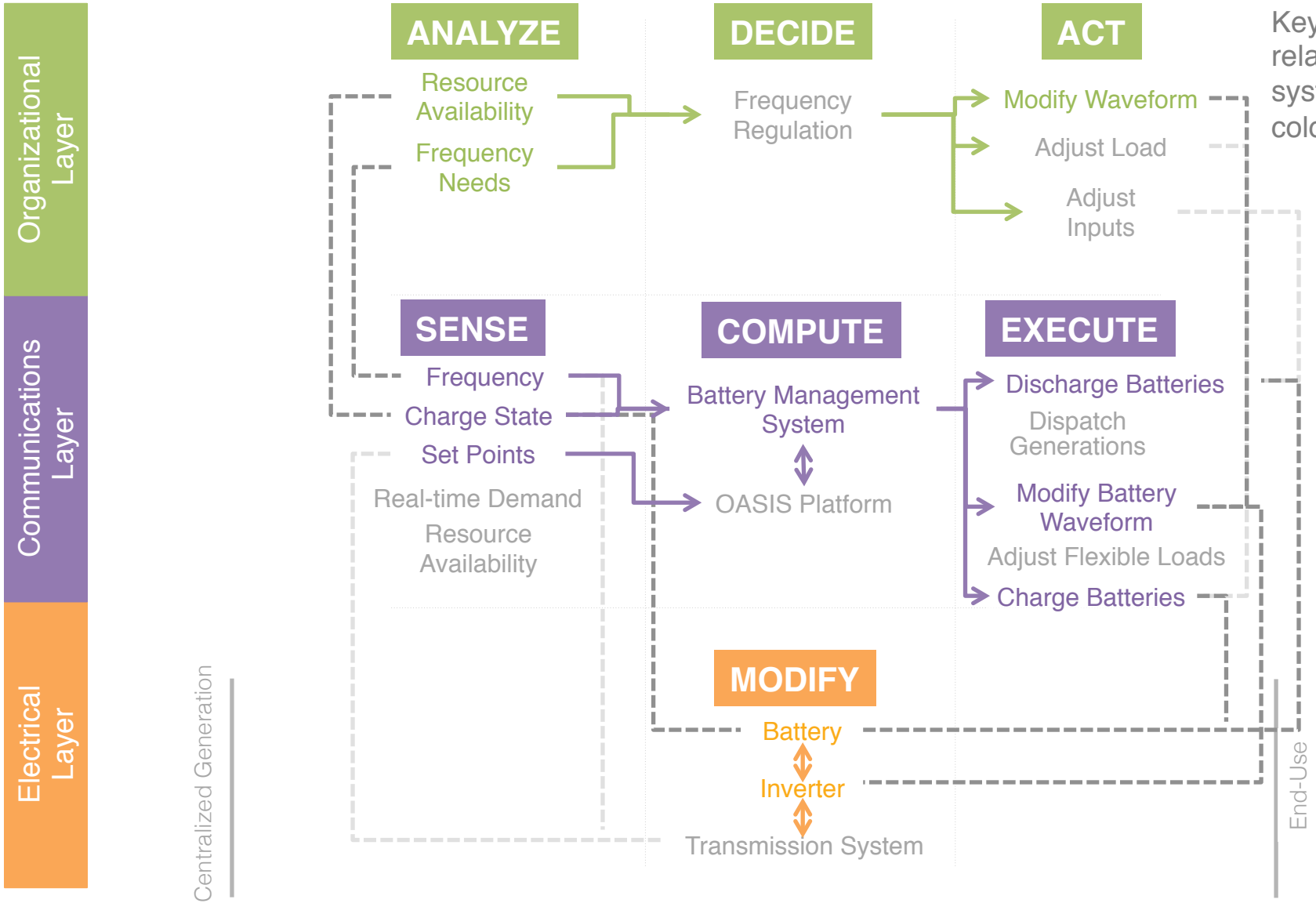


Key functions related to your system are colored

Here we realize that decisions are made on multiple levels and that coordination and communication between the battery management system and the distribution management system (OASIS) is critical.

Simplify by focusing on the key connections to your technology offerings to understand the possible flow of value



Was anything interesting revealed in this process?

- We have identified a few key communication and computation requirements that are necessary for the battery system to participate in an ISO market.
- Additionally, we started to identify other assets in the market that our product offerings would compete with, which may help start the process of a more specific competitive analysis of your system offering.
- Additionally, you could use this same system boundary to explore other values your batteries could provide, and then investigate whether compensation methods currently exist for those values, or if new business models could be developed to receive compensation for those values provided.

RMI intends to use the system value chain in strategic engagements with collaborators.

- The previous examples gave a sense of how the system value chain could be applied to identify additional sources of value in the context of a technology provider.
- While, in reality, the systems described here are more complex, they were simplified to aid in understanding value chain application.
- The full value of applying the system value chain can be realized when it is used as a discussion framework.
- RMI intends to use the system value chain in strategic engagements with collaborators. These sessions will be designed for the engagement at hand, and will allow the collaborator to deeply explore various solutions using a whole-systems perspective.