Decarbonization Readiness Assessment Mapping: Overview and Guide

globalpst.org/what-we-do/system-operator-technical-support/decarbonization-readiness-assessment-mapping-framework

Introduction

The Global Power System Transformation Consortium (G-PST) seeks to use the **Decarbonization Readiness Assessment Mapping (DREAM)** framework aims to inform high-impact technical activities for power system operators, helping address technical challenges as they decarbonize the systems they own or operate. DREAM is a tool that can be used to assess how prepared a system is to operate reliably in its target level of clean energy within a 10-year time frame (this is addressed as readiness in this document). This framework describes a set of actions that are fit-for-purpose for specific power system archetypes, as defined by the characteristics that most influence the operational changes these power systems will experience as they make their way through the energy transition.

What Is a System Operator?

In the context of DREAM, a system operator is the entity responsible for the reliable and secure operation of an electrical grid, generally characterized by responsibilities including monitoring, coordination, and control of a geographical jurisdiction taken on by either an independent institution or a functional business unit/subsidiary of a vertically integrated utility. The forms that system operators could potentially take includes independent system operators, transmission system operators, and regional transmission organizations.

Purpose

The goal of the DREAM framework is to develop a useful framework for identifying the order of operations, or actions and their order of priority, that a power system needs to take in a variety of key areas to achieve its decarbonization goals. This work was initiated based on the widely held assumption that specific power system needs may differ in timing, order, or even presence/absence, depending on a system's size, decarbonization goals, interconnectedness with neighbors, and available renewable or other clean energy resource mix.

By applying this framework to different systems, specific actions can be identified that support the prioritization of activities for various sets of power system circumstances.

These pathways thus enable power system operators to prioritize and plan their own activities and use of resources. They can also inform investment decisions or prioritization for global or regional technical assistance programs. Finally, the pathways can enable efficiencies by connecting system operators with shared power system characteristics for efficient knowledge-sharing and solution co-development. The audience for this work is primarily power system operators; secondarily regulators, technical practitioners, and policymakers; and finally sponsors, researchers, and solutions providers, including networks like G-PST itself (**Figure 1**).

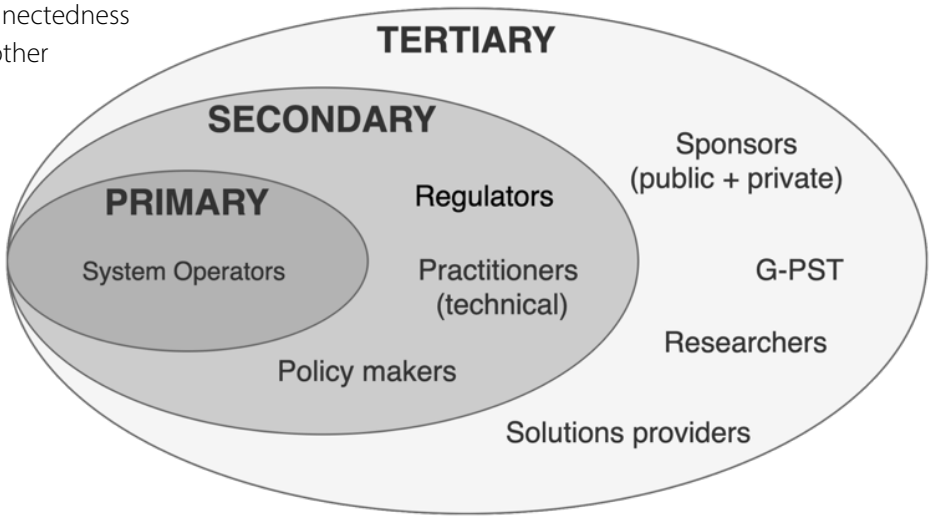

Figure 1. Target audience for DREAM.

Framework

The framework described here is fully implemented in an online version (globalpst.org/what-we-do/system-operator-technical-support/decarbonization-readiness-assessment-mapping-framework).

Input

The DREAM framework evaluates the readiness of an electric power system to reliably operate in the future with high levels of predominantly variable renewable energy (VRE) integration. It employs a comprehensive approach, considering the following key system attributes:

- **Transmission capacity (TC):** Refers to the ability to transport energy across the entire system while maintaining reliability, safety, and economy.
- **Power flexibility (PF):** Refers to the ability of the system to maintain the generation-demand balance under different scenarios and timescales, guaranteeing frequency stability and reliable operation.
- **System security (SS):** Refers to the ability of the system to provide active and reactive power in different timescales and provide damping capabilities to avoid local or systemic instabilities or violations of statutory levels of voltage, frequency, and power quality. More generally, system security is a well-known concept referring to the ability of an interconnected power system to withstand disturbances and maintain a continuous supply of electricity.
- **Energy sufficiency (ES):** Refers to the ability of the system to ensure the future supply of electricity in the medium and long term.
- **VRE integration:** The current and projected levels of VRE (wind and solar) penetration.

The framework uses a quantitative assessment methodology to evaluate these attributes and generate a comprehensive valuation of system readiness.

Each attribute (TC, PF, SS, ES) is assessed by the user in inputting a categorical value: High, Medium (Mid), or Low; which then is translated to numerical values (0, 1, or 2).

Processing

By integrating these quantitative results, the framework leverages fuzzy logic to find an approximate estimation of the system's readiness to accommodate future VRE integration,

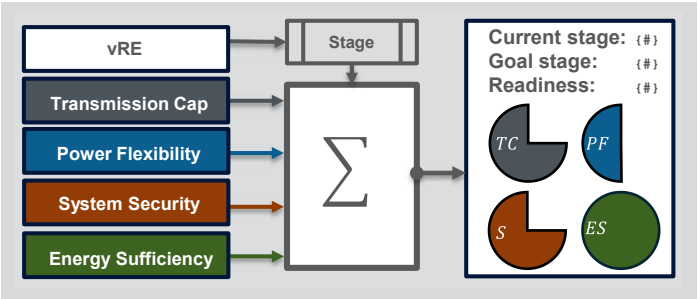

Figure 2. General schematics of the intake, process, and outputs of the framework.

both as an overview and a particular view on each of the four attributes. This seeks to enable informed decision-making regarding the prioritization of activities to achieve a higher level of preparation. **Figure 2** shows the general flow of the framework.

A detailed description of the logic implementation can be found in the **Detailed Description of Logic** Appendix, where the block [∑] is described in extensive detail.

Output

The box in **Figure 2** represents the output of the framework, which informs the user of the evaluation result, both in a general manner (readiness) and specifics (TC, PF, SS, ES). The items are:

- **Current stage [letter from A to D]:** The associated stage of the system as it is in the current year.
- **Goal stage [letter from A to D]:** The associated stage of the system as it will be in 10 years.
- **Readiness [percentage]:** Quantitative valuation of the holistic view of the system's preparation to accommodate future (10-year period) clean energy (likely driven by increased VRE integration).
- **Transmission capacity [percentage]:** Quantitative valuation of the system's transmission capacity readiness to accommodate future (10-year period) clean energy.
- **Power flexibility [percentage]:** Quantitative valuation of the system's PF readiness to accommodate future (10-year period) clean energy.
- **System security [percentage]:** Quantitative valuation of the system's security readiness to accommodate future (10-year period) clean energy.
- **Energy sufficiency [percentage]:** Quantitative valuation of the system's ES readiness to accommodate future (10-year period) clean energy.

Quantitative valuations (percentages) range from 0–100%, where 0% means the system is not ready to safely and reliably operate at the future goal stage, and 100% means fully ready.

System Stages

The stages (Current Stage and Goal Stage in Figure 2) relate to the share of VRE, mainly wind and solar, as a percentage of the total annual electricity generation in the system.

A. **Ready for VRE (0%<VRE≤10%)** is very early stage in which a power system operation is not highly influenced by VRE.

B. **Integrating VRE (10%<VRE≤20%)** is slightly more advanced, in which the power system has VRE operational and some significant challenges emerge.

C. **Ambitious VRE (20%<VRE≤50%)** describes systems with robust capabilities to manage the challenges associated with high VRE integration, currently demonstrated in daily operations. These systems are poised to rapidly and reliably accommodate high shares of VRE.

D. **Dominant VRE (50%<VRE≤100%)** describes power systems reliably running extremely high shares of VRE, both instantaneously and on an annual basis.

Each stage has a general description of the status of development of each attribute for a system at that stage at each attribute (TC, PF, SS, ES). The detailed description can be seen in the "Description of Stage" factsheet, available at globalpst.org/what-we-do/system-operator-technical-support/decarbonization-readiness-assessment-mapping-framework.

Archetypes

An archetype is a characterization of a system that is currently in one stage, but in 10 years' time will be at a more advanced stage. The combination of Current Stage and Goal Stage (outputs of the framework) corresponds to an archetype.[1] Each archetype has a factsheet that describes specific recommendations for improving readiness at the goal stage. Each recommendation in the factsheet is specific to one attribute (TC, PF, SS, ES), and these recommendations are framed in three main themes: stability, grid codes and standards, and services as shown in **Figure 3**.[2]

Six archetypes are identified based on the defined stages of decarbonization (A-B, A-C, A-D, B-C, B-D and C-D), which differ

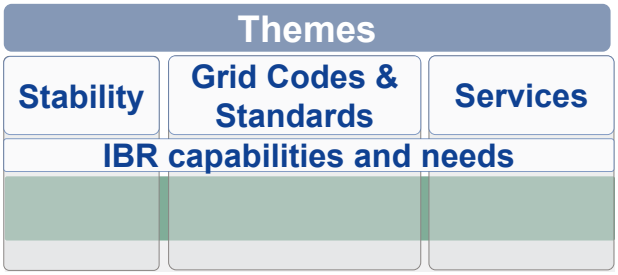

Figure 3. Themes used to frame the recommendations for the DREAM framework.

in the power system's size, interconnection with neighbors, grid strength, natural renewable or other carbon-free resource availability, and decarbonization current status and decadal goals (+10 years).

The specific aspects of each attribute (TC, PF, SS, ES) function as adjustors that influence where a power system lands in the steps of decarbonization. **Figure 4** shows the three archetypes that are the focus of this work. The rest of the archetypes will be addressed in future materials.

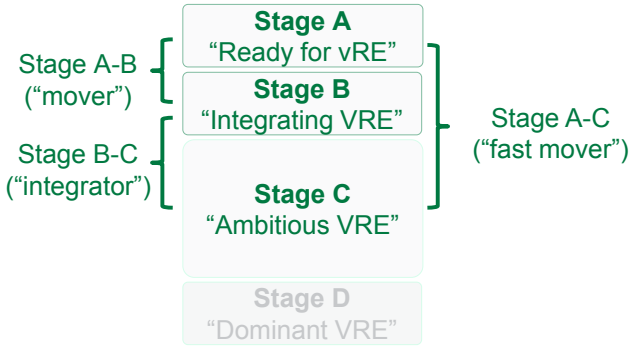

Figure 4. Three archetypes that are the focus of this work.

- **Stage A-B (mover):** A system that currently has less than 10% VRE but is planned to be between 10% and 20% in the coming 10 years.
- **Stage A-C (fast mover):** A system that currently has less than 10% VRE but is planned to be between 20% and 50% in the coming 10 years.
- **Stage B-C (integrator):** A system that currently has less than 20% VRE but more than 10% and is planned to be between 20% and 50% VRE in the coming 10 years.

Both "fast mover" and "integrator" types have the objective to be in Stage C, which means they have the same goals. Therefore, the recommended actions for both systems will be similar, but a "fast mover" will have some extra steps to capture the early stage of technical preparedness of a Stage A system.

[1] The only archetypes considered are the ones increasing their VRE share in time.

[2] This project acknowledges the importance of the control room and cybersecurity; however, these topics are addressed via other G-PST projects and are not covered explicitly under the DREAM framework.

Factsheets

The factsheets that accompany the framework are documents, associated with each archetype, that contain specific recommendations for improving readiness in the goal stage. The documents focus on each of the attributes (TC, PF, SS, ES). **Figure 5** shows an example of the general structure of a factsheet.

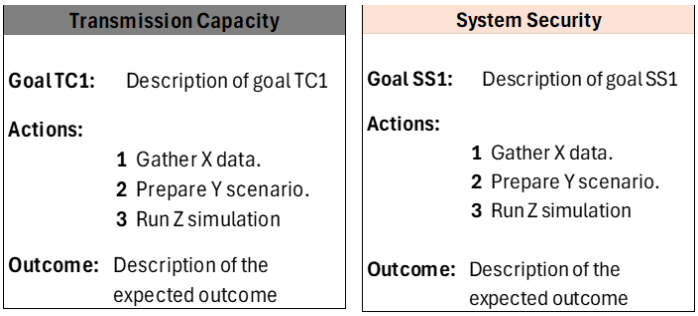

Figure 5. Example of the structure of a factsheet. PF and ES are missing from this example.

Each factsheet aims to detail the general actions that can be implemented to improve the readiness of the system to operate in the goal stage. **Figure 6** shows a schematic of the archetypes and the result of the evaluation with the corresponding factsheet. The figure shows a readiness axis from 0% to 100% in each stage, which signifies the estimated level of preparation that a system must operate at, reliably, at the goal stage. This is the result of computing the intake of each attribute in the logic that is explained in detail in the **Detailed Description of Logic** Appendix. Because the results are intake-dependent, it is clear that the specifics of each system, across the attributes, will yield a different readiness value.

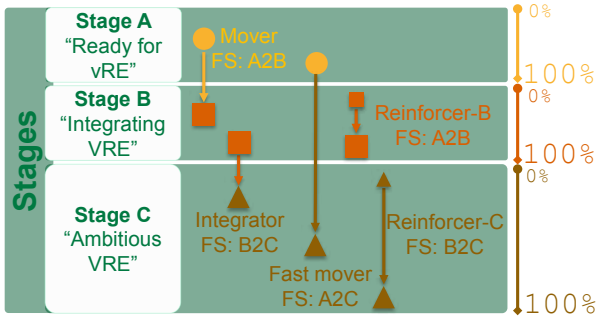

Figure 6. Archetypes and their readiness. FS:= factsheet.

It is worth noting that, besides "mover", "integrator," and "fast mover," there are also "reinforcers" (B and C), which are systems whose 10-year VRE plan places them in the same stage, but who also have plans to strengthen the key attributes for a more reliable operation, improving their readiness score even though they remain in the same stage.

How To Use the Material

The general flow of the materials can be summarized in four main steps: (i) access the form via the G-PST website (globalpst.org/what-we-do/system-operator-technical-support/decarbonization-readiness-assessment-mapping-framework); (ii) answer the questions; (iii) get results; and (iv) open corresponding factsheet for general recommendations (**Figure 7**).

These materials suggest a set of technical steps that all power system operators could take on the path to full decarbonization. The subset of priority steps, or the urgency of particular steps, is influenced by the specific system characteristics in each archetype. Thus, the archetypes help point system operators and other parties toward technical steps that may be most critical and most impactful in terms of maintaining a stable high-VRE power system.

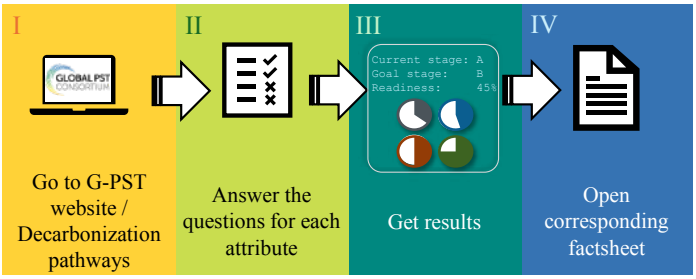

Figure 7. Flow of material.

How To Answer the Form Questions

The **Input subsection** of the **Framework** states that each attribute will be assessed using three categorical values: High, Mid, or Low. To try to reduce uncertainty and subjective evaluation,[3] each stage is described as a set of characteristics. In this sense, the user should be able to compare the current level of system preparation against the description of the goal stage. The description of each stage is made by attribute, as shown in **Figure 8**.

As a rule of thumb, if the system complies with less than one-third of the description, the answer should be oriented to Low; if it complies with at least two-thirds, then it could be oriented toward Mid. If it complies with more than two-thirds of the descriptions, then could be High.

[3] It is recognized that an important level of uncertainty and subjectivity will always be present in a framework as reduced and compact as DREAM.

	Transmission Capacity	Power Flexibility	System Security	Energy Sufficiency
Stage A	1. Charact_TC1 2. … n. Charact_TCn	…	…	…
Stage B	…	1. Charact_PF1 2. … n. Charact_PFn	…	…
Stage C	…	…	1. Charact_SS1 2. … n. Charact_SSn	…
Stage D	…	…	…	1. Charact_ES1 2. … n. Charact_ESn

Figure 8. Schematic of the description of each stage by attribute. The detailed description of each stage can be found in the factsheet "Stages Description," available at globalpst.org.

Periodic Re-Evaluation

The material is intended to be used in a periodic manner, meaning the first assessment can be used to get an initial outline of the work to do in the near term to improve readiness, but once the work is completed and new characteristics are present in the system, then the framework can be used for a new evaluation and possibly to determine new recommendations based on the factsheets. **Figure 9** shows the recommended re-evaluation process.

Figure 9. Intended periodic usage of this material.

This guide and all associated factsheets are intended to fuel critical thinking for power system operators navigating the energy transition. **G-PST explores archetypes and general recommendations but remember: Every system is unique.** Adapt these steps with thorough system studies and a keen eye toward evolving needs.

Appendix: Detailed Description of Intake Processing Logic

Figure 11 provides a great deal more detail than the summary representation shown in Figure 2. First, the attributes are each divided into two or more sub-attributes. This is intended to provide more granular details of these attributes, which are to be assessed using one of three options (High, Medium, or Low), which will later be translated into numerical values. Second, the intricacies of the relationship between each attribute are implicitly described with the connectors inside the big box.

The following sections explain the logic and reasoning behind each connection in the framework.

Description of Sub-Attributes and Numerical Translation of Categorical Assessment

When the user selects a categorical answer, like High, Mid (medium), or Low, for any sub-attribute, a numerical equivalent is used to generate a quantitative estimation of readiness. Below is a description of each sub-attribute and its numerical equivalent.

Transmission Capacity:

- **Cross-border transmission:** Assesses the availability of transmission infrastructure to connect with neighboring grids.
  - High: 2, Mid: 1, Low: 0.
- **Interregional transmission:** Evaluates the capacity within the system to transport power from generation sites to demand centers.
  - High: 2, Mid: 1, Low: 0.

Power Flexibility:

- **Ramping capabilities:** Examines the ability of power plants to quickly adjust their output to match fluctuations in demand and generation.
  - High: 2, Mid: 1, Low: 0.
- **Distributed energy resource and Utility PV share:** Considers the potential contribution of distributed energy resources like rooftop solar, both at distribution level and utility scale.
  - High: 0, Mid: 1, Low: 2.

System Security:

- **Electric model readiness:** Evaluates the accuracy of power system models in simulating the behavior of VRE and other grid components.
  - High: 2, Mid: 1, Low: 0.

- **VRE ancillary services requirements:** Assesses the existing regulatory requirements for VRE sources to provide ancillary services (e.g., frequency regulation) to maintain grid stability.
  - High: 2, Mid: 1, Low: 0.

Energy Sufficiency:

- **Spatial concentration:** Evaluates the geographic distribution of VRE sources. High concentration can increase vulnerability to weather events.
  - High: 0, Mid: 1, Low: 2.
- **Conventional fuel availability:** Assesses the availability of conventional fuel sources.
  - High: 2, Mid: 1, Low: 0.
- **VRE (goal):** Expected share of VRE in 10 years' time.
  - This value gets translated from 0–100% to 0–2 to be taken into account, in the same scale, in SS and ES. This is done with a logistic function as follows:

$$VRE' = \frac{2}{1 + e^{S_{stiff}(VRE - C_{off})}} \qquad (1)$$

If S_{stiff}=40 and C_{off}=20%, then *VRE'* will look like it is shown in **Figure 10**.

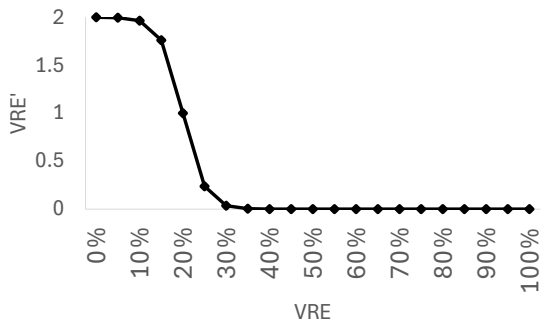

Figure 10. VRE (goal) translation from 0–100% to 0–2 to be used in the framework.

With the numerical translation detailed above, the mathematical operators in **Figure 11** can be easily understood.

Processing Logic

There are three main parts of the processing logic: first is the current and goal stage assessment, second is the individual readiness estimation of each attribute, and third is the overall readiness estimation.

Current and Goal Stage Assessment

Both the current and goal stage are obtained directly from the current and goal share of VRE based on the lookup **Table 1**.

Example: If the user indicates a current VRE share of 18% and a 10-year goal of 35%, then the current stage will be B, while the goal stage will be C. The combination of B-C yields the "integrator" archetype. See the **Archetypes** section.

Stage	VRE_{min}	VRE_{max}
A	0%	10%
B	10%	20%
C	20%	50%
D	50%	100%

Table 1. Stage Mapping According to VRE

Attribute Readiness Estimation

Transmission Capacity (TC_N): Both numerical values of the sub-attributes (cross-border and interregional transmission) are added to get a number between 0 and 4. That number is normalized between 0 and 100%.

Example: If the sub-attributes are High and Mid, they are translated to be 2 and 1, which sum to 3, so the normalization is then 3/4 = 0.75. Thus, the transmission capacity is at 75% readiness.

Note: The interregional transmission numerical value will be used in ES.

Power Flexibility (PF_N): Both numerical values of the sub-attributes (Ramping capabilities [*RC*] and distributed energy resource and/or U-PV [*DPV*] share) are added in the form of $a_{RC}RC+DPV$ to get a number between 0 and ε. Where ε is the upper bound of the addition between these two numbers and it is dependent on a_{RC}, which is the ramping capability adjuster, a scalar that is intended to provide weight to this sub-attribute over the other.

$$\varepsilon = 2a_{RC} + 2 \qquad (2)$$

From **Eq. (2)** it can be noted that if a_{RC}=1 then ε=4, because both sub-attributes will weigh the same and the maximum value out of their addition will be 4, but if a_{RC}=10, then ε=22. Default value for a_{RC} is 10.

Example: If the sub-attributes are High and Mid (respectively), and a_{RC}=10, then ε=22, and the sub-attributes are translated to be *RC*=2 and *DPV*=1, but because a_{RC}=10, then the summation

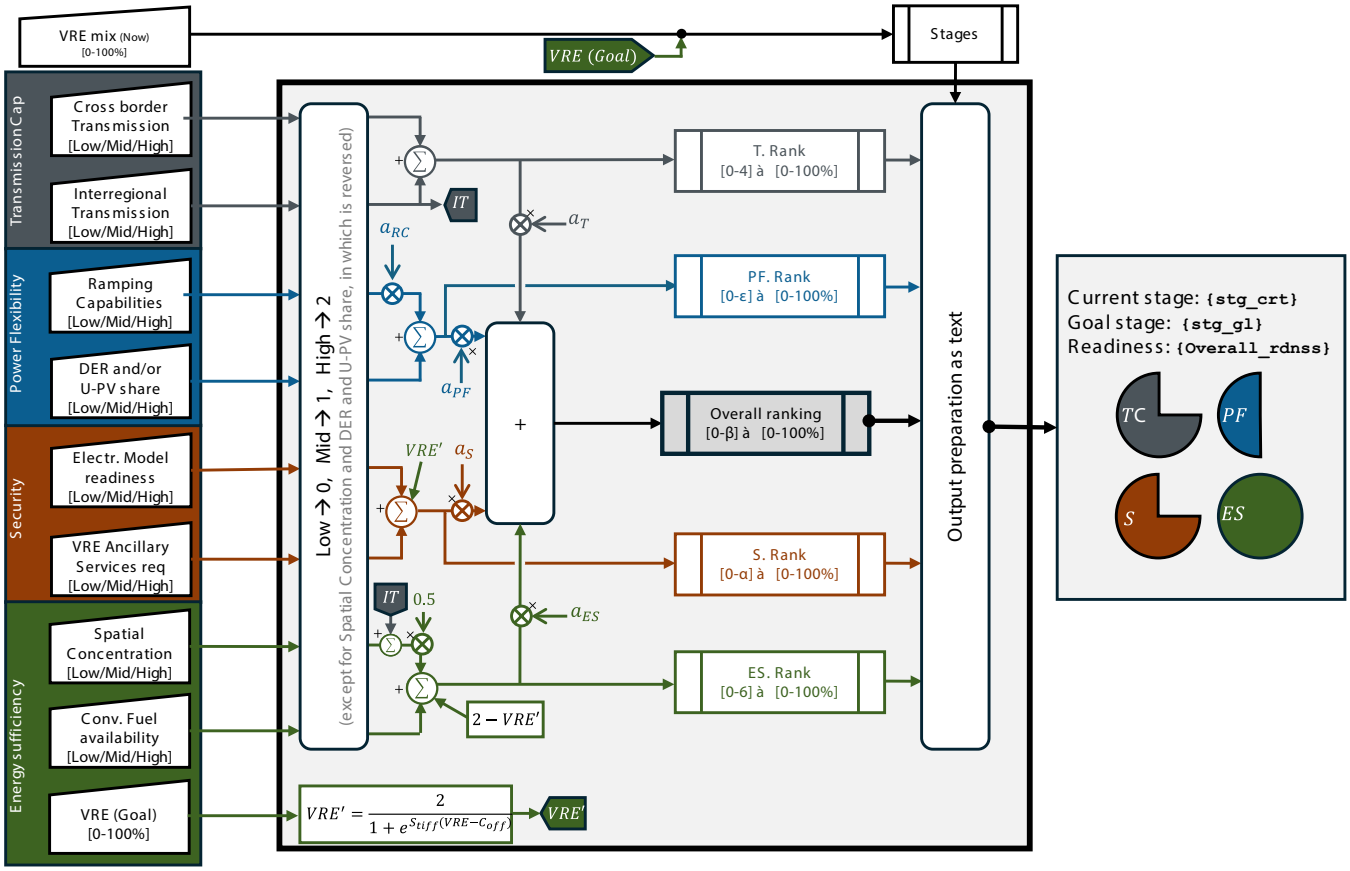

Figure 11. Detailed description of the intake processing logic.

of each other as $a_{RC}RC+DPV$ is 21, the normalization is then 21/22=0.95. Therefore, it will be reported that the *PF* is at 95% readiness.

System Security (SS_N): The numerical values of the sub-attributes (electrical model readiness and VRE ancillary services requirement) and *vRE′* (**Eq (1)**) are added to get a number between 0 and α. Where α is the upper bound of the addition of these three numbers and it is dependent on *vRE* like is shown in **Eq. (3)**:

$$\alpha = 4 + vRE' \qquad (3)$$

The reason to consider *VRE* here (in the form of *vRE′*) is because the framework is more demanding on *SS* when the *VRE* is higher.

Example: If the sub-attributes are High (2) and Mid (1), and *vRE*=100%, then *vRE′*=0 (using **Eq. (1)**), which yields the summation to be 3, the normalization is then 3/(4+0) = 0.75. Then, it will be reported that the *SS* is at 75% readiness. However, if we change *vRE*=10%, then *vRE′*=1.96 (using **Eq. (1)**), and if nothing else changes, then the normalization is (3+1.96)/(4+1.96)=0.83. Then, it will be reported that the *SS* is at 83% readiness. Because in the second example the *VRE* is lower than the first example, then the readiness in *SS* is higher for it.

Energy Sufficiency (ES_N): The numerical values of the sub-attributes (spatial concentration and conventional fuel availability) are operated with other numbers, as shown in **Eq. (4)**.

$$ES_{val} = \frac{SC + IT}{2} + CFA + (2 - vRE') \qquad (4)$$

Where ES_{val} is the energy sufficiency numerical value before normalization, *SC* is the numerical value for spatial concentration, *IT* is the numerical value for interregional transmission, and *CFA* is the numerical value of the conventional fuel availability. ES_{val} will be a number between 0 and 6.

The reason to operate *SC* and *IT* together is because high spatial concentration can be solved by high interregional transmission. Also, the reason for the expression (2-*vRE′*) is to aid the ES_{val} according to higher *vRE* share (i.e., the higher the *vRE* the higher the ES_{val}).

Example 1: If the sub-attributes are High (SC=0) and Mid (*CFA*=1), and *vRE*=100% then *vRE′*=0 (using **eq. (1)**), and *IT*=0 (Low), which yields the summation to be 3, the

normalization is then 3/6=0.5. Then, it will be reported that the *ES* is at 50% readiness.

Example 2: If all else remains the same but *IT*=2 (*High*), then the summation is 4, the normalization is 4/6=0.67. Then, it will be reported that *ES* is at 67% readiness.

Overall Readiness Estimation

This section describes how to obtain the readiness numerical value, which refers to quantitative valuation of the holistic view of the system's preparation to accommodate future (10-year) VRE integration. Let R_N be the readiness numerical value and TC_N, PF_N, SS_N, and ES_N are the numerical values of the attributes (transmission capacity, power flexibility, system security, and energy sufficiency, respectively), which are obtained as detailed in the Attribute Readiness Estimation section. **Eq. (5)** will describe the R_N as follows:

$$R_N = a_T TC_N + a_{PF} PF_N + a_S SS_N + a_{ES} ES_N \qquad (5)$$

Where a_T, a_{PF}, a_S, and a_{ES} are adjusters (or weights) for all attributes. These adjusters have the purpose of providing more importance to one attribute than others. R_N is a number between 0 and β, where β is the upper bound and it is dependent on the adjusters and individual attributes upper bounds (ε and α, for *PF* and *SS*, respectively). β can be defined as shown in **Eq. (6)**.

$$\beta = 4a_T + \varepsilon \cdot a_{PF} + 4a_S + 6a_{ES} \qquad (6)$$

Eq. (7) describes the normalized value of readiness, from 0 to 100%.

$$R = \frac{R_N}{\beta} \times 100\% \qquad (7)$$

Example: Let us assume the inputs shown in **Table 2**.

Cross-Border Transmission	Low
Interregional Transmission	High
Ramping Capabilities	High
Distributed Energy Resource and/ or U-PV Share	Low
Electrical Model Readiness	High
VRE Ancillary Services	Mid
Spatial Concentration	High
Conv. Fuel Availability	Mid
VRE	20%

Table 2. Intake Examples for Overall Readiness Estimation

The adjusters are:

- a_T, a_{PF}, a_S=1
- a_{ES}=2
- a_{RC}=10.

Then, following the instructions in the **Attribute Readiness Estimation** section, the following parameters within **Eq. (5)** are:

- TC_N=2
- PF_N=22
- SS_N=4
- ES_N=3.

Therefore, the usage of **Eq. (5)** yields:

$$R_N = 1 \cdot 2 + 1 \cdot 22 + 1 \cdot 4 + 2 \cdot 3 = 34$$

Next, **Eq. (6)** yields the upper bound of R_N, which is needed to do the normalization and finally obtain a number between 0 and 100%.

$$\beta = 4 \cdot 1 + \varepsilon \cdot 1 + 4 \cdot 1 + 6 \cdot 2$$

Using **Eq. (2)** we can substitute the value of ε as follows:

$$\beta = 4 \cdot 1 + (2 \cdot 10 + 2) \cdot 1 + 4 \cdot 1 + 6 \cdot 2$$
$$\Rightarrow \beta = 42$$

Finally, using **Eq. (7)**, we can find the percentage value of the estimated overall readiness of the system to operate in a reliable manner for a given goal:

$$R = \frac{34}{42} \times 100\% = 81\% \qquad \blacksquare$$