The ZEROgrid Impact Advisory Initiative convenes a group of leading researchers to advance consensus and use of consequential impact assessment methods. This paper was introduced to the Impact Advisory Initiative process for consideration and received unanimous support from the assembled experts. The following advisors elect to add their names in support of this paper:

Ruaridh Macdonald, MIT Energy Initiative
Fabrizio Finozzi, Open Energy Transition
Wilson Ricks, Princeton University
Lee Taylor, REsurety
Gavin McCormick, WattTime

Date: April 24, 2025

Subject: Expert Consensus Support for a Rigorous Definition of "Deliverability" in Scope 2 GHG Accounting

This memorandum conveys the consensus opinion of the ZeroGrid Independent Advisory Initiative advisors regarding the critical importance of a rigorous and empirically defensible definition of deliverability within the Greenhouse Gas Protocol's pending revision of the Scope 2 Market Based accounting framework. Our collective expertise in energy systems, grid operations, and carbon accounting has led us to the firm conclusions that 1) a rigorous definition of deliverability is essential to the credibility of 24/7 carbon-free energy procurement ("24/7 CFE") claims, and 2) that the recent implementations of 24/7 CFE, such as the use of grid regions as a proxy for deliverability in the implementation of the 45V green hydrogen tax credit in the United States, have not been sufficiently rigorous.

In concept, 24/7 CFE attempts to replicate the benefits of physically co-located, behind-the-meter sourcing of energy from carbon-free sources while also benefitting from the scalability, reliability, and flexibility of grid-connected energy generation and consumption. Credibly pursuing those dual benefits is dependent on two specific requirements. First, grid-connected CFE generation and energy consumption must occur in the same time interval (the "Temporal Matching" requirement). Second, grid-connected CFE generation and consumption must occur on the same interconnected grid AND there must be sufficient transmission capacity between the specific location of CFE generation and the specific location of consumption to reasonably expect that the CFE generation can physically reach the point of consumption (the "Deliverability" requirement). In practice, while many electric grids dispatch sub-hourly on a real-time basis, hourly matching of CFE generation and consumption has broadly been accepted as a reasonable definition to satisfy the Temporal Matching requirement. However, there has been no such consensus on how to define and implement the Deliverability requirement in a way that is considered both practically implementable and empirically defensible.

To date, there have been three primary proposals for how to define Deliverability in practice. We list those proposals here in order of declining empirical credibility (most credible to least credible). We have also provided a summary of the strengths and weaknesses of each.

Implementation Method #1: Locational Marginal Price Differential (the "LMP Differential" method)

During any specific hourly time interval, the Locational Marginal Price ("LMP") at the location of CFE generation is compared to the LMP at the location of grid energy consumption. If the LMP at the consumption location does not exceed the LMP at the location of CFE generation by more than a specific threshold — we suggest using a maximum 10% difference for such threshold — then the CFE Generation would be considered "deliverable" to the location of consumption for that hour. However, if the LMP at the consumption location exceeds the LMP at the location of CFE generation by more than 10%, it should be considered evidence of congestion preventing marginal generation from flowing from the producing location to the consuming location. In this case, CFE generation would be considered "undeliverable" for that hour and could not be counted toward 24/7 CFE procurement unless an alternative method is available to establish that power involved in this transaction can credibly claim rights to a share of power flowing during that time interval between the point of production and the point of consumption (noting that further research is needed to establish which, if any, alternative methods are suitable).

- **Pros**: This is the only method of the three listed here that can be consistently, empirically defended and as such provides the strongest credibility in resulting 24/7 CFE claims.

- **Cons**: Implementation complexity is highest for this method given that the definition of deliverability for a given location of consumption and CFE generation can change every hour, as opposed to the static definitions established by the Transmission Zones and Grid Regions methods (see below), respectively. In addition, some US markets and a majority of international markets do not make LMPs available at the nodal level, and as such this method is only implementable in certain markets.

Implementation Method #2: Transmission Zones (the "Transmission Zones" method)
Under this method, transmission zones are designated with specific geographic boundaries explicitly defined based on a lack of persistent or structural transmission congestion within such zones. For this purpose, it may be possible to use established market bidding zones, capacity deliverability zones, load zones, or other established sub-grid region zones within an individual regional transmission organization (such as PJM or ERCOT in the United States), country (such as the UK), or market (such as the European common electricity market), provided such zones are explicitly defined based on a lack of persistent or structural internal transmission congestion. Under this approach, adjacent zones that empirically demonstrate little to no material transmission congestion between each other could also be combined into larger zones. Note that this approach is similar to the definition of Deliverability employed by the European Union's green hydrogen rules.

- **Pros**: This approach aligns geographic definitions of grid operations and transmission congestion for environmental purposes with the definitions of grid operations and transmission congestion for economic purposes — such as real-time and day-ahead power trading or capacity deliverability during critical peak periods. While this approach is less granular and less empirically defensible than the LMP Differential method above, the Transmission Zones method would address many of the most consistent and obvious shortcomings of the Grid Regions method discussed below, such as the widely known congestion challenges between CFE generation in West Texas and the Dallas and Houston consumption regions within the ERCOT grid region, between western and eastern PJM and northern and southern MISO, or between countries within the European common market. In addition, by offering a more persistent definition of Deliverability than the LMP Differential approach, this method provides greater ease of implementation and operational certainty. To be most defensible, the definitions of these zones should be reassessed at periodic intervals (e.g., every several years) to ensure the geographic boundaries are consistent with empirically established measures of congestion.
- **Cons**: While smaller than the regions proposed in the Grid Regions method below, transmission congestion can still occur at certain times and between pairs of locations within these zones. For example, it is well established that some market bidding zones within the European market (e.g., Germany) evidence persistent intrazonal congestions. As such, the empirical defensibility of this method is lower than for the LMP Differential method.

Implementation #3: Grid regions (the "Grid Regions" method)
Under this definition, a larger grid region, such as the territory of the PJM Regional Transmission Operator that covers 13 US states, or the entirety of the European common market, is considered a "copper plate" where any CFE generation is considered deliverable to any location of consumption within the same grid region, if generated and consumed in the same hour. This method is similar to the definition of Deliverability employed by the US 45V clean hydrogen production tax credit.

- **Pros**: This definition of deliverability maximizes the ease of implementation and aligns carbon policy with the institutional boundaries that define electricity market transactions and shape the definition of many of these regions.
- **Cons**: Grid Regions employed by this definition frequently and demonstrably lack the spatial granularity necessary to ensure that material and persistent transmission congestion within defined regions is not occurring between locations of CFE generation and locations of grid energy

consumption. For example, it is well established that congestion frequently occurs on power flows within RTO regions in the United States. Note that where market or grid regions are defined in such a way that they align with the demonstrated absence of intra-zonal congestion, then those boundaries are consistent with the Transmission Zones method above. Given these concerns, we do not believe 24/7 CFE policies should be implemented using definitions of Deliverability as broad as these RTO and TSO grid regions.

To support and expand on the statements made above, please see Exhibit A below, which lists some of the pertinent recent academic and expert literature, including key quotes that relate directly to this topic.

Based on this expert assessment, we strongly urge the Greenhouse Gas Protocol to adopt a definition of deliverability for 24/7 CFE Procurement under Scope 2 that utilizes the most empirically rigorous definition(s) available, while remaining practically feasible to implement.

We believe that a rigorous definition of Deliverability is paramount for the credibility and effectiveness of a 24/7 CFE-based Scope 2 Market Based accounting method. A failure to adequately address this issue risks undermining the environmental integrity of corporate emissions reporting and hindering the deployment of truly impactful clean energy solutions.

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Exhibit A: Review of Relevant Academic and Expert Literature

2024 Princeton's ZERO Lab. *Response to Request for Information: Clean Hydrogen Production Standard (CHPS) Draft Guidance*. https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/chps/princeton-zero-lab.pdf?sfvrsn=bba512a1_1

- *"Our modeling finds that the emissions benefits of an hourly matching requirement with strict additionality may not materialize if the procured clean electricity is not physically deliverable. Even within the same synchronized electricity grid, balancing area (BA), or regional transmission organization (RTO) territory, transmission congestion can prevent procured resources from actually contributing additional clean generation to supply additional electrolysis load. When transmission pathways between procured clean generators and hydrogen electrolyzers are congested, local resources, including fossil generators, increase their output to meet any incremental electricity demand from hydrogen production. The severity of the resulting emissions impact increases with the frequency of congestion, though it is also dependent on the relative emissions rates of the two grid regions. However, when there is no grid congestion between hydrogen producer and contracted clean electricity supplier(s), there is effectively no functional difference between a grid-based hydrogen producer procuring hourly-matched, offsite clean energy and one consuming directly from behind-the-meter clean resources. It is therefore important to define a deliverability condition that ensures hydrogen producers are actually using the clean electricity they procure. We recommend a delivery requirement for grid-based hydrogen producers that allows procured clean generation to be counted toward clean hydrogen production in a given hour only if it can be proven that there is an uncongested transmission pathway between the point of generation and the point of offtake. Locational marginal electricity prices (LMPs) can be used to verify deliverability in real time in grid regions where they are available, with large LMP differences between two grid nodes being indicative of congestion along the transmission pathways connecting them. Under an LMP-based deliverability validation mechanism, procured clean generation would be considered deliverable in a given hour only if (a) the generation and consumption occurred in the same synchronous electricity grid, and (b) the LMP at the point of offtake did not exceed that at the point of generation by more than a given threshold (set suitably high to account for the impact of transmission losses on LMP). This method of enforcement would be easy to apply within the territories of RTOs, which calculate and publish LMPs at realtime, day-ahead, and other intervals. However, robust deliverability validation would not be possible in grid regions without RTOs, where LMPs and other congestion measurement metrics are not readily available. If DOE still wishes to allow grid-based clean hydrogen production in non-RTO regions, electrolysis facilities located in these regions could be required to source qualifying clean electricity from within their own local balancing area (BA). This requirement would minimize (though not necessarily eliminate) the risk of deliverability violations, as BAs are generally geographically limited in scope in non-RTO regions."*

2024. S. Sofia et al. *Carbon Impact of Intra-Regional Transmission Congestion.* https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4972564

- *"Carbon accounting frameworks that require a tight definition of temporal matching (e.g., hourly) but allow for a loose definition of deliverability (e.g., grid-regions) will result in increased costs of operations, due to the need to load shift to match CFE generation, while having limited real world carbon benefit, as a result of intraregional transmission congestion that limits or even reverses the benefits of temporal matching."*
- "*We see that nearly half of ERCOT wind and solar generation and the majority of PJM wind and solar generation is not deliverable to much of the rest of the grid. This results in large variation in the avoided and induced emissions across the grid, causing large discrepancies between the*

induced emissions of a load and avoided emissions of procured renewable energy. Without accounting for intra-regional congestion, carbon accounting methods like hourly-matching or annual energy matching, significantly underestimate the net induced carbon emissions on the grid."

2024. A. Jacobson et al. *Quantifying the impact of energy system model resolution on siting, cost, reliability, and emissions for electricity generation*. Environ. Res.: Energy 1 035009
https://iopscience.iop.org/article/10.1088/2753-3751/ad6d6f/pdf

- *"We find models with high spatial and temporal resolution result in more realistic siting decisions and improved emissions, reliability, and price outcomes. Errors are generally larger in systems with low spatial resolution, which omit key transmission constraints."*
- *"By omitting intraregional transmission constraints, large regions also fail to predict transmission bottlenecks over wider areas, leading to overestimation of resource deliverability. Both effects lead poorly spatially resolved models to overestimate [Variable Renewable Energy] performance, thereby underestimating the amount of capacity needed to meet demand"*
- *"Spatial resolution is more impactful than temporal resolution at the scales tested here. In spatially low resolution models, systems are missing information on the structure of the transmission system and may propose infeasible operations as a result."*
- *"Because the 26-zone, 52-week case with UC is the largest run, it serves as our highest-resolution system or HRS. We note that 26-zones is still relatively low resolution for a real-world transmission network with tens of thousands of nodes"*

2023. W. Ricks et al. *Minimizing emissions from grid-based hydrogen production in the United States*. Environ. Res. Lett. 18 (2023) 014025
https://iopscience.iop.org/article/10.1088/1748-9326/acacb5/pdf

- *"We find that allowing resource procurement over large geographic areas can lead to significant consequential emissions from hydrogen production even when a 100% Hourly Matching requirement would otherwise ensure low consequential impact, as the introduction of transmission constraints prevents physical delivery of procured clean electricity. Transmission congestion can lead to different marginal generating units supplying power on each side of a constrained pathway, and persistent congestion can affect capacity retirements and additions in the long run. Consumption and production on different sides of frequent transmission constraints can thus lead to divergent emissions impacts."*
- *"This finding demonstrates that clean resources subject to transmission constraints that prevent delivery of the procured energy cannot be relied on to eliminate emissions from hydrogen production. In this study, the deliverability condition is operationalized by requiring procurement of clean electricity from within the local model zone. However, unlike the model system studied in this work, the real grid is not divided neatly into well-connected zones with perfect internal deliverability, and transmission bottlenecks of varying severity exist at all spatial scales. When implementing a 100% Hourly Matching requirement for grid-based hydrogen production, prior determination of qualifying grid regions within which transmission constraints are minimized could help to mitigate instances of non-deliverable procurement. If these regions are internally well-connected, then locality (i.e. procurement from within the same region) could stand in as a reasonably proxy for deliverability. A more robust deliverability enforcement mechanism could instead rely on real-time monitoring via existing metrics like locational marginal electricity prices (LMPs), which diverge when congestion exists between two points in the electricity grid. Under this system, grid-based hydrogen production would be allowed to claim use of a noncolocated clean resource only during periods when the LMPs at the point of generation and point of delivery show that the procured energy is physically deliverable."*

2023. D. Esposito et. al. *Smart design of 45V hydrogen production tax credit will reduce emissions and grow the industry.*
https://energyinnovation.org/wp-content/uploads/Smart-Design-Of-45V-Hydrogen-Production-Tax-Credit-Will-Reduce-Emissions-And-Grow-The-Industry.pdf

- *"Deliverability requires electrolyzers to use local sources of clean electricity that are physically deliverable to the electrolyzer, accounting for congestion and transmission line losses. Deliverability administration is possible by requiring hydrogen electrolyzers and contracted sources of new clean energy to be located in the same defined region (such as power market zones)—with criteria for sourcing electricity from adjacent regions—while purchasing enough clean power to cover transmission line losses."*
- *"Transmission connectivity is as important as location—it is necessary but not sufficient to require that project pairings be built in the same interconnection, region, or power market."*
- *"Consider a new wind farm built in wind-rich West Texas and an electrolyzer built in Houston. During times of high congestion, West Texas wind is likely being curtailed, while in import-constrained Houston, the electrolyzer might cause a local fossil fuel resource to ramp up. This dynamic can show up anywhere in the country where transmission congestion limits the delivery of electricity from clean energy resources to electrolyzers."*

2023. G. Pease, et. al. *Tracking physical delivery of electricity from generators to loads with power flow tracing.*
https://zenodo.org/records/8117207

- *"Summarized to the boundary set level, physical delivery metrics can obfuscate significant deviations in performance between regions. [Balancing Authorities] in the US are an extreme example of this. In Florida (the Southeastern U.S.), BAs can be as small as a single town. These small BAs are highly deliverable, with deliverability scores of 75-100%. Elsewhere, large BAs like PJM have much lower expected deliverability (18.12% for PJM). The low load-weighted average BA deliverability score, 32.3% reflects the relative prominence of large, low deliverability ISOs, but obfuscates the fact that some smaller BAs actually have very high deliverability."*