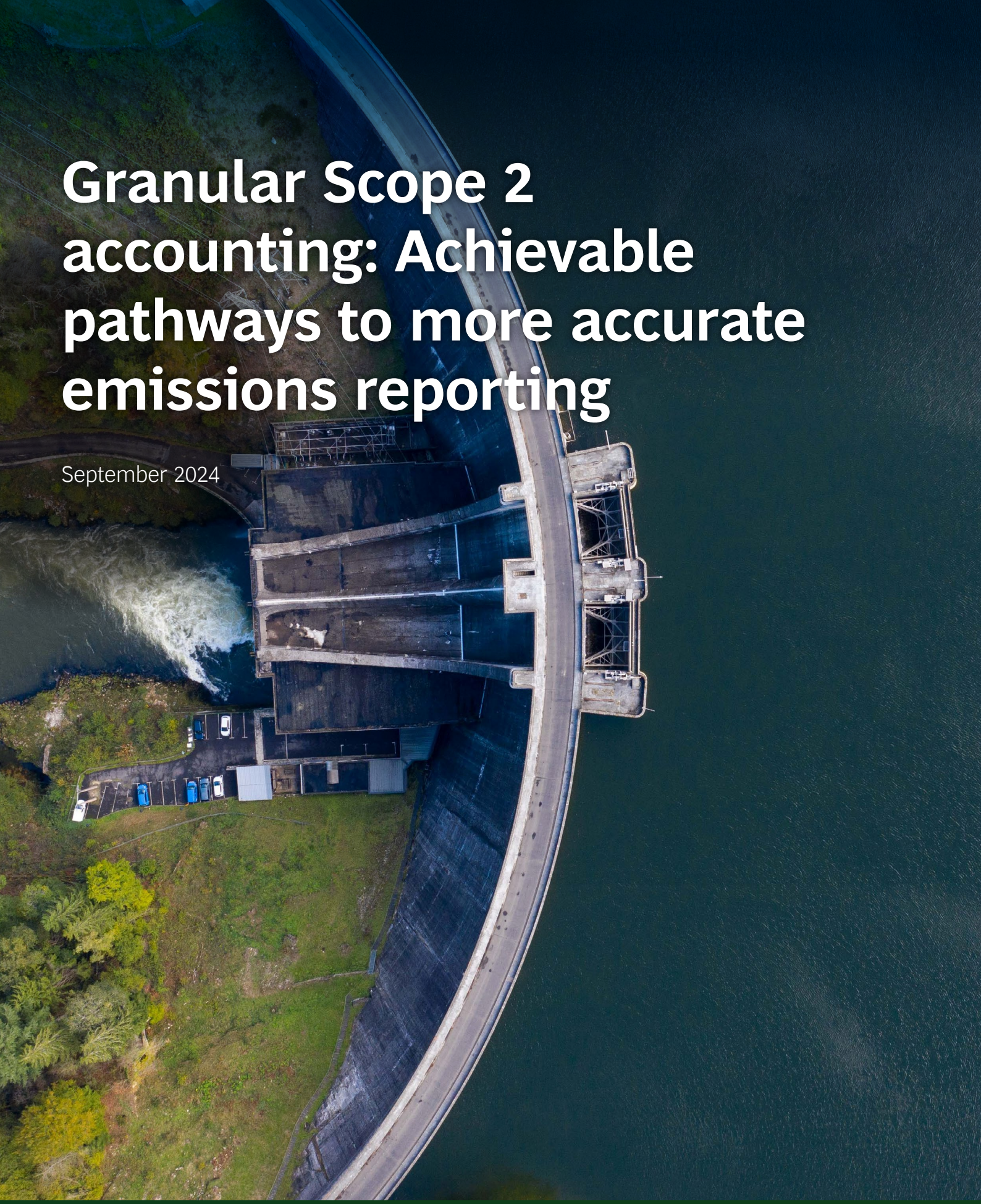
Granular Scope 2 accounting: Achievable pathways to more accurate emissions reporting

September 2024



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This report was prepared in collaboration with Google and with input from key stakeholders, including corporate sustainability leaders, NGOs, energy attribute certificate registries, and third-party solutions providers. The purpose of this report is to assess the readiness of power markets around the world to facilitate a transition to Granular Scope 2 accounting.

For questions please contact us at Scope2@BCG.com.

Contents

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Executive summary

Corporate emissions accounting is crucial for tracking progress towards net zero goals. Accurate Scope 2 accounting is essential, as one quarter of global emissions come from electricity production, with commercial and industrial users representing 60% of global electricity consumption.[1] Today, the Greenhouse Gas Protocol (GHGP) market-based and location-based methods stand as the reference for Scope 2 accounting. The market-based method specifically allows firms to calculate annual emissions from electricity procured through carbon-free energy (CFE) market instruments like power purchase agreements (PPAs), green tariffs, or unbundled energy attribute certificates (EACs).[2]

However, the **current Scope 2 accounting method does not represent a full inventory of emissions caused by a company's energy consumption.** Companies today procure energy attribute certificates in different geographies and times than which they consume the power, creating inaccuracies in reporting.

1. IEA: Electricity Outlook (2019). 2. Key terms defined in glossary.

Granular Scope 2 (GS2) accounting provides a more accurate and credible accounting method that can enable companies to make more informed decarbonization decisions. Under GS2 accounting, companies would report market-based emissions based on clean energy or granular (time-based) energy attributes matched to their consumption on the local grid where energy is consumed. Temporal matching is typically assumed to mean hourly matching, though the exact time intervals to be tracked is a decision yet to be made by standard setters (and could onramp at something less granular such as monthly intervals).

The objective of this report is to assess the ability of companies to implement GS2 accounting around the world based on the availability of necessary inputs. To implement GS2 accounting, companies need to collect higher resolution geographic and temporal data. Narrowing geographic boundaries of procured electricity can be done today with minimal technical barriers. At the same time, there is a general perception that access to more granular temporal data can be a limiting factor to GS2 implementation.

This report finds that GS2 accounting can be implemented today in a wide range of markets. Locational matching is readily achievable with data and EACs that correlate to the grid where a company consumes electricity. Temporal matching can be achieved by using primary data when available or credible estimates in its absence. When primary data is lacking due to access (as in markets like Indonesia or India) or the effort required to access is too high, GS2 accounting can be achieved using estimates that convert annual numbers to more granular increments. This entails using load profiles to derive hourly consumption from electricity bills, third-party models like Electricity Maps for hourly grid emission factors estimates, production profiles to derive hourly production from contracted assets, and parallel accounting systems when local registries do not support granular certificates (also known as time-based energy attribute certificates, or T-EACs). The most precise implementation method, achievable in markets with stronger data availability like Germany or Texas, involves collecting hourly consumption data from connected meters and hourly grid emission factors, then matching them with hourly clean energy production or certificates.

As a practical step towards GS2 accounting, firms can immediately begin refining their accounting approach based on clean energy that is procured within the same local grid boundary where they consume electricity. This not only improves the accuracy and fidelity of their Scope 2 emissions reporting but also lays the groundwork for adopting temporal matching. Locational matching is feasible in most markets today, even in the absence of additional temporal data sources, and can enhance transparency.

Companies that want to pursue greater granularity in their Scope 2 reporting have a path to do so today, regardless of the market they operate in. While this journey takes more time and effort than traditional annual volumetric matching, there is a growing ecosystem of solutions providers working to ease the journey. Granular accounting can confer a fuller, more accurate understanding of how to decarbonize Scope 2 emissions while driving grid-wide emissions reductions.

Greater granularity is needed to ensure the accuracy and credibility of Scope 2 accounting

The production of electricity accounts for roughly one quarter of global emissions, with commercial and industrial users representing 60% of global electricity consumption[3,4]. Scope 2 emissions accounting, measuring a firm's indirect emissions from the purchase of electricity, heat, and cooling, is therefore crucial for understanding and enabling net zero progress. A growing number of corporations have goals to decarbonize their Scope 2 emissions, resulting in the procurement of nearly 200 gigawatts of clean power to date through power purchase agreements (PPAs). These commitments have only grown as time has passed – corporations have committed to purchase over 46 gigawatts of new solar and wind resources in 2023 alone.[5] By making these investments and scaling clean technologies like solar and wind, corporations have sped up deployment beyond what grids would have deployed on their own.[6,7]

Today, most companies that disclose emissions opt to report Scope 2 emissions in accordance with the Greenhouse Gas Protocol (GHGP). **But the current Scope 2 market-based accounting methodology, can lead to inaccurate estimates.** This inaccuracy stems from two characteristics of the GHGP Scope 2 Guidance.

3. Ember Global Electricity Review (2023). 4. IEA: Electricity Outlook (2019). 5. PV Magazine: Corporate Funding for Solar (2024). 6. "From 2014 to 2018, large companies announced transactions with off-site renewable energy projects representing over 15 GW of capacity – equal to around one-quarter of all such new renewable generation capacity installed across the country in that same period. This is a great success story." Columbia Center for Energy Policy (2020). 7. As of the publication of this report, 547 companies have submitted SBTI-approved targets with a net zero commitment. SBTI "Companies Taking Action" Dashboard (2024).

First, firms are able to "match" their electricity consumption to carbon-free electricity production that is located in different grids and power markets.[8] But clean electrons produced in one place often have little or no bearing with electrons consumed many thousands of miles away by a company's operations, because electricity grids are not fully interconnected and power is not always fully deliverable or tradeable across regions. For example, under currently acceptable market boundaries, a firm could use energy attribute certificates (EACs) from Québec to account for consumption in Florida. **As a result, a firm could cause emissions on its local grid and report zero emissions based on energy purchases that have no physical relationship to the firm's operations.**

Second, firms typically report their emissions on an annual volumetric basis. But electricity usage, production, and emissions vary significantly over the course of not only a single day, but across seasons as well. Variable renewable sources like solar and wind almost always lack the generation profiles to fully match energy consumption at every hour of every day. **A company could therefore claim that 100% of its electricity usage is matched by zero-carbon energy, even though during many hours of the day and night that firm could be powered by carbon-emitting sources.**

Why Granular Scope 2 accounting?

A more granular accounting method can improve the accuracy of corporate Scope 2 reporting. Indeed, the GHGP's Scope 2 Quality Criteria encourage companies to procure energy produced in the same market as the consumption during as close a time period as possible.[9] With greater transparency on their emissions, **companies can make more informed decisions to directly decarbonize their Scope 2 emissions, including transforming their energy procurement and consumption strategies.**

Under Granular Scope 2 (GS2) accounting, firms track their electricity consumption on the local grid and on hourly time increments. Greater locational granularity ensures that a firm is only accounting for power that is physically deliverable to the location of its operations. Standards setters have several options for defining a geographic match and exact boundaries might depend on regional contexts. For example, a recent report from Singularity Energy suggests balancing physical deliverability, practicality of implementation, and structural relevance in determining appropriate market boundaries.[10] For the purpose of this analysis, a geographic match is defined as production in the same balancing authority (contiguous area of grid operational control) where demand is located.[11]

Adhering to narrow time increments ensures that a firm can develop an accurate and credible representation of their energy consumption patterns. Tracking on a monthly or seasonal basis improves on the current standard by accounting for variability in consumption patterns throughout the year. Tracking on an hourly basis takes this a step further by ensuring that a firm's reporting captures the often significant intraday variation in energy consumption, production, and emissions impact. As a benchmark for the potential magnitude of the inaccuracy, one study shows that hourly granularity reduces the error in companies' reported location-based Scope 2 emissions by up to 35%.[12] While there is ongoing discussion on the appropriate standard for granularity, this report examines the feasibility of hourly time intervals for granular accounting. It is ultimately the role of standard setters like the GHGP to decide.

8. GHGP requires companies to follow the EAC issuer's rules on where the certificate can be traded and canceled, which can often be a very broad area. It also directs the use of EACs generated "close in time" to the reporting period. Many companies have joined Climate Group's RE100 initiative that has more stringent standards, requiring that EACs be generated within the same "area in which the laws and regulatory framework governing the electricity sector are sufficiently consistent between the areas of production and consumption". Temporally, RE100 requires that EACs be generated "reasonably close in time to the period over which a claim to use of renewable electricity is made", but "reasonably close" is left undefined. GHG Protocol Scope 2 Guidance; RE100 Technical Criteria (2022). 9. GHG Protocol Scope 2 Guidance. 10. Where matters: Integrating deliverability into voluntary clean energy market boundaries (2023). 11. The EnergyTag Standard defines location-matching on several levels. The ideal case is one where the electricity is "physically deliverable" from producer to the consuming load. Alternative definitions include matching within a single power market/bidding zone or an interconnection zone. Energy Tag Granular Certificate Scheme Standard (2024). 12. Hourly accounting of carbon emissions from electricity consumption (2022).

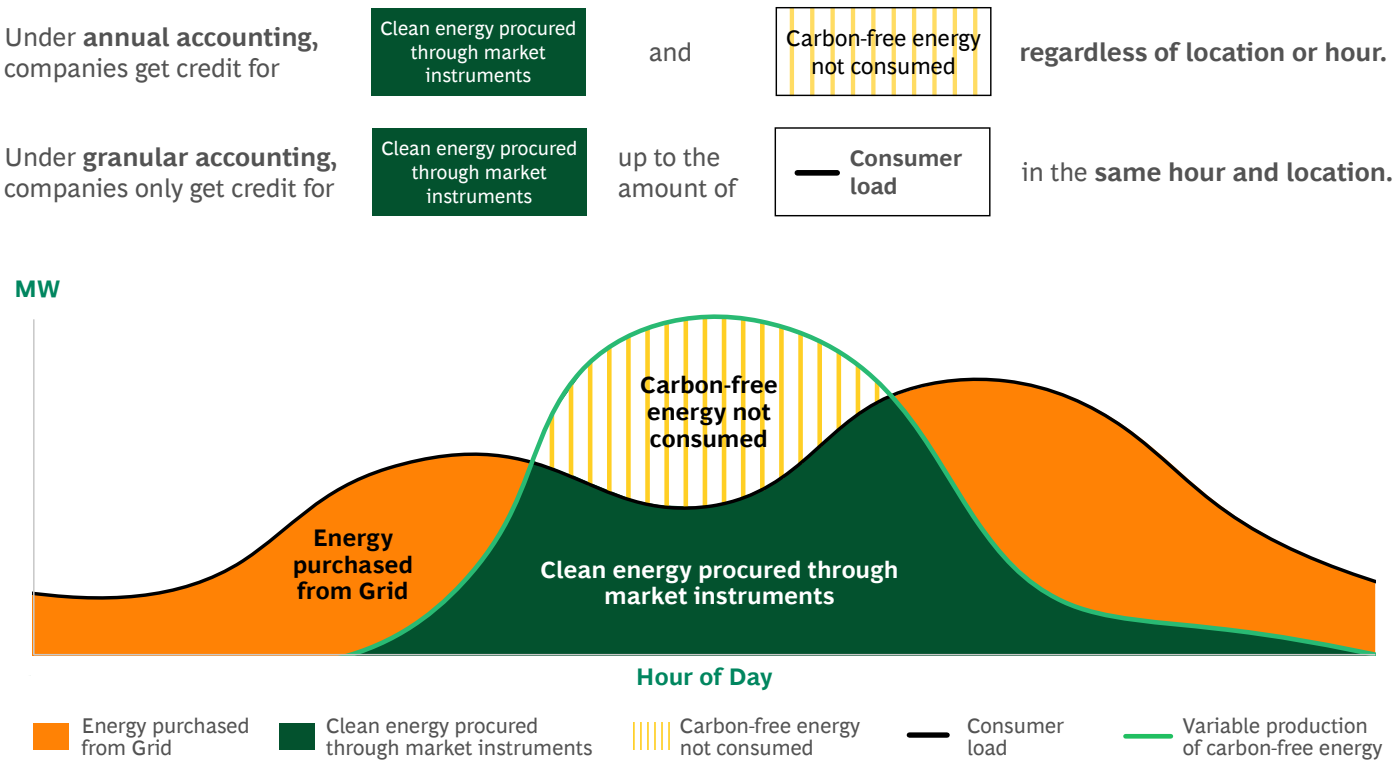


Exhibit 1: *Comparison of GS2 emissions calculation and traditional Scope 2 calculation*

In addition to increasing the overall accuracy of reporting, there is significant evidence suggesting that a more granular accounting standard would benefit electricity markets overall. Researchers estimate that hourly matching of clean electricity to consumption would deliver significant grid-wide emissions reductions compared to annual matching.[13] Modeling from TU Berlin and Princeton suggests that high levels of hourly matching uniquely have a "transformative effect" on the markets for long-duration energy storage and clean firm technologies like advanced nuclear, advanced geothermal, and gas with carbon capture that are needed to achieve full, economy-wide decarbonization, because they can provide energy at hours of the day when intermittent resources are unavailable.[14] Given these grid-wide benefits, GS2 accounting also can end up reducing the Scope 2 location-based emissions that firms must report, which depends upon the average emissions intensity on the local grid.

Public policy has also begun to encourage granularity in accounting and energy procurement. The European Union's Renewable Fuels of Non-biological Origin (RFNBO) rules require eligible fuels to be produced using electricity generated in the same electricity market bidding zone and, starting in 2030, one-hour period.[15] In the US, regulators have proposed rules for the Inflation Reduction Act's hydrogen production tax credit to require regional and eventually hourly matching of clean electricity with hydrogen production to receive the maximum $3 per kilogram credit.[16]

13. For example, on the coal-heavy Wyoming and Colorado grids, the authors estimate that temporal matching by 10-25% of commercial and industrial load could reduce grid-wide emissions by up to 0.65 tCO2e/MWh. System-level Impacts of Voluntary Carbon-free Electricity Procurement Strategies (2023). 14. System-level impacts of 24/7 carbon-free electricity procurement in Europe (2022). 15. Q&A implementation of hydrogen delegated acts (2024). 16. How the 45V Tax Credit Definition Could Make or Break the Clean Hydrogen Economy (2023).

GS2 accounting can be implemented through multiple pathways, using primary data or estimates

Geographical matching as a first step

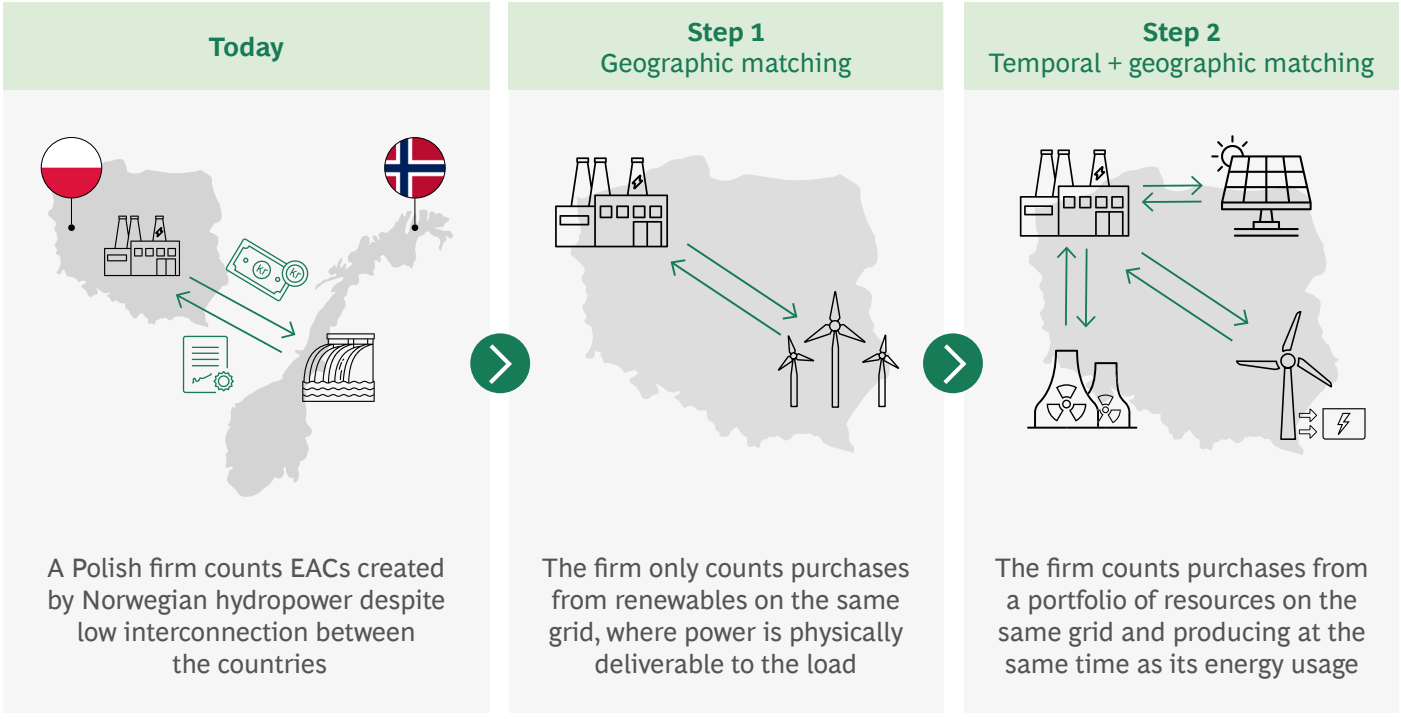


Exhibit 2: *Geographic matching is a first step toward GS2 accounting*

Firms today can improve the granularity of geographic matching of their energy procurement to their energy consumption with minimal technical barriers. Grid-sourced energy (procured from the utility rather than through other market instruments) can be considered inherently geographically matched to a company's facilities, and emissions data at a balancing authority level is often readily available. To reduce the emissions of that electricity consumption, companies can sign power purchase agreements (PPAs) and purchase energy attribute certificates (EACs) from projects that produce power within the same local grid boundary.[17] Energy buyers will know the physical locations of the assets for which they sign PPAs and can use that information to understand whether power is physically deliverable to the consumption location. EACs also encode information about the generators and their locations, which can similarly be used to infer physical deliverability.

As a result, even in the absence of additional data sources, firms can take a practical first step toward GS2 accounting today by refining their accounting approach based on clean energy that is procured within the same local grid boundary where they consume electricity, improving the accuracy and fidelity of their Scope 2 reporting.

Core enablers of temporal matching

GS2 accounting requires companies to collect detailed geographic and temporal data on their energy usage and supply.

While locational data needed for geographic matching may be already available, tracking electricity hourly requires more data than what is required when annually aggregating numbers.

Hourly consumption data and hourly grid emissions data are needed to assess a granular emission footprint. Additionally, hourly production data for contracted assets (PPAs) and granular energy attribute certificates (i.e., EACs that record the hour at which energy was produced, also known as T-EACs) are required to reduce a firm's GS2 emissions.

While such hourly data might not always be available as actuals, **Granular Scope 2 accounting can still be implemented by estimating hourly values from actual data** collected at less granular time intervals.

Granular CFE procurement instruments

While not strictly necessary for GS2, adoption of granular accounting is further enabled by a set of other factors such as the ease of access to direct procurement instruments for carbon-free energy (CFE) - like corporate PPAs and sleeved/green tariffs - and supportive policies like hydrogen incentives requiring hourly matching.

The standard EACs used today for Scope 2 emissions reduction can also be used in GS2 accounting with the support of third-party tools. For example, EnergyTag's "configuration 1" and "configuration 3" standards envision the creation of granular certificates that are tied to standard EACs held (or canceled) in existing registries. There are also movements toward the creation of EACs optimized for granular accounting.[18] For example, the Granular Certificate Trading Alliance plans to launch a new platform in 2024. This platform, developed by LevelTen Energy, works with registries and independent power producers to allow firms to mint, transact, and retire GCs.[19]

1 Energy purchased from grid	Convenient access to hourly consumption data or estimates (e.g., load profiles) in a unified location adhering to clear formatting and time interval standards
2 Grid emissions factor	Access to data on hourly grid mix, emissions factor, and residual mix
3 Energy attribute certificates	Market instruments to procure time-stamped clean energy attributes (e.g., granular certificates/ T-EACs), or in the absence of market instruments, data/estimates on the production of contracted clean energy assets

***Exhibit 3:** Key enablers of GS2 temporal matching*

17. Energy procurement options within more granular geographic boundaries may not always be available. 18. Energy Tag Granular Certificate Scheme Standard (2024). 19. Granular Certificate Trading Alliance (2024).

How companies implement GS2 will largely depend on data availability and accessibility

There are varying levels of data availability and ease of access across global power markets. **A company's chosen pathway for implementing GS2 accounting will depend on data availability in the markets in which they operate–**with different degrees of precision, resources, and effort required in each market.

Across markets, regardless of data availability, firms have the opportunity to geographically match their energy procurement to consumption by purchasing EACs generated on the same grid. For companies that have previously been location-agnostic, this first change can drive a significant improvement in the accuracy of emissions reporting. Once companies match geographically, further increasing the accuracy of their Scope 2 emissions requires understanding the temporal variability of consumption and supply, which is the focus of the balance of this paper.

Across the ten power markets examined in this report, we identified three tiers of data availability and access:

- Markets where GS2 is possible using **estimates**
- Markets where GS2 is possible using **primary data** (with some **accessibility limitations**)
- Markets where GS2 is possible using **primary data** and **significant automation**

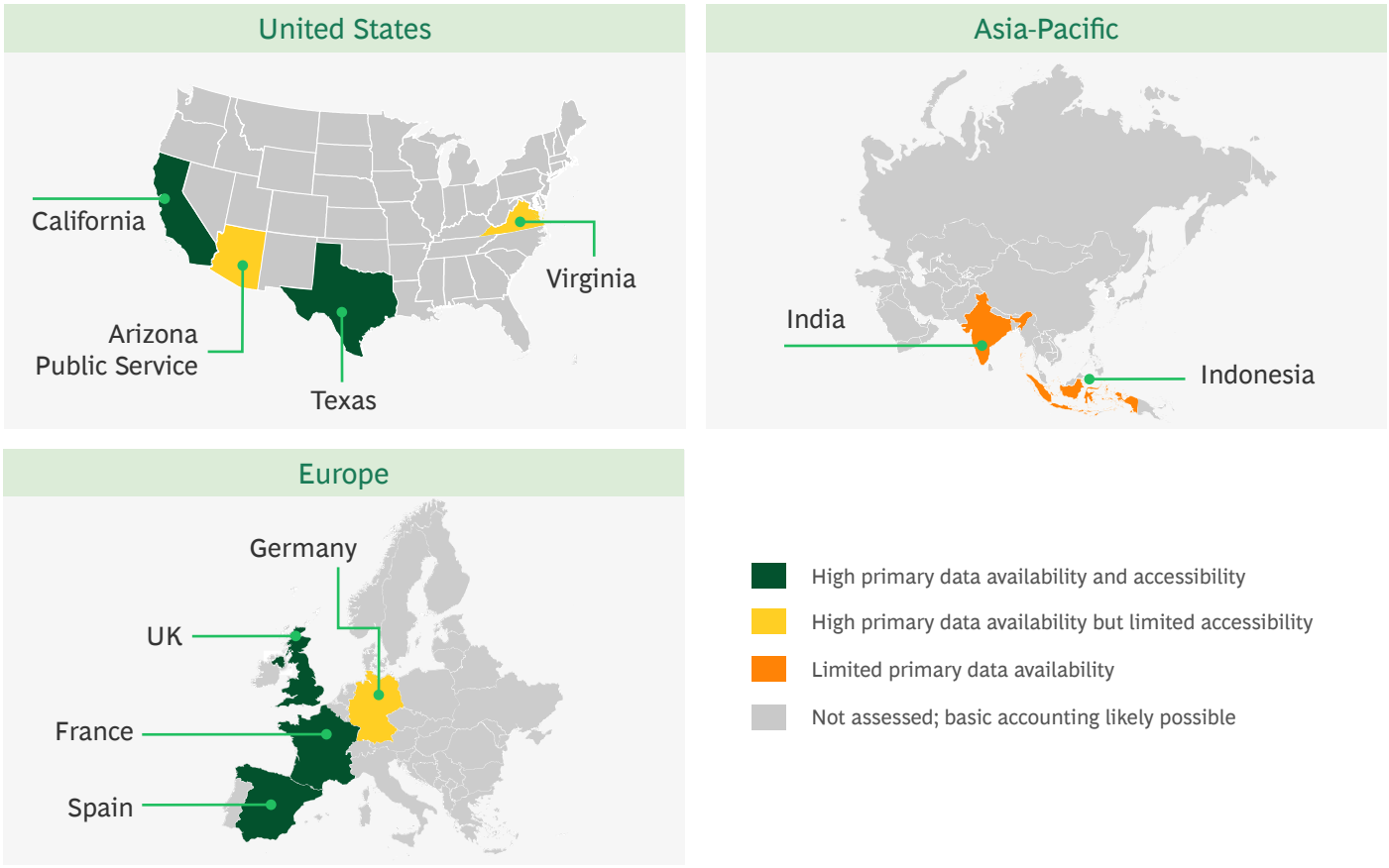


Exhibit 4: *Three tiers across ten major power markets*

Markets where GS2 is possible using estimates

The availability of primary granular data remains limited in some markets. In this study, Indonesia is representative of this market type. Granular consumption data is often limited in these markets by low penetration of advanced metering infrastructure (AMI) – for example, less than 10% of meters in Indonesia can provide hourly load data (although large industrial customers are likely to have much higher penetration). Access to hourly grid emissions factors can also be limited in these markets due to limited disclosure from utility operators. Finally, data on power production is both limited by restrictive market structures that prevent firms from directly procuring power from independent producers and limited availability of granular certificates that track production at an hourly level.

In such markets, GS2 accounting can be implemented in its most basic form using credible estimates whenever primary data access is limited. However, doing so requires firms to invest in the time, tools, and change management efforts that may be necessary to begin reporting granular emissions. Because annual Scope 2 accounting implicitly assumes a flat load profile throughout the year, regardless of resource intermittency or type of energy customer, estimates can significantly increase the accuracy of the emissions inventory.

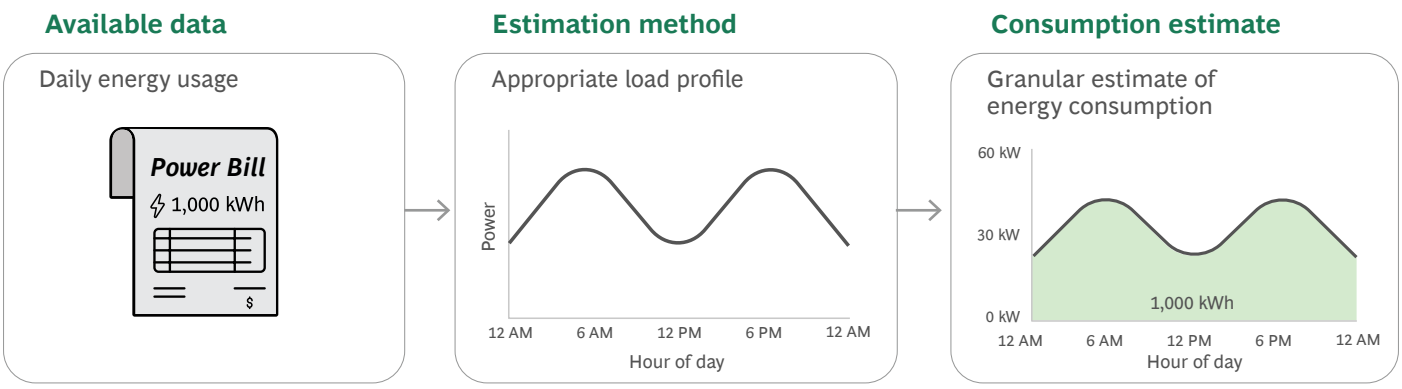


Exhibit 5: *Example estimation of energy purchased from grid*

Hourly consumption

Hourly consumption estimates can be derived from monthly or annual bills using load profiles from credible national agencies that reflect local climate and industry energy use. Load profiles provide a representative hourly electricity usage shape for a given building type and climate zone (e.g., a restaurant in a hot dry climate). By shaping the known overall energy usage in a given period, firms can estimate their load at a given hour. Indeed, in many parts of the world, including relatively high data availability markets, utilities use load profiles for customer billing purposes. For example, US based firms in areas without advanced metering could rely on the US National Renewable Energy Laboratory's (NREL) end-use load profiles, which are calibrated with data from 11 electric utilities and more than 2 million meters in the country. In the absence of a locally developed set of load profiles, firms could also use other publicly available profiles so long as they match the building types and climate zones where a firm operates.

Even in these markets, firms can pursue primary data. While there may be low penetration of advanced metering infrastructure that enables hourly (rather than just monthly or annual) measurement and reporting of energy consumption, large commercial and industrial customers are generally more likely than residential customers to have advanced meters. This is especially true in cases where time-of-use or other dynamic electricity rate structures are available, typically for large commercial and industrial customers. For example, India has low overall AMI penetration, but smart meters are required for customers with PPAs and those in states like Tamil Nadu and Maharashtra that have time-of-day tariffs for industrial customers.[20] In such cases, firms could use actual hourly meter data for GS2 accounting instead of load profile estimates. Firms with energy-intensive assets can even consider installing their own internal meters and sensors to collect more granular data. Beyond accounting, this solution also gives firms deeper insights into how to optimize their energy usage for cost and emissions.

Hourly grid emissions

Hourly grid emission factors can be estimated using high-fidelity commercial third parties like Electricity Maps.[21] In cases when official hourly emissions data from the grid operator is unavailable, these third parties employ a variety of methodologies to estimate the carbon intensity of electricity production throughout the day on a specific grid. Generally, this is accomplished by breaking down annual generation data into an hourly profile by assuming specific production patterns for renewable resources.[22] These commercial third parties tend to have extensive coverage across major power markets; Electricity Maps provides data for power markets in around 80 countries, for example (including many of the largest power markets, like India and Brazil).

While third parties provide wide coverage, for geographies without coverage from commercial third parties, firms will need to approximate grid mix using other third-party data (e.g., IEA annualized data). In cases where the grid has very low penetrations of renewable capacity, GS2 methodology can yield similar results to annual, volumetric Scope 2 accounting, as long as supply and demand are geographically matched. This is because on low penetration grids, firms will have such a low base rate of CFE usage that accounting for hourly variability is unlikely to drive a major difference in calculated emissions. Standards setters should consider creating guidance for such situations.

Hourly energy attribute certificates

Today, most energy attribute certificates are issued with a monthly or annual vintage, meaning that the certificate only records the month or year that the clean energy was produced–rather than the specific hour. While progress is being made on the development of hourly time-stamped certificates, these are generally not widely available. As an alternative, several commercial third parties help operate parallel accounting systems like EnergyTag's "configuration 3" standard, in which hourly production data is collected to create hourly EACs derived from traditional EACs that have been retired in a registry. This approach allows firms to procure and retire their own granular certificates even if the local registry does not offer hourly timestamps.[23] Commercial third parties like Flexidao and Granular Energy have emerged to help firms use hourly EACs while standard registries modernize to offer native hourly EAC functionality. See Appendix B.1 for how configuration 3 accounting works in practice.

In many cases, a practical challenge to implementing a granular energy procurement strategy will be the ability to trade granular certificates. Under configuration 3 accounting, granular certificates are immediately canceled after issuance, preventing their trade and the establishment of an independent market value. And under alternative potential schemes, early corporate adopters

20. DERC invites feedback on draft green energy open access regulations (2024). 21. Another vendor, WattTime, currently provides average emissions factors but in markets that are more likely to have official data available (US, Canada, much of Europe, and Australia). 22. When data is sparse or unreliable, Electricity Maps employs a spectrum of different methodologies to fill in the gaps. For short term gaps, they utilize a "time slicer" estimation model. For larger sections of missing real-time data, they utilize hierarchical estimations. For significant volumes of missing data, they utilize either a construct or reconstruct breakdown estimation model that estimates hourly production using an internally-developed model. https://www.electricitymaps.com/methodology#missing-data 23. Energy Tag Granular Certificate Scheme Standard (2024).

would likely encounter a limited supply of hourly EACs due to the nascency of the market. As in the traditional EAC market, transparent, well-understood market design and standards would help buyers and sellers crowd into the market and provide liquidity.[24,25] For this reason, standards-setters will also need to decide whether a transition period is appropriate for any new granular accounting rules.

In these cases, energy consumption strategies can also be an important complement to the procurement of EACs. Firms can consider shifting load when feasible to times of day when the firm is receiving a relatively cleaner energy supply, in turn reducing their GS2 emissions.

Under the Scope 2 Guidance, when EACs are unavailable, data from contracted assets (i.e., energy procured through PPAs) can be used as a proxy for environmental claims. Typically, if a firm operates in a market where clean energy PPAs are available, the firm should be able to request hourly production data from the asset owner. This is because hourly data is often already required for financial settlement with the grid operator, and most renewable assets are equipped with SCADA systems that communicate data at at least an hourly level to their asset owners.[26] In some cases however, the asset owner may need time to transition to hourly reporting. For example, a solar farm owner may be accustomed to reporting monthly or annually for financial settlement purposes despite having hourly production data recorded on the system inverters, requiring a change in business practices.

In such cases where hourly production data is not immediately available, production profiles can provide estimates of a contracted renewable energy assets' hourly production over the course of a year. These profiles, provided by tools like Renewables.ninja and NREL's PVWatts and Wind Resource Database, offer near-global scientific estimates on the renewable resources at a given location on Earth (e.g., solar irradiance or wind speeds and power density) that can be converted by a contracted asset throughout the day. Asset owners should typically have estimated production profiles available, since they are necessary to forecast a project's performance.

Credibility of estimates

To ensure consistency and credibility, standard setters will need to define precise guidelines on the quality criteria underpinning these estimates. Defining quality criteria is a familiar exercise in emissions accounting with the GHGP already doing so in the existing Scope 2 framework. For example, if a firm chooses to use load profile estimates, standards-setters might consider requiring estimates to be matched to the building type and climate zone. Similarly, standard setters can define guidelines to ensure consistency across corporations' approach to estimating hourly emissions mix, especially if corporate operations span multiple geographies where the level of grid disclosure varies. Because firms are also trying to manage their risk exposure when reporting, it is critical to have standards that can be applied by firms in a wide variety of geographies and business contexts.

Implementing GS2 accounting will require time and effort for companies at this basic level as doing so requires identifying and implementing the appropriate estimation models, along with potentially engaging vendors. In some cases, estimation methodologies will be available 'off-the-shelf.' For example, vendors like Flexidao, Granular Energy, and the Energy Web Foundation provide productized versions of parallel EAC accounting. On the other hand, firms may need to develop their own ways of ingesting and calculating estimated loads even if public load profiles are available.

Case study

Exhibit 6 below shows an example pathway that a firm operating in India could take to implement GS2 accounting.

24. The Role of Hourly EAC Markets in Facilitating the Clean Energy Transition (2023). 25. Performance of markets for European renewable energy certificates (2019). 26. A SCADA (Supervisory Control and Data Acquisition) system is a centralized control system used to monitor and control industrial processes and infrastructure.

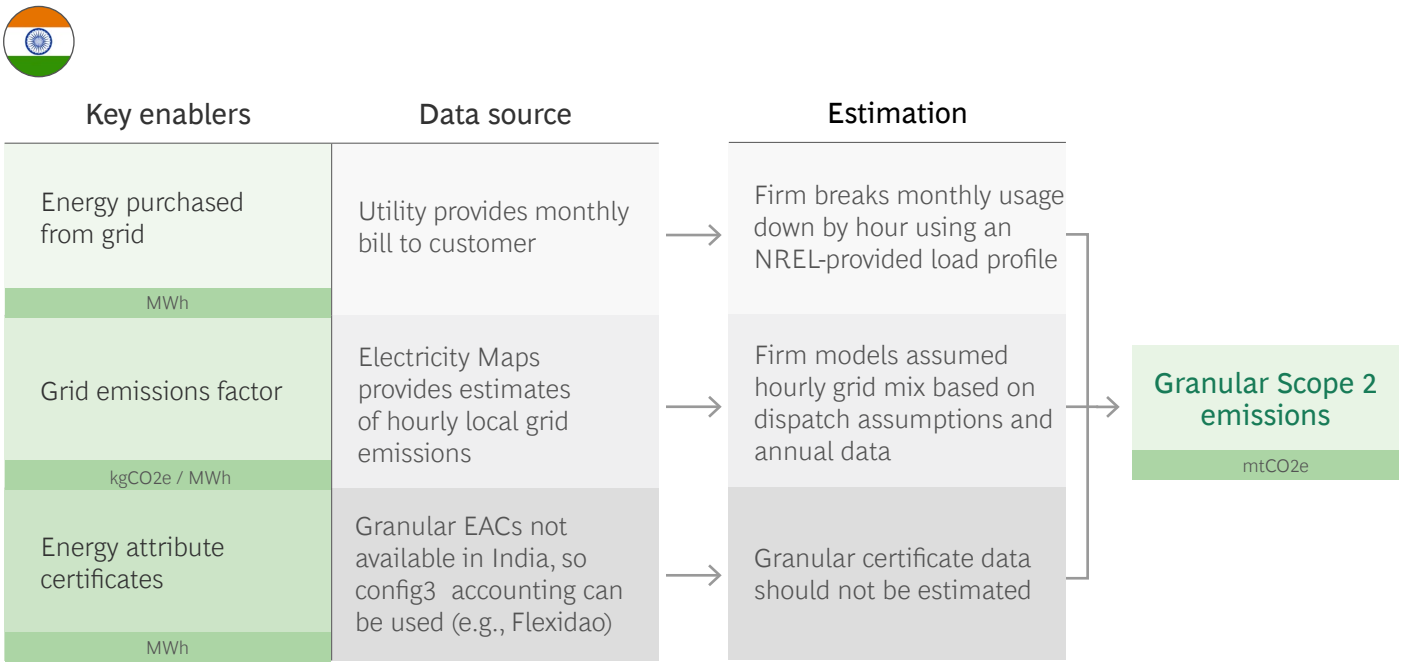


Exhibit 6: *Example GS2 pathway in India*

Market roadmap

Governments can work to accelerate the deployment of advanced metering infrastructure. Widespread AMI deployment can sometimes be a multi-year process, but many governments have already set ambitious targets to accelerate the metering rollout. For example, in India and Indonesia, national governments have set targets to replace all of the ~250 million and ~79 million meters in each country with advanced ones by the end of the decade.[27] In India, about 12 million meters have been deployed to date, while Indonesia has deployed around 1 million.[28,29] If these and other countries' goals are met, this will make GS2 accounting more precise for a wider set of companies around the world. To reap the full benefits of AMI deployment, governments can also ensure that data portability standards are adopted to ensure electricity users and solutions providers can easily access data for accounting purposes. By investing in advanced metering, countries can provide firms with greater certainty over their consumption patterns and drive smarter energy usage.

Utilities and national energy authorities can also invest in the collection and reporting of hourly grid mix and emissions data, and in the development of country and region-specific load profiles that firms can use to proxy their hourly energy consumption. Industry coalitions could also work with research bodies to develop these data sources for common use. These investments would collectively reduce the burden on any individual firm when transitioning to GS2 accounting.

Markets where GS2 is possible using primary data

In markets with stronger availability of primary data, firms can use tha data to implement GS2 accounting in a more sophisticated and precise form.

Hourly consumption

In these markets, primary data on hourly consumption is widely available thanks to strong penetration of AMI, allowing firms to know their actual energy usage on an hourly basis, rather than only monthly or annually. Some markets like France, Spain, Texas, and California boast AMI penetration higher than 85% with commercial and industrial customers.[30]

Hourly grid emissions

In markets where GS2 accounting is highly automatable, primary data on hourly grid emission factors is typically available in centralized, standardized data portals. For example, much of continental Europe is covered by the

27. The smart metering growth story in Asia-Pacific continues (2024). 28. Smart Metering Progress: Deployments pick up pace (2024). 29. PLN: Installation Of AAMI Smart Meters In 8 Provinces Reaches 93.54 Percent (2023). 30. Annual Electric Power Industry Report, Form EIA-861.

ENTSO-E Transparency Platform. This hub provides real-time grid mix and hourly generator-level production data. Consumers in France can reconcile this data with hourly load data directly accessible through the Enedis platform. Similarly, the US EIA maintains a database called the Hourly Electric Grid Monitor which provides hourly generation and grid mix data across the country. Some regional grids in the US like California and Texas also provide hourly access to grid mix data through their websites, and tools like Grid Status and Electricity Maps help centralize data and provide hourly emissions factors.[31]

Hourly energy attribute certificates

In some cases, local EAC registries offer native functionality for minting and retiring hourly certificates. For example, PJM, the largest grid operator in the United States, operates a registry called PJM-GATS that now supports hourly EACs.[32] M-RETS, which covers several midwestern states home to significant amounts of wind power, has a similar offering. In the European Union, the 2023 Renewable Energy Directive III has encouraged EU states to begin issuing granular EACs, including by enabling sub-megawatt-hour measurement.[33]

In other cases, however, EAC registries do not support hourly vintages and firms will need to work with firms like Granular Energy and Flexidao to create and use hourly EACs, as in markets with lower data availability.

In cases where EACs are unavailable, primary hourly production data from contracted assets is typically available from the owners of assets contracted under PPAs. As in markets with lower data availability, in cases where the asset owner is not yet ready to provide the hourly data, production profiles can be used to supplement live production information in the event of data gaps.

Case study

Exhibit 7 below shows how a firm in France, a market with strong primary data availability, could implement GS2 accounting.

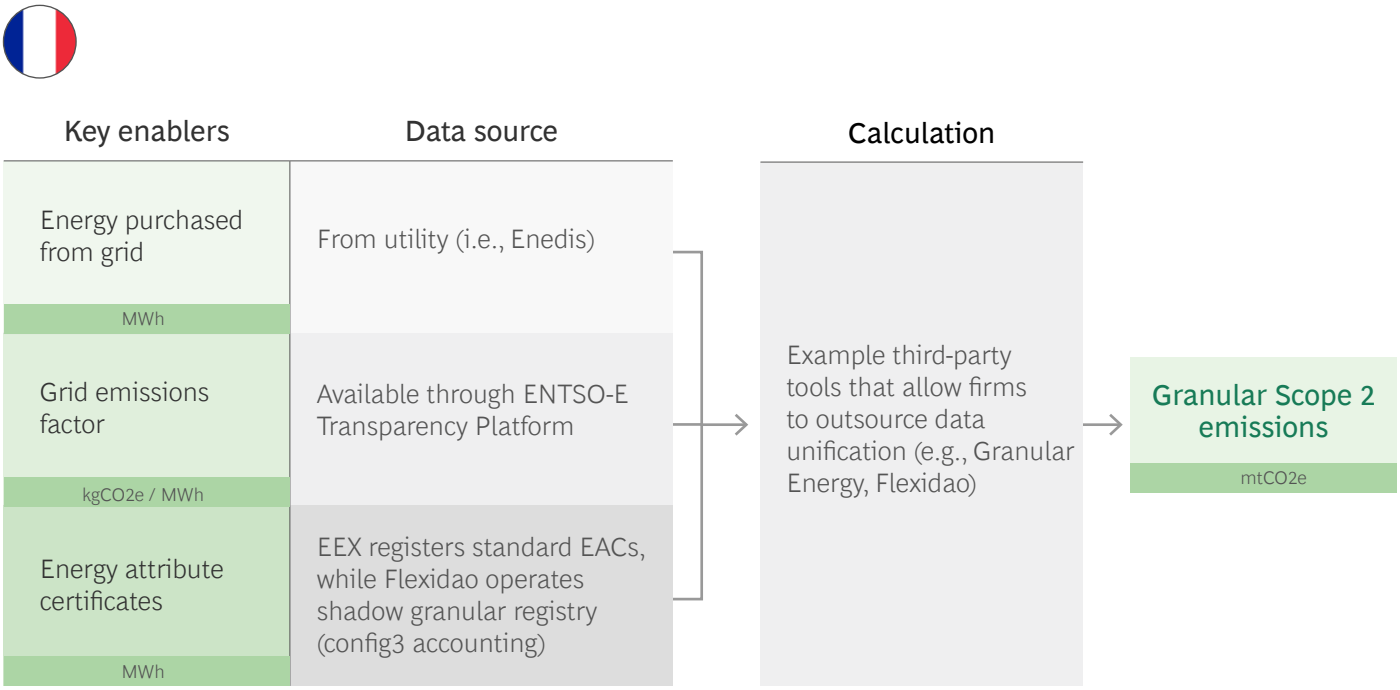


Exhibit 7: *Example GS2 pathway in France*

31. EIA Grid Electricity Monitor (2024). 32. PJM is in the process of improving functionality for hourly EACs, but they can be issued today.
33. Renewable Energy Directive III (2023).

Market roadmap

Implementing GS2 will lead to more precise accounting and using primary data is possible in these markets. Still, there are many opportunities for governments, utilities, and other stakeholders to make GS2 accounting easier.

Markets with data accessibility limitations

Utilities and governments can focus on improving the accessibility of data. The ease of access and standardization of data might vary across markets with high primary data availability, ranging from automatable pulls of consistent, standardized data to manual workflows with data that requires significant further processing.

In many parts of the US, for example, there are no universally adopted standards for formatting and delivering load data to customers. Only one-third of US utilities tracked by the Mission:data advocacy group participate in the Green Button standard, the industry standard.[34] Firms operating across several utilities will need multiple, often manually intensive workflows to adapt to different formats. Utilities might vary in data refresh frequency, data portability, third-party accessibility, or timestamping practices.

Utilities and regulators can also prioritize improving the **machine readability of data**. Some utilities, like APS and Alabama Power, may provide a central location for customers to manually download their monthly billing data but files are rarely, in a format for easy data processing and analysis. For example, load data is often delivered as a PDF document that must be parsed and converted. This prevents firms or their authorized agents from quickly ingesting and processing data. In some cases, software tools like Arcadia or UtilityAPI can help customers easily access data via application programming interfaces (APIs), but these tools often themselves must contend with difficulties pulling data from utilities.[35]

Reducing **delays in data availability** is also critical. In the UK, for example, it can take up to two years for the final settlement and validation of granular generation data, which has meaningful financial implications for energy producers and consumers who need proof of granularity on a rapid basis[36]. Final energy consumption data may only be available months after the actual consumption, and EACs may only be canceled a few times per year. While these delays are not insurmountable, they can cause long timelines for final reconciliation of emissions impact.

Finally, governments can also consider investing in the publication of residual mix data, which enhances the accuracy of both traditional and granular Scope 2 accounting by preventing double-counting of environmental attributes in grid emission factors. Residual mix calculations remove any claimed environmental attributes from the grid average emissions factors. Thus, firms can ensure they do not claim carbon-free energy if the carbon-free properties belong to others. The gap between residual mix and grid average is often small but can range widely; in the US in 2021, Green-e estimated that most grid regions had a less than 1% difference (based on traditional, annual EACs) between residual mix and grid average, but regions with high concentrations of voluntary EAC purchases like Texas saw gaps of around 20%.[37]

Granular carbon-free energy instruments

The initial deployment of hourly EACs in some registries is encouraging and a sign of things to come. Many registries have begun implementing support for hourly EACs, but these offerings are not yet universal. At the same time, these initial deployments demonstrate that hourly registries are possible. There are standards and resources available to improve speed and the cost of implementation; according to some estimates, many US registries could implement hourly tracking in 1-2 years.[38] Regulators and policymakers can support registries to ensure this transition continues at the current pace. In some cases, third-party providers are also building scalable solutions so that firms can trade and transact on hourly credits with relative ease. As registries develop their hourly offerings, they can also consider adding tooling for easier data accessibility. In some cases, registries like Grexel, M-RETS, and WREGIS already provide direct application programming interfaces (APIs) where consumers or commercial third parties can retrieve EAC data. These examples can be emulated to ensure greater standardization and access to data.

34. Green Button Explorer. 35. APIs enable easy communication between different software systems, generally without manual intervention.
36. Energy market investigation: Gas and electricity settlement and metering. 37. 2023 Green-e® Residual Mix Emissions Rates (2021 Data).
38. Readiness for hourly: U.S. renewable energy tracking systems (2023).

Conclusion

Granular Scope 2 (GS2) accounting offers companies across diverse markets the opportunity to improve the accuracy and credibility of their Scope 2 emissions reporting and drive deeper grid-wide decarbonization. GS2 accounting can be done at varying levels of precision in a wide set of markets today, but the tools and methods required to implement it will vary depending on the maturity of the market in which a company operates.

All companies can get started on the path toward more accurate GS2 accounting by **purchasing EACs that are generated on the same local grid** as a company's operations (geographic matching). For temporal matching, even in markets where data availability is limited, companies can still pursue GS2 accounting by relying on **credible hourly estimates**. Estimation tools such as load profiles and third-party models for grid emission factors, allow companies to improve the accuracy of their reporting compared to annual, volumetric accounting. In markets with primary data available, companies can perform a more precise form of GS2 accounting, often in a partially automatable way. This includes leveraging advanced metering infrastructure for hourly consumption data, centralized data portals for grid emission factors, and registries that support granular energy attribute certificates. However, even in some markets with strong primary data availability, there can be a lack of standardization and consistency in data access, requiring more effort to gather and process primary data.

As companies transition to GS2 accounting, they will need to update their approaches to emissions reporting. Firms will need greater engagement with their energy suppliers

and grid operators to better understand granular data. They also will likely evolve their energy procurement and consumption strategies and may need to adopt new technologies. However, this transition does not have to be navigated alone. A growing ecosystem of third-party service providers, including tools and services from companies like Flexidao, WattTime, Electricity Maps, and Granular Energy, is emerging to support this shift.

Importantly, firms must also recognize that their emissions baselines will likely increase since the more accurate and granular methodologies will no longer count power purchases and EACs that are not location and time matched. This reality must be communicated to company stakeholders who will need to be shown that, while GS2 accounting reveals additional work that must be done to decarbonize Scope 2 emissions, it also provides a more accurate picture of where firms stand in the first place.

Government policies will also play a crucial role in facilitating the transition to GS2 accounting. By improving advanced metering penetration, data accessibility and standardization, and load profile availability, governments can significantly ease the implementation of GS2, enabling higher accuracy in corporate carbon footprints and supporting broader decarbonization efforts.

Appendix

A.1 | Market assessment: Rubric

	Sub-components	Definition	Limited primary data availability	High data availability; limited accessibility	High accessibility
1 Energy purchased from grid	Access to metering	Penetration of advanced metering infrastructure (AMI) to enable collection of hourly consumption data	<20% AMI penetration	20-80% AMI penetration	80+% AMI penetration
	Standard time intervals	Temporal resolution of load data provided to consumers	Monthly or above	Daily	Hourly
	Ease of access	Ability for corporate buyers to access consumption data through centralized hub or API	No central portal for data access	Central portal for data access available but not machine readable	Data available in central portal and machine readable
	Data governance	Rules governing access to, privacy, and sharing of data	Third-party access to data not permitted	N/A	Third-party access to data permitted
2 Grid emissions factor	Grid emissions factor	Estimated grid emissions per unit of energy on the grid, based on actual power plant dispatch	Hourly grid mix not available (official or estimated)	Hourly emissions factor requires estimate	Hourly emissions factor published by balancing authority
3 Energy attributes certificates	Existence of registry	The existence of a local registry that adheres to market regulations and standards	No registry options available	Only international registries available	Local registry exists
	Hourly support	Capability of local registry to mint, track, and retire hourly EACs	Registry supports annual vintage	Registry supports monthly vintage	Registry supports hourly vintage
	Fractionality	Local registry support of EACs at a smaller-than-MWh unit level (e.g., kWh or Wh) to encourage market liquidity	Registry only supports MWh EACs	N/A	Registry supports sub-MWh EACs
	Trading support	Capability of a local registry to support the trading and transfer of EACs	Registry does not directly support trading	Registry supports API for third party traders	Registry supports native marketplace or API for 3P connect

A.2 | Summary of market assessment

Limited primary data availability

Data access:
- **Consumption:** <20% AMI penetration, no standard time intervals, no central portal for data access, third-party access to data is limited
- **Production:** Location, intensity, timestamp data not easily accessible
- **Grid factor:** Hourly grid mix data not publicly available or requires significant estimation

CFE instruments
- **EAC registries:** Do not exist OR only support annual vintages, only support MWh EACs, and do not support trading directly on the platform

High data availability; limited accessibility

Data access
- **Consumption:** 20-80% AMI penetration, standard time interval is daily, central data access but not machine readable, third-party access to data permitted
- **Production:** Location, intensity, timestamp data available but not necessarily in a central location
- **Grid factor:** Hourly grid mix data available but emissions factor requires estimate

CFE instruments
- **EAC registries:** local registries only support monthly or above vintages, only support MWh EACs, and do not support trading directly on the platform (but may support API for third party marketplaces)

High accessibility

Data access
- **Consumption:** 80+% AMI penetration, standard time interval is hourly or less, central data access and machine-readable, third-party access permitted
- **Production:** Location, intensity, timestamp data available in a central location
- **Grid factor:** Hourly grid mix data available with low latency directly from balancing authority

CFE instruments
- **EAC registries:** local registries can support hourly vintages or will soon, can support kWh EACs, and can support trading directly on the platform (as well as via API for third party marketplaces)

A.3 | Country by country scorecard: Set of graphics scoring each respective country/region we analyzed against the rubric to assess overall readiness

Europe

Enabler	Europe	France	Germany	Spain	UK
Energy purchased from grid[1]	Approx ~80% AMI penetration across EU. 30 m interval data standard.[2] Access to load profile estimation varies by region	AMI penetration: 92% resi & small comm. 30 min interval data standard. RTE does not provide building -specific loads	AMI penetration: <20% resi & small comm. Data interval depends on utility; at least daily[1]. BNG provides 11 load profiles with regional diff.	AMI penetration: 99%+. 60 min interval data. REE provides 12 load profiles with regional diff.	AMI penetration: 55%-57%. 30 min interval data. RTE does not provide building -specific loads
Grid emissions factor	ENTSO-E tool provides hourly grid mix	ENTSO-E tool provides hourly grid mix	ENTSO-E tool provides hourly grid mix	ENTSO-E tool provides hourly grid mix	Hourly grid mix through National Dashboard
Energy attributes certificates	The EECS is the standardized system for trading GOs across Europe[5]	GOs available on a monthly basis through French EEX registry	GOs available on daily or monthly basis on RNR registry. ETT piloting granular matching[4]	GOs available on daily or monthly basis through CNMC registry	REGOs available on an annual basis through national REGO scheme

Sources in bibliography

Status is in flux/changing

1. German AMI penetration was impacted by a temporary pause in the national rollout. Rollout was resumed in late 2023 2. Source: 77% penetration rate by 2024 (Benchmarking smart metering deployment in the EU-28 - Publications Office of the EU.) 3. ENTSO-E publishes grid-specific energy mix but does not publish an aggregate emissions factor. Tools like Electricity Maps provide the factor following additional analysis 4. Some German TOs are piloting the implementation of energy track and trace (ETT), a new standard for GOs that accounts for hourly matching and location matching 5. The European Electricity Market Directive (Directive 2019/944) and the Regulation on the internal market for electricity (Regulation 2019/943), provide the legal framework for market structure and interoperability

United States

Enabler	United States	TEXAS	California	Virginia/PJM	APS
Energy purchased from grid[1]	Standardized data access w. Green Button. Historical data is easily accessible[1]. DOE provides ResStock and ComStock profiles for load est.	AMI penetration: 68% commercial, 54% residential data at 15 minute intervals	AMI penetration: 75% commercial, 64% residence data at 15 min intervals	AMI penetration: 36% commercial, 43% residence, 30 min interval data	AMI penetration: 51% commercial, 41% residence, 60 min interval data
Grid emissions factor	US EIA provides hourly grid mix	US EIA provides hourly grid mix	US EIA provides hourly grid mix	US EIA provides hourly grid mix	US EIA provides hourly grid mix
Energy attributes certificates	Some registries (like M-RETS) have hourly capabilities while others only support annual vintage	ERCOT registry does not provide T-EACs	WREGIS does not currently support T-EACs[2]	PJM GATS currently integrating T-EACs	WREGIS does not currently support T-EACs[2]

Sources in bibliography

Status is in flux/changing

1. US electric utilities have approximately 119 million advanced (smart) metering infrastructure (AMI) installations. This is equivalent to approximately 72% of total electric meter installations. Green Button standard requires 15m interval data and is stored in a standardized format for authorized parties to access 2. Every investor-owned utility (PG&E, SDG&E, SCE, etc.) in CAISO provides the option of a green tariff to procure some or all of a firm's energy from renewable sources

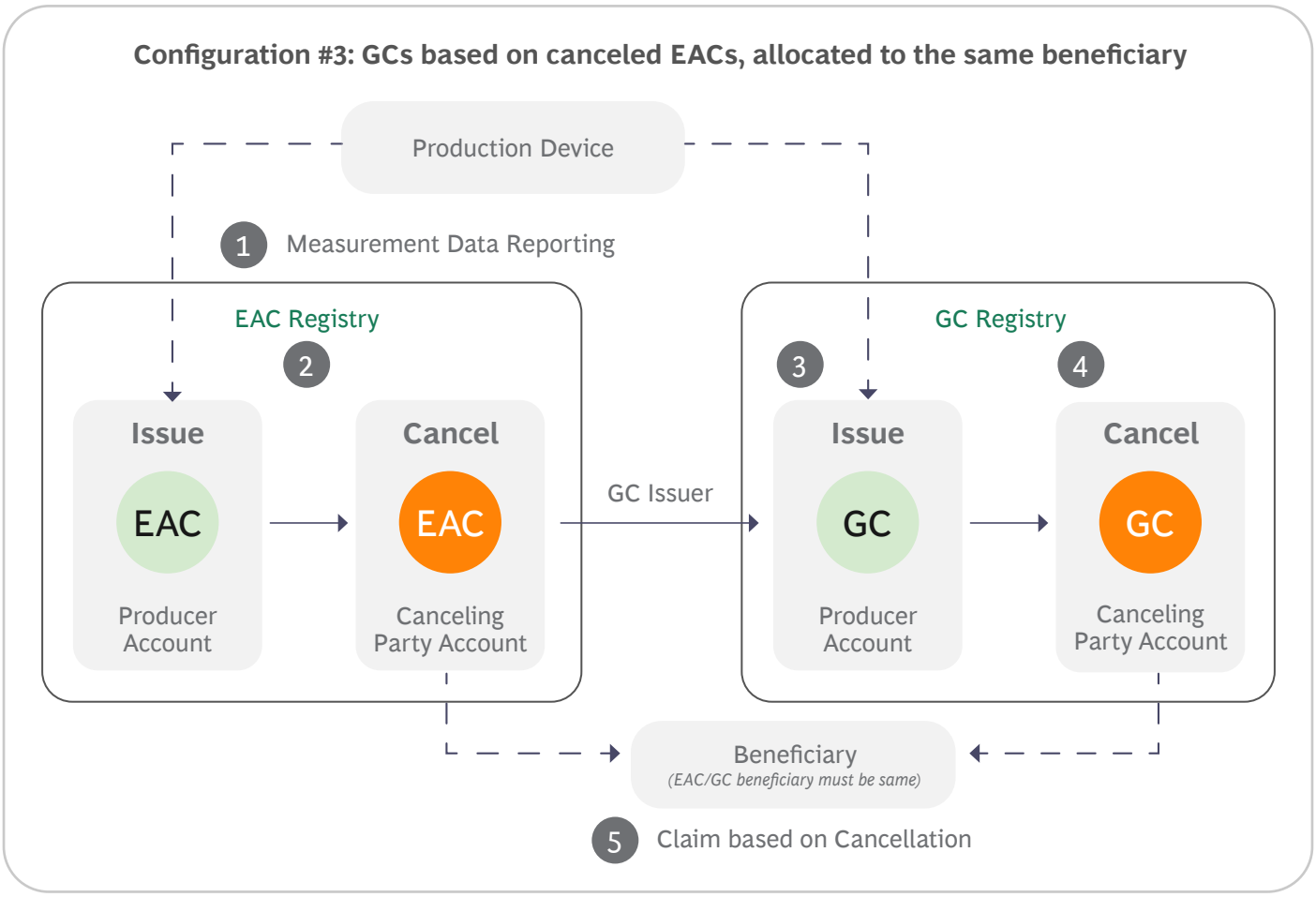
Asia-Pacific

Enabler	India	Indonesia
Energy purchased from grid[1]	Penetration of AMI low but increasing (12m today, 250m by 2025). 15-30 min intervals accessible[1]. No agreed upon load estimation standards	<10% penetration but gov investment driving growth. Data interval standards are still evolving.[2] No fully agreed upon load estimation standards
Grid emissions factor	Hourly grid mix must be estimated (e.g., available through Electricity Maps)	Little to no disclosure on hourly grid mix
Energy attributes certificates	Registry supports voluntary EACs but not hourly	EACs available on daily or monthly basis through PLN registry

Sources in bibliography

1. India currently has 12 million smart meters installed, and the national Smart Meter Programme aims to support the install of 250 million smart meters across india by 2025.

B.1 | Explanation of EnergyTag configuration 3 standard[39]



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"Configuration 3" refers to Granular Crediting Scheme based on canceled EACs where (sub)hourly matching of production Attributes to consumption can take place in a harmonized way: the issuance of a special type of GCs that interact with the EAC system in a way that prevents Double Counting and double issuing risks of the represented energy.

1. **Production Measurement:** The Production Device generates physical energy. The Measurement Body measures each unit of eligible energy and reports it to the EAC Issuing Body and GC Issuer.

2. **EAC Issuance & Cancellation:** Based on this measurement data, the EAC Issuing Body Issues EACs to the Account of an Account Holder. This Account Holder may be the Producer or its assigned agent. The EAC Issuer is responsible for registering EAC ownership and guaranteeing the uniqueness of the EAC. Ultimately, this EAC is then canceled in the name of a specific beneficiary in a process completely independent of GC Issuance.

3. **GC Issuance:** A "Config-3 GC Issuer" takes canceled EACs as an input, connects them with (sub)hourly production data of the represented energy, measured from the same meter where possible, and issues not-transferable GCs. This is subject to the conditions that the total energy volume represented by canceled EACs equals the volume of (sub)hourly measured production and that the beneficiary of GCs is the same beneficiary of canceled EACs. The issued GCs must have unique IDs that relate to the corresponding EACs.

4. **GC Cancellation:** Cancellation occurs immediately upon GC Issuance and for the same Beneficiary as the party stated in the EAC cancellation statement.

39. EnergyTag Granular Certificate Scheme Standard (2024).

Glossary of terms

Advanced metering infrastructure (AMI): According to the US Department of Energy, AMI is “an integrated system of smart meters, communications networks, and data management systems that enables two-way communication between utilities and customers.”

(Time-based) Energy attribute certificates, or granular certificates ((T)-EACs/GCs): An Energy Attribute Certificate (EAC) is a market-based instrument that certifies the ownership of the environmental attributes associated with one megawatt-hour (MWh) of electricity generated from renewable energy sources. A Granular Certificate, also known as a Time-based Energy Attribute Certificate (T-EAC) is a more granular type of EAC that provides detailed information about the time of generation of renewable energy.

Carbon-free energy (CFE): The US EPA defines carbon pollution-free energy as "energy produced from resources that generate no carbon emissions", including marine energy, solar, wind, hydrokinetic and hydroelectric power, geothermal, nuclear, renewable (green) hydrogen, and fossil generation with carbon capture that meets EPA requirements.

Granular Scope 2 (GS2) accounting: Granular Scope 2 accounting is a method for tracking and reporting Scope 2 emissions. This approach focuses on providing more detailed and accurate data on the emissions related to specific periods and locations of energy consumption. Granularity has two characteristics:

1. **Locational (geographic) granularity:** Granular accounting considers the specific locations (e.g., same electric grid) of both the energy generation and consumption. By doing so, it captures the variations in emissions intensity based on the local grid mix and the specific sources of electricity generation.
2. **Temporal granularity:** Instead of using annual or monthly averages, granular accounting involves tracking electricity consumption and the corresponding emissions on a more frequent basis, such as hourly or even in smaller time increments. This allows organizations to understand the specific emissions impact of their electricity use at different times of the day.

Greenhouse Gas Protocol (GHG Protocol): GHGP is a comprehensive global framework for measuring and managing GHG emissions from private and public sector operations, value chains, and mitigation actions. The GHGP was developed through a partnership between the World Resources Institute and the World Business Council for Sustainable Development.

(Virtual) power purchase agreements ((V)PPAs): A PPA is a long-term contract between an electricity generator and purchaser. A VPPA is a financial contract between a generator and purchaser that aims to support the development of renewable energy projects and manage the buyer's electricity costs. Unlike traditional PPAs, VPPAs do not involve the physical delivery of electricity.

Scope 2 accounting: The Greenhouse Gas Protocol defines Scope 2 accounting as the reporting of greenhouse gas (GHG) emissions from the consumption of purchased electricity, steam, heating, and cooling. These emissions are generated at the facility where the energy is produced, not where it is consumed.

EU Market Readiness Assessment

Agency for the Cooperation of Energy Regulators (ACER). (2023). *Energy retail and consumer protection.* ACER. Retrieved from https://www.acer.europa.eu/sites/default/files/documents/Publications/2023_MMR_Energy_Retail_Consumer_Protection.pdf

BloombergNEF. (2023). *Corporate clean power buying grew 12% to new record in 2023, according to BloombergNEF.* BloombergNEF. Retrieved from https://about.bnef.com/blog/corporate-clean-power-buying-grew-12-to-new-record-in-2023-according-to-bloombergnef/

BMWK. (2024). *Smart metering.* BMWK. Retrieved from https://www.bmwk.de/Redaktion/FR/Downloads/smart-metering.pdf?__blob=publicationFile&v=1

Bundesnetzagentur. (2024). *Publication.* Bundesnetzagentur. Retrieved from https://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Sachgebiete/Energie/Unternehmen_Institutionen/NetzentwicklungUndSmartGrid/Stellungnahme_Digitalisierung_Energiewende.pdf?__blob=publicationFile&v=1

Clou Global. (2019). *Real-time data for smart meters and common praxis*. Clou Global. Retrieved from https://clouglobal.com/real-time-data-for-smart-meters-and-common-praxis/

Deloitte. (2023). *Market reform Germany*. Deloitte. Retrieved from https://www2.deloitte.com/content/dam/Deloitte/global/Documents/Energy-and-Resources/gx-er-market-reform-germany.pdf

Deloitte. (2023). *Market reform Spain*. Deloitte. Retrieved from https://www2.deloitte.com/content/dam/Deloitte/global/Documents/Energy-and-Resources/gx-er-market-reform-spain.pdf

Deloitte. (2023). *Market reform UK*. Deloitte. Retrieved from https://www2.deloitte.com/content/dam/Deloitte/global/Documents/Energy-and-Resources/gx-er-market-reform-uk.pdf

Electricity Maps. (2024). *Map*. Retrieved from https://app.electricitymaps.com/map

Endesa. (2018). *The electrical grid: Smart meter.* Endesa. Retrieved from https://www.endesa.com/en/the-e-face/electrical-grid/smart-meter

Energy Monitor. (2023). *Spain leads the European corporate renewable PPA market*. Energy Monitor. Retrieved from https://www.energymonitor.ai/corporate-strategy/data-insight-spain-leads-the-european-corporate-renewable-ppa-market/

EnergyTag. (2023). *EnergyTag whitepaper.* EnergyTag. Retrieved from https://energytag.org/wp-content/uploads/2023/09/EnergyTag-Whitepaper.pdf

Energy Track and Trace. (2023). *Coordinating ETT with the EU GO scheme*. Energy Track and Trace. Retrieved from https://energytrackandtrace.com/wp-content/uploads/2023/11/2022-12-Paper-Coordinating-ETT-with-the-EU-GO-scheme.pdf

Energy Trend. (2024). *Germany emerged as the second, into effect in January 2023*. Energy Trend. Retrieved from https://www.energytrend.com/news/20240418-46533.html

Euractiv. (2023). *Leak: France wins recognition for nuclear in EU's green hydrogen rules*. Euractiv. Retrieved from https://www.euractiv.com/section/energy-environment/news/leak-france-wins-recognition-for-nuclear-in-eus-green-hydrogen-rules/

European Commission. (2024). *Document HDS-022*. European Commission. Retrieved from https://ec.europa.eu/research/participants/documents/dowloadPublic?documentIds=080166e5aba985df&appId=PPGMS

Forschungsstelle für Energiewirtschaft e.V. (FFE). (2024). *The smart meter rollout in Germany and Europe*. FFE. Retrieved from https://www.ffe.de/en/publications/the-smart-meter-rollout-in-germany-and-europe/

Future Energy GO. (2018). *PPA contract architectures. Future Energy GO*. Retrieved from https://futureenergygo.com/ppa-contract-architectures/

German Association of Energy and Water Industries (2023). *BDEW Standard Load Profiles in Germany*. Retrieved from https://cran.r-project.org/web/packages/standardlastprofile/standardlastprofile.pdf

Greenhouse Gas Protocol. (2023). *Scope 2 survey feedback draft summary.* Greenhouse Gas Protocol. Retrieved from https://ghgprotocol.org/sites/default/files/2023-07/Scope%202%20Survey%20Feedback%20Draft%20Summary.pdf

Iberdrola. (2017). *Iberdrola installed over million smart meters in Spain*. Iberdrola. Retrieved from https://www.iberdrola.com/press-room/news/detail/iberdrola-installed-over-million-smart-meters-spain

Iberdrola. (2024). *Smart meters*. Iberdrola. Retrieved from https://www.iberdrola.com/innovation/smart-meters

Jones Day. (2022, May). *France regulates the use of carbon neutrality claims in advertisements.* Jones Day. Retrieved from https://www.jonesday.com/en/insights/2022/05/france-regulates-the-use-of-carbon-neutrality-claims-in-advertisements

Landis+Gyr. (2014). *AMI documentation*. Landis+Gyr. Retrieved from https://www.landisgyr.com/files/efiles/2014/SMH/LandisGyrEmea_2014_Sisus_Digi_KM_Final_v11.pdf

Montel News. (2023). *Hourly matching could boost GO value by 33%: Aurora*. Montel News. Retrieved from https://montelnews.com/news/58a78aa8-a1fa-4c17-9185-7f3ad7d030dc/hourly-matching-could-boost-go-value-by-33-aurora

NVE. (2023). *Norway's smart meter journey completes as 99% of Norwegians now have a smart meter*. NVE. Retrieved from https://www.nve.no/norwegian-energy-regulatory-authority/nve-rme-news/latest-news/norways-smart-meter-journey-completes-as-99-of-norwegians-now-have-a-smart-meter/

NVE. (2023). *Smart metering (AMS)*. NVE. Retrieved from https://www.nve.no/norwegian-energy-regulatory-authority/retail-market/smart-metering-ams/

Pexapark. (2024). *PPA market report 2024*. Pexapark. Retrieved from https://pexapark.com/ppa-market-report-2024/

Regulatory Assistance Project (RAP). (2023). *Mapping metering data access in Europe.* RAP. Retrieved from https://assets-global.website-files.com/5d694b78452430ff30c-7b546/615b2130aa08193cfdb16cc5_Mapping%20metering%20data%20access%20in%20Europe.pdf

Ruhnau, Schiele. (2023). *Flexible green hydrogen: The effect of relaxing simultaneity requirements on project design, economics, and power sector emissions*. Retrieved from https://www.sciencedirect.com/science/article/pii/S0301421523003488?ref=pdf_download&fr=RR-2&rr=89af1d86bfd5f9f9

S&P Global Market Intelligence. (2022). *Despite turmoil, project finance remains keen on offshore wind*. S&P Global Market Intelligence. Retrieved from https://www.spglobal.com/marketintelligence/en/news-insights/blog/despite-turmoil-project-finance-remains-keen-on-offshore-wind

Smart Energy GB. (2024). *Data access and privacy*. Smart Energy GB. Retrieved from https://www.smartenergygb.org/about-smart-meters/smart-facts/data-access-and-privacy

Smart Energy International. (2023). *Norway's smart meter rollout pronounced complete*. Smart Energy International. Retrieved from https://www.smart-energy.com/regional-news/europe-uk/norways-smart-meter-rollout-pronounced-complete/

Smart Energy International. (2023). *Smart metering progresses in Europe, but 11 countries have barely started.* Smart Energy International. Retrieved from *https://www.smart-energy.com/regional-news/europe-uk/smart-metering-progresses-in-europe-but-11-countries-have-barely-started/*

Smart Energy International. Retrieved from https://www.smart-energy.com/regional-news/europe-uk/smart-metering-progresses-in-europe-but-11-countries-have-barely-started/

Smart Energy International. (2024). *Germany mandates smart metering from 2025*. Smart Energy International. Retrieved from https://www.smart-energy.com/regional-news/europe-uk/germany-mandates-smart-metering-from-2025/

US Market Readiness Assessment

American Public Power Association. (2022). *Electricity and hydrogen provisions*. Retrieved from https://ww2.arb.ca.gov/resources/documents/lcfs-electricity-and-hydrogen-provisions

CalCCA. (2024). *CCA map*. Retrieved from https://cal-cca.org/cca-map/

California Air Resources Board. (2024). *LCFS electricity and hydrogen provisions*. Retrieved from https://ww2.arb.ca.gov/resources/documents/lcfs-electricity-and-hydrogen-provisions

California Air Resources Board. (2024). *LCFS guidance 19-01*. Retrieved from https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/guidance/lcfsguidance_19-01.pdf

Dominion Energy. (2024). *Detailed energy use*. Retrieved from https://www.dominionenergy.com/projects-and-facilities/electric-projects/smart-meter-upgrades/detailed-energy-use

Dominion Energy. (2024). *Smart meter FAQs*. Retrieved from https://www.dominionenergy.com/projects-and-facilities/electric-projects/smart-meter-upgrades/smart-meter-faqs

Energy Information Administration (EIA). (2022). *Residential smart meter penetration rates*. Retrieved from https://www.eia.gov/todayinenergy/detail.php?id=34012

Energy Information Administration (EIA). (2023). *Electricity metering*. Retrieved from https://www.eia.gov/tools/faqs/faq.php?id=108&t=3

Energy Information Administration (EIA). (2024). *Annual energy outlook 2024*. Retrieved from https://www.eia.gov/electricity/annual/html/epa_10_05.html

Environmental Protection Agency (EPA). (2024). *EGRID2022 technical guide.* Retrieved from https://www.epa.gov/system/files/documents/2024-01/egrid2022_technical_guide.pdf

Federal Energy Regulatory Commission (FERC). (2022). *Assessment of demand response and advanced metering.* Retrieved from https://www.ferc.gov/sites/default/files/2022-12/2022%20Assessment%20of%20Demand%20Response%20and%20Advanced%20Metering_0.pdf

KS Law. (2024). *Guidance on section 45V clean hydrogen production tax credit*. Retrieved from https://www.kslaw.com/news-and-insights/guidance-on-section-45v-clean-hydrogen-production-tax-credit

Mission Data. (2017). *5 things you don't know about smart meter Texas*. Retrieved from https://www.missiondata.io/news/2017/9/22/5-things-you-dont-know-about-smart-meter-texas

Nord Pool Group. (2023). *Whitepaper May 2023*. Retrieved from https://www.nordpoolgroup.com/49b69a/globalassets/download-center/whitepaper/whitepaper-may-2023.pdf

Pacific Gas and Electric Company (PG&E). (2023). *SmartMeter™ system upgrades*. Retrieved from https://www.pge.com/en/save-energy-and-money/energy-saving-programs/smartmeter.html

Public Utilities Commission of Nevada (PUCN). (2024). *Smart meters non-residential*. Retrieved from https://puc.nv.gov/FAQ/Smart_Meters_Non_Residential/

RECS. (2024). *Public information*. Retrieved from https://recs.org/public-information/

Resource Solutions. (2023). *Readiness for hourly U.S. renewable energy tracking systems*. Retrieved from https://resource-solutions.org/wp-content/uploads/2023/06/Readiness-for-Hourly-U.S.-Renewable-Energy-Tracking-Systems.pdf

SlashPlan. (2023). *Smart meter Texas: Everything you need to know*. Retrieved from https://www.slashplan.com/smart-meter-texas-everything-you-need-to-know/

Sustain.Life. (2019). *California SB 253*. Retrieved from https://www.sustain.life/blog/california-sb-253

U.S. Department of Energy (DOE). (2024). *Alternative fuels data center.* Retrieved from https://afdc.energy.gov/laws/6308

U.S. Securities and Exchange Commission (SEC). (2024). *Press release 2024-31*. Retrieved from https://www.sec.gov/news/press-release/2024-31

White House. (2024, May 28). *Fact sheet: Biden-Harris administration announces new principles for high-integrity voluntary carbon markets*. Retrieved from https://www.whitehouse.gov/briefing-room/statements-releases/2024/05/28/fact-sheet-biden-harris-administration-announces-new-principles-for-high-integrity-voluntary-carbon-markets/

India Market Readiness Assessment

ADB. (2022). *Renewable energy certificates trading in India: A decade in review*. Retrieved from https://www.adb.org/publications/renewable-energy-certificates-trading-in-india-a-decade-in-review

Electricity Maps. (2024). *IN estimation model*. Retrieved from https://github.com/electricitymaps/electricitymaps-contrib/wiki/IN-estimation-model

Harvard Belfer Center. (2023). *India: New global green hydrogen powerhouse*. Retrieved from https://www.belfercenter.org/publication/india-new-global-green-hydrogen-powerhouse

JSA. (2024). *Green hydrogen standard for India*. Retrieved from https://jsalaw.com

Power Line. (2023, July 10). *Rapid uptake: Increased adoption of smart meters in India*. Power Line. Retrieved from https://powerline.net.in/2023/07/10/rapid-uptake-increased-adoption-of-smart-meters-in-india/

ReNew Power. (2024). *Business-to-business solutions for corporate PPA: Our offerings*. ReNew Power. Retrieved from https://renewpower.in/business-to-business-solutions-for-corporate-ppa/our-offerings/

S&P Global Commodity Insights. (2023). *Buying the right renewable energy certificates in India*. S&P Global Commodity Insights. Retrieved from https://www.spglobal.com/commodityinsights/en/ci/research-analysis/buying-the-right-renewable-energy-certificates-in-india.html

SGS. (2023). *BRSR report*. Retrieved from https://www.sgs.com/-/media/sgscorp/documents/corporate/white-papers/sgs-in-lc-brsr-report-2312-lr-en.cdn.en-IN.pdf

Statista. (n.d.). *Smart meters installed by leading state or territory in India*. Retrieved from https://www.statista.com/statistics/1182945/india-smart-meters-installed-by-leading-state-or-territory/

WBCSD. (2023, October). *Corporate renewable PPAs in India – Market and policy update (January 2021)*. Retrieved from https://www.wbcsd.org/wp-content/uploads/2023/10/Corporate-Renewable-PPAs-in-India-%E2%80%93-market-and-policy-update-January-2021.pdf

WBCSD. (2023, November). *Corporate renewable PPAs in India: A market policy update (December 2019)*. Retrieved from https://www.wbcsd.org/wp-content/uploads/2023/11/Corporate-Renewable-PPAs-in-India-a-market-policy-update-December-2019.pdf

Indonesia Market Readiness Assessment

APERC. (2023). *Renewable energy certificates (RECs) in six APEC Southeast Asia economies*. Retrieved from https://aperc.or.jp/file/2023/7/19/Renewable_Energy_Certificates-RECs-in_Six_APEC_Southeast_Asia_Economies.pdf

Climate Transparency. (2022). *CT2022 Indonesia*. Retrieved from https://www.climate-transparency.org/wp-content/uploads/2022/10/CT2022-Indonesia-Web.pdf

Energy News. (2023). I*ndonesia plans $25.2 bln investment in green hydrogen*. Energy News. Retrieved from https://energynews.biz/indonesia-plans-25-2bln-investment-in-green-hydrogen/

Global Compliance News. (2021, October 9). *Indonesia corporate PPAs*. Global Compliance News. Retrieved from https://www.globalcompliancenews.com/2021/10/09/indonesia-corporate-ppas290921/

GSMA. (2023). *IoT and essential utility services: Indonesia market case study*. Retrieved from https://www.gsma.com/solutions-and-impact/connectivity-for-good/mobile-for-development/wp-content/uploads/2023/04/IoT-and-Essential-Utility-Services-Indonesia-market-case-study.pdf

IoT Analytics. (n.d.). *Smart meter adoption*. Retrieved from https://iot-analytics.com/smart-meter-adoption/

Jakarta Post. (2020, June 17). *PLN to install 79 million smart meters in Indonesia after billing fiasco*. Jakarta Post. Retrieved from https://www.thejakartapost.com/news/2020/06/17/pln-to-install-79-million-smart-meters-in-indonesia-after-billing-fiasco.html

OECD. (2023) *Indonesia ETS FGD series summary report*. OECD. Retrieved from https://www.oecd.org/environment/cc/cefim/indonesia/Indonesia-ETS-FGD-series-summary-report.pdf

PLN. (2022). *Consolidated ESG Performance Report*. Retrieved from https://web.pln.co.id/statics/uploads/2024/02/ESG-Performance-Report-2022.pdf

PwC. (2023). *The most recent state and future directions of sustainability reporting in Indonesia*. PwC. Retrieved from https://www.pwc.com/id/en/media-centre/press-release/2023/english/the-most-recent-state-and-future-directions-of-sustainability-reporting-indonesia.html

WBCSD. (2019, December). *Corporate renewable PPAs in India: A market policy update (December 2019)*. Retrieved from https://www.wbcsd.org/wp-content/uploads/2023/11/Corporate-Renewable-PPAs-in-India-a-market-policy-update-December-2019.pdf

WBCSD. (2021, January). *Corporate renewable PPAs in India – Market and policy update (January 2021)*. Retrieved from https://www.wbcsd.org/wp-content/uploads/2023/10/Corporate-Renewable-PPAs-in-India-%E2%80%93-market-and-policy-update-January-2021.pdf

World Resources Institute (WRI). (2023). *Indonesian companies accelerate industrial decarbonization*. WRI. Retrieved from https://www.wri.org/outcomes/indonesian-companies-accelerate-industrial-decarbonization