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Automated visual display of carbon-free electricity profile at high temporal resolution

ABSTRACT

Many energy consumers such as corporations and retail customers purchase carbon-free electricity, e.g., solar, wind, hydroelectricity, etc. These energy consumers often lack an easy or insightful way to visualize the role of carbon-free electricity in the context of their overall energy use, especially in fine-grain temporal detail, e.g., on an hourly or sub-hourly basis. This disclosure describes techniques that generate, at high temporal resolution, an automated, data-driven, visual representation of an energy consumer's carbon-free electricity profile. The visual representation, which can be in the form of a heat map, conveys the relative amounts of carbon-based and carbon-free components in the consumer's energy portfolio.

KEYWORDS

- carbon-free energy (CFE)
- electricity profile
- heat map
- data visualization

BACKGROUND

Many energy consumers such as corporations and retail customers purchase carbon-free electricity, e.g., solar, wind, hydroelectricity, etc. These energy consumers often lack an easy or insightful way to visualize the role of carbon-free electricity in the context of their overall energy use, especially in fine-grain temporal detail, e.g., on an hourly or sub-hourly basis. Some reasons for visualizing one's electricity profile are:

- legal mandates to make progress towards low-carbon operations;
- concern for the environment;

- financial and risk assessment of an energy strategy;
- corporate social responsibility policies that require or encourage movement to CFE;
- requirements to monitor and to report on their energy footprint to stakeholders; etc.

Carbon-free electricity production and consumption are often reported and evaluated at a low-resolution time scale, such as monthly or annually. Even when the impact of carbon-free electricity is evaluated at a high-resolution time scale, e.g., hourly, it is often not visualized in a compelling or an insightful way. For example, an individual may only have easy access to a bar chart or line chart that shows hourly carbon-free electricity production. If energy consumers could easily obtain a more insightful and automated way to visualize their purchase and consumption of carbon-free electricity at high temporal resolution, they would gain a clearer understanding of their progress toward using around-the-clock carbon-free electricity.

DESCRIPTION

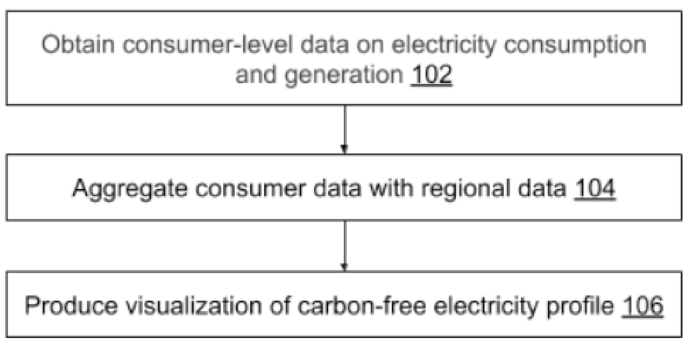

Fig. 1: Automated visual display of CFE profile

Fig. 1 illustrates the automated generation of carbon-free vs. carbon-based electricity profile, per techniques of this disclosure. Consumers securely provide their energy consumption data (102), e.g., to an interactive website or software, that implements the techniques of this disclosure. The uploaded data can comprise the consumer's hourly electricity consumption, e.g., for the total hours (e.g., 8,760 hours) of a particular year, for any other number of hours or time-interval, etc. Hourly electricity consumption is the number of kilowatt-hours the consumer uses per hour. In some cases, consumers generate their own energy, e.g., using on-site power generation. In some cases, the consumer has a contractual claim to off-site CFE sources in their region, e.g., large-scale solar or wind farms etc. In such cases, electricity generation data is also uploaded (102). Sub-hourly data is also accepted for upload. The energy generation data may come from metered data acquired from the relevant generation site; if that data is unavailable, then projected generation numbers can be synthetically derived from weather data, e.g., wind speeds or incident solar radiation intensity, which is strongly correlated with renewable energy output. Data upload can be facilitated by standard industry-wide protocols, e.g., the Green Button energy data-transfer protocol, or by other protocols.

If the energy consumer does not have digital data easily available, they can conceivably upload an image of their energy bills or other energy documentation, e.g., a home energy report. Such documents can be automatically analyzed to extract relevant energy usage or energy production data. If energy data of only relatively low resolution is available, e.g., monthly or weekly data, the disclosed techniques can interpolate probable hourly values. In some cases, energy data for a consumer or government entity is publicly available; in such cases, that data can be directly linked from an open dataset. If no energy data is available for an energy consumer, then such a consumer can choose derived energy data computations that are based on other generally known inputs such as building square footage, zip code, etc.

After consumer data is uploaded or otherwise obtained, either partially or fully, the disclosed techniques aggregate that data with regional data about the broader power grid (104). In particular, the disclosed techniques integrate, as an external data input, the hourly or sub-hourly fraction of regional grid electricity supply that is generated by carbon-free sources. In this context, regional grid electricity refers to the prevailing electricity supply that is distributed from the electric grid to consumer sites in the region. Such hourly data can be directly sourced from regional electric grid operators, e.g. hourly data is available from Regional Transmission Organizations, Independent System Operators, or balancing authorities. In other cases, this hourly grid data is constructed by summing across generation and/or emissions data from individual power plants, where the data is obtained, for example, from government energy or environmental protection departments.

For calculation and visualization purposes, the data on grid supply mix is only relevant for hours (or sub-hourly periods) in which a facility's electricity consumption is less than 100% matched on an hourly basis with its own contracted carbon-free energy generation, e.g., on-site or same-grid generation. For example, in a given hour, if a facility (e.g. data center) makes renewable energy purchases in its grid region that are equal to or greater than the facility's hourly electricity load, then the facility is already matched 100% with CFE sources for that hour; in such a case, grid-supply mix data need not be factored into the calculation. However, if the facility's on-site and off-site contracted renewable generation is not sufficient in a given hour to match the load, the remainder electricity is attributed to the region's grid mix. This methodology may be adjusted or customized by the user.

After data aggregation and calculation of hourly carbon-free electricity profile, disclosed techniques automatically produce a visualization (106) of the carbon-free electricity profile, e.g., in the form of a heat map. An example set of heat maps is illustrated in Fig. 2.

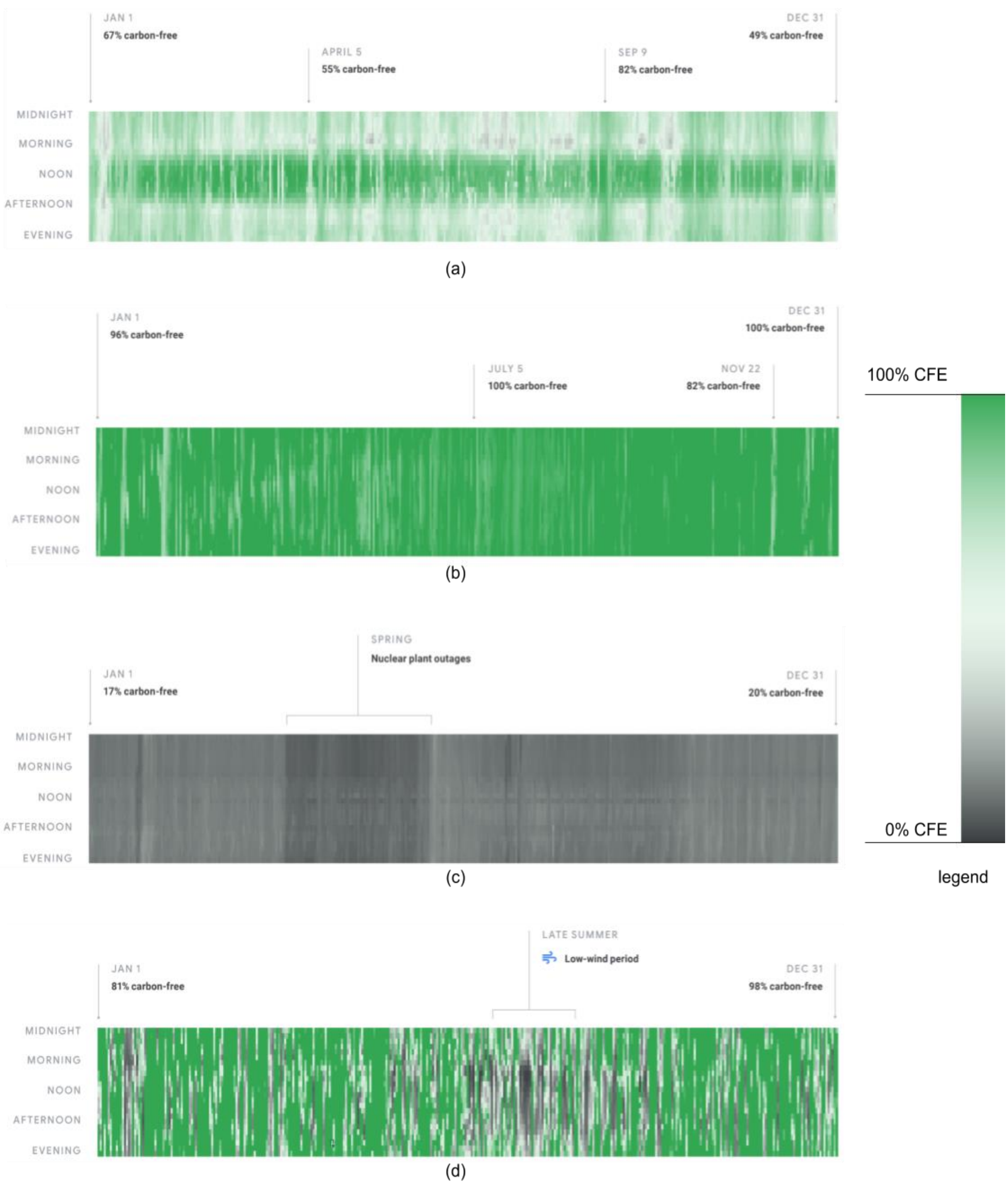

Fig. 2: Visualizations of electricity profile

Fig. 2 illustrates example visualizations of electricity profiles, per techniques of this disclosure. In Fig. 2, the electricity profile is displayed as a heat map, with a pixel of the heat map representing the fraction of electricity associated with CFE sources during that hour. An example formula that can be used to compute the fraction of CFE electricity for a facility is as follows:

$$\text{Hourly CFE fraction} = \frac{(\text{Consumed contracted CFE} + \text{Grid CFE })}{\text{Consumption by facility}}$$

Other formulas can be used to define the hourly CFE, e.g., it can be defined as the number of kilograms of carbon dioxide emissions per hour, associated with a given facility's electricity sourcing and behavior. If the electricity is completely fossil-fuel based (0% CFE) then the pixel is colored black; if the electricity is completely CFE-based, then the pixel is colored green. Intermediate electricity mixes are colored using colors between black and green, as shown in the legend. The Y-axis of each heat map of Fig. 2 represents the twenty-four hours of the day, while the X-axis represents the three hundred and sixty-five days of the year. In this manner, all 8,760 hours of the year are compactly represented in a visually informative manner at high temporal resolution.

For example, it is evident from a quick perusal of Fig. 2 that the energy consumer in Fig. 2(a) is mid-way through a transition from carbon-based to carbon-free energy, and that the hours of the day around noon were the most carbon-free. Similarly, it is evident that the energy consumer of Fig. 2(b) is nearly 100% carbon-free for most hours of the year, while the energy consumer of Fig. 2(c) is yet to make major progress towards carbon-free energy. The energy consumer of Fig. 2(d) is predominantly free of carbon during the majority of hours, save the period of late summer.

The regions of the heat map can be used to correlate energy profile with events on the energy grid, e.g., during spring, the heat map of Fig. 2(c) darkened, corresponding to a nuclear plant outage. Similarly, during the late summer, the heat map of Fig. 2(d) darkened, corresponding to low wind velocity.

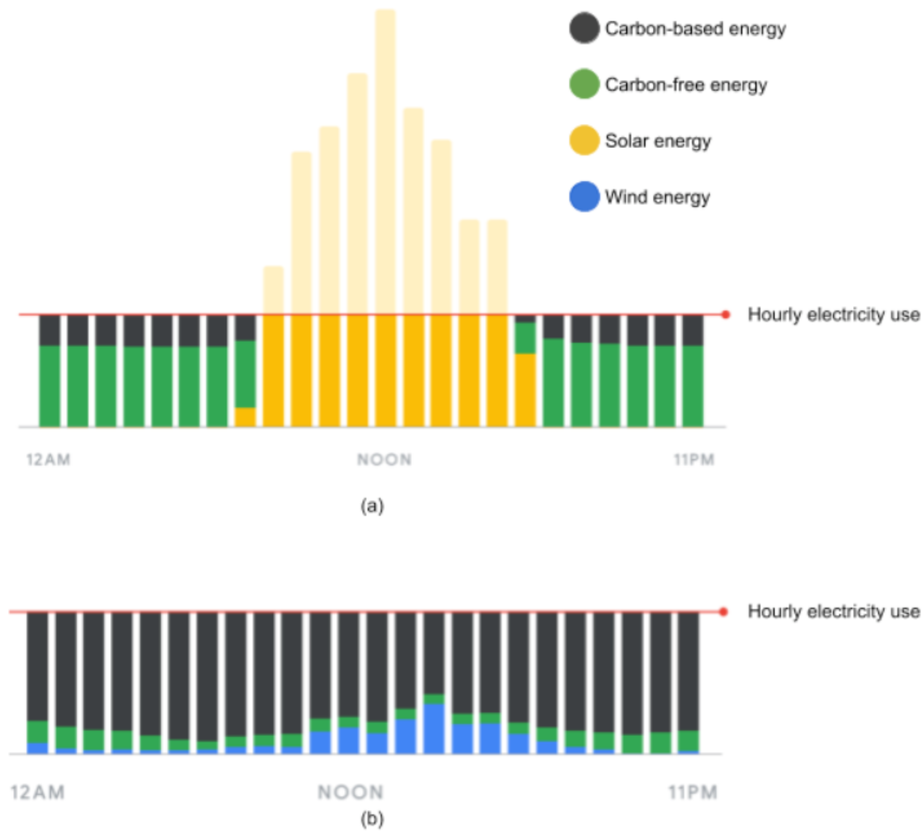

Fig. 3: Visualizations of electricity profile

Fig. 3 illustrates related visualizations that can be produced by the disclosed techniques. Fig. 3(a) illustrates visually that solar CFE is produced in excess of facility consumption during the midday hours of a certain day, while during other hours of that day the consumer's energy profile entailed some amount of carbon-based energy. Fig. 3(b) indicates a day of the year when carbon-based energy played an outsized role in every hour. The user can customize the visualizations with color scale, graphical patterns, textures, etc., that convey the electricity profile of each hourly or sub-hourly interval.

The described techniques can optionally offer a comparison feature that enables an energy consumer to compare a visualization of their current or actual electricity profile against projected scenarios. For example, the visualizations enabled by the techniques can answer questions such as "how will the electricity profile change if new wind power generation was contracted during the months of August-December?" Per the user's preferences, the disclosed techniques can produce various types of comparative visualizations, e.g., over pairs, triplets, or larger sets.

Additional types of visualizations that can be generated for comparison include:

- carbon-free electricity profile that reflects the energy consumer's ownership of carbon-free energy assets vs. status quo electricity profile, e.g., a scenario where the user has no ownership of carbon-free energy assets;
- year-A carbon-free electricity profile vs. year-B carbon-free electricity profile;
- before-project vs. after-project electricity profile, e.g., electricity profile prior to and after the commissioning of, or contractual agreement to supply from, a CFE power source;
- actual carbon-free electricity profile vs. potential electricity profile, e.g., if a particular carbon-free asset or form of flexible electricity demand were to be added or removed, relative to the actual scenario;
- actual carbon-free electricity profile of one facility vs. actual carbon-free electricity profile of another facility, where the other facility is part of the energy consumer's own operations fleet, or the other facility is simply a similar facility whose data is publicly available; etc.

Various potential profiles can be compared at once so that the user can make an informed choice or strategic business decision. In addition to the visualization component, which is in part subject to visual perception, detailed engineering analysis can be presented to the user about which potential profile is the most carbon-free among proposed options.

With user permission, the disclosed techniques can optionally store data of various energy consumers, thereby populating a database that can be used by energy consumers for comparison purposes. With energy data from consumers that have provided permission, a storehouse of data points can be created that can be used to construct an average CFE profile. An energy consumer can compare their own profile to the constructed average CFE profile or to the profile of specific consumers. Profiles can be sorted by geography, building size, company type, or other dimensions. Privacy of individual energy consumers and their data is ensured such that energy consumer's information is not stored or shared unless expressly permitted by the energy consumer.

In this manner, the techniques of this disclosure make strategic energy analysis quicker and easier for energy consumers. The features of the disclosure, e.g., automated data entry, interpolation of unknown data points, aggregation of data relative to regional grid data, fine-grained yet compact visualization of energy profile, etc., help energy consumers rapidly and intuitively understand their carbon-free electricity profile, without themselves having to search for and sort through large volumes of data, or having to invest intense effort to understand their data. The techniques are applicable to a range of energy consumers, from large corporations with several industrial facilities (possibly with in-house power plants) to homeowners contemplating the installation of solar panels. The techniques are also useful towards creating a standard visual metric of electricity profile that can be shared across organizations seeking to make progress towards a common goal of carbon-free energy.

Further to the descriptions above, a user may be provided with controls allowing the user to make an election as to both if and when systems, programs or features described herein may enable collection of user information. Certain data may be treated in one or more ways before it is stored or used, so that personally identifiable information is removed. For example, a user's identity may be treated so that no personally identifiable information can be determined for the user, or a user's geographic location may be generalized where location information is obtained (such as to a city, ZIP code, or state level), so that a particular location of a user cannot be determined. Thus, the user can maintain control over what information is collected about the user, how that information is used, and what information is provided to the user.

CONCLUSION

Many energy consumers such as corporations and retail customers purchase carbon-free electricity, e.g., solar, wind, hydroelectricity, etc. These energy consumers often lack an easy or insightful way to visualize the role of carbon-free electricity in the context of their overall energy use, especially in fine-grain temporal detail, e.g., on an hourly or sub-hourly basis. This disclosure describes techniques that generate, at high temporal resolution, an automated, data-driven, visual representation of an energy consumer's electricity profile. The visual representation, which can be in the form of a heat map, conveys the relative amounts of carbon-based and carbon-free components in the consumer's energy portfolio.

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