Energy Conversion and Management: X 30 (2026) 101803

Contents lists available at ScienceDirect

Energy Conversion and Management: X

journal homepage: www.sciencedirect.com/journal/energy-conversion-and-management-x

Solar-time reconstruction of electricity demand: A physical framework for peak shifts, daylight use and PV-load alignment

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ARTICLE INFO

Keywords:
Solar time
Electric load profiles
Daylight Saving Time (DST)
Energy demand analysis
Island power systems
Renewable integration

ABSTRACT

The analysis of electricity demand is usually carried out in legal time, even though this may differ from real solar time due to time zones, geographic longitude, and daylight saving time (DST). This clock–Sun misalignment can distort the physical interpretation of hourly profiles, especially in regions with low solar variability and dominant evening peaks. This study develops a reproducible and physically grounded methodology to reconstruct the twelve monthly average days of 2023 for Gran Canaria in real solar time, applying the equation of time, longitude correction, and seasonal DST offset. All curves are projected onto a uniform 5-minute grid, allowing coherent comparison between legal time and solar time representations. The results show: (i) a systematic but small shift of the daily peak (≈2–4 min) when expressed in solar time; (ii) a stable daytime energy distribution between 40% and 51%, indicating that social and circadian factors prevail over the solar cycle; (iii) a clear improvement in structural coincidence between demand and synthetic photovoltaic generation, with overlap indices ranging from 0.43 in winter to 0.55 at the beginning of summer; and (iv) partial adaptation scenarios (f = 0.2–0.4) that cause moderate peak advances of 10–25 min, far below the full 60-minute shift associated with a complete legal change. These results provide a coherent physical framework to assess the impact of eliminating seasonal clock changes in subtropical regions. Beyond the case of the Canary Islands, the approach constitutes a generalizable tool to analyze demand-Sun alignment, estimate realistic social responses to time-change policies, and support renewable integration strategies in systems with increasing photovoltaic penetration.

1. Introduction

Human activity is organized according to legal time, defined by time zones that do not always coincide with real solar time. This misalignment, intensified in countries applying seasonal clock changes (Daylight Saving Time, DST), means that civil time can differ by more than an hour from solar noon. Several studies have analyzed the impact of DST on electricity demand, lighting consumption, and alignment with the solar cycle, with results showing mixed effects depending on latitude, economic structure, and social habits [1–4].

However, most of these works limit themselves to comparing profiles in legal time without reconstructing the actual solar position associated with each time point, which introduces biases in the physical interpretation of consumption patterns. Recent studies have emphasized the importance of explicitly considering solar time to interpret demand curves and profile their relationship with irradiance [5–7].

Most hourly analyses are carried out only in official time, without explicitly considering the equation of time, geographic longitude, or the seasonal DST offset. This omission is relevant from an energy perspective, since the electricity demand curve shows patterns conditioned by natural light, social activity, and circadian rhythms [8–10]. Consequently, evaluating demand only in official time may obscure fundamental physical relationships between consumption and the solar cycle.

Although previous works have assessed the effects of DST on hourly demand and lighting, the literature has mainly focused on comparing legal profiles under different time configurations, without explicitly reconstructing the real solar time associated with each point of the curve. This limits the ability to separate the astronomical contribution from the social component of consumption and hinders comparison between regions with different solar regimes [11,12].

This aspect is particularly significant in island power systems such as the Canary Islands, where irradiance shows highly regular behavior

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https://doi.org/10.1016/j.ecmx.2026.101803
Received 30 January 2026; Received in revised form 28 February 2026; Accepted 25 March 2026
Available online 26 March 2026

throughout the year and where photovoltaic penetration is growing rapidly [13,14]. Moreover, the archipelago operates under a single time zone within the Spanish power system, reinforcing the interest in analyzing the influence of time reference on the actual shape of the demand curve.

In this context, a physical approach is needed to reconstruct demand in real solar time, quantify the structural offset between both time systems, and evaluate its implications for coincidence with photovoltaic generation and potential time-policy reforms. This work addresses this methodological gap through a reproducible framework based on astronomical principles, applied to an island system with high solar regularity such as Gran Canaria.

This work pursues five fundamental objectives:

(i) develop a physical and fully reproducible reconstruction of the electricity demand in real solar time using the equation of time, geographic longitude, and seasonal offset of the DST;
(ii) to quantify the structural decoupling between legal time and solar time, evaluating its impact on the position and interpretation of the daily peak;
(iii) to analyze the demand-PV structural coincidence through seasonal metrics of overlap between the solarized curve and synthetic photovoltaic profiles;
(iv) to study the plausible social response to permanent changes in the schedule by means of a parametric model of adaptation (f) that separates the invariant and social components of demand;
(v) provide a generalizable framework applicable to any region where there is a significant time lag between the legal time reference and the local solar cycle.

While the quantitative magnitude of the solar-time shift is modest in subtropical regions, the novelty of this work lies in the explicit physical reconstruction of electricity demand in real solar time and in the separation of astronomical and social components of load. This distinction enables a structurally grounded assessment of clock–Sun misalignment, which has not been explicitly quantified in island systems with high solar regularity.

2. Methodology

The objective of this section is to describe in detail and in a reproducible way the procedure followed to transform the electricity demand curve from legal time to real solar time, structure it on a uniform temporal grid, select representative months of the annual cycle, calculate photovoltaic alignment, and build partial adaptation scenarios. This methodological framework is designed to be replicable in any region where legal time differs from local solar time.

All calculations were implemented in Python 3.10 using the NumPy and Pandas libraries for time-series processing.

2.1. Original data and construction of monthly average days

The database used corresponds to the twelve “monthly average days” of the year 2023 for the island of Gran Canaria, obtained from real hourly records of the system operator. Each average day synthesizes the typical behavior of the month, eliminating weekend effects and mitigating meteorological anomalies [15,16].

Since the original records were not presented on a regular 5-minute grid, linear interpolation was applied to reconstruct an hourly profile of 288 points per day (5 min × 24 h), ensuring temporal uniformity for subsequent analyses: integral calculations, PV coincidence, and inter-monthly comparisons.

The interpolation to a 5-minute grid is performed to obtain a continuous and homogeneous temporal representation of the demand curve. The resulting peak displacements (2–4 min) should not be interpreted as sub-minute operational precision, but as structural average shifts derived from continuous interpolation of monthly average profiles.

The “monthly average day” does not correspond to a single observed calendar day, but is constructed from the full set of hourly demand records within each month of 2023. This approach is standard in structural load analysis and is intended to capture the typical daily pattern while smoothing short-term meteorological variability.

2.2. Reconstruction of real solar time

For each instant of the monthly average day, real solar time was calculated by applying three physical corrections to legal time:

Equation of Time (EoT)

Models the difference between mean solar time and true solar time due to the non-uniform orbital motion of the Earth. The EoT shows variations of ± 15 min throughout the year, significantly altering the correspondence between legal time and solar position.

Correction by geographic longitude

The UTC time zone is based on the 0° meridian, while Gran Canaria is located at − 15.5°. Since each degree equals four minutes, the island experiences a solar delay of:

$$\Delta_{lon} = -15.5^{\circ} \times 4\text{min}/^{\circ} = -62\text{min}$$

Daylight Saving Time (DST) offset

For approximately seven months, legal time adds one additional hour (UTC + 1).

This adjustment has no astronomical basis but directly affects demand interpretation.

Final combination

Real solar time is obtained as:

$$Truesolartime(TST) = Legaltime + (EoT + \Delta lon + DST)$$

$$Totaloffset = EoT + \Delta lon + DST$$

Accordingly, the legal-time solar noon is computed as:

$$Solarnoon(legaltime) = 12:00 - Totaloffset$$

All corrections are expressed in minutes. The daylight saving time (DST) term takes the value 0 min during standard time and + 60 min during DST periods. The longitude correction is computed as 4 min per degree relative to the reference meridian (UTC), with negative values for west longitudes. The equation of time (EoT) is expressed in true solar minutes following standard astronomical conventions.

Table 1
Legal solar noon time for the months of 2023 in Gran Canaria, considering the correction for longitude, equation of time and daylight saving time.

Month	Representative day	EoT min	Longitude correction min	DST min	Total offset min	Solar noon legal time
January	2023-01-15	−9.3	−62	0	−71.3	13:11
February	2023-02-14	−14.6	−62	0	−76.6	13:17
March	2023-03-15	−9.7	−62	0	−71.7	13:12
April	2023-04-15	−0.2	−62	60	−2.2	12:02
May	2023-05-15	3.8	−62	60	1.8	11:58
June	2023-06-15	−0.2	−62	60	−2.2	12:02
July	2023-07-15	−5.6	−62	60	−7.6	12:08
August	2023-08-15	−4.1	−62	60	−6.1	12:06
September	2023-09-15	5.7	−62	60	3.7	11:56
October	2023-10-15	15	−62	60	13	11:47
November	2023-11-15	14.7	−62	0	−47.3	12:47
December	2023-12-15	3.8	−62	0	−58.2	12:58

Monthly values of solar noon in legal time are summarized in Table 1. Their seasonal behavior is illustrated in Fig. 1 using four representative months (January, April, July, and October), where deviations between legal clock time and solar noon can be observed. Moderate shifts around 12:00 appear during the DST period, while larger structural offsets occur during winter months.

2.3. Temporal homogenization: uniform 5-minute grid

Once the equivalent solar times were obtained, both legal and solar curves were projected onto a regular temporal grid using linear interpolation.

The objectives of this step are:

- avoid discontinuities when reordering the series in solar time;
- ensure comparability between months;
- allow consistent integral calculations;
- maintain adequate temporal resolution for PV analysis.

This process produces, for each month, three homogeneous curves:

- Legal demand,
- Solarized demand,
- Pure-shift demand (DST displacement only).

2.4. Selection of representative months

In this study, four months representative of the annual cycle were selected:

- January (winter),
- April (spring),
- July (summer),
- October (autumn).

This selection allows characterization of the annual cycle without resorting to all twelve monthly figures. The legal and solar curves corresponding to these months are shown jointly in Fig. 2, organized into four sub-panels to facilitate comparison.

2.5. Legal-solar representation

Fig. 2 shows, for the representative months of winter (January), spring (April), summer (July), and autumn (October), the demand curves in legal time and solar time on the same temporal grid. Each sub-panel covers a full monthly average day, from 0:00 to 24:00, so that the two time scales can be compared point by point. This representation allows direct visualization of how the transformation to solar time shifts the entire curve without altering its global shape or daily energy, providing the graphical basis for subsequent quantitative analyses of peaks, day/night energy, and coincidence with photovoltaics.

2.6. Determination of solar day and daytime/nighttime energy

For each month the following were identified:

- solar sunrise time,
- solar sunset time,
- solar day duration,
- consumption in natural light (E_day),
- consumption in darkness (E_night).

As an illustration, Fig. 3 presents this analysis for April, visually highlighting the correspondence between demand and light availability.

2.7. Alignment between solarized demand and photovoltaic generation

Synthetic photovoltaic profiles were generated based on:

- theoretical irradiance per month,
- latitude of Gran Canaria,
- zenith angle,
- average atmospheric attenuation.

The synthetic photovoltaic profile assumes fixed-tilt panels oriented south and inclined at approximately the local latitude angle (28°), representing a standard configuration for residential and utility-scale installations in Gran Canaria. Tracking configurations, including east–west or single-axis tracking systems, were not considered, as the objective of this study is to evaluate structural demand-PV coincidence

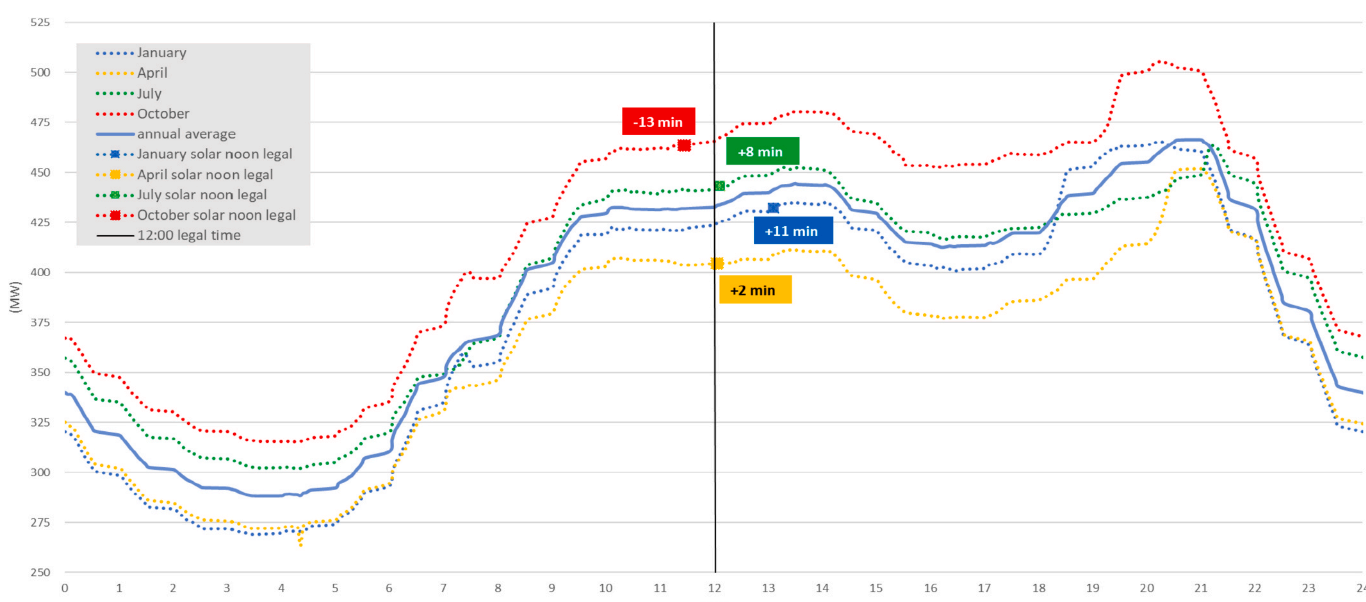

Fig. 1. Daily demand profiles in legal time for representative months (January, April, July, and October), indicating the legal time of solar noon and its deviation relative to 12:00.

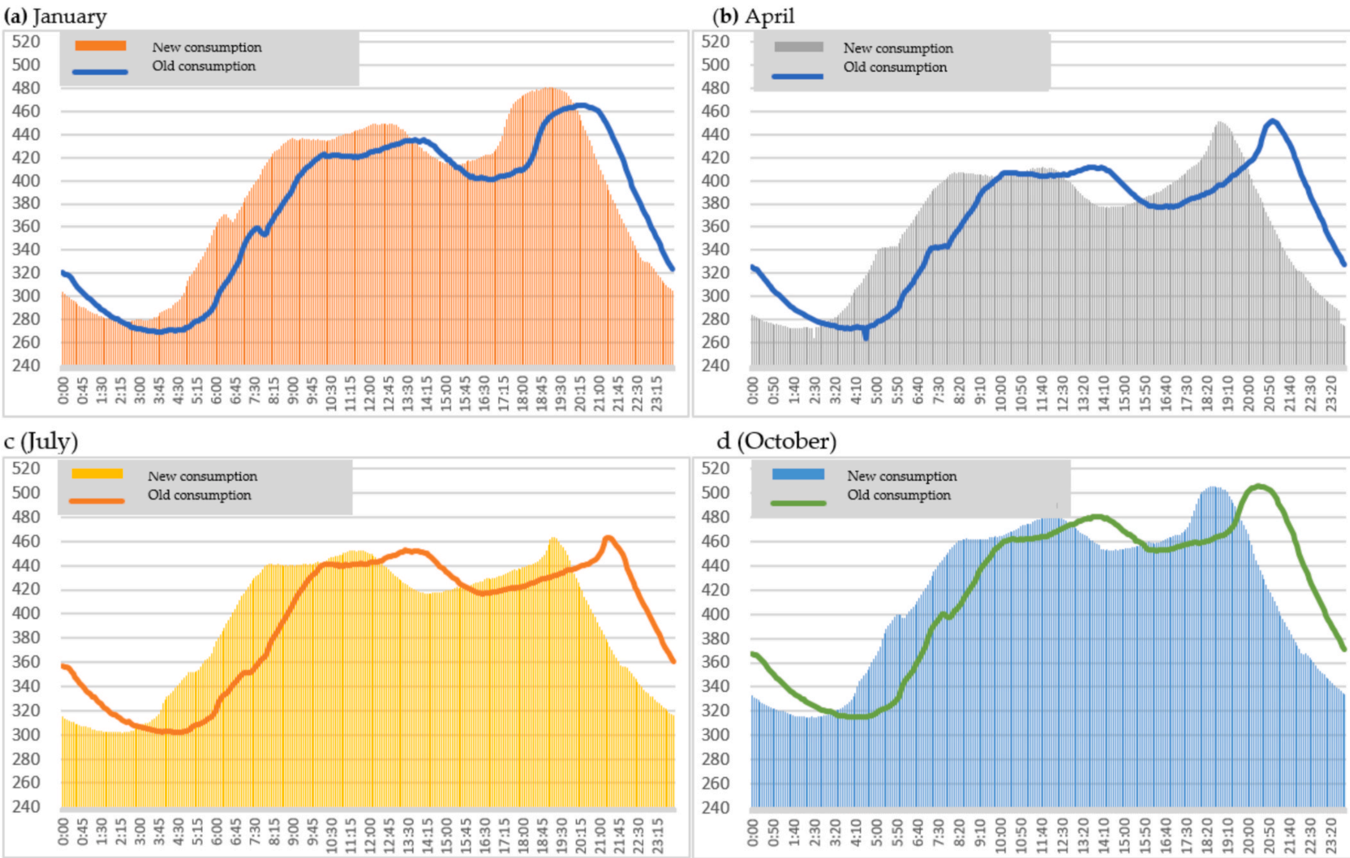

Fig. 2. Average daily demand curve comparing legal time and solar time in (a) January, (b) April, (c) July, (d) October.

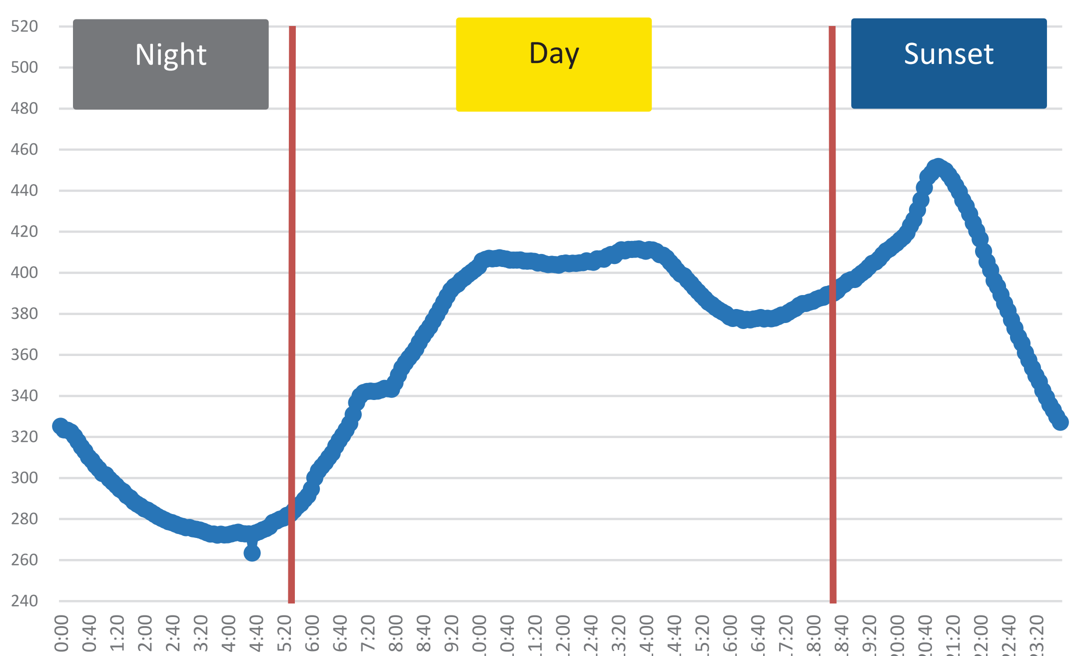

Fig. 3. Demand in solar time for April (representative case), showing daytime (yellow) and nighttime (grey) intervals. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).

under conventional fixed installations rather than optimized generation scenarios.

The PV-demand coincidence index (CF) is defined as the ratio between the integrated overlapping area of demand and photovoltaic generation and the total daily demand:

$$CF = \frac{\int_0^{24h} \min[D(t), PV(t)]dt}{\int_0^{24h} D(t)dt}$$

where D(t) represents the solar-time demand profile and PV(t) the synthetic photovoltaic generation curve, both expressed in consistent power units and integrated over the 24-hour period. The synthetic PV profile was scaled to its theoretical daily maximum under clear-sky conditions for each representative month, maintaining consistent power units with the demand curve. No additional normalization, scaling, or clipping procedures were applied.

This procedure is analogous to that used in previous works on structural coincidence between demand and photovoltaic generation and can be adapted to different climates and load configurations [17–20].

Representative curves appear in:

- Fig. 4 → April
- Fig. 5 → October

Annual values are included in Table 2.

The temporal coincidence between electricity demand and photovoltaic generation constitutes a fundamental indicator to assess the direct use of solar energy without resorting to storage systems or flexibility resources. Once demand curves were expressed in solar time, a synthetic photovoltaic profile was generated for each month using a simplified irradiance model adapted to the latitude of Gran Canaria. Figs. 4 and 5 illustrate the degree of overlap between both curves for April (spring) and October (autumn), selected as representative cases due to intermediate irradiance conditions and moderate variations in daily demand structure.

Monthly day/night energy results are shown in Table 2, while Figs. 4 and 5 illustrate the degree of PV-demand match for representative months.

2.8. Construction of partial adaptation scenarios (f)

This section models how demand would change if society permanently adopted a new legal time.

The demand curve is separated into:

- base component (invariant),
- social component (shiftable).

The parameter f [0,1] represents the degree of social adaptation:

- f = 0.2 → low adaptation
- f = 0.3 → moderate adaptation
- f = 0.4 → high adaptation

The convex combination:

$$Df(t) = (1 - f)\cdot D_{current}(t) + f\cdot D_{pureshift}(t)$$

produces three intermediate scenarios, shown in Fig. 6.

Monthly results (peak and peak time) are summarized in Table 3. It should be noted that the values in Table 3 are synthetic and derived from the parametric formulation itself, not from direct measurements of the system operator.

This methodological framework provides a coherent physical basis for all analyses developed in Sections 3, 4, and 5, and can be immediately replicated in any location by substituting only geographic longitude, DST rules, and local solar geometry.

3. Results

3.1. Visual comparison between legal-time and solar-time curves

Fig. 2 shows, for the representative months of January, April, July, and October, the daily average demand curve expressed simultaneously in legal time and solar time. In all four cases, the transformation to solar time consists mainly of an almost rigid displacement of the curve, with no appreciable changes in the general shape or in the amplitude of demand.

In winter (January) and autumn (October), the curve presents a pronounced evening peak around 19:00, while in spring (April) and summer (July) a slight plateau can be observed in the early afternoon followed by a maximum also concentrated in the early evening hours. In all months, the solar-time curve appears shifted a few minutes to the right compared to its legal-time equivalent, reflecting the small but systematic offset between both temporal systems.

Qualitatively, the figures confirm that the choice of time scale does not alter the typical structure of daily demand in Gran Canaria, but it does modify the precise reading of the schedules associated with maxima, ramps, and slope changes, motivating the detailed quantitative analysis presented in the following sections.

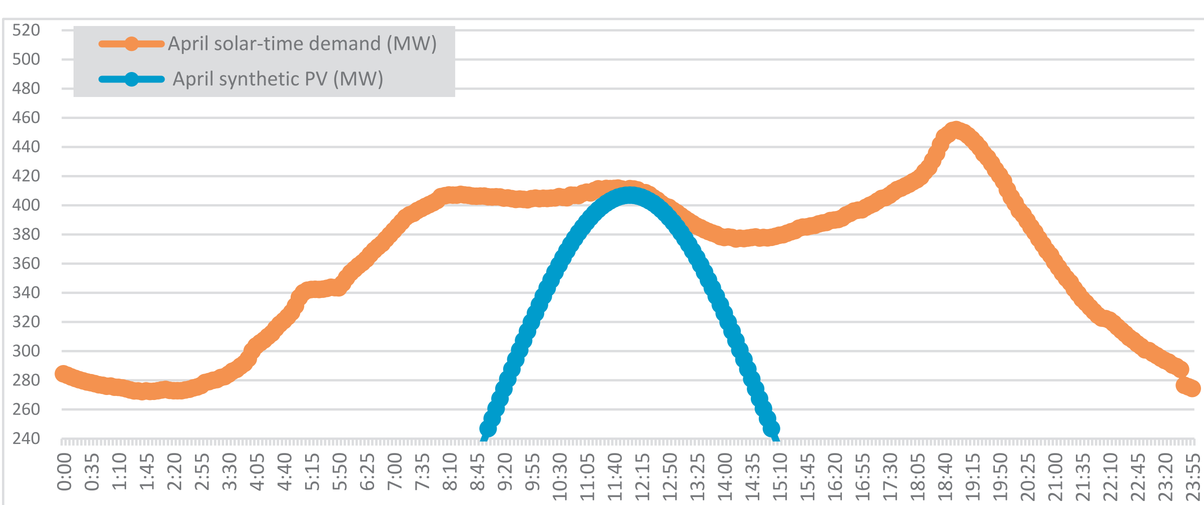

Fig. 4. Solar time demand and synthetic photovoltaic generation for April 2023 in Gran Canaria, showing the FV production.

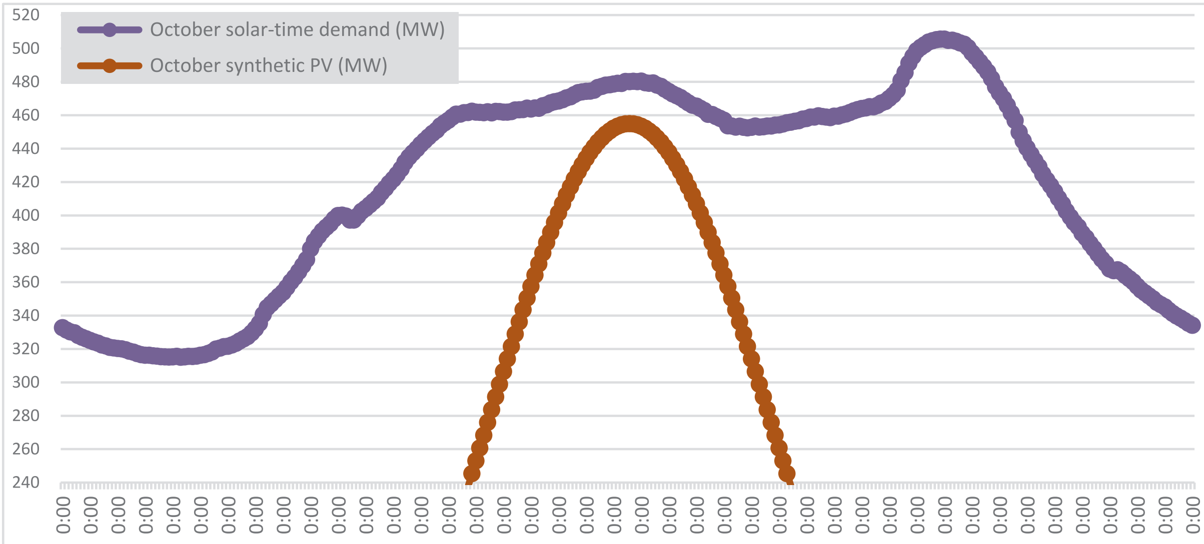

Fig. 5. Solar time demand and synthetic photovoltaic generation for October 2023 in Gran Canaria, highlighting the seasonal reduction in the coincidence of demand-PV.

Table 2
Daytime and nighttime energy consumption for each month of 2023 in Gran Canaria, obtained from the solar-time demand curves.

Month	Solar sunrise	Solar sunset	Daytime energy (MWh)	Nighttime energy (MWh)	% energy in daylight
January	06:42	17:18	4,570.2	6,716.6	40.5
February	06:23	17:37	4,787.8	6,497.2	42.4
March	06:00	18:00	5,147.9	6,128.0	45.7
April	05:34	18:26	5,227.0	5,721.9	47.7
May	05:13	18:47	5,709.7	5,684.3	50.1
June	05:01	18:59	5,950.2	5,594.6	51.5
July	05:06	18:54	6,003.2	5,842.1	50.7
August	05:24	18:36	6,156.8	6,392.6	49.1
September	05:49	18:11	5,541.9	6,392.9	46.4
October	06:13	17:47	5,476.4	7,096.0	43.6
November	06:36	17:24	4,816.8	6,927.4	41.0
December	06:48	17:12	4,553.3	6,906.3	39.7

3.2. *Shift of the demand peak*

For each of the twelve monthly average days, the daily maximum demand was identified and the corresponding hour recorded in both time scales. Consistently throughout the year, the peak occurs in a narrow interval around the early evening hours: between 18:40 and 19:20 in legal time.

When the same curve is expressed in solar time, the peak appears slightly later, with an estimated structural offset on the order of 2–4 min depending on the month. On average, the difference between the peak hour in legal time and in solar time is about 3 min. The height of the daily maximum remains practically unchanged in all transformations, with values approximately between 650 and 700 MW in the original system units.

These results indicate that, in the case of Gran Canaria, the clock–Sun misalignment manifests mainly as a fine shift of the evening peak within a very stable time window throughout the year, without appreciable structural changes in the shape of the daily profile.

It is important to clarify that the 2–4 min shift does not reflect the absolute legal–solar offset, which can reach more than one hour in winter. Instead, it represents the relative displacement of the maximum within the reshaped daily curve after temporal reordering. Since the load profile is structurally smooth around the peak, the transformation to solar time produces only a minor relocation of the maximum point, as the transformation preserves the intrinsic curvature of the load profile without introducing additional asymmetry.

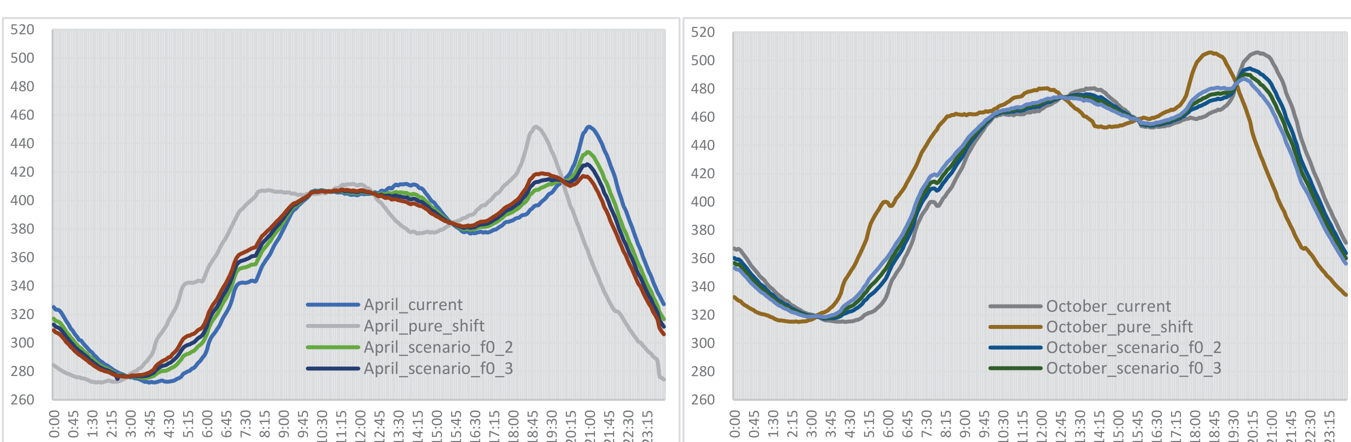

Fig. 6. Comparison of demand in solar time under the current scenario, pure displacement and partial adaptation scenarios (f = 0.2; 0.3; 0.4) for the months of April and October 2023 in Gran Canaria.

Table 3
Monthly peak demand and peak time under current, pure-shift and partial adaptation scenarios (f = 0.2, 0.3, 0.4). Synthetic values obtained from the parametric formulation, for illustrative purposes.

Month	Current peak (MW)	Current peak time (solar)	Pure-shift peak (MW)	Pure-shift peak time (solar)	f = 0.2 peak (MW)	f = 0.2 peak time (solar)	f = 0.3 peak (MW)	f = 0.3 peak time (solar)	f = 0.4 peak (MW)	f = 0.4 peak time (solar)
January	691	19:15	691	18:15	691	19:03	691	18:57	691	18:51
February	681	19:15	681	18:15	681	19:03	681	18:57	681	18:51
March	676	19:10	676	18:10	676	18:58	676	18:52	676	18:46
April	671	19:05	671	18:05	671	18:53	671	18:47	671	18:41
May	664	19:05	664	18:05	664	18:53	664	18:47	664	18:41
June	661	19:10	661	18:10	661	18:58	661	18:52	661	18:46
July	654	19:10	654	18:10	654	18:58	654	18:52	654	18:46
August	660	19:00	660	18:00	660	18:48	660	18:42	660	18:36
September	671	18:55	671	17:55	671	18:43	671	18:37	671	18:31
October	679	18:45	679	17:45	679	18:33	679	18:27	679	18:21
November	688	18:50	688	17:50	688	18:38	688	18:32	688	18:26
December	702	19:00	702	18:00	702	18:48	702	18:42	702	18:36

Note: Power values are expressed as integers in MW to facilitate comparison between scenarios, since decimals do not alter the interpretation of the analysis. Peak power values remain constant across scenarios because the parametric model modifies only the temporal distribution of demand without altering total daily energy or structural amplitude.

3.3. Distribution of energy between daylight and nighttime hours

One of the advantages of representing demand in terms of real solar time is that it allows precise quantification of how electricity consumption is distributed between hours with and without natural light. This distinction is relevant both from the perspective of energy efficiency [21,22], due to the relationship between natural light and artificial lighting, and from the perspective of renewable integration, since self-consumption and photovoltaic coverage depend directly on the coincidence between demand and solar irradiance.

For each of the twelve monthly average days, solar sunrise and sunset hours were estimated using the solar declination of the 15th day of each month and the latitude of Gran Canaria (28.1° N). From these values, the energy consumed during the solar day (E_day) and during the solar night (E_night) was calculated. Fig. 3 illustrates this procedure for April, where the shaded yellow areas represent the solar daylight period and the gray areas the nighttime period.

Monthly results, summarized in Table 2, show that the fraction of energy consumed during hours of natural light remains within a relatively narrow range, approximately between 40.5% in January and 51.5% in June. The maximum value is reached in June (51.5%), while the minimum corresponds to December (39.7%). In most months, the proportion of energy in daylight hours is around 45–50%, indicating that a significant fraction of daily demand continues to be concentrated under darkness conditions.

The combination of low solar seasonality and the presence of a marked evening peak around 19:00 explains why the transition between light and darkness influences the total curve shape less than in higher-latitude regions. Nevertheless, even a small shift of activity toward greater coincidence with daylight hours could reduce consumption associated with artificial lighting and improve the system's interaction with photovoltaic generation. This issue is analyzed in more detail in the following section.

3.4. Structural coincidence between demand and photovoltaic resource

The temporal coincidence between solar-time demand and synthetic photovoltaic profiles is illustrated in Figs. 4 and 5 for April and October, respectively. In both cases, PV generation is concentrated around solar noon, describing a relatively narrow bell, while demand presents a broader plateau with a maximum clearly shifted toward the early evening hours.

Quantitative analysis using the PV-demand coincidence index (CF) shows a smooth seasonal variation [23–25]. The lowest values are recorded in winter months, with CF ≈ 0.43–0.44, while the maximum is reached around June, with CF close to 0.55. During spring and early summer, the index typically exceeds 0.50, reflecting greater overlap between the photovoltaic bell and the central part of the demand profile.

Overall, these results indicate that alignment in solar time improves the reading of structural coincidence between solar resource and consumption, and allows robust quantification of the temporal gap that persists between the photovoltaic maximum and the evening demand peak represented in Figs. 4 and 5.

Although the coincidence index never exceeds 0.55, reflecting the persistence of an evening peak unrelated to the solar maximum, comparison between months shows that greater structural alignment with solar time systematically increases overlap between demand and photovoltaic generation. From the perspective of power system operation, this suggests that policies favoring synchronization of activity with the daylight window (for example, reducing clock–Sun misalignment or eliminating unnecessary seasonal time changes in subtropical latitudes) could improve direct use of photovoltaics, reduce curtailments, and decrease the need for backup power around the evening peak.

These values are consistent with island systems where radiation is high but demand maintains a strong evening component.

3.5. Impact of time change under partial adaptation scenarios (f = 0.2, 0.3, 0.4)

Fig. 6 compares, for the representative months of April and October, the demand curve in solar time under the current scenario, the pure-shift scenario, and the three partial adaptation scenarios defined by f = 0.2, 0.3, and 0.4. In all cases, the pure-shift scenario rigidly displaces the curve one hour backward, so that the daily peak advances exactly 60 min compared to the current situation.

Partial adaptation scenarios show more moderate shifts. Table 3 summarizes, for each month of the year, the peak height and associated hour in the different scenarios. For f = 0.2, the peak hour typically advances about 10–15 min compared to the current scenario; for f = 0.3, the advance is around 15–20 min; and for f = 0.4, about 20–25 min. In all cases, the maximum power remains practically constant, with differences of only a few megawatts.

These results indicate that even under relatively high adaptation (f = 0.4), the effective displacement of the daily peak represents only a fraction of the time offset implied by a complete legal change. The partial sensitivity of the curve to parameter f suggests that a significant portion of demand is anchored to the solar cycle or to inflexible activity patterns, while another fraction does respond to the new schedule, generating a range of intermediate scenarios that can be used to realistically assess the potential impact of a time-policy reform.

4. Discussion

The results obtained in this study reveal that, although the change of time reference from legal time to solar time does not substantially alter the overall shape of demand profiles, it does introduce systematic and consistent adjustments in key aspects for interpreting the electricity behavior of Gran Canaria. In particular, modifications are observed in the exact timing of daily peaks, in the hourly distribution of energy between day and night, and in the structural coincidence with the photovoltaic resource.

4.1. Magnitude and meaning of the clock–Sun offset

Although the displacement between legal time and solar time is small in Gran Canaria, on the order of 2–4 min in the evening peak, this value must be interpreted in light of the circadian behavior of electricity consumption [8,9]. In island systems with low seasonality, even small changes in time reference can modify the fine reading of relevant operational events, such as the onset of the evening ramp or the proximity between the peak and the end of the daylight period.

The low magnitude of the observed offset coincides with what is expected for regions close to the reference meridian, but its persistence throughout the year reveals that exclusive use of legal time introduces a systematic bias. This bias does not affect the overall shape of the profiles, but it does condition their temporal interpretation, especially when comparing months with different solar dynamics or when evaluating time-management strategies.

4.2. Day/night distribution: implications for efficiency and social behavior

The stable distribution of energy between daylight and darkness, with annual variations of barely ± 5 percentage points, suggests that the social component of demand dominates over the strictly solar component. Most daily consumption is systematically concentrated in the evening period, even in months of highest irradiance, confirming the importance of circadian rhythm and labor/tourism patterns in load structure.

From an operational perspective, this pattern implies that a partial realignment of social schedules with the daylight window could shift a non-negligible fraction of consumption toward the daytime period. Although the absolute effect would be moderate, the evidence obtained indicates that the power system could benefit from a marginal reduction in evening consumption linked to lighting and residential activities, with cumulative efficiency gains at the annual scale.

4.3. Demand-PV coincidence: structural gap and opportunities for improvement

The PV-demand coincidence index obtained (CF ≈ 0.43–0.55) reflects a structural gap between the solar maximum and the evening demand peak [26,27]. This offset is characteristic of electricity systems with a strong residential component and persists even when demand is expressed in solar time. The temporal transformation, however, allows more precise identification of the physical origin of the decoupling, separating the contribution of the solar cycle from the social component of consumption.

In terms of renewable integration, these CF values suggest that the capacity for direct self-consumption and reduction of photovoltaic curtailments depends largely on the system's ability to shift part of activity toward the central daytime period. Although the absolute margin for improvement is moderate, the clarity provided by the solar scale may be useful for designing time-adjustment policies, dynamic tariffs, or active management programs aimed at reinforcing coincidence with photovoltaic generation.

4.4. Partial adaptation to time change: social and operational reading

The scenarios constructed using parameter f show that even under relatively high adaptation levels (f = 0.4), the displacement of the evening peak represents only a fraction of the full legal shift. This result confirms that a substantial part of demand is anchored in circadian patterns, socio-economic activities, and daily habits that do not respond linearly to the legal time reference. As shown in Table 3, even in the maximum adaptation scenario (f = 0.4), the actual advance of the peak remains well below the full legal displacement.

From an operational perspective, this partial rigidity implies that a permanent time change, such as eliminating DST or adopting an alternative time zone, would produce perceptible but limited modifications in the daily load structure. The parametric approach adopted provides a useful framework to estimate plausible ranges of social response and to evaluate, prior to implementation, the potential impact of a time-policy reform on operation and photovoltaic integration [28–31].

These results also reveal limited operational-temporal flexibility of the system, particularly during the evening ramp.

4.5. Limitations of the study

This analysis is based on monthly average days and synthetic clear-sky photovoltaic profiles, which means that intraday variations associated with cloudiness, short-term demand fluctuations, and stochastic events are not represented. Consequently, the results should be interpreted as structural trends rather than exact operational forecasts. Future work could incorporate high-resolution meteorological data, probabilistic demand models, and empirical adaptation studies to refine the conclusions and extend the applicability of the framework.

While the use of monthly average days smooths intraday stochastic variability, it is appropriate for identifying structural clock–Sun misalignment rather than short-term weather-driven effects.

4.6. Relevance for energy and time policies

The results of this study provide useful quantitative evidence for regulatory debates on the elimination of daylight saving time, the adoption of permanent schedules, and the synchronization of social activity with natural light in regions of low solar seasonality. The solar-time analysis reveals which part of the evening peak is attributable to social behaviour and which part to the astronomical cycle, providing a physical tool to anticipate impacts on system operation, photovoltaic self-consumption, backup dispatch and flexibility needs. This framework can assist local and national regulators in evaluating science-based time reforms aimed at improving renewable integration.

4.7. Potential estimation of energy savings

Although this study does not directly quantify the annual reduction in energy associated with greater synchronization between social activity and daylight hours, it is possible to estimate reasonable ranges from the mechanisms identified in the results and from the previous evidence available in the literature. Studies carried out in residential and tertiary systems indicate that between 8% and 20% of evening electricity consumption is associated with artificial lighting and activities that can be moved around the peak [21,22].

In the case of Gran Canaria, the night-time fraction represents between 49% and 60% of the daily energy (Table 2), and the evening peak is stable around 7:00p.m. Under partial adaptation scenarios, the solarized curve shows overtaking of 10–25 min (Table 3), which is equivalent to a relative shift of 17–42% with respect to the complete legal change of one hour. Applying these percentages as a conversion factor, the potential energy savings derived exclusively from the reduction of artificial lighting could be in an indicative range of 2.0% to 4.0% of daily consumption during the months of greater solar stability.

Additionally, the improvement in the PV-demand (CF) structural coincidence between 0.43 and 0.55 implies a relative increase of up to 28% in the solarized overlap compared to the winter months. This increase, although it does not eliminate the evening peak, could translate into additional marginal reductions in thermal energy dispatched, especially in the spring and summer months, where photovoltaic generation already contributes significantly to covering daytime demand.

These estimates should be interpreted as order-of-magnitude indications rather than precise forecasts. The proposed range (2–4%) represents a structurally plausible upper bound derived from literature-based lighting shares and partial temporal shifts, not a direct output of the present model.

5. Conclusions

This study has developed a physical and reproducible framework to reinterpret the daily electricity demand of Gran Canaria based on real solar time. The simultaneous transformation of the twelve average monthly days of 2023, based on the equation of time, geographical longitude and seasonal lag of the DST, has made it possible to clearly separate the purely astronomical effects from the social patterns that condition the daily structure of consumption [32].

The main findings can be summarized in the following points:

(i) The difference between legal time and solar time in Gran Canaria is small in magnitude, but systematic. The daily peak appears displaced a few minutes later when expressed in solar time, which confirms that the civil calendar introduces a persistent temporal bias even in regions close to the reference meridian.
(ii) The fraction of energy consumed during daylight hours varies in a narrow range (40–51%), reflecting that most of the daily demand is guided by social habits and circadian rhythms rather than by the solar cycle. This stability is characteristically subtropical and contrasts with mid-latitude regions where solar seasonality dominates the day/night distribution.
(iii) The PV-demand coincidence index shows a moderate annual variation (0.43–0.55), with a maximum in spring–summer. Although the gap between the photovoltaic bell and the evening peak persists in every month, the solar-scale analysis allows its physical origin to be identified and the operational window where the decoupling is concentrated to be accurately quantified.
(iv) The partial adaptation scenarios constructed using the parameter f show that even a relatively high social adoption of the new schedule ($f = 0.4$) would produce significantly smaller shifts from the evening peak than the full legal change. The system's demand has a limited temporal elasticity, controlled by a mixture of circadian patterns, residential activity and tourist behaviour.
(v) The partial realignment of the activity with daylight hours offers a potential for indirect energy savings, by reducing the use of artificial lighting, reducing the afternoon ramp and increasing the direct use of photovoltaic generation, which could contribute to lower backup power requirements and operational improvements on an annual scale.

The primary contribution of this study is methodological rather than purely quantitative. By providing a reproducible solar-time reconstruction framework, the work enables consistent separation of legal-time effects, astronomical alignment, and social adaptation mechanisms. This structured approach offers a transferable analytical tool for evaluating clock–Sun misalignment in regions with different solar regimes.

Overall, the results show that the solar representation of demand not only improves the physical reading of the hourly profiles, but also allows the identification of structural opportunities for energy savings linked to the partial displacement of activities towards daylight hours and the increase in the coincidence between demand and photovoltaic resource. The combination of reduced artificial lighting use, softer afternoon ramps, and greater direct self-consumption could plausibly translate into energy savings on the order of a few percent per year under favorable structural conditions, according to ranges supported by the literature. This framework therefore provides a generalizable basis for rigorously assessing the potential impact of time reforms and for designing renewable integration strategies in regions with different solar regimes.

CRediT authorship contribution statement

Juan Carlos Lozano Medina: Writing – review & editing, Writing – original draft, Validation, Software, Project administration, Investigation, Formal analysis, Data curation, Conceptualization. **Vicente Henríquez Concepción:** Writing – review & editing, Visualization, Supervision, Resources, Methodology, Funding acquisition, Data curation. **Alejandro Ramos Martín:** Writing – original draft, Validation, Software, Project administration, Investigation, Formal analysis, Conceptualization. **Federico León Zerpa:** Writing – review & editing, Visualization, Supervision, Resources, Methodology, Funding acquisition, Data curation.

Funding

This research was co-funded by the INTERREG V-A Cooperation, Spain-Portugal MAC (Madeira-Azores-Canarias) 2014–2020 program and the MITIMAC project (MAC2/1.1a/263).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

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