

Carrier or source?

Decomposing the primary-energy saving in ‘The primary energy fallacy in energy transitions’

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Comment on Rosenow, Eyre, Rissman, Mayfield, Goldstein, Ammar and Bruce-Lockhart (2026), Research Square preprint, DOI 10.21203/rs.3.rs-9661051/v1.

ABSTRACT

Rosenow et al. (2026) compare today’s global energy system with a stylised, highly electrified system that delivers the same useful energy. They report that rejected energy falls by 64%, ambient heat rises from about 2 EJ to 52 EJ, and primary energy falls by 49%, or nearly 300 EJ a year. We accept the central point: primary energy overstates what an electrified system needs, and the gain from electric end uses is real. We reconstruct the undisclosed scenario totals from the paper’s own energy balance and split the saving. Electric end uses, the carrier change, account for 116 EJ named in the paper and a further 43 EJ implied by its balance. Replacing thermal generation with wind and solar, the source change, accounts for 115 EJ. A 26 EJ fall in fuel processing serves both. The authors say the primary-energy figure depends on convention; we size it. Under the substitution convention the Energy Institute used until its 2024 edition, the headline falls by at least 111.2 EJ, more than a third. The paper concludes that its result removes the objection that an electrified system’s primary-energy footprint ‘would be unmanageably large’. Two things that bear on that footprint are held outside the comparison. Manufacturing energy is fixed at today’s level, so the energy to build and rebuild the new system, which is most of the lifetime energy requirement of wind and solar, is not added. And demand for energy services is fixed, so rebound, which one of the authors has written the method neglects, is excluded. We have asked the authors for the figures needed to check the result.

KEYWORDS primary energy · rejected energy · energy accounting · electrification · substitution method

1 Introduction

1.1 *The paper and its result*

Rosenow et al. (2026) argue that the size of today’s fossil energy system is a poor guide to the size of its replacement. They build a global energy-flow model from the Lawrence Livermore National Laboratory framework and IEA energy balances, and an electrified counterfactual delivering the same useful energy. Useful energy is the energy that performs the final service: motion, light, heat at the required temperature. Primary energy is the energy content of natural resources before conversion. Rejected energy is the share of inputs dissipated rather than delivered as useful services, ‘principally as waste heat from combustion, transmission and distribution losses, and end-use inefficiency’ (p. 4). Ambient energy is heat drawn from the environment by heat pumps.

With useful energy held fixed, the paper finds that rejected energy falls by 64%, ambient energy rises roughly twentyfold, and primary energy falls by 49%, ‘or nearly 300 EJ annually’ (p. 7). The authors attribute the fall to four named effects: lower losses in electricity generation, in transport and in other fuel transformation, and greater use of ambient heat.

1.2 *The question*

This note asks one question. How much of the 300 EJ comes from changing the carrier, and how much from changing the source, and what does the source part rest on? A carrier change replaces engines and boilers with electric motors and heat pumps. It saves energy whatever generates the electricity. A source change replaces thermal power stations with wind and solar. How large its saving looks in primary energy depends on how non-combustible electricity is booked, and the costs of weather-dependent supply fall on storage, curtailment, spare capacity and the grid. An earlier essay set out the distinction informally (Lyon, 2026); this note tests it against the paper's numbers.

1.3 *What the note does not claim*

The note does not claim the paper's arithmetic is wrong; its energy identity reconstructs consistently (section 3). It does not argue against electrification, nor that the 64% fall in rejected energy is an artefact, nor that the 20 EJ allowance is too small. The alternative figures below are sensitivities, not the 'true' saving.

1.4 *Roadmap*

Section 2 sets out what the paper gets right; section 3 reconstructs its totals; section 4 splits the saving; section 5 examines the 20 EJ electricity-loss allowance and construction energy; section 6 covers rebound, aviation and disclosure.

2 What the paper gets right

2.1 *Primary energy mismeasures an electric system*

In a fossil system most primary energy is never used. Around two thirds is lost in combustion and conversion (p. 3), and fossil power stations average 40% efficiency (p. 5). A metric that counts a power station's waste heat as system size exaggerates what an electric system needs. The authors are right about this, and that primary energy is a poor measure of progress in an electrifying system.

2.2 *The carrier change is large and holds whatever the source*

Electric vehicles and heat pumps deliver the same service with far less final energy than the engines and boilers they replace. The paper's transport losses fall from 94 EJ to 28 EJ, and ambient heat rises from about 2 EJ to 52 EJ. These gains do not depend on the source of the electricity or on the convention examined below.

2.3 *Scope, and how the result is used*

The authors describe the electrified system as 'not a prediction or forecast but a thought experiment' (pp. 10–11). They say storage is included but 'not modelled ... at a high level of granularity' (p. 9), and that their analysis 'is not a substitute for time-resolved system modelling' (p. 10).

The result is nonetheless put to work. The authors conclude that 'the system-size argument that an electrified, renewable-supplied system would require a primary energy footprint comparable to today's collapses' (p. 8), that rejected energy is 'the indicator that should lead public and policy discourse' (p. 8), and 'recommend that energy-system analysis and policy lead with system-loss and useful-energy indicators' (p. 2). They state the finding narrowly: the analysis 'removes one of the most commonly cited objections to such a system, namely that its primary energy footprint would be unmanageably large' (p. 9). Other factors they treat 'as constraints to be addressed in deployment rather than as reasons that the structural efficiency story is wrong' (p. 10).

We test that narrow finding. The objection concerns the footprint of a real system, and two things that would enlarge it are held outside the comparison: the energy to build and rebuild the system,

including the spare capacity and storage that firm supply needs (sections 5.3 and 5.5), and rebound (section 6.1). Neither is a constraint on deployment. Both are energy, inside the metric the finding is about.

2.4 *The paper's convention is the mainstream one*

For wind, solar and hydro the paper uses the IEA and UN Statistics Division physical energy content method, which ‘records electricity generated rather than incident solar or wind energy’ (p. 11). The older alternative, the substitution method, books non-combustible electricity at the fuel a thermal plant would have burned to produce it. The Energy Institute used substitution until its 2024 edition; ‘starting in 2025, the way in which we measure total energy demand has changed’, and it now uses physical energy content (Energy Institute, 2025). Our World in Data notes that substitution ‘overstates the amount of energy that’s produced’ (Ritchie and Rosado, n.d.). We use it only to measure how much of the result depends on the choice.

3 Reconstructing the accounts

3.1 *What is disclosed*

The paper reports changes and percentages but gives no absolute totals of primary, rejected, useful or final energy for either scenario, in the main text or the Supplementary Information. Final energy is energy delivered to end users after conversion losses.

3.2 *Back-solving from the paper's identity*

The paper states the balance $PE + AE = UE + RE$, with useful energy the same in both scenarios. Three disclosed figures fix the rest. A 300 EJ fall that is 49% of baseline implies baseline primary energy of about 612 EJ. With ambient energy up 50 EJ, the identity fixes the fall in rejected energy at 250 EJ, whatever the level of useful energy; if that is 64%, baseline rejected energy is about 391 EJ. Table 1 sets out the result. Electrified rejected energy computed two ways agrees exactly, and baseline primary energy sits in the published 600–620 EJ range for 2022. [AUTHORS’ REPLY PENDING]

Table 1. Disclosed and reconstructed scenario totals.

Quantity	Baseline system	Electrified system	Change	How obtained
Primary energy (PE)	612 EJ (back-solved)	312 EJ (back-solved)	300 EJ fall, 49% (disclosed)	Back-solved from disclosed 49% and ‘nearly 300 EJ’ (p. 7)
Ambient energy (AE)	about 2 EJ (disclosed)	52 EJ (disclosed)	50 EJ rise (disclosed)	Stated in the paper (p. 7)
Rejected energy (RE)	391 EJ (back-solved)	141 EJ (back-solved)	250 EJ fall, 64% (disclosed percentage)	Fall fixed by the identity $PE + AE = UE + RE$; level from the disclosed 64%
Useful energy (UE)	224 EJ (back-solved)	224 EJ (held fixed by the paper’s design)	No change (by construction)	Baseline PE plus AE, minus baseline RE

3.3 *A 43 EJ remainder*

The four named effects sum to 257 EJ: 115 EJ from electricity generation, 66 EJ from transport, 50 EJ from ambient heat and 26 EJ from other fuel transformation. The headline is nearly 300 EJ. The difference, 43 EJ or 14.3% of the total fall, is not itemised in the paper or its Supplementary Information.

The identity places it. Primary energy falls by 300 EJ because rejected energy falls by 250 EJ and ambient energy rises by 50 EJ. The three named loss boxes, generation, transport and fuel

transformation, account for 115, 66 and 26 EJ of the 250 EJ. Unless it reflects non-energy use or the rounding of ‘nearly 300 EJ’, the remaining 43 EJ must be end-use losses outside transport, in the residential, commercial, manufacturing and other sectors (p. 12), where boilers and furnaces give way to heat pumps and electric heat. It is a carrier saving, inferred rather than stated; the paper does not give it by sector. [AUTHORS’ REPLY PENDING]

3.4 *The electricity share*

The paper reports that electricity rises from 17% to 67% of final energy. Neither the paper nor the Supplementary Information gives total final energy or electricity consumption in EJ for either scenario, so the share cannot be reproduced. Section 5 needs that figure.

4 Carrier or source

4.1 *The split*

Table 2 assigns the paper’s named effects, and the remainder its balance implies, to carrier or source. The generation effect, 115 EJ, is the source change: thermal generation replaced by wind and solar. Transport and ambient heat, 116 EJ, are the carrier change the paper names; with the 43 EJ of other end-use losses the carrier change is 159 EJ. The fall in other fuel transformation, 26 EJ, is mixed. That box includes ‘energy use in coal mining, and oil and gas production’ (p. 11), which serves power stations as well as end users, and the paper does not split it. We leave it unassigned.

Table 2. Decomposition of the paper’s primary-energy saving.

Component	Class in this note	Saving	Paper’s description
Electricity generation losses, 135 EJ to 20 EJ	Source change	115 EJ	Thermal generation ‘largely replaced by non-combustible renewable electricity’ (p. 7)
Transport losses, 94 EJ to 28 EJ	Carrier change	66 EJ	Electric drivetrains more efficient than combustion engines (p. 7)
Ambient energy, about 2 EJ to 52 EJ	Carrier change	50 EJ	Environmental heat upgraded by heat pumps (p. 7)
Other end-use losses: residential, commercial, manufacturing, other	Carrier change (inferred from the identity)	43 EJ	Not itemised; the rest of the 250 EJ fall in rejected energy
<i>Carrier change, subtotal</i>	Carrier change	159 EJ	116 EJ named plus 43 EJ inferred
Other fuel transformation losses, 40 EJ to 14 EJ	Mixed: serves end users and power stations	26 EJ	‘Reduced fossil fuel extraction, processing, and refining’ (p. 7)

4.2 *The source term is the largest single item*

The authors agree: ‘Reductions in electricity generation losses are the single largest contributor to lower primary energy use’ (p. 8). They add that these reductions are ‘an inherent consequence of replacing thermal generation, independent of changes in electricity demand’ (p. 8). That is the source change.

Physically, a thermal plant’s rejected heat is the price of electricity on demand from a stored fuel. Wind and solar avoid that loss but generate when the weather allows. The physical energy content method counts the avoided loss in full; the cost of turning weather-dependent output into supply on demand is not a conversion loss, so the question is where the accounts record it. Section 5 asks.

4.3 *Same electricity, different source*

The paper gives the generation saving but not the electricity behind it. At its own 40% average fossil efficiency, a 115 EJ fall in generation losses implies that about 76.7 EJ of electricity has moved

from thermal plant to non-combustible generation, roughly 21,300 TWh. We call this the swapped electricity. It is modelled, not stated, and rests on one average efficiency for a fleet of coal, gas and oil plant.

It is also a floor. The 135 EJ and 20 EJ figures include grid and storage losses (section 5.1), so the 115 EJ is net: if the electrified system loses more per unit in the grid and in storage, part of the gross combustion saving is consumed inside it, and the swapped electricity exceeds 76.7 EJ. An illustrative bound puts it at 76.7–85.3 EJ. Losses computed on it below are lower estimates on that count.

Table 3 asks what the same 76.7 EJ of electricity would save against the 40% fossil baseline if it came from other sources.

Table 3. Generation-side saving for the same swapped electricity (76.7 EJ) under different supply.

Supply of the swapped electricity	Conversion efficiency assumed	Generation loss on 76.7 EJ of electricity	Saving against the 40% fossil baseline
Wind and solar, physical energy content method (the paper's case)	Output counted as input, so no conversion loss	0 EJ	115 EJ (matches the paper)
Gas combined-cycle plant	49% (paper's gas figure)	79.8 EJ	35.2 EJ
Nuclear plant	33% (IEA convention for nuclear)	155.7 EJ	Minus 40.7 EJ (a larger loss than the fossil baseline)
Today's average fossil fleet (the baseline)	40% (paper's fossil average)	115.0 EJ	0 EJ, by construction
Wind and solar, substitution method (Energy Institute to 2024)	40.8% notional factor	111.2 EJ, notional rather than physical	3.8 EJ

A check: the authors state that retaining nuclear at its existing level 'would increase waste heat loss by 20EJ/year' (p. 14). Today's nuclear output, 2,682 TWh in 2022 (IEA, 2023), at 33% thermal efficiency gives a generation loss of 19.6 EJ. The two agree.

The carrier gain survives any source; the 115 EJ source gain is specific to non-combustible generation booked at output. Gas would save a third of it; nuclear would lose ground against today's average. We take as given the paper's reason for removing nuclear, replacement 'by more efficient and lower-cost generation options' (p. 14), and note only that on this indicator nuclear scores below the fossil average, because the indicator measures conversion loss, not carbon or whether supply is there when needed.

4.4 How much of the source term depends on convention

Under the substitution method, the 76.7 EJ of swapped electricity is booked at the fuel a 40.8%-efficient thermal plant would need, the Energy Institute's factor for 2022, the paper's base year (Energy Institute, 2024): 187.9 EJ of primary energy. The extra 111.2 EJ is notional, not a physical loss. Fossil fuels are booked the same way under both conventions, so the source term falls by 111.2 EJ. What little remains, 3.8 EJ, is not a robust core; it is the gap between the paper's 40% fleet efficiency and the 40.8% substitution factor.

This is a partial re-run. Substitution applies to all non-combustible electricity in both scenarios: to today's hydro, wind and solar in the baseline, and to the added electricity the carrier change draws in the electrified system. A full re-run needs totals the paper does not give (section 6.3), and would remove more, not less, because the electrified system has more non-combustible electricity than the baseline. What the partial re-run establishes is a floor: at least 111.2 EJ of the 300 EJ headline, more than a third, depends on the convention. The fall in power-station waste heat is physical, and rejected energy, the paper's lead indicator, does not depend on the convention; what depends on convention

is how much of it is reported as a fall in primary energy. The authors concede that the primary energy figure ‘depends on a convention’ (p. 8); this note supplies its minimum size. Physical energy content remains the better convention (section 2.4); the point is how much of the headline rests on it.

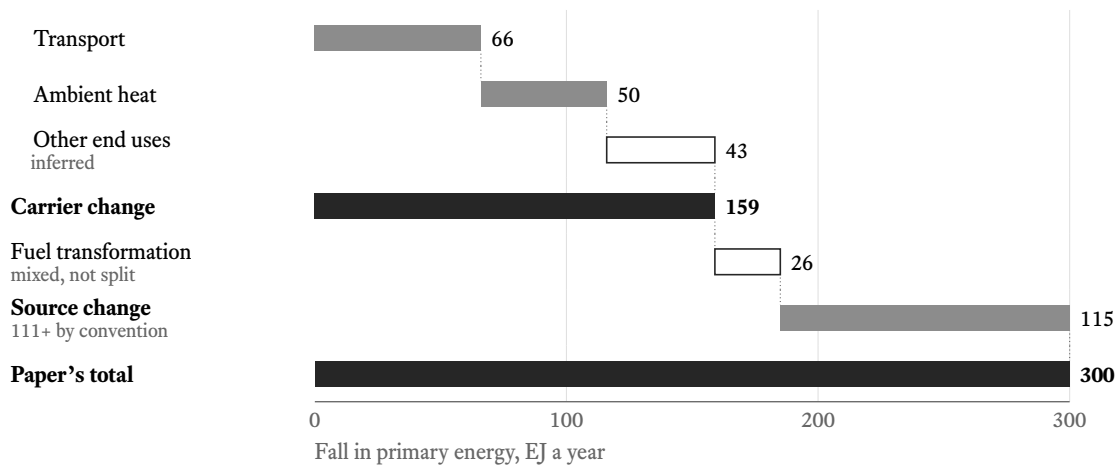


Figure 1. This note’s decomposition of the paper’s 300 EJ fall in primary energy, under physical energy content. Transport, ambient heat, fuel transformation and generation are named in the paper; other end-use losses are inferred from its energy identity; fuel transformation serves both end users and power stations and is not split. Sources: Rosenow et al. (2026), p. 7; Table 2.

5 The source side and the 20 EJ box

5.1 What the box holds

The paper’s electrified system has 20 EJ of losses under ‘Electricity Generation’. The methodology says what that box contains. ‘For electricity generation, this includes losses in electricity transmission, distribution and storage, as well as generation and electricity input to fossil fuel transformation processes’ (p. 11). Data-centre, charging and power-electronics losses are ‘captured ... within electricity system losses’ (p. 9).

So the 20 EJ is not a thermal loss with storage costed elsewhere; it is the whole loss account of a system in which electricity supplies 67% of final energy.

5.2 Is 20 EJ enough?

Total electrified generation is not disclosed, so the box cannot be audited directly; two bounded tests are possible.

The first applies published loss rates to the swapped electricity. Transmission and distribution losses, from generator to user, were 6.8% of output worldwide in 2022 (World Bank, 2026). Round-trip efficiency is the share of electricity put into a store that comes back out. Curtailment is available wind or solar output not generated because the grid cannot use or store it. Table 4 applies low, central and high rates to 76.7 EJ.

Table 4. Illustrative losses on the swapped electricity (76.7 EJ, a floor).

Loss component	Rate range (low / central / high)	Loss on 76.7 EJ (low / central / high)	Source and grade
Transmission and distribution	5% / 6.8% / 18% of output	3.8 EJ / 5.2 EJ / 13.8 EJ	World Bank (2026) world average for 2022, full fetch; low and high from IEA (n.d.)
Battery or pumped-hydro stor- age loss (one minus round-trip efficiency), if all output were stored once	5% / 10% / 15%	3.8 EJ / 7.7 EJ / 11.5 EJ	Commercial lithium-ion range; 90% central as paraphrased by House of Lords Science and Technology Committee (2024); secondary- grade
Curtailment of available wind and solar output, for scale only	5% / 11% / 20%	3.8 EJ / 8.4 EJ / 15.3 EJ	Never recorded under physical energy content (section 5.3), so not in the box; extrapolated from today's grids
Transmission, distribution and battery, central	Central rates, curtailment and hydrogen excluded	12.9 EJ	Upper illustration: assumes every unit is stored once

At central rates, transmission, distribution and battery losses on the swapped electricity come to 12.9 EJ, even if every unit passes through storage once. That fits inside 20 EJ. The authors expect it to: added electrification loads ‘at plausible scales would not materially affect the direction or magnitude of the results’ (p. 10), and retaining nuclear, which adds 20 EJ of waste heat, ‘would change the reduction in total waste heat between the two scenarios by less than 10%’ (p. 14). We do not dispute either statement. The point is disclosure: the box is the whole loss account of a system two-thirds electric, and its contents are not given.

The second test uses total generation. The electrified system must generate at least today’s 29,033 TWh (IEA, 2023), since electricity demand rises. Transmission and distribution losses alone at 6.8% on that floor come to 7.1 EJ. That fits within 20 EJ, before storage, curtailment, residual thermal loss and any growth in generation. [AUTHORS’ REPLY PENDING]

One further item sits in the box. The paper retains geothermal generation at its existing level, about 101 TWh or 0.36 EJ in 2022 (REN21, 2023). Booked like wind and solar, output equal to input, its loss is 0 EJ. Booked at the IEA default of 10% efficiency, used when plant efficiency is not reported (IEA, 2026), it is about 3.3 EJ, 16% of the box. The paper says it follows the IEA/UNSD method but does not say which rule it applied to geothermal. We carry both readings. [AUTHORS’ REPLY PENDING]

5.3 Curtailment and overbuild are invisible by construction

The physical energy content method ‘records electricity generated’ (p. 11). Available output that is curtailed is never generated, so it never enters the accounts as a loss. Nor does capacity built to cover still or dark periods and idle otherwise; its cost falls on capital, land and materials, not on the energy balance. The paper says its storage serves to ‘mitigate losses such as curtailed electricity’ (p. 9). Storage does turn some would-be curtailment into delivered energy, at a round-trip loss that enters the box, but it cannot make unstored curtailment visible. Part of the physical cost of a weather-dependent supply never appears as energy, and the cost of covering the worst week, when demand is high and wind and sun are low, lies outside an annual balance, as the authors acknowledge: ‘weather-driven variability and reliability remain real constraints on a fully electrified, renewable-supplied system’ (p. 10). In energy terms the cost of firm supply appears in two places: storage losses, inside

the 20 EJ box, and the energy to build the spare capacity, storage and grid it requires, which is part of section 5.5.

5.4 *The storage basis*

The paper scales its storage allowance from ‘an analysis of the need for short-, medium- and long-term energy storage in a fully renewable electricity system in the UK’ (p. 14), its reference 42, the Royal Society’s 2023 report on large-scale electricity storage (Royal Society, 2023). The paper states neither the loss rate taken from it, nor the share of global output passing through storage, nor how a national study was scaled to the world. Those figures decide how much of the 20 EJ is storage.

[AUTHORS’ REPLY PENDING]

5.5 *Construction energy is held at today’s level*

The paper counts the fossil system’s operating self-use, ‘energy use in coal mining, and oil and gas production, as well as oil refining’ (p. 11), as rejected energy. Energy for manufacturing is inside the balance too, as end use, and the Supplementary Information lists iron and steel, non-metallic minerals and machinery among the sectors. But useful energy, manufacturing included, is held at today’s level. The comparison therefore adds no energy for building the electrified system, and none for rebuilding it as it wears out; embodied energy, life-cycle energy and energy return are not mentioned.

This matters more for one side than the other. For fossil fuels ‘the main energy requirements are associated with the extraction, processing, and delivery of energy resources’, whereas ‘for non-biomass renewables, almost all energy requirements are from upfront energy demand for the construction of energy infrastructure’ (Slameršak et al., 2022, p. 10). Investment is about 2% of lifetime energy costs for gas power and 98% for wind (King and van den Bergh, 2018). The fossil system’s continuing energy requirement is counted; the renewable system’s is held at the level of today’s manufacturing.

The paper treats build-out as a question of ‘materials demand’ and ‘land use’ (p. 10), not of energy. A referee may say that an annual operating balance is not a life-cycle assessment. The answer is that machines wear out: in a steady state part of the system is rebuilt every year, and that is an annual flow of manufacturing energy, inside the primary-energy footprint the finding is about.

Published energy returns for wind and solar vary widely, and whether the energy for storage should be charged to them is disputed (Barnhart et al., 2013; Weissbach et al., 2013; Rauegi et al., 2015). We therefore put no figure on it. The point is the direction: the comparison holds fixed the energy requirement that dominates for wind and solar, while counting the one that dominates for fossil fuels. [AUTHORS’ REPLY PENDING]

6 Discussion

6.1 *Rebound*

The paper holds useful energy fixed by design. The word ‘rebound’ does not appear in the paper or its Supplementary Information. Its foundational reference, Eyre (2021), by one of the present authors, raises it: ‘By treating demand for energy services as fixed, the methodology also neglects any rebound effects from improved energy efficiency’, adding that ‘rebound effects specific to the improved conversion efficiencies addressed here are unknown’.

The authors may reply that they expect the 300 EJ figure to be ‘proportionately larger if, as we expect, useful energy demand rises’ (p. 8). That compares the two systems at the same, higher, level of service. Rebound is different. It is the extra service demanded because more efficient conversion makes each unit of service cheaper, so the electrified system would supply more useful energy than

the system it is compared with, and part of its saving would be taken back. The evidence that such effects can be large is substantial: Brockway et al. (2021), whom Eyre cites, conclude that ‘economy-wide rebound effects may erode more than half of the expected energy savings from improved energy efficiency’. Against that, Eyre (2021) notes that higher-priced fuels may prevent historical rebound recurring. How much applies here is, as he says, unknown, and we offer no figure. The paper’s finding is that the objection of an unmanageably large primary-energy footprint is removed (p. 9). That objection is about the real system, whose footprint rebound would enlarge. The paper should carry its co-author’s caveat.

6.2 *The feasibility rule and aviation*

The Supplementary Information electrifies an end use only where the technology ‘has been developed, demonstrated and is already used commercially or is very close to commercial deployment’ (SI, S.1). Aviation sits in tension with this rule. The paper electrifies 33% of air travel because journeys under 2,000 km ‘might reasonably be electrified (Schafer et al, 2019)’ (SI, S3). Schäfer et al. (2019) place the batteries this needs decades away: a 2,222 km range needs ‘at least 1,600 Wh/kg’, which ‘may remain a significant technology challenge for decades to come’. The authors flag ‘considerable uncertainty around the feasibility of aviation electrification’ and note that aviation is a tenth of transport energy, so the effect is limited (SI, S3). We agree it is small. It is a point of consistency with the stated rule, not of size.

6.3 *Minimum disclosure asked of the authors*

The results can be checked only if the following are disclosed. We asked the authors for them on 27 September 2026 and will revise this note if they are supplied. [AUTHORS’ REPLY PENDING]

1. Absolute totals of primary, rejected, useful and final energy for both scenarios, in EJ.
2. Total electricity generation in the electrified system, and its split by source.
3. The make-up of the 20 EJ electricity box: transmission and distribution, storage round-trip losses, curtailment, and the convention used for geothermal.
4. The storage-routed share of output and the round-trip efficiencies assumed.
5. The 43 EJ of other end-use losses by sector, and the split of the 26 EJ fuel-transformation fall between fuel for power stations and fuel for end users.
6. An estimate of the annual energy to build and replace the electrified system’s generation, storage and grid, against the manufacturing energy held at today’s level.

7 Conclusion and data availability

The paper’s 300 EJ saving adds different kinds of change. The carrier change, 116 EJ named and a further 43 EJ implied by the paper’s own balance, is real whatever the source of the electricity. The source change, 115 EJ, is the largest single item; the fall in waste heat is physical, but at least 111.2 EJ of the headline depends on the convention used to book wind and solar, and the full figure needs totals the paper does not give. The fall is booked net of a 20 EJ loss allowance whose contents are not stated. It holds manufacturing at today’s level, so it counts the fuel supply on which fossil energy mainly depends but adds nothing for the construction on which wind and solar mainly depend; and it holds service demand fixed, so it excludes rebound. Both bear on the paper’s finding that the objection of an unmanageably large primary-energy footprint is removed. None of this shows the paper’s arithmetic wrong or its preference for rejected energy mistaken. It shows which part of the result is physics and which is accounting, and identifies the numbers needed to tell them apart. We have asked the authors for them. [AUTHORS’ REPLY PENDING]

Data availability. The reconstruction is released with this note as `numbers/model.py`, a deterministic Python script using the standard library only, and `numbers/results.csv`, its output. Every constant carries its source. The model can be re-run and corrected against the paper’s totals if they are published.

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