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WHITE PAPER SERIES

WE DON'T HAVE TO REPLACE IT ALL: DEBUNKING THE PRIMARY ENERGY FALLACY

August 2026

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THE PRIMARY ENERGY FALLACY: WHY THE ENERGY TRANSITION NEEDS FAR LESS ENERGY THAN YOU THINK

Primary Energy Comparisons misleading the Net-Zero conversation and neglecting the role of Energy Efficiency

EXECUTVE SUMMARY

The energy transition is widely assumed to require replacing today's vast fossil fuel inputs with an equivalent volume of renewable generation – a costly, capital-intensive undertaking that critics argue is unrealistic at scale. This assumption rests on a comparison of primary energy inputs, what Canadian energy analyst Paul Martin and others call the Primary Energy Fallacy: conflating raw energy inputs with the useful services people actually consume, while ignoring the large conversion losses inherent in today's combustion-heavy system.

Once these losses are accounted for, the picture changes materially. Electrification and energy efficiency deliver the same services – heat, mobility, light – using far less input energy, and a fully electrified global energy system could cut final energy demand by 40%, avoiding a proportionate share of the renewable capacity, storage and grid infrastructure otherwise required. This paper explains the Primary Energy Fallacy, quantifies the efficiency advantage through EV, heat pump and power generation examples, and sets out the macroeconomic and investment case for allocating to the demand side of the energy transition.

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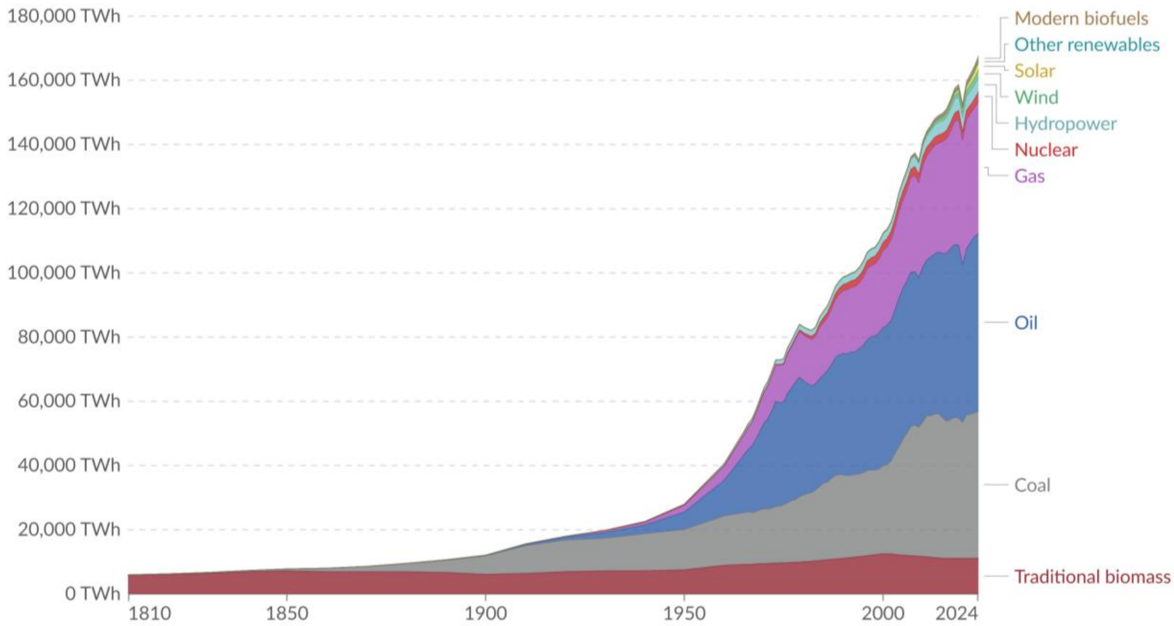
Debunking the Primary Energy Fallacy

A seductive chart – and the mistake behind it

Critics often share a long-run chart of global primary energy consumption (see graph below) to claim that renewables are clearly too small to matter when compared to coal, oil and gas.

Fig 1: Global direct primary energy consumption[1]



Source: Energy Institute – Statistical Review of World Energy (2025); Smil (2017)

The implicit assumption is that all fossil inputs shown must be replaced one for one with renewable inputs. That is the Primary Energy Fallacy. In fact, we do not need to replace all inputs. We need to deliver the same services, i.e. heat, motion, light and materials more efficiently. This is something electrification and demand-side solutions can do at large scale. As the University of Oxford's Professor of Energy and Climate Policy Jan Rosenow summarises, primary energy-framing inflates fossil fuel importance and hides efficiency gains from electrification.

Solas Capital's own white paper series has repeatedly emphasised [“the power of less”](), showing that reducing demand via efficiency and shifting to efficient electric end-uses shrink the cost- and time-problem the energy system must solve to accomplish a successful energy transition. That is the same logic at the heart of the primary energy critique.

[1] Energy consumption is measured in terawatt-hours, in terms of direct primary energy. This means that fossil fuels include the energy lost due to inefficiencies in energy production.

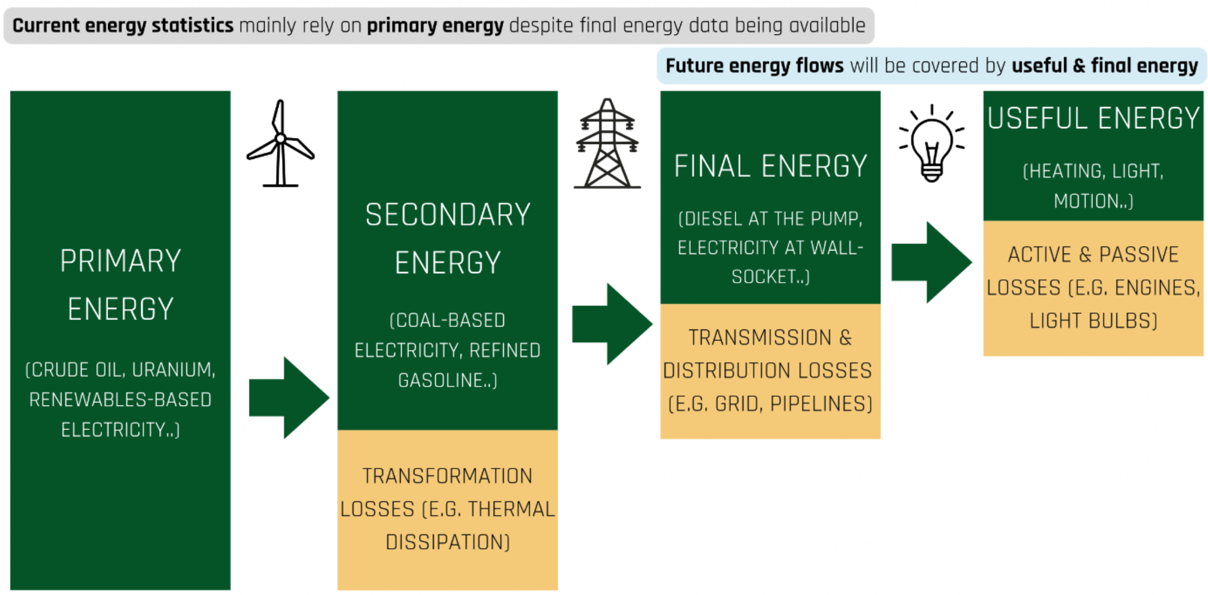
What primary energy is and why it misleads

Primary energy is an accounting construct. It adds up the energy content of fuels and non-combustible sources before any conversion through human-engineered processes takes place. People, however, do not gain any benefit from energy in its natural 'raw' form but instead purchase energy in its 'final' form; when it has been transformed to a *useful* energy service.

The energy chain describes the transformation of energy from its original form to useful services through four stages:

1) **Primary energy** is energy in its first measurable form entering the energy system: crude oil in the ground, coal in a mine, natural gas, uranium ore, or electricity generated directly from renewable sources such as wind, hydro, and solar (treated as "primary electricity" since no fuel-conversion step is recorded).
2) **Secondary energy** is obtained after converting or processing primary sources: gasoline refined from crude oil, or electricity generated from burning coal.
3) **Final energy** is what is delivered to the end user: electricity at the wall socket, gasoline at the pump, or natural gas piped into homes.
4) **Useful energy** is the actual service provided: light from a bulb, motion of a car, heat warming a room, or cold air from a refrigerator.

Fig 2: How energy statistics quantify energy



Source: Graphic by Solas Capital

At each conversion stage, energy losses occur, predominantly as waste heat. These losses accumulate and are disproportionately large in today's combustion-heavy system. In typical thermal power, up to two-thirds of the energy in coal or gas is dissipated as heat before a single kilowatt-hour is delivered to the end user. Consequently, fossil fuels appear large in the primary energy context even when they, in fact, deliver the same service as an efficient electric alternative. That inflates fossil importance relative to renewables in any stacked primary energy bar chart as evidenced in figure 1.

The role of accounting methods in energy statistics

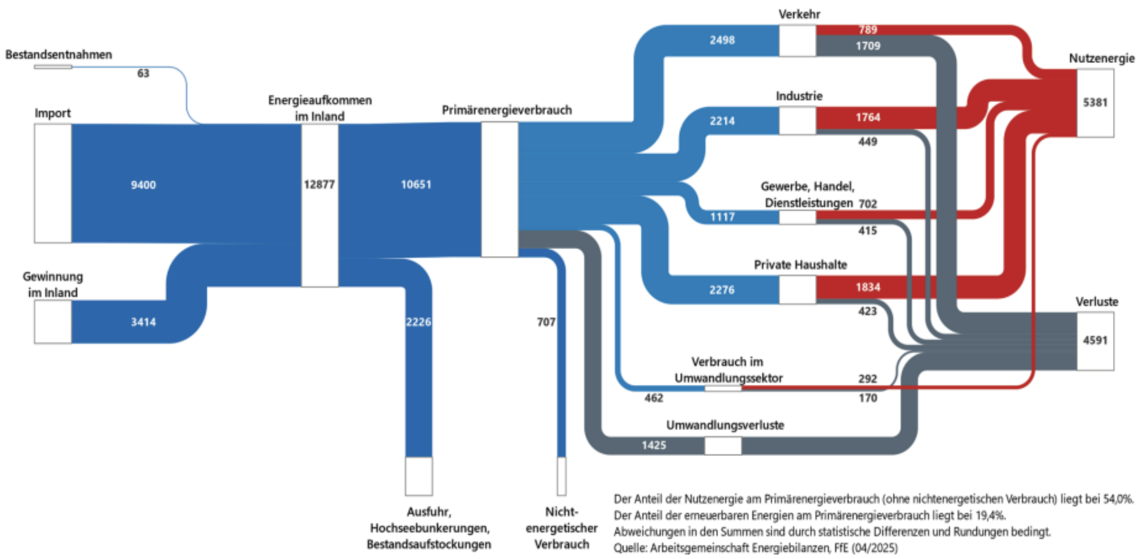
A second layer of confusion comes from how non-combustible electricity is counted. Under the **direct (physical content) method**, wind, solar and hydro are recorded as the electricity they produce, i.e. there is no imaginary boiler loss. Under the **substitution method**, the same renewable electricity is scaled up by a thermal efficiency factor (0.4 in recent years) to the fossil input that would have been required if a conventional fossil fuel power plant had generated it. Although this adjustment makes renewables appear larger in primary energy terms, it still does not consider downstream savings from more efficient/electrified end-uses. The accounting method used will therefore impact any conclusion.

A simple thought experiment illustrates why primary energy comparisons can be deceptive: Consider replacing a coal power plant with solar panels, both delivering 1 MWh of electricity. The coal plant requires approximately 3 MWh of primary energy in the form of thermal coal based on a 33% conversion efficiency. Solar panels, depending on the accounting method, are often counted as having a 1:1 primary-to-final energy ratio. Switching from coal to solar thus reduces reported primary energy consumption by roughly two-thirds – not because less useful energy was delivered, but simply because conversion losses disappear. The ratio changes dramatically while electricity output remains identical.

Making losses visible with Sankey Diagrams

Sankey diagrams, named after Irish Captain Matthew Sankey, who created the first known diagram in 1898 to visualize the efficiency of a steam engine, depict energy flows from source to end-use and distinguish between energy services and rejected energy (losses). They are valuable precisely because they visualise what stacked bar charts of primary energy conceal: the sheer magnitude of losses in the current fossil fuel-based system. By highlighting where energy is lost, Sankey diagrams point policymakers and investors to the real levers of transition: cutting waste, electrifying end-uses, and maximising efficiency.

Fig 3: German Energy Consumption 2023, PJ



Source: By Ruprecht & Kracht based on data from AGEB, BDEW, HEA, FIE[2]

[2] Ruprecht & Kracht (2025)

Looking at the **Sankey diagram for Germany above**, 46% of input energy is "lost", mainly as waste heat from combustion in power plants and vehicles (grey bars), and only about half of primary energy becomes actual useful energy services (red bars). In comparison, the Sankey diagram for the US reveals that 2/3 of primary energy is rejected and only 1/3 therefore becomes useful energy.

Germany's heightened efficiency is attributable to the country's higher share of renewable electricity, which avoids the thermal conversion losses inherent to fossil fuel plants. Additional contributing factors include stricter building codes, greater heat pump adoption, and more extensive public transit infrastructure that reduces losses in the transport sector. Overall, energy systems efficiency matters substantially for the share of primary energy that ultimately provides useful energy services.

Why Energy Efficiency demands attention now

Beyond efficiency losses, the Sankey diagram reveals another important challenge: Germany's dependence on imported fossil fuels to meet primary energy demand, sitting at almost 75% in 2023. In 2025 alone, Germany spent €102 billion on fossil fuel imports – leaving a €68 billion trade deficit in this category[3].

For Europe as a whole, the EU's fossil fuel import bill reached €374 billion in 2024, representing 2.1% of EU GDP. This remains above its ten-year average of 1.97% after peaking at 3.4% of GDP during the 2022 crisis[4]. This year's closure of the Strait of Hormuz – that alone carries 34% of global crude oil trade and 20% of LNG trade[5] – has once again demonstrated the vulnerability of EU energy consumers to global price movements as the bloc still imports more than 90% of the oil and gas it consumes[6]. Improving efficiency and electrifying heat and transport, remain the most direct levers to limit this exposure, while keeping capital in the European economy rather than flowing to energy exporters.

Regulatory tailwinds underpinning the case for energy efficiency investments

European policymakers have responded to the past years' energy shocks with measures that reduce demand at the point of consumption rather than adding further supply;

- **REPowerEU,** launched after the 2022 crisis, targets 10 million heat pump installations by 2027 – existing heat pumps already reduce German gas imports by 8.4 billion m³ annually[7].
- The revised **Energy Performance of Buildings Directive** (EPBD) from 2024, sets binding renovation thresholds – the worst-performing 16% of non-residential buildings by 2030, rising to 26% by 2033, alongside a full fossil-fuel boiler phase-out by 2040.
- Most recently, the European Commission's **AccelerateEU** package placed efficiency and electrification at the centre of its response to renewed energy cost pressure.

With only around 1% of Europe's building stock renovated annually, the EU estimates a €150 billion annual investment shortfall against the EPBD mandate[8] – a financing gap set against fixed compliance

[3] Official numbers from Statistisches Bundesamt (Destatis)
[4] Eurostat data
[5] Strait of Hormuz - About - IEA
[6] EU Report on energy prices and costs in Europe 2025
[7] Germany Heat Pump Market Analysis 2024
[8] The €150 billion annual investment shortfall

deadlines, not a discretionary spending target. This is the structural distinction investors should draw between the two pillars of the energy transition:

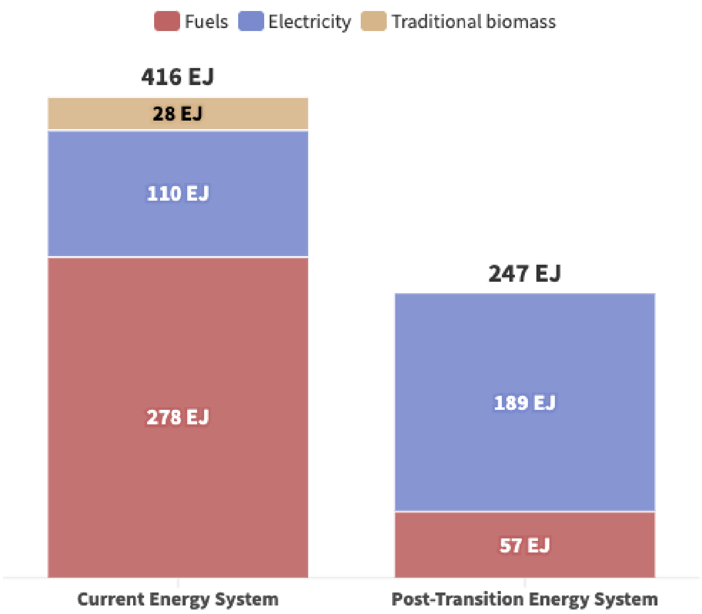
1) **Utility-scale renewables** built their investment case over the past two decades on 15–25-year Feed-in-Tariffs and long-term Power Purchase Agreements – support mechanisms now giving way to shorter contract durations and growing merchant price exposure as subsidy regimes mature and phase out.
2) **Energy efficiency** faces the opposite trajectory: demand is legislated rather than subsidised, and it strengthens every year as the EPBD deadline approaches, while reducing the need for building Capex-intensive offshore wind farms, large-scale battery parks, and grid infrastructure.

Reducing the need for a costly replacement of fossil fuels

Energy efficiency represents approximately one-third of the emissions abatement needed by 2030 for a net-zero trajectory, according to the International Energy Agency[9]. Oxford Professor Nick Eyre shows that a complete conversion of the global energy system with broad electrification could cut energy demand by 40% while delivering similar or better services[10].

The chart below shows why the transition is not a one-for-one substitution of clean electrons for fossil molecules: due to increased energy efficiency, global final energy demand falls from 416 EJ to 247 EJ even as electricity demand rises from 110 EJ to 189 EJ. Demand falls precisely because the system electrifies. The 169 EJ that disappears between the two bars is not shifted onto the renewable system; it is eliminated, having only ever been consumed to overcome the losses of combustion.

Fig 4: Global final energy demand pre- and post- energy transition



Source: Graphic by Hannah Ritchie using data from Nick Eyre (2021)[11]

[9] Executive summary – Energy Efficiency 2024 – Analysis - IEA
[10] Eyre (2021): From using heat to using work: reconceptualising the zero-carbon energy transition
[11] Ritchie (2023): The world will need less energy after the energy transition

The investment implication is direct. Roughly 40% of the clean generation capacity that today's system would require to be built – if seeking a one-for-one replacement of fossil fuels – is avoidable.

Since renewables are capital-intensive with near-zero marginal cost, avoided demand is avoided Capex. The savings also compound: lower energy consumption means less overbuild, storage and grid reinforcement. This reframes where the value sits. The decarbonisation story is usually told from the supply side, yet Figure 4 shows that the demand side accounts for 40% of the transition effort. As the economy moves to "Electrify All," investors focused on renewables generation move within a crowded, capital-intensive space that only solves half of the transition challenge, completely overlooking the demand side: retrofits, heat pumps, industrial electrification, which abate the same emissions at lower capital intensity and earn returns from energy-cost savings before any carbon value is counted.

Case Study

FINANCING INDUSTRIAL ENERGY EFFICIENCY UPGRADES FOR DUTCH DAIRY PRODUCER

Solas Capital's financing partnership with ENCORE Efficiency illustrates the scalability of industrial energy efficiency financing and its relevance to the wider energy transition debate. ENCORE is a German company specialising in industrial energy efficiency projects across the Netherlands, Belgium and Germany.

Financing arranged for a leading Dutch dairy producer – a multinational with annual revenues of approximately €13 billion and around 20,000 employees worldwide – has funded 32 projects across multiple production facilities, targeting heating, cooling and lighting systems that were consuming materially more input energy than the underlying process required. Over the investment period, this has delivered substantial savings of:

- **967'000 MWh** primary energy reductions
- **192'000 tCO2** emissions reductions
- **€40.5 million** energy cost savings

Business Model

ENCORE enters long-term Energy Performance Contracts (EPCs) with large corporates, deploying industrial efficiency technologies, guaranteeing the energy savings. Customers pay a fixed monthly fee over the project tenor, removing any upfront investment cost. For the dairy producer, this structure has funded efficiency upgrades entirely through EPCs – no upfront capital spend and permanent energy savings counting directly towards the group's own climate targets.

Why this matters for the energy transition debate

A common assumption is that every unit of fossil-based energy consumed today must be replaced with an equivalent unit of new renewable generation. Efficiency works differently: it removes demand at the point of use, so the gains come from eliminating avoidable losses – not from switching fuels – and the energy is never generated in the first place.

To illustrate the scale, generating **967,000 MWh from renewables** (corresponding to the energy savings achieved from the implemented efficiency solutions) would require in the order of:

- **460 MW of onshore wind** (60-90 average-sized turbines); or
- **920 MW of solar PV** (using EU-wide capacity factors)

Because ENCORE's installations eliminated that demand instead, no equivalent new capacity – fossil or renewable – needs to be built to replace it.

Simple examples: Quantifying the efficiency advantage

The following three examples illustrate how electrification and efficiency reduces primary energy requirements while delivering identical or better services to consumers and businesses.

Example 1: Buildings — Gas Boilers vs Heat Pumps

A modern condensing gas boiler operates at 90-95% efficiency, meaning nearly all the gas energy becomes useful heat. Heat pumps, however, do not generate heat. Instead, they move it from outside air or ground into buildings, achieving coefficients of performance (COP) of 3–5. This means they deliver 3–5 kWh of heat for every 1 kWh of electricity consumed, reaching effective efficiencies of 300–500%[12].

To illustrate the impact in practice: heating a typical home with gas or oil requires around 21 MWh/year after adjusting for 15% upstream losses and 90% furnace efficiency. Switching to a heat pump with a year-round COP of 3, and allowing 10% for grid losses, reduces energy consumption to just 6 MWh. This corresponds to ***a 70% reduction in primary energy demand*** with no reduction in comfort.

The superiority of heat pumps becomes even more apparent when compared to other proposed decarbonisation pathways: In France, replacing all electric resistance heaters with heat pumps (whose average COP was around 2.3 in 2020) would save 30% of the electricity currently dedicated to space heating. Perhaps more strikingly, heating a house with hydrogen produced via water electrolysis powered by renewable electricity would require nearly six times more electricity than a heat pump[13].

The Scandinavian countries demonstrate that large-scale adoption is already underway across Europe, with heat pumps now accounting for more than 40% of heating systems installed in existing buildings and achieving a market share of 94% of all new heating systems currently sold[14].

Example 2: Cars — Petrol/Diesel vs Electric Vehicles

Electric motors convert around 80% of the energy supplied into motion. Accounting for additional losses during battery charging, elective vehicles achieve an overall efficiency of at least 65%. In comparison, diesel engines reach around 45% efficiency, while petrol engines under optimal conditions achieve only 30–35%. When energy losses during fuel supply (extraction, refining, and transport from well to tank) are factored in, only around 20% of the original energy in fossil fuels is utilised for mobility[15].

The differences become concrete when comparing popular European vehicles. A VW Golf doing 17 km/L requires approximately 0.75 kWh/km after accounting for upstream losses in fuel production and distribution. The equivalent electric VW ID.3 uses just 0.19 kWh/km, after adjusting for grid and charging losses. This corresponds to ***a 75% reduction in primary energy demand*** with no reduction in mobility[16].

A study by Wiener Stadtwerke further underscores why direct electrification outperforms green alternatives: hydrogen vehicles exhibit efficiency levels of only 22%, and e-fuels achieve even less at merely 13% — far from the efficiency of modern electric vehicles.

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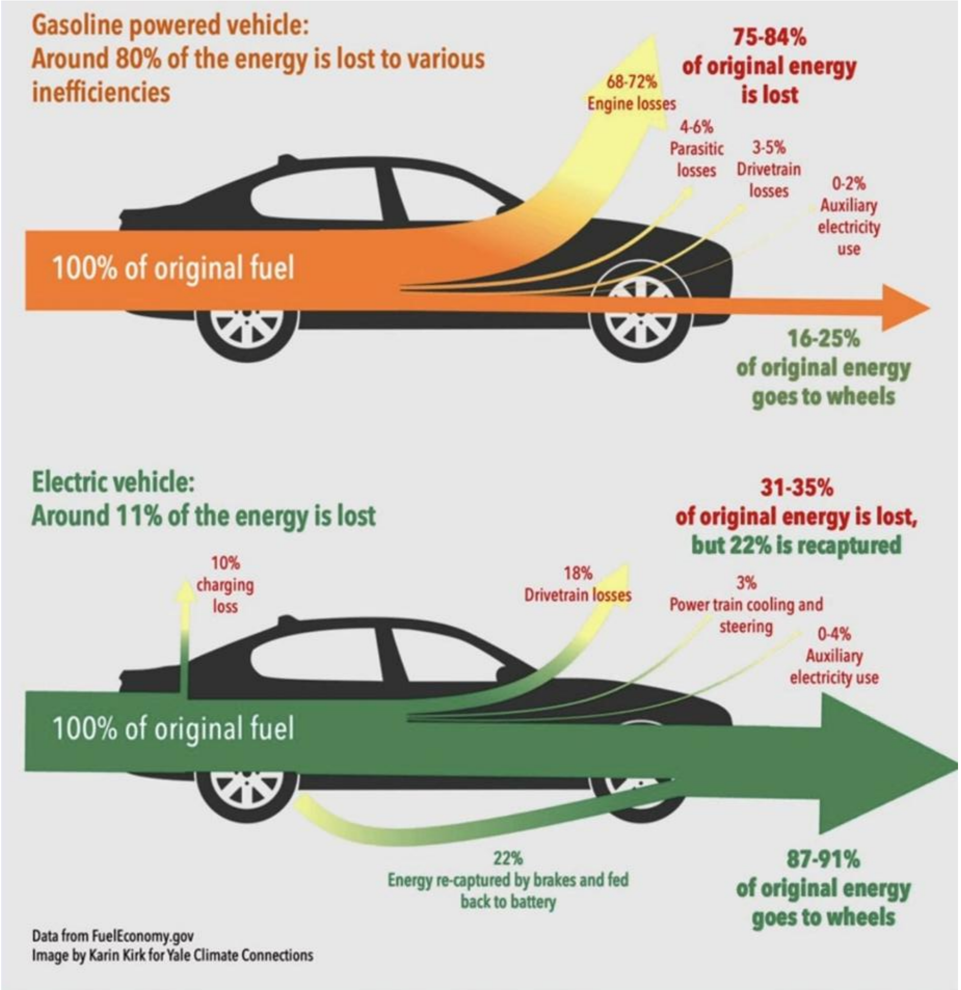
[12] Zenon Research (2023): Beyond primary energy; ,Rödl & Partner (2023)
[13] Zenon Research (2023)
[14] KfW Research (2025): Heat pumps are gaining ground in Europe – electricity prices matter
[15] Rödl & Partner (2023)
[16] Liebreich, BloombergNEF (2024): Net Zero Will Be Harder Than You Think – And Easier. Part II: Easier

Fig 5: Energy losses in combustion vs. electric vehicles



Source: Picture by Karin Kirk for Yale Climate Connections using data from FuelEconomy.gov[17]

Example 3: Power Generation – Thermal vs Direct Electricity

On average, the efficiency of fossil fuel power plants in Germany is only 46%. This means that more than half of the energy contained in coal or gas is dissipated as waste heat before electricity reaches end users[18]. The loss during energy conversion costs the German economy over €10 billion annually; money effectively wasted through chimneys, cooling towers, or discharged as heat into rivers[19].

Of the 12,800 PJ of primary energy consumed in Germany, only about 5,400 PJ are ultimately used as final energy as evidence in the Sankey diagram (fig 3)[20]. Renewable sources are therefore underrepresented in primary energy analysis. Since they have virtually no conversion losses and require no energy for fuel shipping, renewable power sources like solar and wind can offset roughly three times the amount of fossil fuels in terms of useful energy delivered[21].

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[17] Jan Rosenow (2026)

[18] Durchschnittlicher Brutto-Wirkungsgrad des eingesetzten fossilen Kraftwerksparks | Umweltbundesamt

[19] Rödl & Partner (2023)

[20] AG Energibalanzen, Germany 2023

[21] Rödl & Partner (2023)

Conclusion – Investing in Energy Services not Fuels

The energy transition does not require matching today's fossil-based primary energy with an equal volume of renewables. It requires delivering the same services – heat, mobility, light, materials – far more efficiently, and roughly 40% of the clean generation capacity implied by primary energy charts is never needed at all, because the demand it would have served is eliminated rather than shifted. This has a direct macroeconomic and investment consequence. Every unit of energy efficiency deployed today reduces Europe's need for capital-intensive, subsidy-dependent renewable build-out, while also reducing the fossil fuel imports that expose European economies to volatile global energy prices and undermine energy security. Efficiency is therefore not a secondary lever to be pursued once supply-side decarbonisation is further along – it is the more capital-efficient route to the same outcome.

For investors focused on the energy transition, the real scoreboard should be useful energy delivered, emissions avoided, and import exposure reduced. Capital directed at the demand side of the transition captures the same decarbonisation outcome as supply-side renewables, at lower capital intensity, with the added benefit of strengthening Europe's energy security.

About Solas Capital

Solas Capital is the European specialist in building and industrial decarbonisation energy infrastructure investments. Unlike traditional renewable energy investments focusing on supply, we specialise in reducing energy demand at scale. With 40% of Europe's energy consumed in buildings, we address a crucial pillar of the energy transition advancing Europe's climate and energy security agenda.

We are Europe's largest investment team dedicated to financing energy efficiency projects in buildings. Our project finance strategy offers institutional investors fixed-income-like cash flows from EU Taxonomy-eligible assets.

We partner with energy service companies, structuring tailor-made project finance solutions to fund their energy efficiency and behind-the-meter projects across Europe. To date, our financed projects have delivered €429 million in cost savings, 4'319 GWh in energy reductions and avoided 1'709 kt of CO_2.

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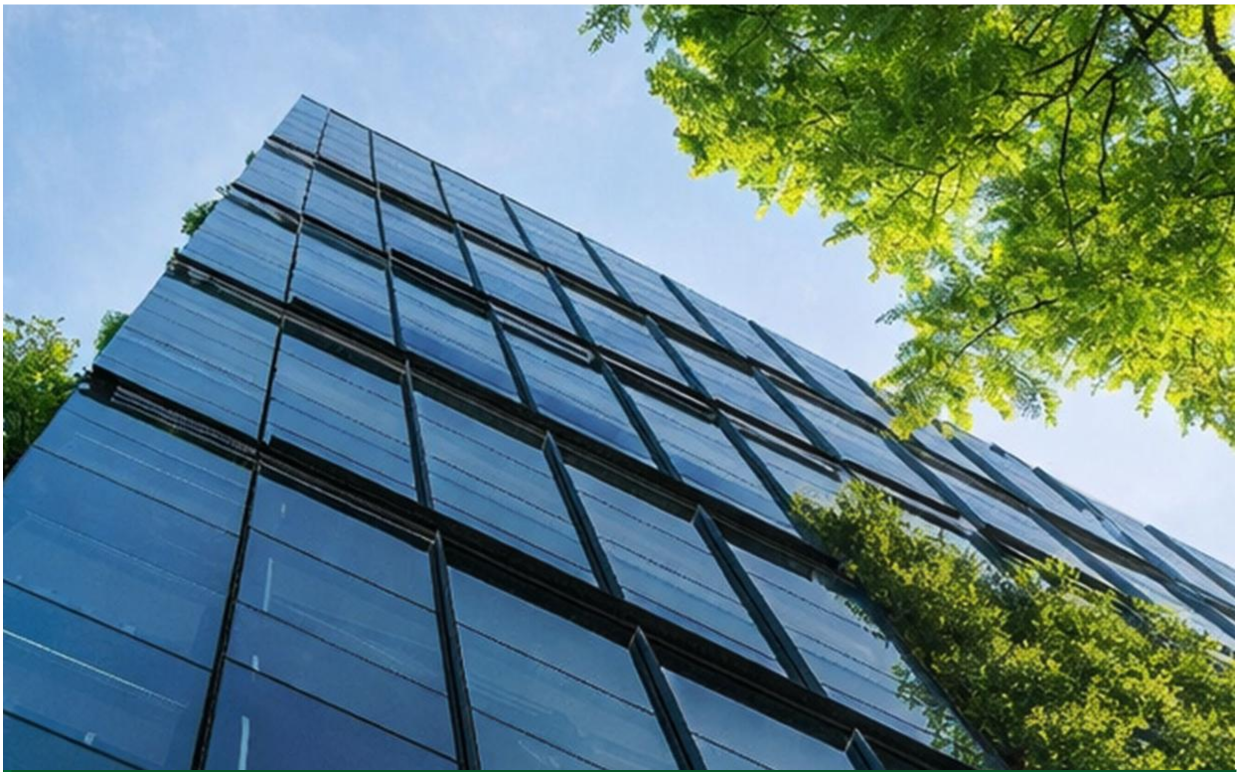

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