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PAPER

Leveraging demand-side potentials for energy security and resilience in Austria

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Supplementary material for this article is available online

Abstract

Energy security is a major concern for Austria. Austria is an energy importer, with a notable and historically grown reliance on fossil fuel imports, mainly Russian gas for industry and heating and oil for transport. The related vulnerability of the Austrian economy following the Ukraine and now Iran war and the related energy crises necessitate action to bolster the system's resilience. The Austrian government and other stakeholders have prioritised to enhance energy security. Some demand-side interventions and actions by users have shown notable potential. However, prevailing policy approaches predominantly emphasise energy supply, especially diversifying gas imports to reduce the dependence on Russia and reactive emergency measures targeted at affordability. Focusing on security of supply comes with the danger of novel lock-ins and overlooking the transformational potential of demand-side interventions and their many co-benefits for societal resilience, including health, trade balance, employment, and climate. To this end, we investigate how different supply- and demand-side interventions perform across diverse indicators of energy security for Austria using an accounting model. These interventions cover sectors such as buildings, transport, and industry. We show that demand-side actions demonstrate superior efficacy and provide an untapped readily available potential compared to conventional focus on import diversification in bolstering resilience and fortifying Austria against energy-related challenges, contributing to other policy goals such as climate change mitigation. We end with a call for action to Austrian policymakers to support demand-side actions to harness these resource potentials and diverse co-benefits instead of locking the energy system into expensive supply side infrastructure hampering transformational change opportunities.

1. Introduction

1.1. Energy security as a multidimensional concept

Energy crises often share a common pattern: the shock hits, emergency measures are improvised, prices eventually stabilise, and structural reform quietly recedes from the political agenda until the next crisis. The 1973 oil embargo, the 2006 and 2009 Russia-Ukraine gas disputes, and the 2022 price shock following Russia's invasion of Ukraine each triggered urgent declarations of transformation, yet each time the underlying vulnerabilities, concentrated import dependence, fossil-locked infrastructure, and supply-centric policy thinking, were left largely intact. The lesson is that treating energy security as a supply problem to be solved by finding the next cheapest source forecloses the deeper structural changes that would make future crises less damaging or ideally in the longterm irrelevant. The latest energy crisis following the 2026 United States war in Iran has revived previous discussions on energy security.

A more preventive approach frames energy security as a multidimensional property of the broader system through which societies meet human needs. Scholars of provisioning systems have drawn attention to the full sociotechnical chain connecting resource extraction and infrastructure to the practices,

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institutions, and social norms that shape end-use demand (Gough 2018, Sahakian *et al* 2021). This is a perspective that usefully redirects attention from primary resource inputs toward the services that energy ultimately delivers, services whose (resource) demand is far more malleable than supply-centric frameworks assume. From this perspective, energy security encompasses not only the physical availability and reliability of supply, but also its economic affordability, social equity, and environmental sustainability (Sovacool and Mukherjee 2011). These dimensions interact: a system dependent on volatile global commodity markets is economically fragile; one that concentrates energy costs on lower-income households is socially precarious; one locked into fossil infrastructure generates the climatic instability that compounds future physical risks. And none of them are resilient to future shocks. Resilience, the capacity of the provisioning system to absorb shocks, adapt, and continue meeting human needs across all these dimensions, is therefore the more fundamental policy objective.

The stakes of this reframing extend beyond energy policy itself. Societies burdened by recurring energy crises must divert fiscal resources, political attention, and human and institutional capacity toward emergency response, crowding out long-term investments in education, public health, and ecological transition. A genuinely resilient and malleable provisioning system frees governance capacity for these broader challenges. The question is not only how to secure energy supply, but how to build a system resilient enough that energy crises cease to dominate the political agenda where and whenever possible.

1.2. Austria's energy context and fossil fuel dependence

Austria is a landlocked country and a central infrastructure hub in the European gas network, with significant transit capacities but insignificant domestic fossil fuel production. Austria had widely accepted a historically grown dependence on imported fossil fuels, foremost Russian gas. Before the start of the war in Ukraine in early 2022, approximately 80% of Austrian gas (∼63 TWh) originated from Russia under long-term pipeline contracts between OMV (main Austrian-based oil, gas, and petrochemical company) and Gazprom (state-owned Russian energy corporation). Some of these contracts dated back to 1968 and were extended as recently as 2018 until 2040 (BMK 2024c) 0F[3]. This dependence was not accidental but the outcome of deliberate economic ties and the political normalisation of supply risk: cheap Russian gas was treated as a structural asset rather than a strategic liability, with supply security categorised as a private-sector matter and Austria's neutrality invoked to deflect external criticism (Lechner 2023).

The Russian war on Ukraine brought this as a critical vulnerability to the surface. Overnight, decades of reliance on 'endless and cheap' Russian gas became a source of destabilisation risk, inflationary pressure, and societal uncertainty. Global market disruptions and Gazprom supply interruptions triggered severe price spikes, and Russian import shares paradoxically reached to up to 98% in December 2023 as exchange economics continued to favour Russian supply over alternatives. Legislative efforts to mandate diversification, requiring progressive increases in non-Russian gas to reach 100% by 2027/2028, failed to obtain the required constitutional majority in parliament (BMK 2024a). The definitive structural break came only in late 2024, when OMV terminated its Gazprom contract, followed by Ukraine's ending of its transit agreement in January 2025, halting the last remaining pipeline route for Russian gas to Austria (Gepp 2025).

Austria's broader energy import structure reflects the same fossil dependence. Of total primary energy (PE) supply of 1310 PJ in 2024, fossil fuels account for approximately 62% (BMWET 2025). Imports, which decreased recently, cover mostly fossil fuels (90%) (BMWET 2025), costing more than 25.9 billion EUR in 2022 alone when the war started, equivalent to 4.2% of GDP in trade deficit terms (Statistik Austria 2023).

The 2026 Middle East conflict, which has created the largest disruption to global oil supply in history (IEA 2026a), has exposed an analogous dependence in Austria's transport sector, where fossil fuels remain near-universal. Rising oil prices have brought affordability back to the centre of policy debate, yet the response has followed a familiar pattern: price caps, compensatory measures, and appeals to individual behaviour change, while the structural drivers of oil dependence, such as untargeted commuter subsidies, car-dependent settlement patterns, and underinvestment in public transport, remain largely unaddressed. As with gas, the influence of incumbent actors continues to favour demand-compensation over demand-transformation. Austria is therefore navigating two concurrent energy security crises rooted in the same underlying condition: structural dependence on imported fossil fuels across multiple end-use sectors, and a policy repertoire still oriented primarily toward managing that dependence through import

[3] Note that the ministry's name changed to BMWET.

diversification rather than reducing the energy system size (see supplementary materials for a deep dive into the Austrian energy security landscape)

1.3. The demand-side blind spot and article aim

Austria's response to the 2022 energy crisis predominantly prioritised supply-side measures: diversifying gas imports, securing LNG access, and managing storage. Demand-side actions remained episodic, framed as emergency austerity rather than structural investment (except for boiler replacements). The co-benefits that demand-side transformation offers, from climate mitigation and trade balance improvement to job creation and household wellbeing, have not been systematically integrated into Austrian energy security planning, and the security value of demand reduction remains underutilised in policy discourse (Brad *et al* 2025). A narrow supply-security focus risks costly infrastructure lock-ins, foregone co-benefits, and contradiction with Austria's own climate commitments.

Bento *et al* (2024) provide a methodological basis for addressing this gap. Studying 14 high, medium, and low-income countries, they show that demand-side strategies consistently outperform supply-side measures across a multidimensional set of energy security indicators. We apply their accounting model and indicator set to Austria, which is a high-income OECD country with concentrated prior dependence on Russian gas, an ability to diversify quickly given its infrastructure and ambitious climate goals. This case provides useful lessons to other developed countries namely for understanding the potential and limits of rapid energy diversification. We extend it with two Austria-specific policy scenarios capturing observed post-crisis changes and the potential of combined strategies. This provides us with a structured, real-world and in-depth case study that enhances our understanding of which strategies a high-income, energy importing country may prioritise when aiming to improve energy security. Rooted in empirics we reflect on the Austrian policy discourse surrounding energy security, in particular gas and oil security.

Existing assessments of Austria's energy security predominantly rely on empirical or accounting-based methods applied retrospectively or to near-term policy scenarios (e.g. Pichler *et al* 2024, who use a dynamic input-output model to quantify the economic impacts of a gas supply shock or focus on an energy carrier as in Zwickl-Bernhard *et al* (2024) on Austrian gas grid under declining gas demand). Longer-horizon transition pathway studies employing integrated assessment models (IAMs) or energy /electricity system optimisation models, by contrast, generate variables closely related to established energy security indicators as by-products of their broader modelling framework (Schmidt *et al* 2025, Kettner *et al* 2024, Sayer *et al* 2024, Steininger *et al* 2024), without explicitly engaging with the energy security indicator literature or reporting these as security-relevant metrics in their own right (APCC 2025). They do use energy security (mostly of supply) in motivating scenario design (Schmidt *et al* 2025) and find that low energy demand is conducive for supply security (Steininger *et al* 2024, APCC 2025, Schmidt *et al* 2025). Recently, sourcing and resilience for energy supply (Zwickl-Bernhard *et al* 2026), and a need for more research on energy demand options in decarbonising the energy system in view of changing risk profiles in Europe's value chains (Mayer *et al* 2024) have gained traction in energy system modelling. This paper addresses this research gap by applying a broader indicator framework consistently across a set of policy strategies. It provides indicator values that can be directly compared against both the empirical shock-response literature and the implicit security-relevant outputs of more complex transition models.

The paper proceeds as follows. Section 2 develops the conceptual framework, situating energy security within a multidimensional perspective and making the case for demand-side measures as resilience levers. S section 3 presents method, data and scenario design. Section 4 reports results for Austria individually, in comparative perspective, and with respect to co-benefits. Sections 5 and 6 discuss implications for Austrian energy strategy and draw conclusions for policy and research.

2. Conceptual framework: energy security and demand-side resilience

2.1. Dimensions of energy security beyond supply

Energy security scholarship has progressively expanded beyond its origins in supply reliability and geopolitical risk toward a richer multidimensional conception. The most widely adopted framework organises energy security along four dimensions: availability, affordability, accessibility, and sustainability (IEA 2007, Sovacool and Mukherjee 2011). Availability concerns the physical sufficiency of energy resources and the reliability of supply chains and infrastructure. Affordability addresses the economic costs of energy to households, firms, and the macroeconomy, including vulnerability to price volatility. Accessibility captures the extent to which all population groups can reliably obtain energy services, a dimension with strong equity implications often overlooked in aggregate supply-side assessments.

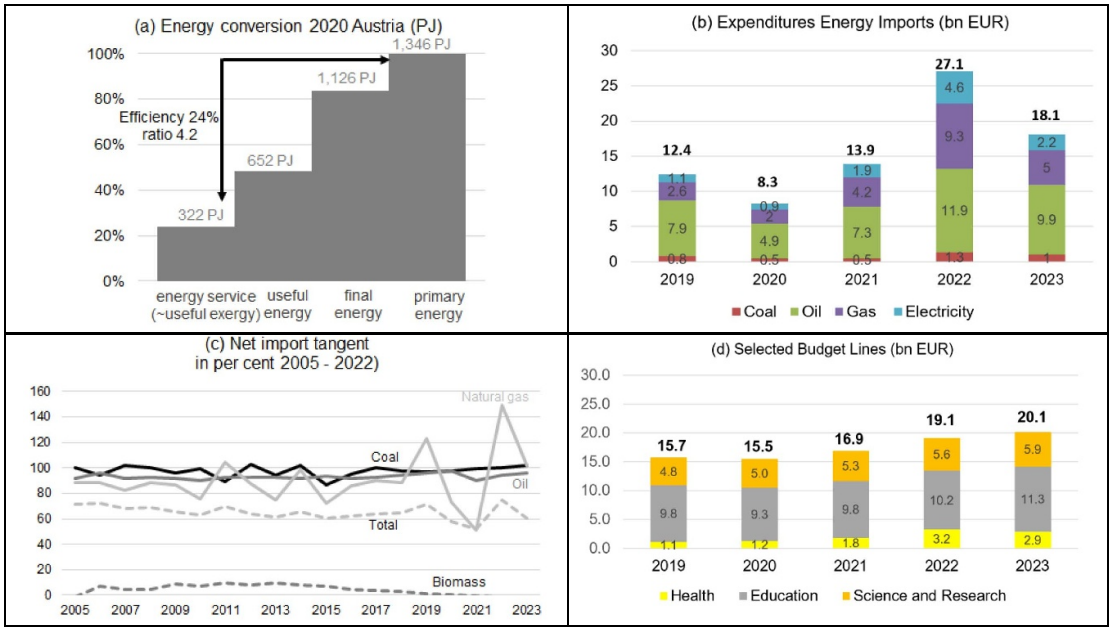

Figure 1. Panel (a) Energy conversion cascade for Austria in 2020. Data source: (Marshall *et al* 2023). Panel (b) Energy import expenditures 2019–2022 in bn EUR. Data source: (Statistik Austria 2023). Panel (c) Net energy import tangent 2005–2022. Data source: (Statistik Austria 2024). Panel (d) Budget expenditures for health, education and science and research in bn EUR. Data source: (BMF 2025). Created by the authors.

Sustainability encompasses the environmental and climatic consequences of the energy system, recognising that fossil-dependent security strategies generate the long-run instability they purport to avoid.

Operationalising these dimensions requires composite indicator approaches. Prominent frameworks include the World Energy Council's Energy Trilemma Index (WEC 2023), which balances security, equity, and sustainability; the Energy Security Index (Sovacool and Mukherjee 2011) drawing on 320 indicators across 88 countries; and the PENTEST framework (Ang *et al* 2015), which systematically maps indicators to dimensions and has been widely applied in European contexts. Critically, most applied energy security assessments remain supply-weighted in their indicator selection, with demand-side resilience, social vulnerability, and behavioural adaptive capacity underrepresented (Bento *et al* 2024, Nikas *et al* 2024). This aligns with the International Energy Agency (IEA) definition of energy security as security of energy supply (IEA 2023a). Informed by this broader perspective, this paper treats demand-side transformation and systemic resilience as core rather than residual dimensions of energy security.

2.2. Demand-side measures as resilience levers

Demand-side approaches that focus on the provisioning of energy services offer three distinct leverage opportunities: identifying inefficiencies along the resource conversion chain, reorienting policy toward human needs and wellbeing rather than primary resource inputs and unlocking a wide range of co-benefits beyond energy security itself (Creutzig *et al* 2016, Finn and Brockway 2023).

The conversion chain argument is particularly powerful in fossil-dominated systems. Conversion losses occur when energy is transformed from one form to another, such as from PE (e.g. crude oil) via final energy (FE)(e.g. gasoline) to useful energy (UE) (e.g. power to the wheel of a car) to energy service level (e.g. mobility for a certain distance). In Austria, UE (exergy) accounts for only around 24% of PE input (Marshall *et al* 2023) (figure 1, panel a), meaning that one unit of avoided end-use demand translates to approximately four units of PE that need not be supplied. This leverage effect is compounded by the malleability of demand itself, unlike primary resource supply, as end-use demand is shaped by infrastructure, regulation, and social norms, and can therefore be actively governed rather than merely projected. As electrification based on renewables expands, these conversion losses will shrink considerably, but the leverage effect of demand reduction remains substantial throughout the transition.

The co-benefits of demand-side action span multiple policy domains, making them attractive beyond their energy security value. On costs and trade balance, demand-side measures deliver the lowest electricity-sector investment costs and the smallest price spikes in European energy security scenarios (Nikas *et al* 2024), while Austria's stark fossil fuel imports highlights macroeconomic stakes of import dependency (figure 1, panels (b)–(d)). On employment, consistent evidence across national contexts

shows that spending on energy efficiency and renewables generates two to three times more jobs per unit of investment than equivalent expenditure on fossil fuels (Houser *et al* 2009, Spencer *et al* 2012, Garrett-Peltier 2017). On air pollution and health, reductions in fossil fuel combustion yield substantial co-benefits for ambient air quality and related health outcomes, including reductions in cardiovascular and respiratory disease burden (Finn and Brockway 2023). On climate, efficiency and sufficiency measures represent among the highest-potential near-term options for greenhouse gas emission reduction (Creutzig 2022a, 2022b). Finally, demand-side transitions that are participatory and equitably designed show higher social acceptance and durability (Creutzig *et al* 2022, Wiese *et al* 2024).

3. Methods

For this analysis, we use the approach presented in (Bento *et al* 2024), who studied 14 countries covering around two thirds of global energy use in 2019. We apply and extend this approach to Austria relying on their model structure and indicator calculations without modification. We add two policy simulations. We describe the approach briefly below but refer any interested reader to the original paper and Supplementary Materials where this is laid out in greater detail.

3.1. Accounting model

The excel-based accounting model of Bento *et al* (2024) relies on physical energy flows and conversion efficiencies of the energy system. The impact of policy interventions on energy security target different steps in the energy conversion chain: PE, FE (energy converted and delivered to an end user, e.g. electricity or gasoline for vehicles), and UE (energy actually put to the intended use. e.g. light from the electricity-powered light bulb). Any changes are handed on from useful for specific end uses (mobility, thermal comfort etc) via final to PE. This reflects, for example, how reduced gas use for low-temperature heat (UE) would affect the PE balance for gas, the respective potential to reduce gas imports and related energy security indicators. The underlying reason for reduced gas use for low-temperature heat at the UE level can be achieved through different means, such as insulation, changed end-use behaviour for heating temperature set-points, switches in heating technology or others.

We adopt an accounting approach rather than complex macroeconomic models, such as integrated assessment, or computable general equilibrium or input–output models, because our aim is to simulate transparent and comparable changes in key security indicators in the short run to assist the analysis of short-term crises response, rather than to capture indicator changes that emerge endogenously and require longer time horizons to materialise. Accounting models have proven useful for short-term illustrations and ex-post analysis, closer to policy making as we simulate strategies using the actual values as counterfactuals.

3.2. Data

The data sources are the PDUDB-Primary, Final and UE Database, IEA's World Energy Balances, UN COMTRADE, BACI and World Development indicators by the World Bank (table 1 and supplementary materials part 3). Where Austria-specific data differed from sources, we updated inputs accordingly.

We use 2019 as the base year for two reasons: to avoid the structural distortions introduced by COVID-related demand collapses in 2020–2021, and to maintain comparability with the 14-country analysis of Bento *et al* (2024). The policy scenarios (4.4.), including GAS, are therefore best understood as stylised simulations of the energy security implications of observed or proposed changes, applied to a stable pre-crisis baseline rather than as reconstructions of what occurred in specific years. The GAS scenario is parameterised using empirically observed magnitudes, i.e. the phase-out of Russian gas imports and the reduction in gas demand recorded in Austria between 2022 and 2024. These are treated as policy-equivalent inputs to the 2019 baseline rather than year-specific outcomes. This approach allows direct comparison across all six scenarios on a common structural foundation, at the cost of abstracting from the year-on-year dynamics of the crisis period itself.

3.3. Indicators

Changes in energy security are compared across 12 indicators for both demand and supply perspectives, following (Bento *et al* 2024) (table 2). They applied three criteria when selecting the indicators: representativeness, feasibility, and complementarity. Four diversity indices are applied to capture distinct dimensions of energy system configuration, including the geographic distribution of import sources, the mix of

Table 1. Data sources. Note: direct equivalent approach for all non-fossil energy carriers in PE.

Database	Description	Source
PFUDB	Primary energy (PE) for 13 fuels (coal, crude oil, oil products, natural gas, nuclear, hydro, geothermal solar, wind, biomass, other electricity, heat) final energy (FE) and useful energy (UE) for 7 uses (high-temperature heat, low-temperature heat, stationary power, transport, light (illumination), other); Population	De Stercke (2023)
World Energy Balances	Origin (domestic production or imports) of the energy sources; relative shares of the main energy importers for coal, oil, natural gas	IEA (2023b)
UN COMTRADE and BACI-Comtrade	Trade data on energy imports and exports by source (oil, natural gas, etc) and by country of origin and destination, in physical and monetary terms; relative shares of the main energy importers for coal, oil and natural gas	UN COMTRADE (2023), Gaulier and Zignano (2010), CEPII (2023)
World Development indicators	Socioeconomics: GDP	World Bank (2024)

PE carriers, and the structure of FE demand. The indicator set includes more demand-side than supply-side indicators, reflecting the multidimensional co-benefit structure of demand-side measures. We calculate the energy security indicators per country for the year of 2019 for the base case and the policy simulations (4.4.).

3.4. Simulation of policy interventions

The objective is to simulate the impact of policy measures each equivalent to approximately 10% of total PE demand, assessed across a range of energy security indicators. We adopt the four policy strategies proposed by Bento *et al* (2024), named according to the step in the energy conversion chain they target: import diversification (PE1), fuel substitution (FE1), reduction of fossil fuels in low-temperature heat in buildings (UE1), and transport electrification (UE2). These strategies span the energy and industry sector (PE1), the transport sector (FE1, UE2), and the building sector (UE1). To these we add two Austria-specific scenarios: GAS, which reflects observed changes in the Austrian gas supply and demand following the Ukraine crisis, and COMBINED, which aggregates all four strategies simultaneously. FE1 and UE2 are most directly relevant to oil import dependence, underscored by the 2026 crisis.

The uniform 10% PE target allows strategies to be compared on a common scale. However, because the strategies intervene at different points in the conversion chain, their upstream implications differ. Interventions at the PE level (PE1) directly adjust the composition of PE supply. For instance, relocating 10% of gas imports to alternative sources, while leaving total PE demand unchanged. Interventions at the FE level (FE1), such as substituting 10% of oil in transport with domestic biomass fuels, are translated upstream to their PE equivalents using the relevant conversion efficiency between final and PE. Interventions at the UE level (UE1, UE2) propagate further upstream through two conversion stages, from useful to final and from final to PE, applying the sector-specific efficiencies that reflect each subsector's contribution to total national final and UE demand. This upstream propagation means that demand-side interventions at the UE level achieve a given PE target with a smaller absolute change at the point of intervention, the leverage effect described in section 2.2. Energy security indicators are then calculated for each scenario and compared against the base case.

The 10% PE target applied uniformly across strategies is both analytically convenient and empirically grounded. Interventions of this order of magnitude have been achieved across all four strategy types within relatively short timeframes. On the supply side, Germany's rapid diversification away from Russian gas following the 2022 invasion reoriented approximately one third of PE supply, well exceeding the threshold. On the demand side, Norway's sustained promotion of electric vehicles achieved a 10% reduction in transport PE by 2021, and US fuel economy standards have delivered cumulative savings of comparable magnitude (Geller *et al* 2006). For Austria specifically, the target is consistent with observed post-2022 trajectories: total gas demand fell by approximately 25% between 2021 and 2023, confirming that changes of this scale are achievable under real policy conditions. In the Austrian case the 10% PE translates to ∼0.14 EJ of PE (of a total PE of 1.4 EJ in 2019). The 10% benchmark therefore represents a

Table 2. Energy security indicators included. Based on Bento *et al* (2024) Box S5.

Indicator	Energy security aspect | Issues	Definition	Energy system level
	Demand-side indicators		
Final energy efficiency [trillion USD2015/EJ]	Affordability, sustainability | Vulnerability to price and supply disruptions	Total final energy divided by GDP	FE
Compound Shannon FE	Continuity | Vulnerability to disruption in energy carriers	SWDI using FE shares	FE
Compound Shannon FE incl. electricity by source	Continuity | Vulnerability to energy carriers disruptions and limited switching	SWDI using FE shares and electricity sources	FE
Share of energy expenditures on GDP [%]	Affordability | Price change risk	Relative size of energy expenditures estimated with decadal maximum and minimum prices	FE
Savings in expenditures on fossil TPE on GDP index [base = 100]	Affordability, sustainability | Vulnerability to climate and trade disruptions on fossil fuel	Impact on reducing the share of GDP non-devoted to expenditures on fossil fuels	PE
Savings in energy expenditures index [base = 100]	Affordability | Vulnerability to energy burden increase due to energy crisis	Impact on reducing the share of GDP non-devoted to energy	PE
Savings in primary energy demand index [base = 100]	Affordability, sustainability | vulnerability due to increasing exposure to energy supply and prices disruptions	Impact on reducing primary energy consumption	PE
	Supply-side indicators		
Share of non-fossil fuels [%]	Sustainability | Climate and geopolitical risks	Share of coal, oil and Natural gas in total primary	PE
Import independence [%]	Continuity | Risk of trade disruption	Energy import divided by total primary energy	PE
Shannon diversity index PE	Continuity | General vulnerability to disruptions in energy import	Shannon–Weaver Diversity Index (SWDI)	PE
Compound Shannon diversity index PE	Continuity | Weighted dependence in diversity issues	SWDI adjusted for net imports	PE
Compounds Shannon diversity index PE with import diversification	Continuity | Weighted dependence to major energy importers in diversity issues	SWDI adjusted for concentration ratio (CR2)	PE

level of intervention that policy has repeatedly approached or exceeded, while remaining tractable within a static accounting framework.

Table 3 provides details of each policy, its quantitative parameterisation for the Austrian case, and its relationship to recent policy developments. With these six policy scenarios we pursue four analytical objectives. First, we assess how individual supply-side and demand-side measures compare across a multidimensional set of energy security indicators, testing whether the dominance of import diversification in policy discourse is matched by its performance across the indicator set. Second, we examine how the changes observed in Austria since the Ukraine crisis have affected these indicators, using the GAS scenario to ground the stylised analysis in empirical developments and draw potential lessons for the emerging 2026 oil crisis, when analysing FE1 and UE2 impacts. Third, we explore the cumulative potential of combining strategies through the COMBINED scenario, illustrating the energy security gains achievable if current trajectories are sustained and complementary measures pursued in parallel across sector. Fourth, we assess the scope of co-benefits that accompany different strategic orientations, making the case for a broader accounting of what energy security policy can and should deliver.

Table 3. Policy interventions overview.

Name	Type	Description and Austrian context	Quantitative change in Austria
PE1	Import diversification	Description: The largest energy importer of the dominating imported energy carrier is substituted (primary energy level). Austria: This policy example reflects several Austrian gas import diversification proposals and what happened, following the end of OMV-GAZPROM contract and the end of the Ukraine gas transit in late 2024. The highest shares of Russian gas imports in late 2023 and early 2024 crossed 90%, which is in line with our figures for 2019.	0.23 EJ PE (92%) Russian gas imported from other countries
FE1	Fuel substitution	Description: Domestic biofuel substitutes oil in final energy in the transport sector. (Relevant to oil import dependence and the emerging 2026 energy crisis.) Austria: Suggestion by AEA (2022) to increase domestic generation of renewable gases to reduce import dependence by 14 TWh (0.05 EJ PE—a third of the scenario which also includes other energy carriers).	0.14 EJ FE change for 0.14 EJ PE change (rounding)
UE1	Heating demand in buildings	Description: Reduction of fossil fuels in useful thermal energy for residential buildings, for example through insulation. Austria: Several policy measures in Austria target reducing heating demand in buildings (i.e. switch of heating system, insulation programmes, behavioural responses within the *Mission 11%* of reducing energy demand by 11% with mixed measures across household energy use). The stylised reduction of 0.14 EJ PE is more ambitious than suggested reductions in gas consumption by, for example, AEA (2024) which suggests a reduction of around 0.10 EJ (29TWh) Overall, Austrian gas consumption in 2023 was 25% lower which translate to reductions of around 0.09 PE (this includes climate, electricity generation and price effects). Gas demand reductions through demand changes only (including industry and electricity generation) in 2023 were 4.5%.	0.09 EJ UE for 0.14 EJ PE, phasing out oil in heating and nearly phasing out all gas in heating.
UE2	Transport electrification	Description: This policy assumes increased transport electrification achieved by expansion of renewable energy (split proportionally according to the available mix) and is relevant to oil import dependence and the emerging 2026 energy crisis. Austria: This is in line with plans of decarbonising the transport sector and expanding renewables.	0.05 EJ PE equivalent additional renewables needed at UE level to achieve 0.14 EJ FE change.
GAS	Combined observed changes related to gas	Description: "Observed case with focus gas" combining what has happened since 2019 related to gas. Austria: What has happened: a. Reduced gas demand (−5%) and another −20% climate related in total (0.09 EJ PE) reflect 2/3rds of UE1 impact observed. We assume more pervasive reductions and keep UE1. Note that ambitious scenarios such as AEA (2024) suggest −33% gas demand getting close to UE1 (and minus −54% gas import requirements). b. Phase out of Russian gas (import diversification = PE1)	Combined UE1 and PE1
COMBINED	Combination of all	Description: combination of all 4 strategies. a. PE1: Diversification: PE 1 replace 0.23 EJ PE (92%) Russian gas imported from other countries b. FE1: Fuel substitution FE 1 (0.05 EJ PE). c. UE1: Demand reduction—plan −25% (0.09 EJ PE) d. UE2: Electrification transport UE2 (0.05 EJ PE equivalent additional renewables needed at UE level to achieve 0.14 EJ FE change).	PE1 + FE1 + UE1 + UE2

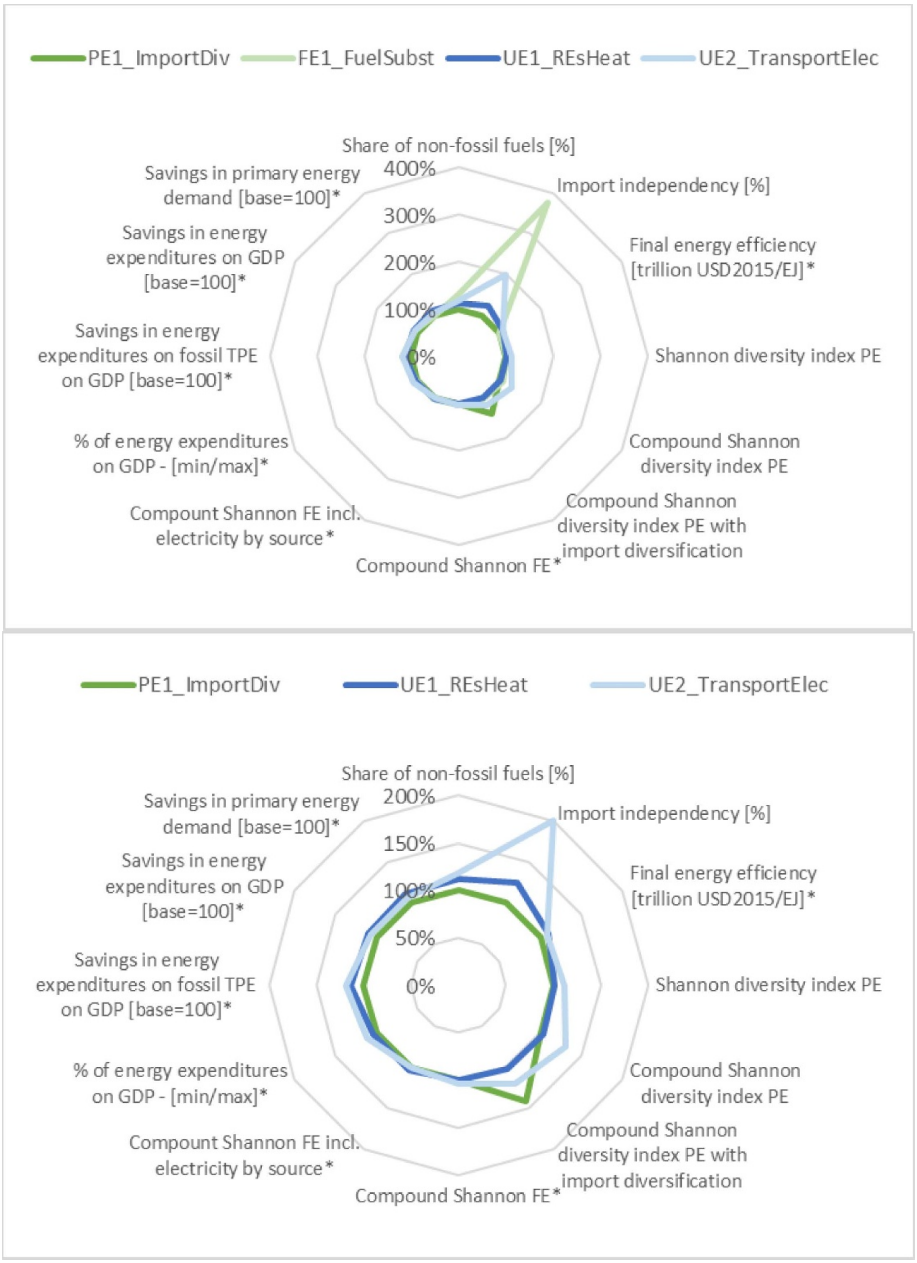

Figure 2. Impact of policy interventions on enhancing energy security in Austria, following Bento *et al* (2024). Twelve indicators, five supply-side and seven demand side, reflect impacts of four policy interventions, each aimed at achieving 10% reduction in primary energy. Impacts are shown in index values relative to preintervention baseline normalised to 100, with larger values reflecting greater security (upper panel). Excluding FE1-FuelSubstitution (lower panel).

4. Results

4.1. Policy simulations

Following Bento *et al* (2024), results are presented as percentage changes relative to the base case (Base = 100), allowing direct comparison of policy strategies across a common scale. Five supply-side and seven demand-side indicators of energy security are assessed; supply-side strategies are presented in green and demand-side strategies in blue throughout the figures. Figure 2 summarises the results (figures S1 and S2 in the supplementary materials provides detailed results across the full indicator set and the underlying data for figure 2, respectively). A central finding of Bento *et al* (2024) is that the choice of indicator is decisive for how energy security performance is assessed. This is confirmed and extended by the Austrian case analysis, as discussed below. The tables show the impact of the policy interventions to reach the same target of 10% of the focal country's PE. Interventions at FE and UE levels are smaller since conversion losses increase the effect at the PE level.

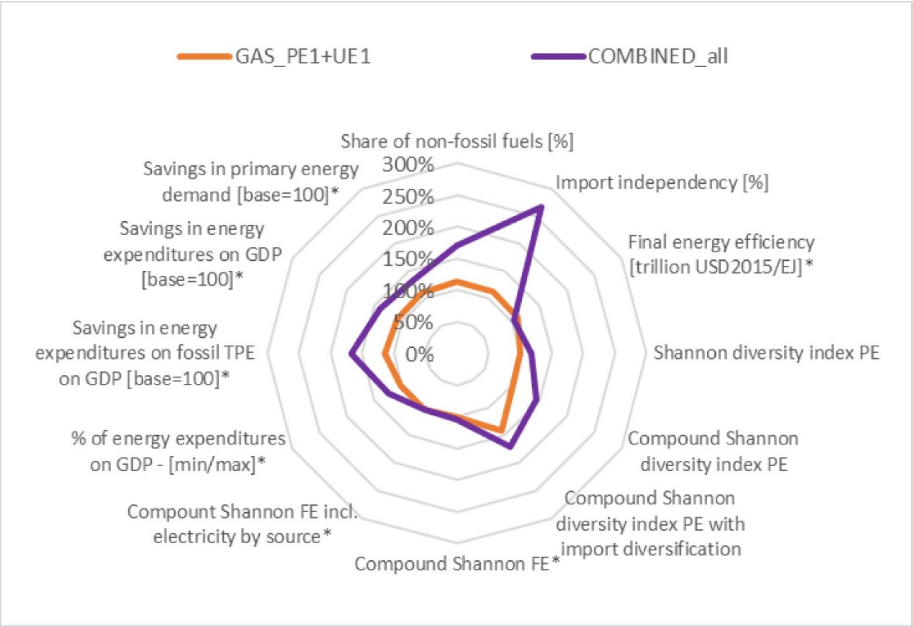

Figure 3. Impact of combined GAS achievements versus all polices together.

Supply-side strategies show limited and narrowly distributed benefits across the indicator set. Gas import diversification (PE1), a measure through that has dominated Austrian energy security discourse since 2022 performs best on only a single indicator (i.e. Compound Shannon Index with Import Diversification) and produces no measurable change across the remainder. Note that this is the indicator that import diversification policy was effectively designed to optimise. This finding is significant: the strategy that has received the greatest political attention and institutional investment delivers the narrowest energy security improvement when assessed against a multidimensional framework. Domestic biofuel substitution (FE1) produces a clear improvement in import independence, increasing the domestic share from approximately 4%–15%, a more than threefold increase, but again this gain is concentrated in a single indicator, with no material improvement elsewhere.

Demand-side strategies show broader and more consistent performance. Transport electrification (UE2), which replaces oil with electricity in the transport sector, delivers the greatest overall leverage, reflecting the efficiency gains inherent in electrified drivetrains relative to internal combustion. This strategy supports Austria's oil dependence which is of timely importance. Reducing fossil fuels in low-temperature heat (UE1) outperforms both supply-side strategies across multiple indicators simultaneously, with particularly strong improvements in energy efficiency and cost-related indicators. This finding underscores the analytical point made in section 2.2: demand-side measures operating closer to the energy service level have greater leverage across the conversion chain and deliver more systemic improvements than equivalent interventions at the supply level.

To situate the stylised policy strategies in the context of Austria's actual recent energy system trajectory and policy, two additional scenarios are assessed (figure 3). The GAS scenario reflects the broad contours of changes that have occurred in Austria's gas sector since 2022: the elimination of Russian gas imports, diversification to alternative sources, and demand reductions achieved through a combination of measures, primarily behavioural change, and supported by price and climatic effects. Results show improvements across multiple indicators, confirming that Austria's energy system resilience has genuinely increased because of recent actions.

However, the GAS scenario also illustrates a methodologically important finding: indicator choice remains decisive even when both supply-side and demand-side changes are occurring simultaneously. Of the supply-side changes captured in the GAS scenario, import diversification affects only the compound Shannon index with import diversification; the improvements observed across other indicators are attributable predominantly to the demand-side component, the reduction in overall gas consumption. This reinforces the central argument of this paper: assessments that focus on import diversification as the primary metric of energy security progress will systematically overattribute improvement to supply-side action and underattribute it to demand-side change.

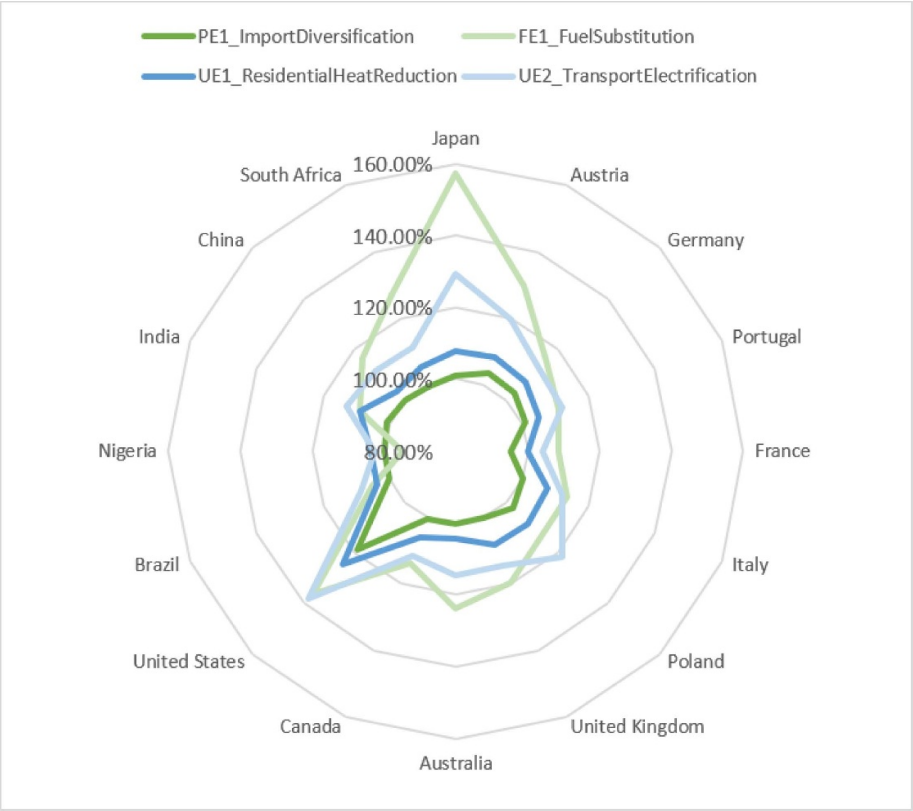

Figure 4. Average impact of policy interventions on enhancing energy security across countries. Impacts are shown in index values relative to preintervention baseline normalised to 100, with larger values reflecting greater security., following Bento *et al* (2024).

The COMBINED scenario is a hypothetical composite that aggregates all four core strategies: the gas sector changes captured in the GAS scenario, continued progress on transport electrification, and the achievement of proposed domestic biofuel production targets, supportive of improving oil dependence. This scenario is not intended as a policy prescription but as an analytical device to illustrate the cumulative energy security gains that would result if current trajectories were sustained and complementary measures pursued in parallel. Similarly to the GAS scenario, we see that in the combined scenario the classic energy security indicator import independence, is affected by the reduced energy demand and is this not improving as much as in the individual baseline scenario FE1. The COMBINED scenario shows the potential additional savings (77% of based case) in energy expenditure compared to the GAS scenario (92% of base case).

Results show substantially larger and more broadly distributed improvements across the indicator set than any single strategy achieves in isolation, confirming that the strongest energy security outcomes are achieved through policy combinations that integrate both supply-side diversification and demand-side transformation. The scenario also illustrates the potential gap between Austria's current trajectory and what a more strategically integrated approach could deliver. This is a gap that is most visible in the indicators where supply-side measures alone show no improvement.

Next, we situate the Austrian results in a comparative context with other countries.

4.2. Austria in comparative perspective

Figure 4 disaggregates results by country, situating Austria within the full set of 15 countries analysed by (Bento *et al* 2024) plus Portugal, together representing approximately two thirds of global PE consumption and population. Several findings emerge from the cross-country comparison. Import diversification (PE1) delivers the weakest average performance across indicators of all strategies examined. A result that holds across virtually the entire country sample. This is a striking finding given that import diversification has dominated energy security policy discourse not only in Austria but across most of the countries represented. The one notable exception is Nigeria, an energy exporter for which the indicator construction naturally produces different results. The consistency of the finding across such a geographically and structurally diverse sample which spans high-income OECD economies, emerging markets, and major

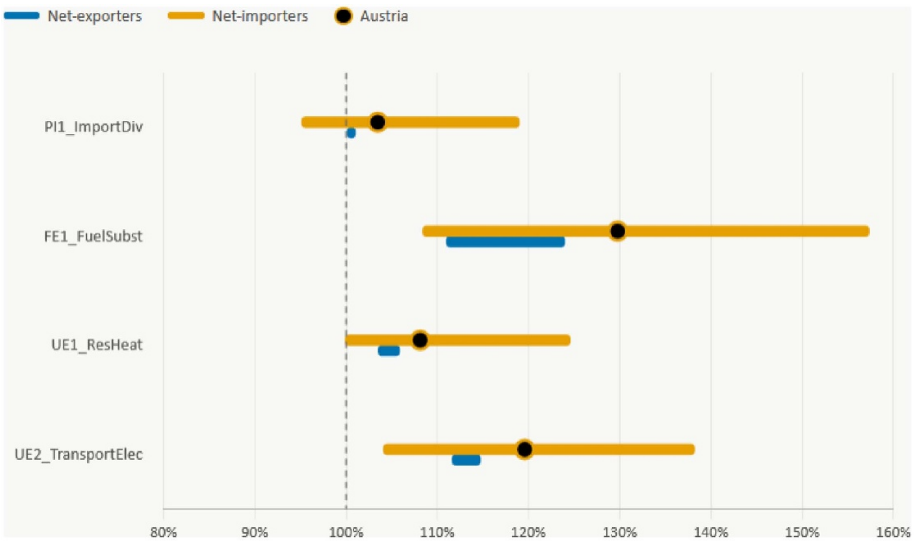

Figure 5. Average impact of policy interventions on enhancing energy security across net exporters (blue) and net importers (yellow) vis-à-vis Austria (a net importer). Net exporters are Australia, Canada, and South Africa. Net-importers are Germany, France, India, Italy, Japan. Poland, Portugal, United Kingdom, and United States. Net importer and exporter categories follow Bento *et al* (2024). China, Nigeria, and Brazil are not shown as their simulated import diversification policy could not reach the 10% Primary Energy reduction target. Impacts are shown in index values relative to preintervention baseline normalised to 100, with larger values reflecting greater security. Austria is shown in black.

energy importers, substantially strengthens the conclusion that import diversification is an insufficient basis for a comprehensive energy security strategy. Figure 4 reveals that Austria's performance pattern most closely resembles that of Japan, another high-income, resource-poor, heavily import-dependent economy though the magnitudes differ. France, Germany, and Australia show broadly similar patterns, reflecting comparable structural features: high energy import dependence, significant transport fossil use, and established but incomplete heating decarbonisation. This family of countries represents a natural peer group for Austria in terms of both energy security vulnerability and the policy levers most likely to be effective.

Figure 5 shows that overall there is not much difference between net-exporters and net-importers in terms of the direction of the effects. Import Diversification (PE1) tends to be the weakest option. Net-importers show larger range as they comprise more countries. There is a larger difference between groups for Fuel Substitution (FE1). Austria is close to the middle within the range of the effects on net importers, indicating that is good case study for this group. In terms of order for Austria, FE1 (fuel substitution), is followed by UE2 (transport elec.) and then UE1 (low residential heat) before PE1 (import diversification).

4.3. Co-benefits for decarbonisation

Several of the energy security indicators discussed above already incorporate co-benefits implicitly: a smaller and more efficient energy system directly reduces fossil fuel combustion, lowering air pollution and its associated health burden. Similarly, given that Austria's fossil fuels are predominantly imported, reductions in energy expenditure generate positive spillovers for the trade balance, household energy affordability, and employment, as the reinvestment of avoided energy costs circulates through the domestic economy rather than accruing to exporting countries.

Figure 6 illustrates the greenhouse gas emission reduction potential associated with each strategy. The results are unambiguous in one respect: import diversification contributes nothing to decarbonisation, since it substitutes one fossil source for another without reducing overall combustion. The other strategies all achieve around 15% of reduction. Fuel substitution contributes to emission reductions, but its scope is constrained by the scale of biofuel availability and sustainability concerns. Both demand-side strategies, deliver the substantial emission reductions, reinforcing the alignment between energy security and climate objectives that the multidimensional framework in section 2 anticipates.

The GAS scenario, reflecting Austria's actual recent trajectory, captures emission reductions attributable primarily to the demand-side component since import diversification from Russian to non-Russian gas does not alter the overall combustion volume. Most significantly, the COMBINED scenario approaches a 40% reduction in current energy system emissions, as it aggregates the emission reductions

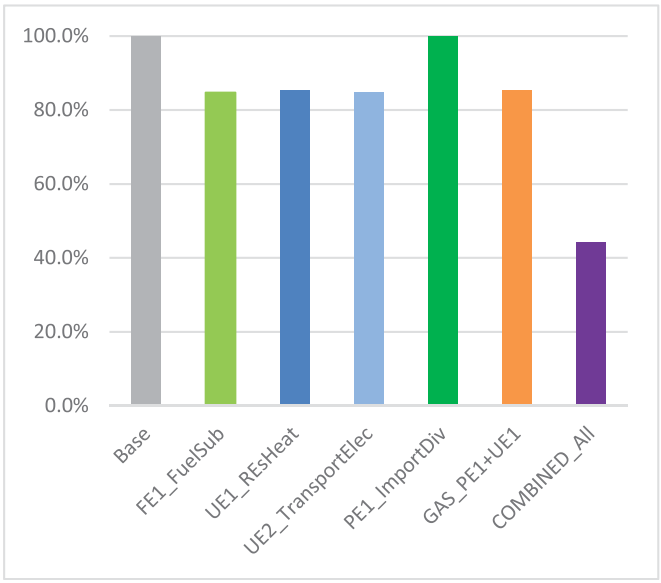

Figure 6. CO_2 emissions of different strategies in relation to the base case.

of the four individual sector strategies. This figure is essentially unchanged whether import diversification is included or not. This is perhaps the starkest illustration of the paper's central argument: import diversification, the dominant preoccupation of Austrian and European energy security governance since 2022, contributes neither to indicator performance across most dimensions nor to the decarbonisation co-benefits that could make the energy transition and energy security mutually reinforcing rather than competing objectives. The emission reduction potential of combining strategies will encounter trade-offs with increasing electrification and renewable energies in the system.

(Grubler *et al* 2026) quantify arrange of co-benefits of targeted emission reductions of similar strategies in the Austrian energy system, including employment, trade balance, air quality, and household welfare effects is.

5. Discussion

5.1. Why demand-side potential remains untapped

Despite their demonstrated co-benefits, demand-side measures remain marginalised in Austrian energy security governance. Three factors explain this persistence. First, institutional inertia: supply security has historically been treated as a private-sector concern, insulating incumbents from public interest obligations, and the failure of mandatory diversification legislation in 2024 to achieve a constitutional majority illustrates the continued influence of vested interests (BMK 2024a). The Austrian Court of Audit's (2025) omission of demand-side measures from its recommendations is itself symptomatic of this reflex (Rechnungshof Oesterreich 2025). Second, measurement gaps: standard energy security assessments privilege supply metrics over the multidimensional co-benefits that demand reduction delivers, rendering demand-side options less legible to policymakers working within conventional frameworks (Sovacool and Mukherjee 2011, Bento *et al* 2024). Third, the political economy of fossil fuel subsidies: Austria's continued spending on imported fossil fuels reflects a structural bias toward incumbent industries, compounded by the persistent framing of demand reduction as austerity rather than investment.

5.2. Making behavioural change stick by changing structures

The Austrian post-2022 experience confirms that energy demand is malleable under acute pressure. The harder challenge is creating the institutional conditions that make this malleability work in the direction of lasting structural change rather than temporary adjustment. The decomposition analysis found that real behavioural savings amounted to only 4.5% in 2023 once weather and price effects were stripped out (WIFO 2024). The challenge is not whether demand can be reduced but whether the conditions exist to make reductions durable.

Three requirements follow from the analysis. Regulatory standards, such as building codes, minimum performance requirements, boiler phase-out regulations, are more robust than voluntary campaigns because they restructure default choices rather than nudging behaviour within unchanged infrastructure; the Renewable Heat Act 2024 is a step in this direction. Fiscal reorientation away from untargeted commuter subsidies toward public transport and active mobility investment would dismantle the infrastructural architecture that actively reproduces high transport energy demand. Finally, Austria's energy communities and climate-energy model regions represent an underutilised infrastructure for sustained collective engagement; connecting these explicitly to energy security objectives, rather than treating them solely as climate instruments, could broaden the political coalition for demand-side transformation.

5.3. Implications for Austria's energy and climate strategy

Austria's post-2022 response resolved the immediate geopolitical concentration risk but relocated rather than reduced fossil dependence. The central strategic tension is between supply diversification and decarbonisation: replacing Russian pipeline gas with Norwegian gas and LNG does not reduce fossil gas consumption, and the infrastructure investments required risk becoming stranded assets within the timeframe of Austria's own NetZero2040 target. Using a stakeholder-coupled energy and power system modelling approach, Schmidt *et al* (2025) similarly identify demand-side strategies as the key determinant of whether Austria's transition increases or decreases import dependence, corroborating our findings despite the markedly different methodological approach. Pichler *et al* (2024), using a dynamic input-output model, show that gas supply shocks below ∼12% can be fully absorbed through demand-side measures alone, reinforcing our finding that demand-side action can substantially offset structural import dependence.

The same dynamic is visible at EU level, where post-Ukraine LNG investments have paradoxically expanded fossil import capacity, including for Russian LNG arriving via alternative routes. Supply-side investments should be explicitly screened for carbon lock-in risk before commitment. At the EU level, Sampedro *et al* (2024) use the IAM GCAM to show that a cost-optimal response to reduced Russian pipeline gas can take multiple forms (i.e. import substitution, domestic supply substitution, or efficiency-led demand reduction) a multiplicity of viable strategies our scenario comparisons also reflect, though without endogenously selecting among them.

The fiscal misalignment is equally stark. Austria's continued focus on fossil fuels, also in years of peak energy security concern, directly contradicts both its climate commitments and the indicator results presented here. Redirecting a portion of these flows toward building renovation, heat pump deployment, and public transport would simultaneously reduce import dependence, lower household energy costs, and cut emissions. Supply diversification alone cannot deliver these outcomes.

Taken together, these implications point toward a demand-first reorientation: one in which efficiency, sufficiency, and electrification are treated as primary security instruments, supply diversification as necessary but insufficient, and fiscal policy as a tool for structural transition rather than crisis compensation. Without this shift, Austria risks managing the next shock with the same toolkit that left it exposed to this one.

5.4. Limitations

Several limitations warrant acknowledgement. The indicator framework, while deliberately multidimensional, underrepresents the social and distributional dimensions of energy security, including the concentration of energy cost burdens across income groups and differential regional exposure, due to gaps in publicly available Austrian data. The single-country focus enables depth but limits generalisability; Austria's distinctive combination of high storage capacity, hydropower endowment, and historically concentrated Russian gas dependence may not transfer directly to other European contexts.

The used accounting framework provides the structure for the simulation analysis. The impacts of external shocks or response policies are computed in the short run, when most factors (e.g. labour, capital) are difficult to adjust, enabling static comparisons. For this reason, the framework does not incorporate long-term factors, such as price elasticities, factor substitution dynamics, or feedbacks. This approach has different strengths than other macroeconomic tools. which investigate longer time horizons. In the short-to-medium term, however–where switching costs and infrastructure lock-in constrain adjustment–the static snapshot remains a reasonable approximation. Accordingly, our results are best interpreted as structured comparisons of first-order PE effects under stylised assumptions for the earlier years of each pathway, rather than as equilibrium projections extending to the endpoint.

Engagement with dynamic modelling approaches offers a productive direction for future work. Input-output models, such as the dynamic disequilibrium framework applied by Pichler *et al* (2024) to quantify the economy-wide propagation of a gas supply shock to Austria, could capture how an initial change in the supply mix cascades through sectoral interdependencies rather than affecting final demand in isolation. Energy system optimisation or IAMs, such as those applied to Austrian transition pathways by Schmidt *et al* (2025), would allow the system to respond endogenously to cost and policy constraints, rather than being specified exogenously as in our scenarios. One could test whether the energy security indicator trajectories identified here persist and are in line with security preferences identified by the stakeholders in by Schmidt *et al* (2025).

We do not model rebound effects, which represent a material uncertainty in projections of demand-side savings (Sorrell *et al* 2020) and which would partially offset the PE savings reported, without materially altering the comparative ranking of strategies. Nor do we conduct counterfactual modelling to disentangle policy effects from price signals and weather variation, a methodologically demanding task attempted only partially in the existing literature (WIFO 2024).

The GAS scenario reflects observed aggregate changes in Austria's energy system following the 2022 crisis and is treated symmetrically with the other scenarios to permit structured comparison. As the other strategies, it does not disentangle the contributions of price signals, policy measures, and weather variation, a separation that would require counterfactual modelling methods beyond the scope of this framework. In addition to the rebound effects noted above, this means that the demand reductions attributed to the GAS scenario may partially reflect transitory behavioural responses to high prices rather than durable structural change.

Results are necessarily sensitive to the choice of indicators and the accounting structure underlying them. Following Bento *et al* (2024), we employ several complementary indicators precisely to reduce dependence on any single measure and to capture the multidimensional character of energy security, considering both supply- and demand-side indicators, the latter being often omitted in the literature. Nonetheless, readers should bear in mind that alternative indicator designs and analytical methods may yield different relative rankings, particularly for scenarios where improvements are concentrated in a subset of dimensions. Assessing the robustness of different indicators across different methodological approaches (incl. longer term energy scenarios from different models) is one potential avenue for future research (see 6.3).

The 2019 base year and the use of observed post-2022 changes as stylised scenario inputs mean that year-on-year dynamics of the crisis period are abstracted away, and findings may require revision as Austria's new supply arrangements and demand trajectories consolidate. Finally, the analysis does not address implementation feasibility, such as including workforce capacity, supply chain constraints, and political economy obstacles, which a fuller treatment of the transition pathway would require.

6. Conclusions and policy recommendations

6.1. Summary of findings

Austria's energy security trajectory since 2022 illustrates both the urgency and the incompleteness of crisis-driven reform. The Russian invasion of Ukraine exposed decades of structural dependence on a dominating fossil fuel supplier. This was a vulnerability that had been normalised, politically insulated, and fiscally entrenched. The policy response was predominantly supply-oriented: contract renegotiation, pipeline diversification, LNG access, and storage mandates. These measures resolved the immediate geopolitical concentration risk but left the deeper structural vulnerabilities intact.

This paper has shown that demand-side measures constitute underutilised but powerful levers for genuine energy system resilience. The conversion chain analysis demonstrates that currently avoided end-use demand has approximately fourfold leverage on PE requirements in Austria's current fossil-dominated system. The paper's indicator analysis shows that demand-side strategies consistently outperform import diversification across a multidimensional assessment; the broader literature confirms that these gains extend to co-benefits including employment, trade balance improvement, air quality, and greenhouse gas emission reduction (Finn and Brockway 2023, Bento *et al* 2024, Nikas *et al* 2024), yet the institutional and fiscal conditions to sustain this transformation remain largely absent.

The 2026 Middle East conflict has renewed the urgency of this analysis: Austria's near-total fossil dependence in transport represents a structurally analogous vulnerability to the Russian gas dependence examined here, and the UE2 scenario provides a first-order illustration of the energy security gains

available from transport electrification. The paper's central finding holds across both crises: supply-side responses alone are insufficient, and the costs of delay are borne in the next shock.

6.2. Call to action for policymakers

Three implications for Austrian policymakers follow directly from the results.

The first implication is therefore that demand-side measures should be elevated from emergency response to primary security instruments. UE1 and UE2 consistently outperform supply-side strategies across the indicator set; embedding the demand reductions achieved since 2022 in permanent regulatory standards and providing an environment with investment security without changing policy landscapes rather than allowing post-crisis reversal, is the most direct translation of this finding into policy.

Second, the GAS and UE2 scenarios together illustrate that gas and oil dependence require parallel structural responses. The near-complete fossil dependence of Austria's transport sector represents an exposure structurally analogous to the Russian gas dependence that proved so costly after 2022. The UE2 results show transport electrification delivers among the strongest energy security improvements of any strategy examined; accelerating this transition, supported by targeted rather than blanket commuter subsidies, and complemented by public transport investment (incl., Klimaticket flat rate transit passes). The latter, together with measures to reduce sprawl and aiming for denser spatial planning with mixed use, could further decrease energy use in the transport sector. This would address both the 2026 oil exposure and Austria's longer-term decarbonisation commitments simultaneously.

Third, the co-benefits analysis in section 4.3 demonstrates that import diversification contributes nothing to decarbonisation, while demand-side strategies approach a 40% reduction in energy system emissions when combined. Austria's energy security planning should therefore explicitly screen supply-side infrastructure investments for consistency with the NetZero2040 target, treating carbon lock-in as a material security risk rather than a separate climate concern.

More generally, we identify structural conditions of high import dependence and limited domestic fossil production under which these findings may carry transferable lessons from Austria for comparable economies. Especially regarding expansion in supply side infrastructure that risk prolonging the dependence on fossil fuels imports and becoming stranded assets when considering the EU's climate targets. Importantly, time is lost when import diversification strategies are exclusively focused on. Demand-side transformations show great potential to enhance energy security despite being often overlooked in the policies, therefore deserving more attention namely by broader actor coalitions across governance levels.

6.3. Research outlook

This study has several natural extensions. Most immediately, future work should systematically compare the energy security benefits of supply-side and demand-side policy measures using a common multidimensional indicator framework, moving beyond the partial and supply-weighted assessments that currently dominate the field. The lack of comparative assessments in policy making that puts the demand side on equal footing with supply side has been on the agenda at the EU and member states' levels, dissipating as the energy efficiency first principle and related revised cost-benefit analysis rules (Berger *et al* 2026) The equity and distributional dimensions of energy security of who bears the cost of import dependence, who benefits from fossil fuel subsidies, and who is most exposed to supply disruption, are underrepresented in existing indicator frameworks and warrant dedicated empirical attention, including through household-level expenditure data and regional disaggregation within Austria in particular.

Given the short-term and static aspects of the used methodology, an extension should focus on integrating these with longer-term scenarios. The indicator framework applied here could be used as an input or be directly integrated into an integrated assessment or energy system optimisation model, allowing energy security indicator trajectories to be tested under endogenously determined energy system configurations, and enabling direct comparison with the implicit security-relevant outputs of Austrian energy system models (Schipfer *et al* 2026). Characterising different pathways in security terms across diverse indicators in dynamic modelling work that encompasses socioeconomic feedbacks would provide valuable policy insights. The integration could yield insights into the direct (on security) and indirect (energy system, socio-economic systems) impacts of acting now or delaying action. The persistence question identified in section 5.2 merits dedicated longitudinal investigation: under what institutional and infrastructural conditions do crisis-era behavioural shifts translate into durable structural change, and what role do participatory governance mechanisms play in sustaining public engagement beyond the acute shock period? Comparative analysis across EU member states that experienced the 2022 crisis differently, including those with higher renewable shares, more robust building renovation programmes, or stronger demand-side governance, would help establish which elements of Austria's experience are nationally specific and which reflect broader patterns in fossil-dependent import-reliant energy systems.

Finally, the 2026 oil shock offers a timely test of whether the framework developed here travels beyond gas security. Austria's near-total fossil dependence in transport represents a structurally analogous vulnerability to the Russian gas dependence examined in this paper, and early policy responses suggest the same supply-centric pattern is reasserting itself. A dedicated oil security analysis falls outside the scope of this study, not least because the shock is still evolving and the data required for a robust scenario assessment are not yet available, but the UE2 scenario offers an initial indication of the energy security gains available from transport electrification under these conditions, and we treat it as a first-order illustration pending more granular analysis. Extending this framework to transport-sector vulnerability and household exposure to fuel price shocks is the most immediate next step, and one that the current crisis makes urgent.

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Data availability statement

All data that support the findings of this study are included within the article (and any supplementary information files).

Supplementary Materials available at https://doi.org/10.1088/2753-3751/ae9e33/data1.

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References

AEA 2022 *Austria: Strategic Options for Gas Supply without Imports from Russia* (Austrian Energy Agency) (available at: www.energyagency.at/fileadmin/1_energyagency/presseaussendungen)

AEA 2024 *Szenarien Der Gasversorgung in Österreich* (available at: www.bmk.gv.at/themen/energie/publikationen/szenarien_gasversorgung.html)

Ang B W, Choong W L and Ng T S 2015 Energy security: definitions, dimensions and indexes *Renew. Sustain. Energy Rev.* **42** 1077–93

APCC 2025 Second Austrian assessment report on climate change (AAR2) ed D Huppmann, M Keiler, K Riahi and H Rieder (Austrian Academy of Sciences Press in Vienna)

Bento N, Grubler A, Boza-Kiss B, De Stercke S, Krey V, McCollum D L, Zimm C and Alves T 2024 Leverage demand-side policies for energy security *Science* **383** 946–9

Berger F, Mandel T, Reinfandt N and Eichhammer W 2026 Does the scope for interpretation risk undermining the energy efficiency first principle's ambition? *Energy Policy* **215**

BMF 2025 Das Budget in Zahlen (available at: www.bmf.gv.at/themen/budget.html)

BMK 2024a *Diversifizierungsverpflichtung Soll Russengas-Anteil Senken* (available at: https://infothek.bmimi.gv.at/weg-von-abhaengigkeiten-diversifizierungsverpflichtung-soll-anteil-russischen-gases-senken/)

BMK 2024b *Elektrizitäts-Versorgungssicherheitsstrategie* (available at: www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=www.bmk.gv.at/dam/jcr:151bfc8d-7ec6-49ab-8c5a-970374612fb1/Elektrizitaets-Versorgungssicherheitsstrategie.pdf&ved=2ahUKEwjXoq2UibeMAxWGBdsEHWFoHT8QFnoECCQQAQ&usg=AOvVaw3GLxpCDItmwi5obJ9jMCOF)

BMK 2024c *Gut Zu Wissen Über Gas* (available at: https://energie.gv.at/gas/gas)

BMWET 2025 *Energie in Zahlen 2025* (available at: www.bmwet.gv.at/Services/Publikationen/publikationen-energie/zahlen.html)
Brad A, Schneider E, Dorninger C, Haas W, Hirt C, Wiedenhofer D and Gingrich S 2025 Existing demand-side climate change mitigation policies neglect avoid options *Commun. Earth Environ.* **6** 773
CEPII 2023 BACI Database (available at: www.cepii.fr/CEPII/en/bdd_modele/bdd_modele_item.asp?id=37)
Creutzig F 2022b Fuel crisis: slash demand in three sectors to protect economies and climate *Nature* **606** 460–2
Creutzig F *et al* 2022 Demand-side solutions to climate change mitigation consistent with high levels of well-being *Nat. Clim. Change* **12** 36–46
Creutzig F, Fernandez B, Haberl H, Khosla R, Mulugetta Y and Seto K C 2016 Beyond technology: demand-side solutions for climate change mitigation *Annu. Rev. Environ. Resour.* **41** 173–98
De Stercke S 2023 Primary, final and useful energy database (PFUDB)" (IIASA models and ● database" *Version IIASA Models and Databases* (available at: https://iiasa.ac.at/models-tools-data/pfudb)
Felix C 2022a *Demand, Services and Social Aspects of Mitigation* (Cambridge University Press)
Finn O and Brockway P E 2023 Much broader than health: surveying the diverse co-benefits of energy demand reduction in Europe *Energy Res. Soc. Sci.* **95** 102890
Garrett-Peltier H 2017 Green versus brown: comparing the employment impacts of energy efficiency, renewable energy, and fossil fuels using an input-output model *Econ. Model.* **61** 439–47
Gaulier G and Zignano S 2010 BACI: international trade database at the product-level, 1994–2007 Version *CEPII Working Paper N 2010–23*
Geller H, Harrington P, Rosenfeld A H, Tanishima S and Unander F 2006 Polices for increasing energy efficiency: thirty years of experience in OECD countries *Energy Policy* **34** 556–73
Gepp J 2025 Kein Russisches Gas Mehr Durch Die Ukraine: das Stille Ende Einer Ära Für Österreich *derStandard.At* (available at: www.derstandard.at/story/3000000251215/das-stille-ende-einer-196ra)
Gough I 2018 *Heat Greed and Human Need: Climate Change, Capitalism and Sustainable Wellbeing* pp 115–8
Grubler A *et al* 2026 The undervalued quality-of-life benefits of demand-side energy and climate strategies *Commun. Sustain.* **1** 97
Houser T, Mohan S and Heilmayr R 2009 *A Green Global Recovery?: Assessing US Economic Stimulus and the Prospects for International Coordination* (Peterson Institute for International Economics)
IEA 2007 *Energy Security and Climate Policy: Assessing Interactions*
IEA 2023a *Emergency Response and Energy Security: ensuring the Uninterrupted Availability of Energy Sources at an Affordable Price* (IEA/OECD) (available at: www.iea.org/areas-of-work/energy-security)
IEA 2023b World energy balances 2023 (available at: www.iea.org/data-and-statistics/data-product/world-energy-balances)
IEA 2026a *Sheltering From Oil Shocks* (IEA) (available at: www.iea.org/reports/sheltering-from-oil-shocks)
IEA 2026b Austria 2026: energy policy review (IEA) (available at: www.iea.org/reports/austria-2026)
Kettner C, Böheim M, Sommer M, Gaugl R, Bachhiesl U, Gruber L, Klatzer T F, Wogrin S and Kratena K 2024 Transformation to a renewable electricity system in Austria: insights from an integrated model analysis *Renew. Energy* **223** 119957
Lechner H 2023 *An Der Gasleine* (Austrian Energy Agency) (available at: www.energyagency.at/aktuelles/an-der-gasleine)
Marshall Z, Heun M K and Brockway P E 2023 *Country-Level Primary-Final-Useful (CL-PFU) Energy and Exergy Database V1* (University of Leeds) 10.5518/1199
Mayer J, Süsser D, Pickering B, Bachner G and Sanvito F D 2024 Economy-wide impacts of socio-politically driven net-zero energy systems in Europe *Energy* **291** 130425
Nikas A *et al* 2024 Three different directions in which the European union could replace russian natural gas *Energy* **290** 130254
Pichler A, Hurt J, Reisch T, Stangl J and Thurner S 2024 Economic impacts of a drastic gas supply shock and short-term mitigation strategies *J. Econ. Behav. Organ.* **227** 106750
Rechnungshof Oesterreich 2025 *Erdgas-Versorgungssicherheit. Bericht Des Rechnungshofes. Reihe BUND 2025/1* (Rechnungshof Oesterreich) (available at: www.rechnungshof.gv.at/rh/home/home/2025_1_Erdgas_Versorgungssicherheit.pdf)
Sahakian M, Fuchs D, Lorek S and Di Giulio A 2021 Advancing the concept of consumption corridors and exploring its implications *Sustain.: Sci., Practice and Policy* **17** 305–15
Sampedro J, Van de Ven D-J, Horowitz R, Rodés-bachs C, Frilingou N, Nikas A, Binsted M, Iyer G and Yarlagadda B 2024 Energy system analysis of cutting off Russian gas supply to the European Union *Energy Strateg. Rev.* **54** 101450
Sayer M, Ajanovic A and Haas R 2024 Scenarios on future electricity storage requirements in the Austrian electricity system with high shares of variable renewables Smart Energy **15** 100148
Schipfer F *et al* 2026 Are we ready to plan for synergies? System integration impact assessment in the Austrian energy system modelling community *Energy Res. Soc. Sci.* **131** 104505
Schmidt J, Mitter H, Baumann M, Boza-Kiss B, Huppmann D, Wehrle S, Zwieb L and Klingler M 2025 Need for speed: co-creating scenarios for climate neutral energy systems in Austria in 2040 *Energy Policy* **198** 114493
Sorrell S, Gatersleben B and Druckman A 2020 The limits of energy sufficiency: a review of the evidence for rebound effects and negative spillovers from behavioural change *Energy Res. Soc. Sci.* **64** 101439
Sovacool B K and Mukherjee I 2011 Conceptualizing and measuring energy security: a synthesized approach *Energy* **36** 5343–55
Spencer T, Bernoth K, Chancel L, Guerin E and Neuhoff K 2012 Green investments in a European growth package *Work. Pap* 11 p 12
Statistik Austria 2023 *Teure Energieimporte Ließen Außenhandelsdefizit 2022 Stark Ansteigen Gasimportwert Verdoppelte Sich Im Vergleich Zum Vorjahr* (available at: www.statistik.at/fileadmin/announcement/2023/06/20230628Aussenhandel2022.pdf)
Statistik Austria 2024 Nettoimporttangente Energietraeger
Steininger K, Alaux N, Glas N, Hoff H, Kueschnig M and Kulmer V 2024 Austria's climate neutrality: a consistent cross-sector analysis and policy package, distributional and financial implications (final report of the project INTEGRATE) (ACRP) (available at: www.klimafonds.gv.at/wp-content/uploads/2025/10/C264873-ACRP14-INTEGRATE-KR21KB0K00001-EB.pdf) (Accessed 4 August 2026)
UN COMTRADE 2023 The United Nations Commodity trade statistics database (comtrade database) (United Nations Statistics Division) (available at: https://comtradeplus.un.org/TradeFlow)
WEC 2023 *World Energy Trilemma Index 2023* (World Energy Council) (available at: www.worldenergy.org/publications/entry/world-energy-trilemma-index-2023)
Wiese F *et al* 2024 The key role of sufficiency for low demand-based carbon neutrality and energy security across Europe *Nat. Commun.* **15** 9043
WIFO 2024 *Temperaturkorrigierte Einsparungen Des Gasverbrauchs* (WIFO) (available at: https://energie.wifo.ac.at/analysis/gas-savings)

World Bank 2024 World development indicators (available at: https://databank.worldbank.org/source/world-development-indicators)
Zwickl-Bernhard S, Oitzinger M, Fischer H A, Sesini M and Hobbs B F 2026 Extending energy system models to assess technology sourcing and resilience *Chem. Circularity* **11** 1302–17
Zwickl-Bernhard S, Rodgarkia-dara A, Gatzen C, Sonnen F, Lane K, Otti S, Golab D and Auer H 2024 Modeling insights from the Austrian national gas grid under declining natural gas demand and increasing domestic renewable gas generation by 2040 *Energy Rep.* **11** 1302–17