SUMMARY

Metallurgical Flexibility

Enabling the aluminium and steel sectors for demand response

Context: The paradigm shift

Climate change and recent development in Europe's energy landscape have made industrial decarbonisation an urgent priority. The energy crisis, coupled with the continent's move away from Russian fossil fuels, highlighted the finite nature of energy resources. **The shift towards decarbonisation by means of electrification will put a significant strain on Europe's electricity grids**, which are already struggling to cope with the growing supply of decentralised renewables.

The steel industry is an example of the challenges ahead. A transition to hydrogen-based Direct Reduced Iron (DRI) and Electric Arc Furnace (EAF) plants by 2030 would consume more than double the industry's current electricity demand, from 75 TWh to 165 TWh in 2030 and 400 TWh in 2050. Without matching investment in renewables, this increased demand risks stalling the energy transition by failing to match new electrification projects with additional renewable capacity. The situation is further complicated by the intermittence of renewables and the saturation of electricity infrastructure, which could lead to increased reliance on thermal power plants, higher carbon intensity of the grid and higher electricity costs.

To avoid these pitfalls, **energy-intensive industries need to become more responsive to grid conditions**, shifting their operations to less congested hours of the day where possible and reducing the pressure on already strained power grids. This shift is essential to avoid unnecessary investment in thermal reserve capacity and grid reinforcement that would only be used during peak periods.

Demand response (DR): Benefits and challenges

Demand Response (DR) is a modern grid management strategy designed to balance electricity supply and demand more effectively, particularly as efforts to increase the share of renewable energy in power grids and to phase out thermal power plants continue.

Traditionally, grid operators have been managing supply fluctuations by building excess thermal generation to act as reserve capacity to meet demand during peak periods, which is both cost-inefficient and polluting. DR addresses these challenges by encouraging reductions or shifts in energy consumption patterns, allowing consumers to adapt their energy use in response to external signals, such as electricity prices or requests from grid operators.

Key benefits of systematic and participative implementation of DR

- **It reduces the carbon intensity of the grid** by minimising reliance on expensive and polluting thermal back-up units that operate only occasionally and use fossil fuels inefficiently in standby mode

- **It supports the integration of renewables** by shifting demand to times when renewables have a higher share or when there is even excess supply.

- **It reduces electricity prices** by limiting the market power of thermal generators, thereby promoting more competitive energy markets.

- **It reduces grid congestion and enables more cost-effective upgrades** by delaying or reducing the need for significant investment in new infrastructure and optimising the use of existing capacity.

Industries are well suited to DR programmes due to their high energy consumption and potential to provide grid flexibility. Many energy-intensive industries already have advanced energy management systems in place, including sensors and metering technologies, making them ready to participate. In addition, as these industries often purchase energy on wholesale markets and have direct relationships with Transmission System Operators (TSOs), they can negotiate customised flexibility solutions and financial incentives that meet their specific operational needs. However, integrating DR into industrial sectors presents several challenges.

The challenges of integrating DR into industrial sectors

- **Industrial processes are optimised for peak efficiency and high capacity**, making it difficult to adjust power consumption without affecting operating costs, short-term efficiencies or stable customer relationships.

- **The integrated nature of many industrial processes makes it difficult to isolate or interrupt specific components**, risking production stoppages and disruption of critical operational constraints.

- **Fluctuations in industrial production** due to economic cycles, demand shifts and external factors hinder consistent and predictable DR participation, reducing real-time responsiveness compared to more flexible thermal generation.

- **The financial benefits of DR participation must outweigh the costs of production interruptions**, which can be difficult to assess accurately.

The case of aluminium

Primary aluminium is poorly suited to DR because traditional smelters, designed to operate at full capacity, struggle to maintain thermal balance and recover lost output even after recovery periods. Smelters are typically a last resort for load curtailment, as pots take time to regain peak efficiency, increasing both energy and carbon intensity during recovery. The smelting process imposes physical limits on the duration of load curtailment. However, rotating potlines can extend the curtailment period by doubling the duration, albeit at half the intensity.

Retrofit technologies such as Enpot offer the potential for more frequent, intense and longer load shedding, overcoming the inflexibility of traditional smelters. On the positive side, even traditional smelters can provide ancillary services such as grid frequency stabilisation – a rare capability for plants in energy-intensive industries. However, this comes with risks, including reduced efficiency and increased maintenance costs.

	Conservative		**Enpot's assumptions**		**Enpot's application**
	Both potlines	*Potline rotation*	*Both potlines*	*Potline rotation*	*Both potlines*
Energy saved	36.3 MWh	36.3 MWh (18.15 MWh per hour)	145.2 MWh (72.6 MWh per hour)	145.2 MWh (36.3 MWh per hour)	580.8 MWh (72.6 MWh per hour)
Curtailment period	1 hour	2 hours	2 hours	4 hours	8 hours
Loss of output (no recoup)	2.4 tonnes	2.4 tonnes	/	/	/

The case of steel

For steel, the Direct Reduced Iron (DRI) – Electric Arc Furnace (EAF) route utilising hydrogen from electrolysis as the reducing agent, offers a more flexible approach to steelmaking than the traditional BF-BOF process by allowing a higher proportion of scrap in the feedstock. This is particularly advantageous as it complements the ability to produce and store cold DRI at off-peak times, providing significant operational flexibility as the EAF and secondary metallurgy facilities can continue to operate independently.

By operating the electrolysers only during off-peak hours, electricity costs can be significantly reduced, potentially eliminating the need for subsidies. This is particularly important in the DRI-EAF route, where over 80% of the electricity used per tonne of steel is consumed between the electrolyser and the shaft furnace, with a traditional scrap ratio of 15%. The integration of energy storage solutions can further optimise operations by capturing excess electricity during off-peak hours and extending hydrogen production into peak hours. Conversely, shutting down the entire mill, including the EAF and secondary metallurgy facilities, results in production losses, making flexibility an economically difficult decision.

Contaminants in post-consumer scrap pose a significant challenge to the flexibility of steelmaking. The scrap available to steelmakers is rarely a perfect substitute without additional processing at the recycling stage, which increases costs. Increasing the flexibility of the DRI-EAF route ultimately depends on improving the quality of post-consumer scrap, which would mean steelmakers paying a premium for scrap with lower impurity levels.

	Static 30% scrap	Static 50% scrap	Static 80% scrap	Dynamic 30/50% scrap	Complete shutdown
Energy saved	1.44 GWh	3.9 GWh	7.59 GWh	1.85 GWh	1.68 GWh
Curtailment period	3.5 hours	9.5 hours	18.5 hours	4.5 hours	3.5 hours
Loss of output (no recoup)	/	/	/	/	500 tonnes

Key results and recommendations

As electrification deepens the link between industry and electricity systems, decarbonising both sectors will require the energy demand to match the supply, reversing the traditional model of supply meeting demand. Maintaining thermal generation for occasional balancing is costly and polluting, while operating electro-intensive industries at constant loads can exacerbate peak demand and trigger thermal peaking units. **To maximise renewables integration and cost-effectively upgrade grids, non-fossil flexibility instruments must replace traditional capacity mechanisms to reduce reliance on thermal power for balancing and ancillary services.**

Building flexibility into industrial processes requires new strategies, from oversizing machinery to storing excess production. Tailored plant designs are needed for greenfield and redeveloped brownfield sites to accommodate intermittent schedules. Energy storage and improved inventory management can minimise disruption, while distributors can help bridge supply gaps. Meanwhile, due to the wide variation in operating costs, efficiencies and profit margins between plants, fair compensation for demand response requires tailored bilateral negotiations with grid operators, as a one-size-fits-all approach is impractical.

Industrial flexibility does not necessarily lead to lower production output. Scenarios have shown that with the right retrofit technologies and balanced feedstock ratios, the aluminium and steel industries can participate in DR programmes without losing volumes.

For industries with high-capacity machinery, especially electrolysers, **investment in additional renewable capacity is critical to avoid overloading the grid and triggering thermal generation.**

Ultimately, **industry participation in DR is only the first step towards a fully flexible, fossil-free electricity system**, where manufacturing operations are synchronised with the availability of renewable energy to meet energy needs without precluding access for other users.

Sandbag is an independent think tank dedicated to advancing data-driven, evidence-based climate policies that drive effective emissions reductions in Europe and beyond.

Read our publications | Discover our data tools | Follow us: LinkedIn and X | EU Transparency register: 277895137794-73