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Daily News Feed

D.N.F

20.05.2025

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The ongoing oil price tensions

Global oil demand is approaching a plateau, with the International Energy Agency expecting it to grow only by 0.73% in 2025 despite sharply lower prices. The 'peak demand' theory does not appear as outlandish now as it did two years ago when the Agency predicted that global oil consumption would peak before 2030



A view of Aramco's oil field in the Empty Quarter, Shaybah, Saudi Arabia, in January 2024.

WORLD INSIGHT

Mahesh Sachdev

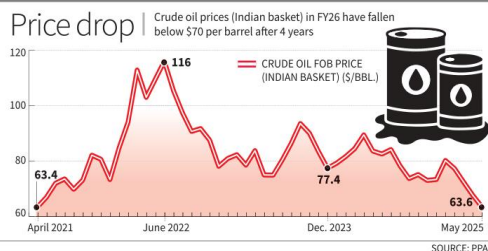
Just when you had your surfeit of headlines screaming of blood and gore, come the drumbeats of a new conflict. However, in this new one, the belligerents do not swap bullets but barrels. Yet, this incipient conflict is shaping to be a "mother of all battles" perhaps with a more universal impact than the destruction being wrecked in various corners of the world.

This prognosis may surprise observers who not only missed the weeks of its run-up skirmishes but also the bugle of war, when on May 3, the Organization of the Petroleum Exporting Countries Plus (OPEC+) decided to go ahead with a collective output increase of 4,11,000 barrels per day (bpd) from next month (June). This was the third month in a row that the oil cartel decided to raise crude production, cumulatively undoing the 9,60,000 bpd or nearly half of the 2.2 million bpd "voluntary" output cuts eight of its members undertook in 2023, to increase global oil prices in an oversupplied market. There are hints that the full 2.2 million bpd cut would be unwound by October 2025. Though the announced production rise was less than half a per cent of global daily production, the oil market was so jittery that the Brent crude price plummeted by almost 2% to \$60.23/barrel, the lowest since the pandemic. It has since recovered to \$65/barrel with support from the U.S.-China stopgap trade deal and reports of stalemate in the U.S.-Iran nuclear talks.

Saudi's strategy

The oil market is still gutted and crude price is nowhere near the triple dollar mark that OPEC+ aimed for. Why, then, has this 23-member producer clique decided to reverse its tactic from reducing supplies to raising production? To find the reasons, we need to deep dive into the oil market of the post-COVID era.

Despite the expectation of a quick turnaround, global post-COVID economic recovery was mostly K-shaped leading to an anaemic growth in oil demand. Meanwhile, oil producers were desperate to ramp up their outputs to make up for lost revenue. It also did not help that several new producers, from the Shale oilers to non-OPEC+ countries, such as Brazil and Guyana, also wanted a piece of the shrunken demand. To square the circle, OPEC+ decided to take a collective production cut of five million bpd, nearly 10% of its total pre-pandemic output.



When even this move did not shore up the oil price, a further "voluntary" cut of 2.2 million bpd was taken by eight members. This rope trick also failed to raise oil prices which continued to slide downwards.

While these processes were ongoing, Saudi Arabia, OPEC+'s largest producer, which took nearly three million bpd or 40% of the total production cuts, got increasingly infuriated by endemic OPEC+ overproducers, such as Kazakhstan, Iraq, the UAE and Nigeria. The Kingdom, often called a "swing producer" for its large spare production capacity, prefers stable and moderately high oil prices to ensure a steady oil revenue. However, it has made exceptions in 1985-86, 1998, 2014-16, and 2020 to pursue a market share chasing strategy to punish perceived overproducers. In the past, this market flooding strategy of Saudi enabled Riyadh to eventually impose production discipline among its peers, allowing prices to return to Riyadh's desired levels.

Now, when repeated pleas failed to stop overproducers, and when Saudi Arabia's average production fell below nine million bpd in 2024, its lowest level since 2011, Riyadh decided to repeat the playbook: an oil price war in the guise of accelerated restoration of voluntary production cuts.

An oversupplied oil market

However, many observers are less sanguine about the outcome of the Saudi campaign this time owing to several unique and different fundamentals. To begin with, this time the Saudis do not have the usual deep pockets needed to prevail. The oil market is more fragmented with large flocks of freelancing producers. High Capex has been sunk in ultra-deep offshore fields and other difficult geographies which need recovering, even at marginal costs, to avoid adverse political and economic consequences. Moreover, the crude

exports by major oil producers such as Russia, Iran and Venezuela are currently hobbled by U.S. economic sanctions which may not last long.

The global oil demand is approaching a plateau and the International Energy Agency (IEA) expects it to grow only by 0.73% in 2025 despite sharply lower prices. The controversial "peak demand" theory does not appear as outlandish now as it did only two years ago when the IEA predicted that global oil consumption would peak before 2030. The signs in that direction are ubiquitous – from the global economic slowdown to the growing popularity of non-internal combustion engine vehicles, particularly in China, the largest oil importer, and growing climate change mitigation. These pessimistic projections are likely to be further compounded by the huge disruption unleashed by U.S. President Trump's tariff war. The S&P Global agency lowered its global GDP forecasts to 2.2% for 2025 and 2.4% for 2026 – historically weak levels since the 2008-09 recession except for the pandemic period. The World Trade Organization recently predicted a 0.2% annual decline in world trade in 2025 unless other influences intervene. The aforementioned bearish factors can create an inelastic situation causing oil prices to not return to previous levels even after supply-side impetuses are reversed.

All this background begets the question: why has Riyadh picked this moment to unleash the oil war? To some observers, the likely rationale lies in a mix of economic and political factors. To begin with, faced with the inevitable long-term prospects of a buyers' market for the foreseeable future, Saudi Arabia may be trying to frontload and maximise their oil revenue. They may also be aiming at positioning themselves at the lower end of the oil price spectrum in anticipation of sanctions being removed from Iran, Russia and Venezuela, three of

the biggest producers as well as the full rollout of Mr. Trump's "Drill, Baby, Drill" campaign. Last, but not least, the move was probably intended as a curtain raiser for President Trump's high-profile state visit to the Kingdom with Al-Saud wishing to be seen as heeding Mr. Trump's call for lower oil prices to help contain U.S. domestic inflation despite his higher import tariffs hurting consumers. With defence guarantees, a nuclear agreement and over \$100 billion in American weapon sales lined up, the Saudis have a lot to gain from the U.S. President's successful visit.

The impact on India

Although the low-intensity oil war may not hit the headlines the way shooting wars do, it is arguably far more consequential. It is particularly true for India, the world's third-largest crude importer, which shelled out \$137 billion in 2024-25 for crude. India's crude demand rose by 3.2% or nearly four times the global growth. A U.S. study last year predicted that in 2025, nearly a quarter of global crude consumption growth would come from India. Even further down the line, India's oil demand is widely expected to be the single largest driver for the commodity till 2040. Consequently, although we may not be a combatant in the oil war, we have high stakes, with a one-dollar decline in oil price yielding an annual saving of roughly \$1.5 billion.

While the downward drift of crude prices in the short run due to the ongoing "oil war" may be in our interest, the picture is not entirely linear. Lower oil revenue hurts our economic interests in several ways. It causes a general economic decline of oil exporters which are among our largest economic partners, affecting bilateral trade, project exports, inbound investments and tourism. Lower crude prices also affect the value of our refined petroleum exports, often the largest item in our export basket, and could push down refinery margins. Moreover, the lower unit price of oil and gas reduces our pro rata tax revenues. The Gulf economies sustain over nine million of our expatriates, many of whom may lose their jobs. Their annual remittances, estimated at over \$50 billion, may suffer, hurting our balance of payments. Irrespective of the outcome of the ongoing oil war, unless we find a new set of drivers to replace hydrocarbons, the lower synergy may become the "new normal" across the Arabian Sea.

Mahesh Sachdev, retired Indian Ambassador, focusses on the Arab world and oil issues. He is currently president of Eco-Diplomacy and Strategies, New Delhi.

THE GIST

On May 3, the Organization of the Petroleum Exporting Countries Plus (OPEC+) decided to go ahead with a collective output increase of 4,11,000 barrels per day (bpd) from next month (June).

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Despite the expectation of a quick turnaround, global economic recovery was mostly K-shaped leading to an anaemic growth in oil demand. Meanwhile, oil producers were desperate to ramp up their outputs to make up for lost revenue.

Understanding India's relationship with Turkey and Azerbaijan

Data suggests that even if an official trade ban is issued against these two nations, India stands to lose little

DATA POINT

Nitika Francis
Sambavi Parthasarathy
Vignesh Radhakrishnan

Following Türkiye and Azerbaijan's support for Pakistan after India's military confrontation in the wake of the Pahalgam massacre, many online travel platforms reported a sharp spike in cancellations of tour bookings to these countries. Many Indian tour operators withdrew offers and promotional packages for trips to Türkiye and Azerbaijan. On social media, calls to "boycott" both countries gained traction. Institutions such as IIT Bombay, IIT Roorkee, and Jawaharlal Nehru University suspended MoUs with some Turkish universities.

Data show that the relationship between Pakistan and Türkiye has been strengthened by arms trade. The two countries have also shown reciprocal support during past geopolitical standoffs. For instance, Türkiye has backed Pakistan on the Kashmir issue, while Pakistan has supported Türkiye in disputes related to Cyprus.

Similarly, in 2020, it was with Turkish backing that Azerbaijan captured much of the Armenian-populated enclave from Armenia. Though Azerbaijan regained full control of the region in 2023, Türkiye denied any direct involvement in that year's operation.

Data from the Stockholm International Peace Research Institute (SIPRI) shows that Türkiye has been exporting arms to Pakistan since the 1990s. **Chart 1** shows Türkiye's arms exports to Pakistan between 1995 and 2023 by category and volume. A significant share of this trade comprised artillery – defined as naval, fixed, self-propelled guns, howitzers, and multiple rocket launchers. Pakistan also received armoured vehicles from Türkiye, including tanks, armoured cars, and personnel carriers.

India has supplied weapons to Armenia (**Chart 2**). Most of these exports comprise surface-to-air missile systems and a few multiple rocket launchers. In contrast, SIPRI data shows no official arms transactions between India and Azerbaijan, or India and Türkiye.

Last week, some Indian trader associations passed resolutions to boycott all forms of trade and commercial engagement with Türkiye and Azerbaijan. However, data suggests that even if this escalates into an official trade ban, India stands to lose little. Crude oil is the primary import from both countries, but their combined share in India's total crude imports has remained below 1% over the past six years (**Chart 3**). In contrast, Azerbaijan could face a greater impact, as India was its third largest destination for crude oil as of 2023.

Another major import from Türkiye is machinery and mechanical appliances, including nuclear reactors, boilers, and related parts. But even in this category, Türkiye accounts for only about 1% of India's total imports (**Chart 4**). India remains far more dependent on countries such as China and Germany for such equipment.

While calls to boycott Türkiye and Azerbaijan have led to "mass cancellations" of travel bookings from India, data shows that Indian tourists formed less than 1% of all tourists to Türkiye in 2024. That said, the number of Indian visitors to Türkiye has been rising steadily in recent years (**Chart 5**).

In 2023, Indians made up less than 6% of all tourists in Azerbaijan, but this share rose to around 10% in 2024. The boycott calls, therefore, come at a time when Indian travel to both these countries was on the rise (**Chart 6**).

The number of Indian students pursuing higher education in Türkiye and Azerbaijan has also increased in recent years. In 2017, the number of Indian students in these countries was less than 100. As of January 2024, it increased by at least seven times (777).

Interests in conflict

The data for the charts were sourced from SIPRI, the Lok Sabha, Turkey's Ministry of Culture and Tourism, the Azerbaijan Tourism Board, UN Comtrade, the Ministry of Commerce, and the Azerbaijan State Statistical Committee

Chart 1: The chart shows Türkiye's arms exports to Pakistan between 1995 and 2023

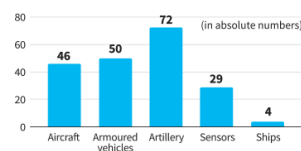


Chart 2: The chart shows India's weapons exports to Armenia over the years

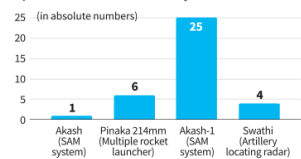


Chart 3: The country-wise share of India's imports of crude oil over the six years

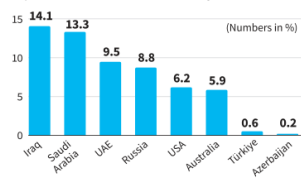


Chart 4: The country-wise share of India's imports of nuclear reactors and machinery

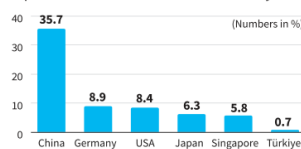


Chart 5: The chart shows the number of tourists from India and Pakistan to Türkiye

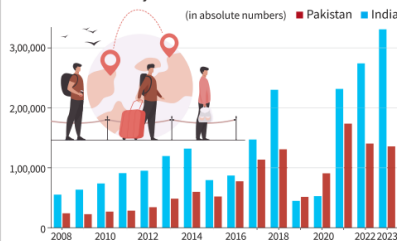
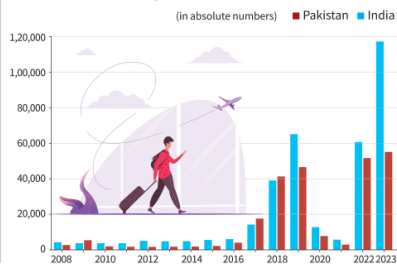


Chart 6: The chart shows the number of tourists from India and Pakistan to Azerbaijan



Getting the 'micropicture' at the panchayat level

Evidence-based decision-making has been the buzzword for the government for quite some time now. However, the extent of data-based decision-making in practice remains an open question.

Critics point to the delay in conducting Census operations and releasing Census data to researchers. They also highlight the other surveys carried out by the government and/or the change in methodology, thereby making the availability of time series data difficult, as obstacles to overcome in evidence-based decision-making at all levels of government. But government officials point to the availability of mammoth data in the portals of different Ministries and also the National Data Sharing and Accessibility Policy (NDSAP), 2012 of the Government of India. This policy intended to make non-sensitive government data available to the public in an open, accessible, and reusable format (<https://data.gov.in>).

However, researchers complain that the data made available are not in a format which can be easily understood by the public or elected representatives. Citizens and even trained researchers feel overwhelmed by the voluminous data. Data visualisation tools on <https://data.gov.in> as well as other government portals are relatively under-developed. Data analytics leaves a lot to be desired. Consequently, decisions continue to be made based on experience and/or the intuitions of Ministers and senior bureaucrats at the Union and State levels.

Data generation and use

At the grassroots level – the gram panchayats, blocks and districts – data are only generated and fed into the system for use by senior officials at the State and national headquarters. Generally, portals are designed to meet the requirements of the heads of departments and secretaries and certainly not of government functionaries and elected representatives at the district, block or gram panchayat levels. Thus, we always get the 'mega picture' and not the 'micro picture'. Data at the gram panchayat level gets linked to a household and family and so becomes difficult to ignore if presented in an easily understandable



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The PAI portal can become a useful tool for officials of line departments and help local and State governments

form to residents.

On the PAI

It is in this context that the magnitude of the work that has gone into the making of Panchayat Advancement Index (PAI) Baseline Report 2022-23 (officially released in April 2025 by the Ministry of Panchayati Raj) needs to be understood. PAI is a composite Index and has been compiled based on 435 unique local Indicators (331 mandatory and 104 optional) with 566 unique data points across nine themes of LSDGs (Localization of Sustainable Development Goals) aligned with the National Indicator Framework (NIF) of the Ministry of Statistics and Programme Implementation. Validated data relating to over 2.16 lakh gram panchayats have been analysed and presented in a form where even a sarpanch or ward member can understand (with some support) not only where their GP stands in relation to the nine LSDGs but also what needs to be done to achieve them. Data relating to a little over 11,000 GPs were not included in PAI as they could not be validated as in laid down procedure. While 25 States/Union Territories provided validated data of almost 100%GPs, it is a matter of serious concern that Uttar Pradesh provided data for only 23,207 GPs (40%) out of its 57,702 GPs. This omission raises serious questions about the state of development in U.P. The PAI portal (www.pai.gov.in) can serve as a useful tool for officials of line departments. A constituency-wise report generation facility can prove very useful for even Members of Parliament and Members of the Legislative Assembly if they wish to make a specific intervention in respect of any LSDG.

It is a dramatic shift that data have now been linked to outcome. For instance, is the GP really a healthy panchayat? Based on the scores of GP on Healthy Panchayat indicators, gaps can now be easily identified and plugged in a short period. Further, the role of all stakeholders such as the individual, community, elected representatives and frontline workers of the health department would also suggest themselves. Excellent coordination between the frontline workers of development departments such as rural

development, panchayati raj, education, health, drinking water and elected panchayat representatives and civil society organisations (CSOs) is seen as a very important factor in the performance of GPs on PAI.

It would be ideal if over 4,000 institutions linked with the Unnat Bharat Abhiyan undertake a study of at least five gram panchayats in their vicinity and explain to the community the implications of their PAI score and what could be done by them to improve their score. Hand-holding of GPs by these institutions and CSOs would go a long way in supplementing the role of departmental officials and attaining the SDGs. The PAI score card also has implications for how corporate social responsibility funds, the Prime Minister's Mineral Area Fund administered by the District Mineral Foundation (DMF), Members of Parliament Local Area Development Scheme (MPLADS) and Member of Legislative Assembly Local Area Development Scheme (MLALAD) among others can be used for realisation of SDGs by 2030.

Need for analysts

There is an urgent need to provide trained data analysts at the block and district panchayat levels who can prepare and provide regular report cards for various stakeholders. More than the Union Government, PAI can be a gamechanger for State and local governments. A Similar Achievement Index should also be formulated for urban local governments. A baseline PAI report should be followed by publications of reports at regular intervals especially after the difficult groundwork has been done.

PAI is much more than a ranking of GPs, Districts or States. It is a call for action. GPs faring poorly are in need of support. We need to not only understand where funds are going or how they are being used (or misused). We need to use the latest data visualisation tools to make all stakeholders understand their critical role and ensure that the goal of making India march forward on the path of development becomes a reality.

The views expressed are personal



In the wake of crisis, the need for bipartisanship

The terrorist attack in Pahalgalam, on April 22, 2025 has once again shaken our collective conscience, reminding us of the fragility of peace in a region long burdened by the weight of history. As India grieves the loss of innocent lives and strengthens its resolve against terror, we must also recognise the critical importance of bipartisanship – both in shaping our response and in ensuring that national security does not become another theatre for political posturing.

There is a distressing pattern that emerges whenever India faces a crisis of this nature: political parties, instead of closing ranks in defence of the nation, often resort to scoring points – weaponising grief for electoral advantage rather than forging a unified front. We saw this after the Pulwama attack in 2019, where swift retaliatory action became intertwined with campaign narratives. That was perhaps inevitable, since the general election was only weeks away from being called, and the national discourse swiftly veered from security imperatives to domestic politicking. But there is no doubt that this cycle weakens our ability to formulate a cohesive and long-term strategy, one that can fortify our defences without compromising our democratic integrity.

Security beyond partisan interests

The challenge before us is clear: terrorism is a scourge that demands a decisive, well-coordinated response, not knee-jerk reactions shaped by party ideologies. Whether dealing with counter-terror operations, diplomatic negotiations, or intelligence reforms, decisions must be made collectively, informed by strategic foresight rather than short-term gains. National security is too vital an issue to be circumscribed by party affiliations; it must transcend ideological divides.

Take, for instance, the Kargil conflict of 1999 – a moment when India, despite political differences between the ruling Bharatiya Janata Party and Opposition Congress, stood together in defence of the nation. The war effort saw bipartisan cooperation, ensuring that security strategies were aligned with national interests rather than partisan agendas. The Opposition, led by Congress President Sonia Gandhi, largely supported the government's military response. She praised the armed forces, stating: "The bravery of our soldiers in Kargil has made every Indian proud. Their sacrifice will never be forgotten." Similarly, when India conducted surgical strikes in 2016 in response to the Uri terror attack, it was done with clear messaging – demonstrating strength without overstepping into prolonged conflict – and the nation was united in applauding the action across political lines.



Shashi Tharoor

is a fourth-term Member of Parliament (Congress), Lok Sabha, for Thiruvananthapuram, Chairman of the Parliamentary Standing Committee on External Affairs, and the Sahitya Akademi Award-winning author of 27 books, including 'The Battle of Belonging: On Nationalism, Patriotism, and what it Means to Be Indian'

As India strengthens its resolve to fight terror, it is crucial to ensure that national security does not become another theatre for political posturing

Recent global history is replete with examples of bipartisanship across political divides in response to terrorism in various democracies. Following the September 11 attacks, both parties in the United States recognised the need for a more unified approach to national security, and a bipartisan effort ensured a swift and coordinated response to terrorism. After the terrorist attack on two mosques in Christchurch in 2019, then New Zealand Prime Minister Jacinda Ardern led a bipartisan effort to reform gun laws. Within weeks, the government passed legislation banning military-style semi-automatic weapons, with support from both major parties. More recently, after Russia's invasion of Ukraine, bipartisan support emerged across Western Europe for military aid to Kyiv and sanctions against Russia. Traditionally neutral countries such as Sweden and Finland joined the North Atlantic Treaty Organization (NATO), with broad political consensus across party lines.

The greys are now blacks and whites

These examples highlight how, despite political differences, nations can unite in times of crisis to prioritise security, unity and effective action. Should Pahalgalam and its aftermath be any different?

When I first became Chairman of the Parliamentary Standing Committee on External Affairs, I declared that "there is no such thing as a Congress foreign policy and a BJP foreign policy; there is only Indian foreign policy, and Indian national interests." I was reminded of a famous episode of Indian diplomatic history in 1994, when Prime Minister P.V. Narasimha Rao picked Opposition Leader (and then Chairman of the External Affairs Committee) Atal Bihari Vajpayee to lead the Indian delegation to present India's case on Kashmir, and counter Pakistan's falsehoods, at a United Nations session in Geneva. The Congress Minister of State for External Affairs, Salman Khurshid, was named as A.B. Vajpayee's deputy. Later, as Prime Minister, A.B. Vajpayee recalled with amusement just how bewildered the Pakistani governing class was at seeing an Opposition leader representing his nation's interests at such a prestigious forum, and at such a crucial moment. But such, he concluded, is our "*vichitra loktantra*" – as clamorous and chaotic as it is miraculous and mesmerising.

Sadly, this episode has not been repeated in the last three decades, as our politics has turned ever more rancorous and bitter. There is very little mutual respect and friendship on display between the ruling party and the Opposition. The core assumption of democratic politics is supposed to be that both sides understand that the other is as committed to the national interest as itself, even if they disagree on how best to

ensure the nation's well-being. In that sense the two sides are not enemies but adversaries. But that assumption has yielded to a bitter polarisation in recent years. One could, of course, argue that this is merely a natural consequence of the pushes and pulls that are inevitable in a democratic polity. But the Indian discourse has taken on extreme hues that imperil any possibility of consensus. The Overton's Window of political mobilisation (in other words, what is considered acceptable in the political arena) has become more vengeful, driven by resentment and an obsession to expiate past wrongs. And social media has emerged as an important tool for divisive discourse, through which the political benefits of this polarisation are reaped. From public debates to dinner-table conversations, the greys have given way to Manichaean blacks and whites.

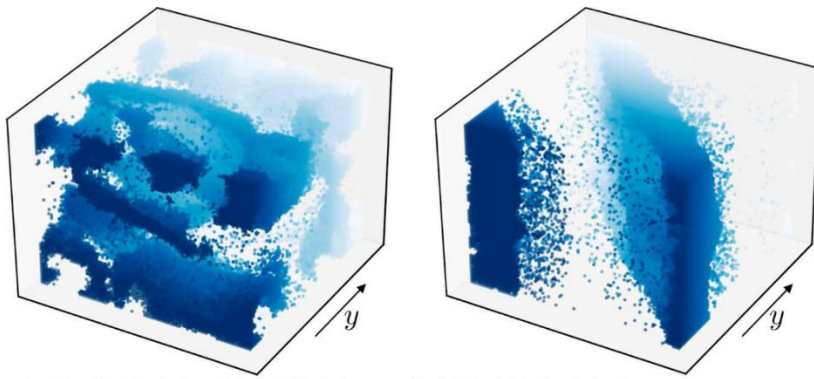
The result is that in recent years, political discourse on security has frequently devolved into blame games, sidestepping the actual need for strategic recalibration. India's relationship with Pakistan, though complex and fraught, requires clarity. There can be no ambiguity in condemning acts of terror; the line between national security and political point-scoring is not a thin one. It is in India's interest to unite in the response to terror, because a perception of division at home always emboldens the enemy. Inflammatory rhetoric, though politically expedient, serves no substantive purpose. If India is to emerge as a responsible power, it must ensure that its politics is mature, that the nation always comes ahead of party interests, and that its diplomacy walks in step with defence preparedness – balancing deterrence with restraint, security with stability, and democratic politics with national unity.

Need for a non-partisan security doctrine

What India needs today is a structured national security doctrine that remains insulated from electoral cycles – one that provides a clear vision on counter-terrorism, intelligence-sharing, and strategic deterrence without becoming a tool for political one-upmanship. Policies regarding defence, zero-tolerance of terror, the security of the homeland, regional strategy and global diplomacy, must be formulated with bipartisan consensus, ensuring that they remain consistent, regardless of which party is in power.

True political leadership demands statesmanship over populism, clarity over chaos. If our lawmakers recognise this imperative, they will understand that safeguarding India's security is not a party matter but a collective responsibility. In moments of grief and crisis, let bipartisanship be the force that unites us – not just in words, but in action. The promise of a secure, stable, and resilient India depends on it.





A non-reciprocal Ising model in 3D, shown here in two particular states. The blue dots show $\uparrow\downarrow$ states and the shade depicts the depth of dots along the y axis. ARXIV:2405.07482V2

‘Minimal’ model captures neurons, flow of opinions, exotic matter

The Ising model and tweaks to it revolutionised the study of physics, often by revealing simple rules lying at the obscured heart of seemingly complex systems; by extending it to non-reciprocal interactions, two new studies have now expanded the model’s usefulness to more domains

Yasudevan Mukunth

B iologists have the fruit fly. Botanists have the thale cress. Neurologists have the roundworm. These are model organisms: plants and animals that scientists in each of these fields study to make sense of almost all other plants and animals in the world.

For example, in the 1990s, Victor Ambros and Gary Ruvkun discovered a new form of RNA called microRNA (miRNA) in the roundworm *Caenorhabditis elegans*. For revealing that miRNA regulates genes and allows certain physiological processes in all organisms – including humans – to function properly, Ambros and Ruvkun received the medicine Nobel Prize in 2024.

Similarly, scientists studying recombinant DNA have *Escherichia coli*; toxicologists have rats, anatomists have zebrafish, those studying hepatitis have rhesus macaques, and so on.

In the same vein, condensed-matter physicists have the Ising model.

A simple, powerful model

The German physicist Ernst Ising created the Ising model in 1924 following a suggestion by his PhD supervisor Wilhelm Lenz. The Ising model provides a simple way to solve problems involving systems where different types of units interact with each other.

For example, say there’s a gas of a few million hydrogen atoms trapped in a chamber and a magnetic field is applied. You need to find out how much the energy of the gas has changed. Since each of these atoms itself is like a tiny magnet and has a north pole (or south pole) pointing in some direction, you can represent it as a grid of atoms:

↑↑↑↑
↑↑↑↑
↓↓↓↓

... where ↑ means ‘north is pointing up’ and ↓ means ‘north is pointing down’.

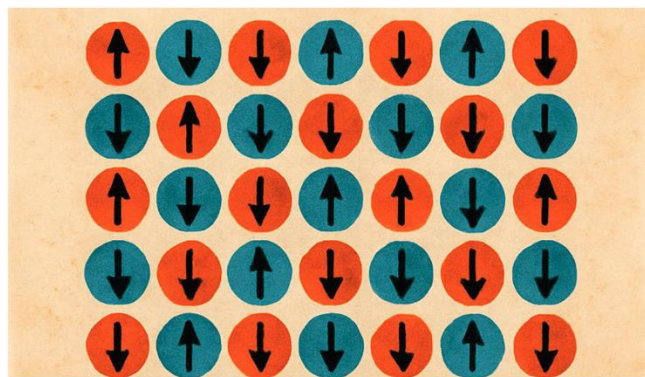
This is a basic instance of the Ising model. You can say that if two neighbouring atoms are ↑↑ or ↓↓ (anti-aligned), it entails an energy of X, and if they’re ↑↑ or ↓↓ (aligned), an energy of Y. This way, you have a simple mathematical way to estimate various values of X and Y throughout the grid and use them to quickly calculate the overall energy.

The Ising model has been used to understand the properties of many solids and liquids in various conditions – including magnetism in metals and alloys and the motion of atoms.

Scientists have also used it to simulate land-use change, the flow of opinions in families and religious congregations, and to make sense of neural networks and lay the foundations of modern artificial intelligence (AI). Such work won the US physicist John Hopfield a share of the physics Nobel Prize last year.

Not a two-way street

But for the great applicability and ease of use of the Ising model, there are also many natural systems whose dynamics it doesn’t capture. This is disappointing. One important class of systems is where the direction of effect matters. In the first neural network that Hopfield designed, for example, information could flow in either direction in a connection between two nodes in a network. But in a subsequent version called a feedforward neural network, information could only flow from node A to node B, not from B to A. Such networks were important to build AI



If it looks like the starting position of a simple game... why not? IMAGE CREATED WITH CHATGPT

A new study has introduced a new form of the Ising model that, by incorporating non-reciprocal interactions, could recreate many properties of one-way networks. As a result, the new model can simulate a larger variety of real-world systems

models with memory.

A new study published in *Physical Review Letters* has introduced a new form of the classic Ising model that, by incorporating non-reciprocal interactions, could recreate many properties of one-way networks. As a result, the new model can simulate a larger variety of real-world systems, including social networks, political strategies, and ecological dynamics.

Scientists develop models to understand the simplest set of rules required to explain how a given system works at different scales. “While minimalistic,” the researchers wrote in their paper, the new model “contains features arising in models of the human brain, opinion dynamics, ... and microchemical oscillators.” This means these features’ properties can now be explored using the model.

The researchers are Yael Avni, David Martin, Daniel Seara, and Vincenzo Vitelli of the University of Chicago and Michel Fruchart of ESPCI Paris.

If a system has non-reciprocal interactions, it means the relationship between two components is asymmetric. For example, the way atom A affects atom B won’t be the same way atom B affects atom A. Such interactions are prevalent in the real world, including in neuroscience, ecology, and active matter.

For example, in a hierarchical network like a political party, party members are influenced by the leader’s decision but the leader isn’t affected by the members’ decisions. In biology, the population of a parasite species could affect the well-being of the host but the reverse relationship need not hold.

Similarly, power grids often use one-way signals to manage small parts of the network – including to adjust power flow, detect faults, and to send updates between substations. To understand the behaviour of any of these systems, physicists and

engineers need models that can anticipate the effects of asymmetric relationships.

Non-reciprocal systems also often display a phenomenon called a limit cycle: as changes propagate within a system, the entire system develops sustained, time-dependent oscillations. Models like the new non-reciprocal Ising model are required to understand how they evolve over time.

Two rules and one condition

In the new study, the researchers developed a non-reciprocal Ising model with two kinds of atoms, P and Q, each of which can be ↑ or ↓. These atoms are arranged on two grids, one in two dimensions and the other in three dimensions. Both grids follow two rules:

(i) Ps next to Ps and Qs next to Qs tend to align. This means that over time Ps and Qs can form islands of uniform alignment.

(ii) If a P is next to a Q, then the P will try to align with the Q (↑ to ↑ or ↓ to ↓). However, a Q next to a P will tend to become anti-aligned with the P (↑ to ↓ or ↓ to ↑). This is the non-reciprocal interaction.

In the reciprocal Ising model, neighbouring atoms being ↑↓ or ↓↑ entailed an energy of X and being ↑↑ or ↓↓ entailed an energy of Y. This meant the overall energy of the system would have been some combination of X and Y. When he created his neural network in the 1980s, John Hopfield set up a similar grid, then gave each node in the grid a condition to follow: whether it was ↑ or ↓ depended on which state made sure the system’s overall energy was lower. By minimising that energy, all the nodes in the network settled down into a given pattern of ↑ and ↓.

Similarly, in the new study, the researchers gave their Ps and Qs a rule to follow. Rather than minimise the overall energy of the grid, each P or Q would have to minimise its own “selfish energy”.

A clock in the grid

The properties of this non-reciprocal Ising model, whatever they are, also tell us about real-world setups that are constructed the same way, e.g., information flowing in political parties and parasites and hosts interacting in an ecosystem. So what did the researchers

find?

First, they found that at any given time, the non-reciprocal Ising model could have one of three phases: disordered, where the ↑s and ↓s are all arranged too randomly for there to be an overall ‘order’; ordered, where the ↑s and ↓s have a fixed arrangement that doesn’t keep varying; and the swap phase, where which species has the most order – Ps or Qs – keeps alternating over time, like the ticktock of a clock.

The researchers also found important differences between the 2D and 3D versions of the model. In 2D, both the ordered and the swap phases were suppressed whereas in 3D, the swap phase was able to attain a stable state.

(According to another paper by the same group of researchers published in *Physical Review E*, the 3D swap phase had the properties of a time crystal. This is wonderfully strange: time crystals are an unusual state of matter in which a material has a stable, oscillating state.)

Finally, the researchers found that if they introduced an asymmetry between Ps and Qs in some form – e.g., the rate at which they flipped from ↑ to ↓ or vice versa – the ordered phase was able to stabilise in the 2D grid.

Wealth of applications

The Ising model and various revisions to it revolutionised the study of condensed-matter physics – often by revealing the simple rules lying at the obscured heart of seemingly complex systems. By extending the Ising model to include non-reciprocal interactions, the researchers behind the new studies have now expanded the model’s usefulness to more domains across scientific fields.

The phase transitions found in the new model may now reveal hitherto unrecognised dynamics in these domains.

The findings also have potential applications in understanding rhythmic activities in biological systems and designing synthetic “active materials” – which take in energy and perform some function, like bacteria swimming in water, starlings murmuring in mesaging patterns in the sky, and even microscopic robots figuring out which formation to fly in.

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Amit Shah launches e-Zero FIR initiative

The Hindu Bureau

NEW DELHI

The Indian Cybercrime Coordination Centre (I4C) has introduced a new system that automatically converts financial cybercrime complaints with a fraud value above ₹10 lakh, and registered on the 1930 helpline or cybercrime.gov.in portal, into first information reports (FIRs). The e-Zero FIR initiative has been launched on a pilot basis first in Delhi, Union Home Minister Amit Shah said on Monday.

The new system that will drive investigations to swiftly cracking down on cybercriminals will soon be extended to the entire nation, the Ministry of Home Affairs said.

Mr. Shah directed the implementation of the initiative at a recent review meeting of the I4C, keeping in view the difficulties faced by victims of financial cybercrimes in recovering the money lost.

The newly introduced process involves the integration of I4C's National Cybercrime Reporting Portal system, the Delhi Police's e-FIR system, and the National Crime Record Bureau's Crime and Criminal Tracking Network and Systems.



