

ENERGY MIX PATTERNS AND VARIATIONS

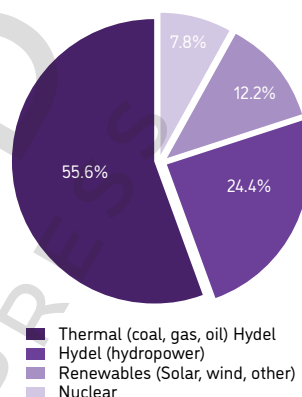
What is an Energy Mix?

An energy mix is the combination of different energy sources used by a country to meet its energy needs. Pakistan uses a mixture of nonrenewable energy sources; oil, natural gas, LNG, coal and nuclear power, and renewable energy sources, including hydroelectric power (HEP), solar, wind, biofuels and fuelwood. Tidal and wave energy also have potential for future development.

Having a variety of energy sources is important because no single source can meet all of Pakistan's energy requirements reliably, affordably and sustainably.

Patterns of Electricity Production

Pakistan's total electricity generation reflects a mix of thermal (non-renewable) and hydel, nuclear and renewable (low-carbon) sources. During the first nine months of the 2024–25 fiscal year, Pakistan generated a total of 90,145 gigawatt-hours (GWh) of electricity. Figure 1 shows how this total was shared between the four main source categories. Thermal sources (coal, natural gas/LNG and oil) still supply more than half of Pakistan's electricity, though this share has fallen in recent years as hydel and renewable capacity has expanded. Hydel power, generated mainly from large dams such as Tarbela and Mangla, is the second-largest source, benefiting from Pakistan's mountainous northern rivers. Nuclear power, though a smaller overall share, is expanding rapidly with new plants coming online near Karachi.



Source | Pakistan economic survey of 2024-25 (data on total electricity generation of 90,145 GWh)

KEY TERMS

Energy Mix

The combination of energy sources used to meet a country's energy requirements.

Installed Capacity

The maximum generating capacity of installed electricity-generating equipment under specified conditions.

Energy Efficiency

Obtaining the same or greater useful output while using less energy.

Energy Security

Having sufficient, reliable and affordable energy to meet the needs of people and the economy.

Indigenous Energy

Energy obtained from resources within the country.

Distributed Solar

Electricity generated by smaller solar installations located close to users, such as rooftop systems.

Net Metering

A billing arrangement allowing households or businesses with their own generation (e.g. solar panels) to feed surplus electricity back into the grid.

Circular Debt

Unpaid bills that accumulate through the power-sector supply chain when the full cost of electricity supplied is not recovered.

Energy Trilemma

The challenge of balancing energy security, affordability and environmental sustainability.

A CLOSER LOOK: INDIVIDUAL ENERGY SOURCES

Figure 1 groups sources into broad categories. Table 1 breaks the thermal and renewable categories down further, using a different measurement period (2023–24), and shows that HEP was in fact the single largest individual source of grid electricity, ahead of any one thermal source.

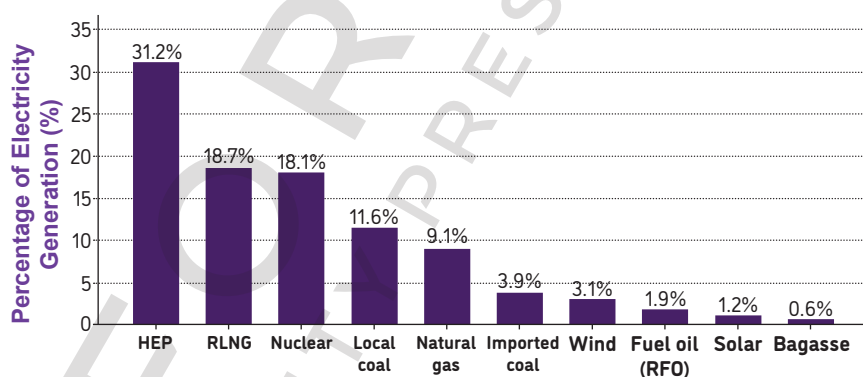
INSTALLED CAPACITY IS NOT THE SAME AS ELECTRICITY GENERATION

It is important to distinguish between installed capacity and generation.

- **Installed Capacity** is the maximum amount of electricity that generating equipment is capable of producing under specified conditions.
- **Electricity Generation** is the amount of electricity actually produced.

A source may therefore have a large installed capacity but contribute a much smaller proportion of actual electricity generation. For example, in 2023–24 HEP represented about one-quarter of installed grid capacity but generated approximately 31% of electricity, while fuel oil power stations had considerable installed capacity but produced a much smaller proportion of electricity. This happens because power stations are not operating at maximum output all the time. Generation can be affected by fuel availability and cost, maintenance, electricity demand, water availability and weather conditions.

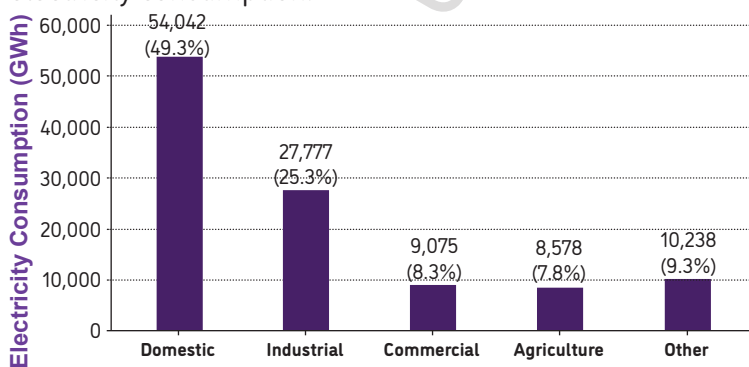
ENERGY SOURCE	APPROXIMATE SHARE OF GENERATION (%)
HEP	31.2
RLNG	18.7
Nuclear	18.1
Local coal	11.6
Natural gas	9.1
Imported coal	3.9
Wind	3.1
Fuel oil (RFO)	1.9
Solar	1.2
Bagasse	0.6



▲ Source | NEPRA, state of industry report 2024. figure are rounded.

Patterns of Energy Consumption

Energy is required throughout Pakistan's economy. Homes, industries, businesses and agriculture all depend on electricity. In 2024, domestic users accounted for approximately half of Pakistan's electricity consumption.



▲ Source | NEPRA

SECTOR	ELECTRICITY CONSUMPTION (GWH)
Domestic	54,042
Industrial	27,777
Commercial	9,075
Agriculture	8,578
Other	10,238

WHAT DOES THE PATTERN SHOW?

- **Domestic Consumption is the Largest:** Pakistan has a large and growing population, and electricity is required for lighting, fans, cooling, appliances and other household needs.
- **Industry is another Major Consumer:** Manufacturing and processing industries require electricity to operate machinery and other equipment.
- **Agriculture also Requires Electricity:** For example to operate tube wells and irrigation equipment.
- **Commercial Activities Require Reliable Electricity:** Shops, offices, banks, hotels and other services increasingly depend on electricity and digital technology.

As Pakistan's population and economy develop, demand for reliable energy is likely to remain an important development issue.

Why does Pakistan's Energy Mix Vary?

Pakistan's energy mix is dynamic: the contribution of different energy sources can change between regions, seasons and years, for several interconnected reasons.

1. PHYSICAL GEOGRAPHY AND RESOURCE AVAILABILITY

Energy resources are unevenly distributed. The mountainous north including Khyber Pakhtunkhwa, Gilgit-Baltistan and Azad Jammu and Kashmir has fast-flowing rivers ideal for HEP, while the flat, sunexposed plains of Punjab and Sindh, and the windy coastal belt of Sindh, are better suited to solar and wind power respectively. Balochistan and Sindh contain most of Pakistan's domestic natural gas and coal reserves including the Thar coalfield, making thermal generation more practical near these areas.

2. COST AND INFRASTRUCTURE

Different energy sources have different construction, fuel and operating costs. Large dams and nuclear power stations are expensive to construct; thermal power stations may depend on costly imported fuel; solar and wind require initial investment but no continuous fuel purchases. Rural and off-grid communities increasingly rely on solar panels and biofuels/fuelwood because extending the national grid is expensive, while urban and industrial centres depend more on grid electricity from large power stations. Energy production also requires supporting infrastructure such as power stations, pipelines, roads, ports and transmission lines, and a region may have excellent energy potential but remain undeveloped if this infrastructure is absent or expensive to build.

3. DEPENDENCE ON IMPORTED FUELS

Pakistan imports fuels including oil and LNG. Changes in world fuel prices can therefore increase the cost of producing energy. Imported fuels also require foreign currency, so heavy dependence on imports can place pressure on Pakistan's balance of payments and make the energy system vulnerable to international price and supply shocks.

4. SEASONAL AND CLIMATIC CONDITIONS

Some renewable resources depend on natural conditions. HEP generation is highest in summer, when glacial melt and monsoon rain increase river flow, but falls in winter, one reason Pakistan still depends on thermal back-up capacity. Solar output depends on sunlight, while wind generation depends on suitable wind speeds.

5. TECHNOLOGY AND INVESTMENT

Some energy developments require advanced technology, skilled workers and substantial investment. This affects the speed at which resources such as nuclear, solar, wind, tidal and wave power can be developed.

6. GOVERNMENT POLICY

Government policy can influence the energy mix by encouraging investment in particular sources, developing major power projects and promoting energy efficiency. Incentives such as net metering and falling solar panel import costs have driven a rapid rise in household and commercial solar use since 2023, changing the consumption pattern independently of the national grid mix.

7. ENVIRONMENTAL CONSIDERATIONS

Burning fossil fuels contributes to air pollution and greenhouse-gas emissions. Increasing environmental concerns can encourage greater use of lower-carbon and renewable energy sources.

New Developments in Energy

Pakistan needs to develop its energy system because demand changes over time and reliable energy is essential for economic and social development. Pakistan is investing heavily in new energy infrastructure to reduce reliance on imported fuel, close the generation–demand gap, and diversify the energy mix. New developments include constructing or expanding power projects, increasing the use of renewable resources, improving the electricity network, and increasing energy efficiency. Solar generation nearly doubled between 2024 and 2025, driven by falling panel costs, net-metering incentives and rising household adoption in response to high grid electricity prices. Wind generation, concentrated in Sindh's coastal corridor, has also grown steadily, supported by consistently strong wind speeds.

Major New Power Projects

Several large-scale power projects are under construction or recently completed across Pakistan, spanning hydropower, nuclear, solar and wind sources. Figure 3 shows the location of some of the most significant projects.

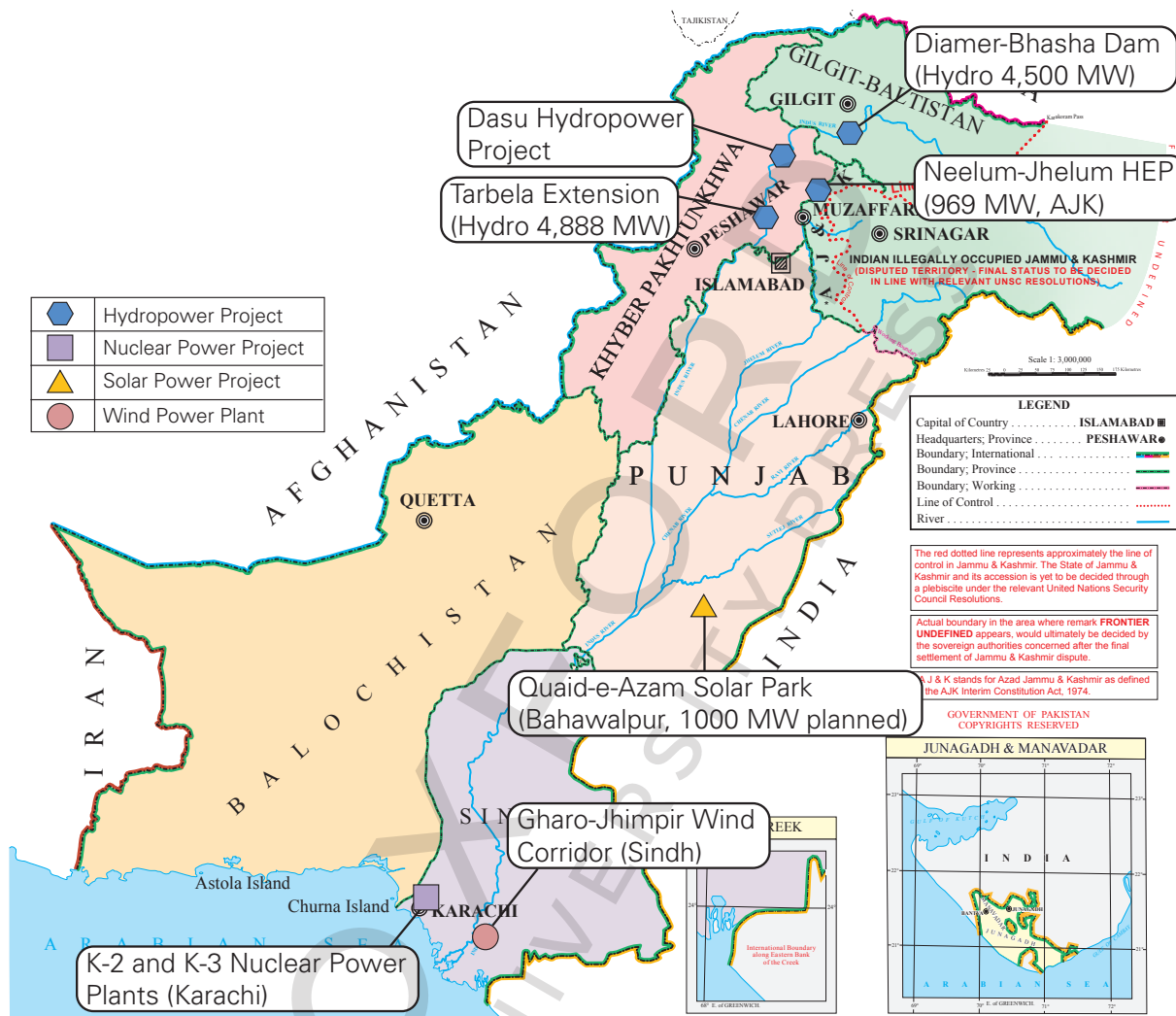
- **Diamer-Bhasha Dam (Gilgit-Baltistan):** A 4,500 MW multi-purpose dam on the Indus River, expected to be one of the world's largest roller-compacted concrete dams once complete.
- **Dasu Hydropower Project (Khyber Pakhtunkhwa):** A major run-of-river hydropower scheme being built in stages on the Indus River.
- **Tarbela Extension (Khyber Pakhtunkhwa):** Successive extensions to Pakistan's largest existing dam have added new generating units — the 5th Extension alone added 1,530 MW — taking the project's total capacity into the thousands of megawatts.
- **Neelum–Jhelum HEP (Azad Jammu and Kashmir):** A 969 MW hydropower project.
- **K-2 and K-3 Nuclear Power Plants (Karachi):** Two 1,100 MW reactors that have significantly increased Pakistan's nuclear generation capacity, alongside the existing Chashma nuclear complex, as part of a longer-term plan to expand nuclear power.
- **Quaid-e-Azam Solar Park (Bahawalpur, Punjab):** Pakistan's largest solar power project, with 400 MW operational and a planned total capacity of 1,000 MW.
- **Gharo-Jhimpir Wind Corridor (Sindh):** A coastal wind energy zone with strong, consistent winds, hosting multiple wind farms with further large-scale potential.

IN FOCUS

Describe patterns shown in energy mix data (using pie charts, bar graphs or tables) and explain at least three reasons for regional variation in energy source use.

Development of Hydroelectric Power (HEP)

Pakistan continues to develop its hydroelectric resources. HEP can produce large quantities of renewable electricity without continuously purchasing fuel, which can improve energy security by reducing exposure to imported fuel prices. However, large HEP projects require very high initial investment, may take many years to construct, can displace communities, may affect ecosystems, and depend on water availability.



Development of Nuclear Power

Nuclear energy provides another important source of electricity. Pakistan operates nuclear power stations at Chashma and near Karachi; the Pakistan Atomic Energy Commission reports six operating reactors with a combined capacity of about 3,530 MW, including the new K-2 and K-3 reactors at Karachi. A major further development is Chashma-5 (C-5), a 1,200 MW nuclear project under construction.

- **Advantages:** produces large amounts of reliable, low-emission electricity and helps diversify the energy mix.
- **Disadvantages:** very high construction costs, long construction periods, radioactive waste that must be managed safely, and dependence on advanced technology, skilled workers and imported uranium, a non-renewable resource.

Improving Energy Efficiency

Increasing electricity generation is only one way of meeting Pakistan's energy needs. Another solution is to use existing energy more efficiently. Energy efficiency means obtaining the same or greater useful output while using less energy. Pakistan can improve energy efficiency by:

- Using energy-efficient lights and appliances
- Replacing inefficient industrial machinery
- Improving the efficiency of buildings
- Upgrading ageing transmission infrastructure to reduce transmission and distribution losses, historically a major source of wasted electricity
- Expanding net metering, allowing households and businesses with solar panels to feed surplus electricity back into the grid, reducing demand on centralised power stations
- Long-term planning frameworks, such as the Indicative Generation Capacity Expansion Plan (IGCEP), which map out how new hydropower, nuclear, LNG and renewable projects will be added to the system up to 2035

IN FOCUS

Describe at least two major new power projects, and explain how new developments in energy including efficiency measures, can improve energy security.

Greater efficiency means less energy is wasted, lowering the overall energy requirement, fuel needs, costs and import dependence — improving both environmental impact and energy security. Energy efficiency can therefore be cheaper and more sustainable than simply constructing additional power stations.

What is Energy Security?

A country with good energy security should be able to provide households and businesses with energy when they require it, without being excessively vulnerable to interruptions or sudden increases in cost.

Threats to Pakistan's Energy Security

- Dependence on imported fuels
- Changes in international oil, LNG and coal prices
- Shortages of foreign exchange
- Increasing energy demand
- Inadequate or inefficient transmission infrastructure and electricity losses
- Seasonal variation in renewable electricity generation
- Interruptions to fuel supplies
- Insufficient investment
- Circular debt within the power sector, which reduces the funds available for maintenance, fuel purchase and new investment

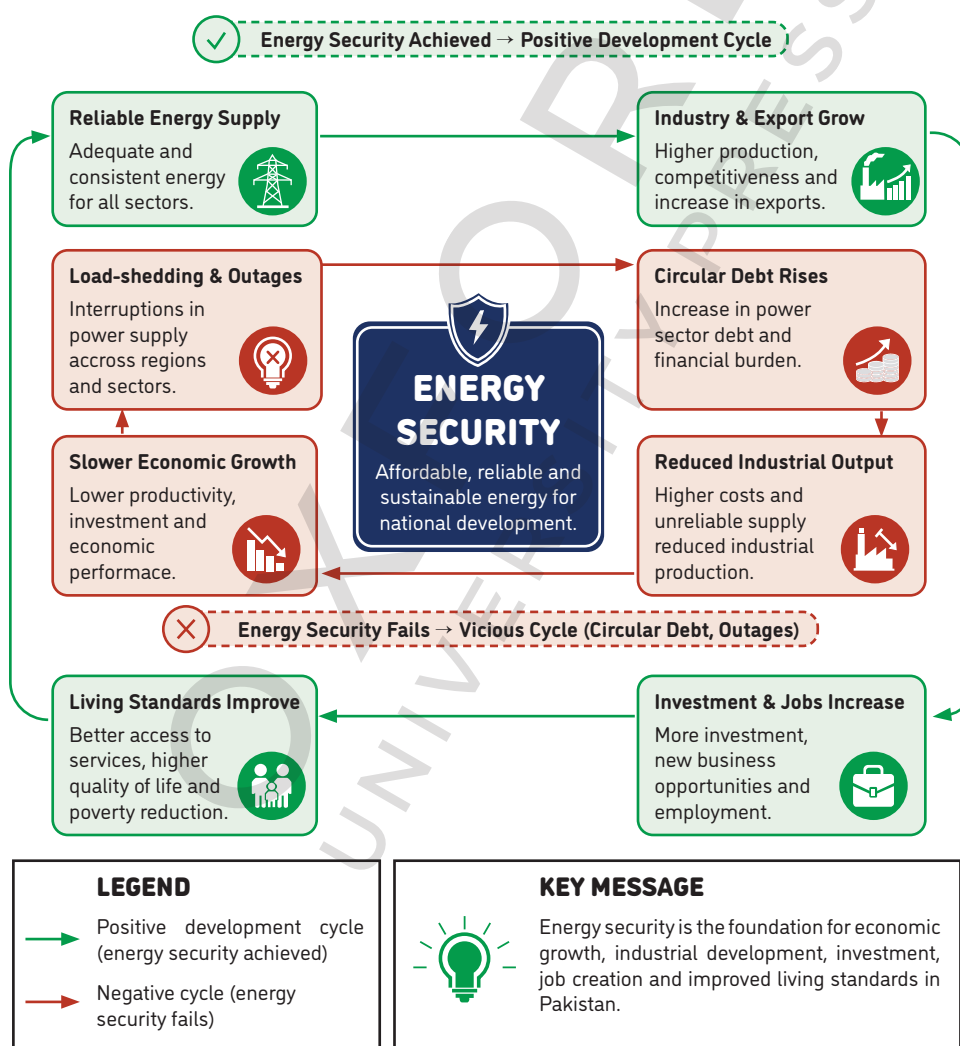
How can Pakistan Improve Energy Security?

STRATEGY	HOW IT CAN IMPROVE ENERGY SECURITY
Diversify the energy mix	Reduces dependence on a single energy source
Develop domestic resources	Reduces dependence on imported energy

Increase renewable energy	Uses Pakistan's rivers, sunshine and wind
Improve energy efficiency	Reduces unnecessary demand
Improve transmission networks	Reduces losses and improves reliability
Develop new generating capacity	Helps meet increasing demand
Encourage distributed energy	Allows electricity to be generated close to users

Energy Security and Development

Energy security is not just a technical issue, it directly shapes Pakistan's social and economic development. Reliable energy is essential for both economic and social development. Figure 4 shows how energy security can lead to a positive development cycle, while energy insecurity can trigger a damaging, self-reinforcing cycle of debt and economic slowdown.



Economic impacts

- **Industrial Productivity:** Reliable electricity allows factories to operate machinery consistently, so fewer interruptions mean greater industrial output, lower production losses and greater competitiveness; energy shortages and load-shedding directly reduce output in key export sectors such as textiles, cement and fertiliser manufacturing.

- **Circular Debt:** When distribution companies cannot recover the full cost of electricity supplied, unpaid bills accumulate through the supply chain — from power producers to fuel suppliers — creating a financial crisis known as circular debt, which had reached over Rs 2.3 trillion in the power sector alone by early 2025.
- **Agriculture:** Electricity is needed for tube wells, irrigation, machinery, refrigeration and food processing, so reliable energy can increase agricultural productivity and contribute to food security.
- **Investment Climate:** Unreliable electricity supply and high energy costs discourage domestic and foreign investment, slowing long-term economic growth; conversely, improved energy security can encourage investment, helping industries and services expand and creating employment and income.
- **Foreign Reserves:** Heavy reliance on imported fuels (oil and LNG) puts pressure on Pakistan's foreign currency reserves, particularly when global fuel prices rise. Social impacts
- **Healthcare:** Hospitals require reliable electricity for lighting, medical equipment, refrigeration and cooling; load-shedding disrupts essential services, particularly in areas with the least reliable grid infrastructure.
- **Education:** Schools require electricity for lighting, fans, computers and internet access; students in areas with frequent outages face disrupted study time, particularly during exam preparation periods.
- **Energy Poverty:** Low-income households often cannot afford consistent access to electricity or clean cooking fuel, and continue to rely on fuelwood and biomass, which increases indoor air pollution and health risks.
- **Gender Impact:** Women and girls in rural households are often most affected by reliance on traditional biomass fuels, as they typically bear the greatest responsibility for fuel collection and cooking.
- **Homes and Services:** Reliable electricity allows households to use lighting, cooling, communication technology and appliances, and supports water pumping, treatment and distribution, as well as mobile networks and internet services.

These wide-reaching effects mean that improving energy security through a more diverse energy mix, reduced transmission losses, new generating capacity, and financially sustainable pricing is essential to Pakistan's long-term social and economic development.

Energy Security and Sustainability: Is there a Perfect Solution?

Improving energy security does not simply mean producing as much electricity as possible. Pakistan needs to balance three objectives, sometimes described as the energy trilemma:

- **Energy Security:** Is sufficient and reliable energy available?
- **Affordability:** Can households and businesses afford the energy they need?
- **Sustainability:** Can energy be supplied without causing unacceptable long-term environmental damage?

Different energy sources involve different trade-offs between these three objectives:

IN FOCUS

Explain how energy security (or the lack of it) affects both the economy (e.g. industry, investment, circular debt, foreign reserves) and society (e.g. education, health, gender) in Pakistan. Support your answer with examples.

STRATEGY	HOW IT CAN IMPROVE ENERGY SECURITY	HOW IT CAN IMPROVE ENERGY SECURITY
Local coal	Domestic resource; reduces some import dependence	Air pollution and greenhouse-gas emissions
LNG	Flexible thermal generation	Imported and affected by world prices
Nuclear	Reliable large-scale electricity	Expensive construction and radioactive waste
HEP	Renewable domestic resource with no fuel imports	High construction cost and water-flow variation
Solar	Abundant domestic renewable resource	Intermittent; storage can be expensive
Wind	Renewable and requires no imported fuel	Output varies with wind conditions

Pakistan therefore needs a diversified energy mix rather than relying excessively on any single energy source.

IN FOCUS

Case Study: The Rapid Growth of Solar Energy

Pakistan has considerable solar-energy potential because many areas receive strong sunshine. Solar energy has expanded rapidly, particularly through distributed solar systems installed on homes, businesses and farms — as shown in Figure 2, where solar generation nearly doubled between 2024 and 2025. Research published by Transition Zero estimated approximately 27.5 GW of distributed solar capacity in Pakistan by 2025, although there is considerable uncertainty because many small installations are not recorded in conventional electricity statistics.

Why is Solar Energy Becoming More Popular?

Falling cost of solar equipment → solar becomes accessible to more users → households, farms and businesses install solar systems → some electricity is produced where it is consumed → dependence on grid electricity may decrease → energy security for individual users may improve. Other reasons include abundant sunshine, concerns about electricity prices, demand for more reliable electricity, use of solar power for agricultural pumping, and reduced dependence on purchased fuel for some activities.

Advantages

- Renewable and does not require imported fuel
- Low emissions during operation
- Suitable for decentralised electricity production, away from the main grid

Limitations

- Electricity production falls at night and output varies with weather conditions
- Batteries and storage can increase costs
- Initial installation may be unaffordable for poorer households
- Rapid growth of private solar systems can create challenges for managing the national electricity system

GEO FOCUS

Does rapid growth of solar power improve energy security equally for all Pakistanis?
Explain your answer.

4 marks

EXAM STYLE QUESTIONS

1. Identify the pattern shown by the resource. Use figures where appropriate.
2. Give reasons and develop links between cause and effect. For example:
"Pakistan can increase solar electricity because it receives high levels of sunshine. This provides an indigenous source of energy and reduces the need for imported fuels, which can improve energy security."
3. Consider both benefits and limitations before reaching a supported judgement. For example:
"HEP can improve Pakistan's energy security because it is a domestic renewable source and does not require imported fuel. However, dams are expensive and generation may be affected by water availability. Therefore, HEP can make an important contribution but should form part of a diversified energy mix rather than being Pakistan's only major source."
4. Define energy mix.
5. State the difference between installed capacity and electricity generation.
6. Describe two features of Pakistan's electricity-generation mix.
7. Explain three reasons why Pakistan's energy mix varies.
8. Explain why dependence on imported fuels can reduce energy security.
9. Explain two ways in which greater energy efficiency can benefit Pakistan.
10. Explain how reliable energy supplies can support industrial development.
11. Explain how energy security can improve quality of life.
12. Using named examples from Figure 3, describe two major new power projects and explain how they could improve Pakistan's energy security.
13. Assess whether increasing solar power is the best way of improving Pakistan's energy security.
14. Explain how circular debt links Pakistan's energy security to its wider economic development.
15. Which combination of energy sources would you recommend for Pakistan's future? Justify your decision using economic, social and environmental evidence.