Chapter 20
Energy Security Issues

20.1 Introduction

Given the paramount importance of energy for all economic activities around the world, issues related to energy security have gained importance in the wake of recent high oil prices and the fear of supply shortages for natural gas and electricity in many countries. Energy security concerns first emerged in the aftermath of the first oil shock in the 1970s, when oil importing countries were caught unguarded and had to struggle to cope with the adverse effects of oil price rise. Since then countries have followed diverse policies to mitigate the problem. Low oil prices since mid-1980s and the shift of focus in the 1990s to market reform and restructuring meant little attention to the issue of security of supply. It was believed that markets would be able to solve the problems of the energy sector. However, concerns about peaking of oil supply and supply capacity to match the demand have brought back an era of sustained high oil prices. Once again the issue of energy security has become a major policy concern.

This chapter intends to provide an understanding of the concept, its economic dimension and an analysis of various alternative options to deal with it.

20.2 Energy Security: The Concept

"Energy security is commonly defined as reliable and adequate supply of energy at reasonable prices" (Bielecki 2002). Reliable and adequate supply implies uninterrupted supply of energy to meet the demand of the global community. This segment of the definition establishes the link between adequate supply and energy demand at any given time. Supply adequacy and reliability is not a matter of external dependency alone. In many countries (developing and developed) the internal sources of supply could equally be problematic. However, of the literature on energy security focuses on external supply alone as the control over external supply can be limited in most cases.

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Reasonable price on the other hand is a more difficult term as there is no universally accepted benchmark. Economically it would mean market-clearing price in a competitive market where supply and demand balances. But as we shall see below energy security involves externality and therefore internalisation of costs would be essential for efficient resource allocation.

The term is used by different people to mean different things and accordingly, energy security has geopolitical, military, technical and economic dimensions (Bielecki 2002). There is a time dimension of it as well: in the short-term, the main concern relates to the risks of disruption to existing supplies essentially due to act of god, technical or political problem; in the long-term, the risks related to future energy supply also arise.

Like any other concept, this concept is evolving as well. For example, initially, the focus was only on oil and oil products. Now it covers all energies and various types of risks to reliable and adequate supplies (including accidents, terrorist activities, and under investment). The geopolitical, internal and temporal aspects of the issue require a multi-dimensional policy approach to deal with the problem.

The literature has focused on the oil supply security in particular and identifies a number of components of the energy security problem (Toman 2002): (a) exercise of market power by suppliers to raise prices, (b) macroeconomic disruption due to energy price volatility, (c) threats to infrastructure, (d) localised reliability problems, and (e) environmental security. But the problem is not limited to oil supply alone and recent studies focus on the entire gamut of the problem.

20.2.1 Simple Indicators of Energy Security

Two types of indicators are commonly used in the supply security literature: an indicator that expresses the level of exposure in terms of dependence level and an indicator of vulnerability. The level of import dependence of a fuel provides an idea about the price and quantity risks associated with importing the fuel and accordingly, a higher level of imports is generally considered to be a riskier option. Similarly, in the case of an electricity system, high dependence on a single fuel is considered to be a riskier option. But as the risk of supply disruption is associated with the concentration of supply sources and the probability of disruption of supply from each source, a highly import dependent system that is well diversified need not necessarily be a risky one.

20.2.1.1 Indicators of Dependence

Indicators that are relevant for energy diversity and energy security are (IAEA 2005):

(1) Import dependence—this indicator can be used for the overall supply position of a country or a region or for a particular fuel. For example, the ratio of net

energy imports to the primary energy supply in a particular year would provide how reliant the country is on imported supply. If a country consumes 100 Mtoe of primary energy and 90 Mtoe is imported, its import dependence is 90%. High import reliance normally tends to increase the price risk and volume risk related to supply interruption.

Import dependence at the fuel level shows the degree of exposure for each fuel. Often, the import dependence of different fuels varies significantly and a country could have a high import dependence for one fuel but highly self-sufficient in another.

At a more disaggregated level, the import dependence by origin of supply could provide a more accurate picture about the risk. If a country depends on a single country for its imports, the risk is particularly high. On the other hand, a diversified source of imports could reduce the risk of supply disruption.

High import dependence of a fuel does not necessarily mean high risk for a country. It depends on a number of factors: the importance of the fuel in the overall demand; how diversified is the source of supply; and the amount of market power of the suppliers. If all of these factors tend to be adverse for a country, the risk will be high.

The evolution of import dependence of a country can be viewed from a plot of the ratio over a period of time. Similarly, using supply forecasts, the expected changes in the future can be captured.

(2) Fuel Mix—this indicator basically shows the share of a particular fuel in the energy demand of a country or its importance in the energy supply. Depending on the focus of the analysis, this ratio can be determined at different levels:

(a) The primary energy consumption mix tells how diversified the overall energy demand is. For example, if a country used 90% oil and oil products and 10% gas to meet its primary energy demand, it cannot be said to have a diversified fuel mix.
(b) The final energy consumption mix gives an indication of fuel diversity at the end-user level.
(c) The sector level fuel mix provides a similar picture at the end-use sector level. The extension of the analysis at the sector level provides a clearer picture of vulnerability of different sectors. For example, if the industry relies only on electricity and natural gas for its energy needs, and if electricity is dependent on natural gas supply, then the industry is highly exposed to changes in the natural gas supply.
(d) Electricity generation mix tells which fuels (and technologies) a country uses for its electricity supply.

An analysis of the fuel mix trend can be used to identify any possible adverse changes in the fuel diversity. Corrective policies can then be considered. Similarly, forecasts of future fuel mix can suggest if the country is moving in the right direction or not. For example, the expected closure of coal and nuclear power plants in the UK by 2025 is expected to increase the share of gas in the electricity generation mix. With domestic gas supply declining, such reliance of gas-based power would necessitate gas imports, making the country vulnerable.

(3) Stocks of critical fuels—this indicates the availability of national stocks of a fuel and the length of time that the fuel could be used if supply disruption takes place, assuming current level of consumption. For example, IEA member countries maintain a 90-day stock of critical fuels.

20.2.1.2 Indicators of Concentration and Diversity of Supply

The following indicators are commonly used:

(a) Herfindahl–Hirschman index: The Herfindahl–Hirschman Index (HHI for short) is generally used for market concentration analysis. This is measured by the sum of the squares of the individual market share of each firm in the industry. The HHI ranges from 0 to 10,000, with the lower range obtained when very large number of firms exist in the industry and the higher range reached with a single producer.

The Herfindahl–Hirschman Index is represented as:

$$HHI = \sum_i x_i^2 \tag{20.1}$$

where x_i is the market share.

The level of concentration is high with HHI above 1800. For energy security purposes, the HHI Index can be used to measure the level of concentration of imports from different sources. Thus, by considering x_i to represent the proportion of imports from supply origins, the level of import concentration can be measured.

The HHI has its own shortcomings as it fails to take into account domestic production. It cannot take the political risk into consideration. Percebois (2007) indicated that the HHI of French oil import in 2004 was 2538 and it was 2469 for natural gas. In 2005, the European Union of 25 had the HHI of 2544 for oil imports and 3538 for gas imports. These indices show high levels of import concentrations.

(b) Shannon–Wiener index: The Shannon–Wiener-Index (SWI) is a diversity index. The SW index for the share of imports from different sources is given by:

$$\mathrm{SW} = -\sum_i x_i \ln(x_i) \tag{20.2}$$

where x_i represents the import share from each country (or source). The negative sign at the front of the equation makes sure that the outcome of the SW index is always positive. When all imports come from a single source, the minimum value is reached (which is zero). As the number of countries supplying the fuel increases, the SW index also increases. Therefore, a higher value of the calculated SWI means good situation as regards imports diversification and supply security while a lower value means a worse situation. The main limitations of the HHI remain here also: it cannot take domestic production separately from the imports and the political risk cannot be incorporated.

The UK Energy Digest provides the SW index for the power generation diversity in the country.

(c) Adjusted Shannon–Wiener–Neumann index (SWN index): The adjusted Shannon Wiener Neumann Index (SWNI) removes the limitations of the Shannon–Wiener-Index (SWI). If the political stability factor is included alone, the index takes the form

$$SWN1 = -\sum_{i} b_i x_i \ln(x_i) \tag{20.3}$$

where b_i is the political stability factor of the country from where imports are coming. The World Bank Report on Governance Matters can be used for the political stability factor. Imports from unstable regions of the world tend to reduce the original Shannon-Wiener-Index and vice versa.

To include the share of indigenous production, the SWN index can be modified as follows:

$$SWN2 = -\sum (b_i x_i \ln(x_i)(1 + g_i)) \tag{20.4}$$

where g_i represents the indigenous production for the country in question.

20.2.2 *Diversity of Electricity Generation in Selected European Countries*

The diversity of fuel-mix of electricity generation in some European countries is considered below. The analysis is presented using two indices: SWI and HHI.

Table 20.1 presents the fuel mix of electricity generation in 5 European countries retained in this study for 1995 and 2005. As can be seen, coal was displaced by natural gas in the UK to a large extent and in Spain and Netherlands to a lesser extent. In Italy, fuel–oil based generation which was the dominant form of power in the mid-1990s was replaced by natural gas. Natural gas consolidated its position as the leader in the Netherlands during this period. Dependence on fossil fuels in electricity generation remained very high in the Netherlands (88%), Italy (79%) and the UK (above 70%). Spain was moderately dependent on fossil fuels in the mid-1990s but its exposure has increased in 2005 to around 60%.

Table 20.1 Fuel-mix of electricity generation in five European countries

		Coal (%)	Natural gas (%)	Oi (%)	Nuclear (%)	Hydro (%)	Others (%)
UK	1995	57.40	15.50		25.20		1.90
	2005	40.85	36.65		19.75		2.75
Germany	1995	54.02	8.05	1.67	28.73	4.51	4.02
	2005	43.46	11.03	1.70	26.29	4.31	13.21
Italy	1995	9.93	19.46	50.03	0.00	17.36	3.22
	2005	14.36	49.15	15.52	0.00	14.13	6.84
Spain	1995	34.95	2.25	8.74	33.14	14.68	6.24
	2005	25.04	26.87	8.30	19.57	7.83	12.39
Netherlands	1995	32.16	51.85	4.77	4.96	0.10	6.16
	2005	23.45	57.73	2.26	3.99	0.08	12.49

Source Bhattacharyya (2009)

Figure 20.1 presents the level of fuel-mix concentration of generation for the period between 1995 and 2005 using HHI. As can be seen, all the countries chosen in the study have HHI above 2000, indicating that the electricity supply in these countries is highly concentrated. The level of concentration has declined in the UK in the early 1990s and then stabilized. Similarly, Spain and Italy have also recorded some improvement in terms concentration in the later half of the 1990s but the improvement in these two cases were over a longer period compared to the UK. Germany did not show any change in the level of concentration of generation fuel mix over the past decade while the situation has deteriorated in the Netherlands. Of the five countries considered here, Spain had the lowest HHI since 1996 while the Netherlands, with an HHI of above 4000, had the highest over the same period. The dominant position of natural gas with a share of above 50% in the fuel mix of electricity generation has adversely affected the concentration in the Netherlands while a well distributed fuel mix of Spain has clearly improved its level of concentration.

Figure 20.2, which provides the trend of SWI of fuel mix for electricity generation in the above five countries between 1995 and 2005, also leads to the same observations as above. In all the five cases, the SWI ranged between 1 and 2, implying that these countries are not dependent on one or two fuels for their

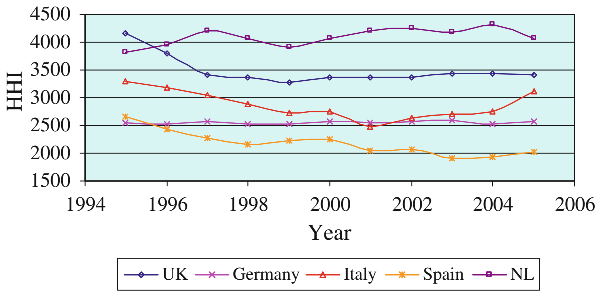

Fig. 20.1 HHI of electricity generation mix in selected European countries. *Source* Bhattacharyya (2009)

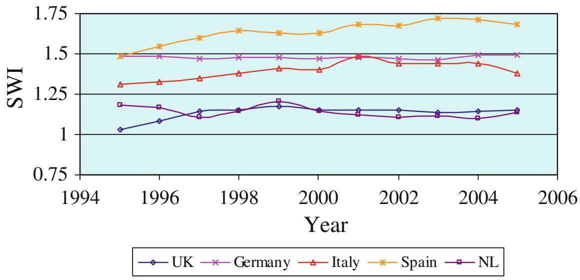

Fig. 20.2 SWI of electricity generation mix in selected European countries. *Source* Bhattacharyya (2009)

electricity generation but their fuel diversity is not highly commendable either. Spain has the most diversified generating system in the sample and the level of diversity has improved during the past decade. Germany and Italy occupy an intermediate position, where the diversity level in the German system has not changed appreciably while the Italian system has recorded an improvement until 2001 followed by a somewhat reduction in the diversity. The liberalised markets of UK and the Netherlands have the least diversified generating systems in the sample and their level of diversity did not change in the past decade.

It is clear that the above five countries rely on fossil fuels to a great extent for their electricity generation. Although their systems are not highly concentrated in terms of fuel mix, they cannot be considered to be in a highly desirable situation either. As the fossil fuel prices have risen in recent times, their electricity system is likely to be vulnerable. It is to this aspect that I now turn to.

20.3 Economics of Energy Security

Energy supply disruptions consider interruptions of supply due to a variety of factors: act of sabotage, failure of a supply technology, breakdown of supply infrastructure, etc. The level of insecurity is reflected by the risk of a physical, real or imaginary supply disruption (Owen 2004). Normally, a high level of insecurity would result in high and unstable prices over a prolonged period.

In order to understand the economics of energy security, it is important to categorise the sources of insecurity. Two types of supply disruption risks could be considered (Markandya and Hunt 2004): strategic and random. A strategic risk would arise due to political instability, market power or even inadequate investments in supply facilities. OPEC deliberately manipulating the supply and prices comes under this category. Random shocks such as terrorist acts on the other hand are more speculative in nature and may not follow any set pattern. Although these risks could affect both domestic and the international markets, the strategic risk has less relevance for the domestic systems. The domestic systems on the other hand could face supply disruption due to insufficient infrastructure, technical failures, social unrest, or due to acts of terrorism (Owen 2004).

This section focuses on the economic aspects of two main components of the energy security issue: the effect of market power on the cost of imported energy and the cost of supply disruption. Oil is used as an example as it is the most traded commodity in the world market and oil imports account for a significant share of imports in many countries. However, the same logic applies to other energies to a great extent.

First, the cost of oil imports is presented. This is followed by a discussion of the cost of supply disruption and analysis of measures to mitigate the risks.

20.3.1 External Costs of Oil Imports[1]

Although oil is a commodity, it has a certain special characteristics:

(a) oil is concentrated in a relatively small area in the Persian Gulf, which allows for monopolistic behaviour in the oil market;
(b) oil has limited (if at all) substitutes in its main uses, which removes the flexibility of users to move away from use of oil;
(c) oil supply shocks may leave nations to serious adjustment problems; and
(d) all stages of oil fuel cycle impose unintended and damaging environmental effects.

Consequently, the market failure argument applies here and the market price of delivered oil to the consumers departs from the full social cost of oil. The social costs may include costs due to non-competitive markets, costs due to environmental damages, and economic losses due to price shocks. Oil consumers do not pay for these costs in the price but the society as a whole pays for them.

One commonly identified externality related to oil import arises due to the monopsony power of certain importers that affect the price of oil in the world market. For a price taker in the international oil market, the price paid by the consumers is equal to the cost of the extra oil to the economy and hence there is no externality here. But if a consumer has a large market share in consumption (say the US), then any extra demand for imports by this consumer would adversely affect the global demand and consequently, the world oil price would increase. This raises the country's total oil import bill—for marginal and infra-marginal imports. While the private cost to consumers is the marginal cost of imports, the society bears the cost higher payments for the infra-marginal quantities, making the social cost higher than the private cost. The difference between the social and private costs is called the monopsony wedge.

The logic of externality would suggest that the market does not convey the correct signal to the consumers and accordingly, the consumption decision would

[1] This section relies on Leiby et al. (1997), Toman (1993), Markandya and Hunt (2004) and Huntington (2009).

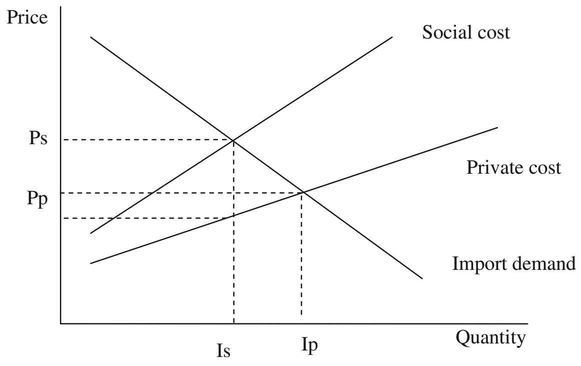

Fig. 20.3 Social cost of oil imports

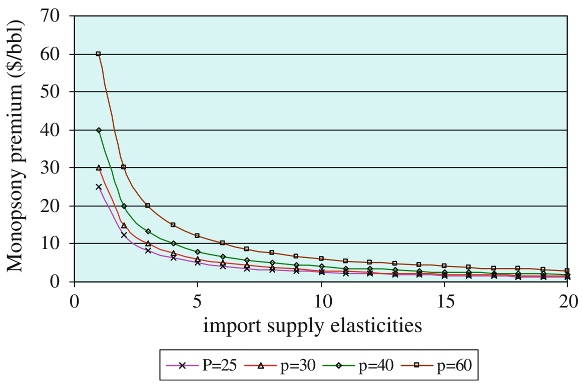

Fig. 20.4 Monopsony premium plot. *Source* Based on Parry and Darmstader (2003)

be based on private costs and not on the social costs. This is shown in Fig. 20.3. While the import based on private cost is Ip, the efficient level of import would be Is based on the social costs.

The effect monopsony power depends on two factors (Parry and Darmstader 2003): the level of import dependence and the effect of monopsony demand on the world oil market. If the country does not depend on import (i.e. import dependence is zero), there is no externality due to monopsony power. With higher level of import dependence, the monopsony wedge increases. Similarly, if the world oil market was perfectly elastic and competitive, the extra import demand from a major consumer would not have any effect on the world oil price and the externality would not exist. But the presence of the OPEC makes the supply non-elastic and the world price is affected by the supply from non-OPEC producers as well.

Parry and Darmstader (2003) suggest a simple relation to capture the monopsony premium or wedge. Generally, if P is the world price of oil and e is the elasticity of import supply, then the monopsony wedge (or premium) is given by P/e. If e is infinite (i.e. the import supply is perfectly elastic), the premium is zero. For various oil prices and import supply elasticities, the premium would vary as shown in Fig. 20.4.

As can be seen from the above plot, the premium could be high for inelastic import supply; otherwise, the premium fall quite sharply and could be low. The literature provides a wide range of estimates for the US, ranging from $0 to $14 per barrel, while Parry and Darmstader (2003) prefer to use $5 per barrel as the premium. However, most of these estimates were based on low oil prices and may not be valid in a high oil price regime. For example, Leiby (2007) estimated the monopsony premium for the US at $8.9 per barrel (at $2004 constant prices) considering the conditions prevailing in the new millennium.

20.4 Optimal Level of Energy Independence

Here the marginal cost approach is used to get some idea of optimal dependence. This requires us to construct the curve depicting marginal cost of its import dependence (MDC) and the curve showing marginal cost of security (MSC) as shown in Fig. 20.5 (Percebois 1989).[2]

The marginal import dependence cost (MDC) curve captures the costs of increased energy import dependency. This would include direct and indirect costs to the economy (including military costs, economic disruption costs, etc.). Normally, this curve is expected to be downward sloping with respect to import independence. When a country is fully self-sufficient, the marginal cost of import dependence is zero and it could be very high for 100% import dependence. It is not easy to develop such a curve as the cost depends on many factors such as import diversity, ease of energy substitution, importance given by the society on energy import, etc.

The marginal cost of security curve (MSC) on the other hand is the cost the society is willing to bear for increasing the national energy independence. A country could reduce its import dependence through energy stocks, energy rationing, promoting national supply, etc. The incremental cost of increasing independence would be captured here. It is generally assumed that the marginal cost of security is zero for domestic energy supply (although this need not be true). Costs start to increase at a faster rate with higher levels of independence. So the curve does not start at the origin (there is an offset) and has a steep slope.

The optimal rate of energy independence is given by the intersection of the two marginal curves as shown in Fig. 20.5. The graph suggests that: for an optimal level of energy independence; it is important to consider the costs of ensuring security of supply and the cost of the damage. It is not economically efficient to improve energy independence beyond the optimal level; this is so because the cost of providing the security of supply would be much higher compared to the marginal dependence cost. There is a price (P*) that the society is willing to pay to

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[2] This part is based on Percebois (1989).

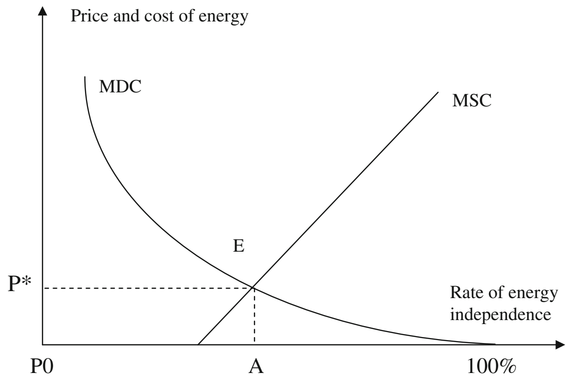


Fig. 20.5 Optimal rate of energy independence. *Source* Percebois (1989)

ensure the optimal level of security of supply—this is the premium that has to be paid to ensure security of energy supply.

20.5 Policy Options Relating to Import Dependence

If oil import imposes external costs to the society, what are the options available to mitigate them? The literature on energy security has considered a number of options and we discuss a few of them in the following paragraphs.

20.5.1 Restraints on Imports

Such a policy aims at imposing import restrictions through tariffs or quotas to mitigate the costs related to import dependence. Alternative policies that would eventually limit energy imports (such as tax on fuels, promotion of domestic supply, fuel substitution, promotion of alternative sources of energies, etc.) could also be considered under this category. We analyse the economic logic of using import quota and import taxes.

20.5.1.1 Effect of Import Tax and Import Restriction

Let us consider an energy importing country whose energy demand and domestic supply are given by schedules D and S respectively in Fig. 20.6. If the country does not participate in international trade, the domestic price would be the market clearing price p1. Assume that the international price p2 and is lower than p1. In an open economy, the supply would be met by a combination of local production and import. The country will produce q3 and import q2–q3. This volume of import would involve a significant foreign exchange outflow for the country.

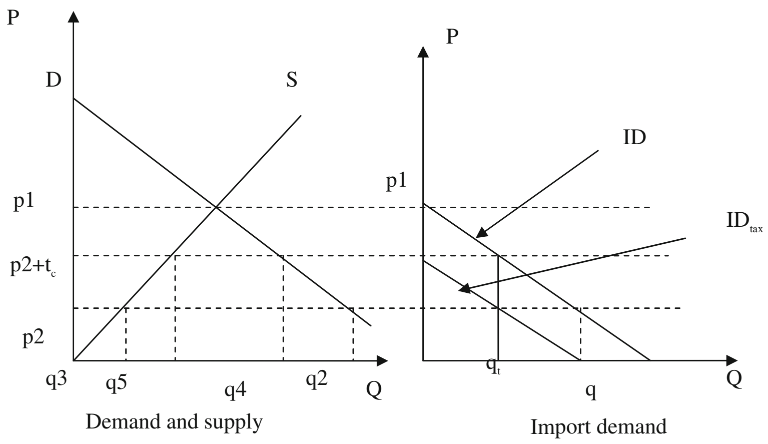


Fig. 20.6 Effect of import tax and import restriction

Consider now that the government is concerned about the energy security and that it imposes an import tax equal to t_c per unit of import. With this tax, importing energy would be costlier which makes import to shrink. The domestic supply would be encouraged at this higher level of price, as more domestic suppliers would be willing to produce. Import volume reduces to q4–q5.

The import demand function for the country is shown in the right hand panel. In absence of any import tax, the import demand is given by ID. At price p1, the import demand is zero but it increases to q when the price is p2. When the tax is imposed, the demand curve shifts to ID_{tax}. At price $(p1 - t_c)$, the demand is zero while with tax t_c, the import volume reduces to q_t. Thus, the import schedule shifts leftwards by $(q - q_t)$.

Now consider the effect of imposing an import quota system. Assume that the government imposes a quota at level q_t (i.e. the imports should not exceed this level). This is shown in the right hand panel. As the imported supply cannot exceed the quota, the price rises to $p2 + t_c$ level, thereby reducing the demand as before. The domestic supply receives encouragement at this price and import remains restricted. In a quota system, the import demand function is represented by $p1Aq_{t.}$ At prices below $p2 + t_c$, the quota is a binding constraint and the level of import remains fixed at q_t.

The tax system is a price-based mechanism. The import demand varies depending on the oil price and the level of tax. The import demand curve is shown by ID_{tax}. The effectiveness of the instrument could be less. The tax revenue accrues to the government. It does not require any additional administrative system. In a quota system, there is no ambiguity about the import level (hence a certain instrument). It requires additional administrative machinery to implement the quota system. It could also lead to corrupt practices (through grant of exemptions) or illegal smuggling of the products. More importantly, the higher revenue goes to the suppliers and not to the government. In fact, as quota is price insensitive beyond a threshold, the exporters have incentives to adjust prices to the higher level.

Thus the two policy options have different economic consequences. In the case of a quota, revenue transfer to the exporting countries would take place, if they are in a position to exploit the situation. It may also involve a higher transaction cost. While in the case of import taxes, the government could earn revenues by reducing import demand.

Therefore, for an importing country it may be beneficial to use an import tax system as long as such a system is compatible with the international trade regimes.

20.5.2 Import Diversification

The logic is simple: do not put all the eggs in one basket. This is because the risk of supply disruption is high when a country relies on a single source for its energy supply (i.e. becomes a captive consumer).

This risk can be mitigated through diversification of the source of supply. From an economic point of view, this implies finding the least-cost supply solution taking supply risks into consideration. However, for oil and to a lesser extent for gas, the global reliance on the Middle East is expected to increase where most of the reserves are located. This coupled with political instability of the region and increasing demand from the developing economies raise concerns for future oil supply security.

Two new developments in the area of import diversification perhaps are worth mentioning.

- The first relates to an increased level of activities and investments in production facilities by importing countries in foreign oil producing regions. Chinese oil companies are now forerunners of this trend and are investing massively around the world. Japan also relied on such a strategy in the 1970s and 1980s although may be less aggressively.
- A second trend appears to be emerging in the form of seeking cooperative solutions rather than relying on competitive outcomes. This trend is noticed in various areas:
  - *Importer-importer co-operation*: China which was engaged in competition with India through rival bidding for acquisition of energy assets elsewhere have now joined hands to jointly develop and acquire such assets. The cooperative strategy is expected to reduce the cost of procurement (and hence the supply) and better use of other resources.
  - *Importer-exporter cooperation*: Joint development by importing and exporting countries would ensure flow of required investments for the development of facilities and could reduce transactional risks.

The framework of cost-benefit analysis plays a vital role in such decisions. A nationalised company can employ a different threshold for decisions compared to a private company (regarding discount rates, profitability ratio, future market conditions, etc.). The long-term nature of these investments and uncertainties about the future as well as risk-averseness of the investors would influence the decisions. However, wrong investment decisions may lead to outgo of significant financial resources and costly supply in the future.

20.5.3 Diversification of Fuel Mix

Diversification of fuel mix in an economy tries to reduce dependence on a particular fuel and to achieve a diversified portfolio of energy supply options. For example, Salameh (2003) indicates that the US has been diversifying its fuel mix for ages to replace oil and coal by natural gas and nuclear. In the future, renewable and other technologies on which it is investing heavily could add more diversity.

The choice is often limited by: the availability of resources, available technological options to exploit such resources, costs and investment requirements, and other considerations including environmental and social concerns.

It is difficult to generalise but a few trends could be indicated.

(a) **Effects of restructuring on fuel diversity in electricity**: Reliance on market forces upon restructuring and reform of the energy industries in the 1990s led to promotion of competitive solutions in the electricity markets. This has resulted in a shift in technology choice for supply as the private investors are now looking for quick recovery of investments. Consequently, low cost options are being preferred compared to capital intensive solutions, reducing supply diversity.

(b) **Come-back fuels**: Coal and nuclear are re-emerging as preferred alternative options for power generation. Stability of coal prices, availability of technological options and higher availability of coal in the demand areas has created a positive mood, although environmental considerations act as a hindrance. Security of supply is forcing many countries to rethink about the nuclear option.

(c) **More renewable energies**: Renewable energies are being promoted for various uses to replace or reduce reliance on fossil fuels, thereby adding diversity and improving security. Various policies such as renewable energy targets or obligations, fixed feed-in tariffs, quicker depreciation and recovery of capital, and fiscal incentives are being used to promote renewable energies.

20.5.4 Energy Efficiency Improvements

Efficient use of energy reduces energy demand, which in turn reduces import requirement. This also reduces environmental damages and resource depletion.

Although significant efforts have gone into energy efficiency improvements and demand-side management programmes, availability of cheap energy has reduced their appeal in the past. With higher energy prices, it could again become easier to pursue some of these objectives.

In this respect, the importance of rational energy pricing needs to be emphasised. If domestic retail prices are maintained at inefficient levels, consumers remain insulated from the price movements and do not appreciate the need for efficient use of energies. Removal of energy subsidies could provide the necessary incentive to consumers, although efforts so far in this direction have yielded little result. The efforts are hindered by non-availability of information, need for sophisticated decision-making, use of non-standard procedures, etc.

20.6 Costs of Energy Supply Disruption

Any supply disruption imposes some costs on the economy due to loss of economic activities, price effects and costs of alternative supply arrangements. For oil, it is considered that the supply interruption will lead to higher import prices, given the dependence of the economy on the imported energy source. This then results in economic loss directly through loss of outputs, unused factors of production, cost of stand-by generation capacities, etc., and indirectly, through increased cost of business due to inefficiencies, misallocation of resources, etc.

The estimation of disruption cost involves the following steps (Razavi 1997):

- formulation of supply interruption scenarios providing information on the volume of supply unavailability over expected disruption periods; The level of insecurity is reflected by the risk of a physical, real or imaginary supply disruption (Owen 2004). Normally, a high level of insecurity would result in high and unstable prices over a prolonged period.
- assessment of how prices would be affected due to such supply interruptions.
- an estimation of GDP loss due to price increases.

Leiby (2007) suggested that the above can be represented as follows:

$$E_{\{\Delta Q\}}[C_d] = \sum \phi_j[C_{Id}(\Delta P(\Delta Q_j)) + C_{GNPd}(\Delta P(\Delta Q_j))] \qquad (20.5)$$

where C_d = cost of disruption
C_{Id} = cost due to import disruption
C_{GNPd} = cost of losses due to economic dislocation
ϕ_j = annual probability of supply losses
ΔP = price change
ΔQ = quantity change
$E\ (C_d)$ = Expected cost of disruption

The disruption premium is obtained by considering the marginal change of the above expected cost with respect to import quantity. Leiby (2007) estimated the disruption premium for the US at $4.68 per barrel of oil at ($2004 constant prices). However, as can be imagined, the estimation of such a premium is not easy and involves a large number of assumptions and forecasts about future events. Thus the estimates vary depending quite significantly depending on the choices made.

An understanding of the disruption cost is important for deciding the mitigation strategies. If the cost is high, higher levels of supply reliability could be justified and vice versa.

20.6.1 Strategic Oil Reserves for Mitigating Supply Disruption

The Strategic Petroleum Reserve was a response of the developed countries to the oil price shocks of the 1970s. The objective was to provide a deterrent to deliberate, politically motivated reduction in supplies. This initiative was engineered by the International Energy Agency (IEA) in 1974 under the auspices of the Agreement on an International Energy Program.

Under this agreement, IEA member countries hold a stock of oil equivalent to 90 days of net imports in the previous year. Supply can be released in emergency conditions when the supply disruption exceeds 7% of IEA or any member country supply. Similarly, the EU also has adopted a comprehensive set of measures including the obligation to maintain stocks of three types of petroleum products (namely motor spirit, middle distillates and fuel oil) for at least 90 days of average daily consumption in the preceding calendar year. Although the IEA program and EU measures have some minor variations, the two serve similar purposes and member countries tend to use same stocks for complying with both the obligations (Bielecki 2002).

There are several advantages of such strategic reserves: (a) stock releases pacify markets and dampen price rises; (b) allow time for economies to adjust to the changes, (c) although a few countries are members to the plan, consumers globally benefit from the stock due to market reaction, and (d) they allow room for expanded co-operation among countries. The stockpile can be viewed 'as a publicly provided insurance policy against petroleum market shocks' (Taylor and Van Doren 2005). But what justifies public provision of this service?

Public provision of the stock may be required for a number of reasons (Taylor and Van Doren 2005; Toman 1993):

(a) *non-optimal stockpiling by the private sector*: privately owned inventory may be held at a smaller level than the economically efficient level because:

- the market price may not provide effective signals to investors about the total benefits and costs.
- the presence of externality would create a divergence between the private and social costs and benefits, requiring such an intervention.

- Moreover, the private stockholder may not be able to capture the entire benefit of holding stock when there are significant macroeconomic benefits (Toman 1993; Taylor and Van Doren 2005).
- Finally, changes in the regulatory or fiscal environments could deprive the stockholder some or most of the benefits of holding the stock and thereby discourage non-optimal private stockholding (Taylor and Van Doren 2005).

(b) *Behavioural problem*: private entities guided by profit-maximising behaviour may hold stock rather than releasing it at the time of high prices in the hope of higher profits.
(c) *Cost consideration*: private stockpiling may be costly compared to publicly-owned stockpiling because of technology choice, storage location and size.

However, for any such strategic reserve, a number of issues arise (Toman 1993):

(a) *Reserve sizing*: the sizing of the stock and its use are influenced by the cost of economic disturbance to be mitigated, its probability, size and duration, and the interaction of private and public stocks could also influence the sizing decision.
(b) *Timing and method of stock utilisation*: often the literature on stockpile release profiles provide little help as the models rely on simplified assumptions.
(c) *Arrangements for stock use*: the question of institutional arrangements for using such reserves has been analysed as well. Often it is assumed that the stocks would be sold in the spot market periodically using sealed-bid auctions. Forward sales and sale of options to purchase oil from the reserve at predetermined strike prices are also possible (Toman 1993).

But such reserves also add to the cost (of building and carrying the stock among others) and hence the optimal stock size depends on the costs and benefits derived from the stockpile. Following Razavi (1997) the desired level of stock of strategic reserve (S*) could be determined using a simple framework by comparing the cost of maintaining the reserve and the benefits of avoiding a sudden supply shock (see Fig. 20.7).

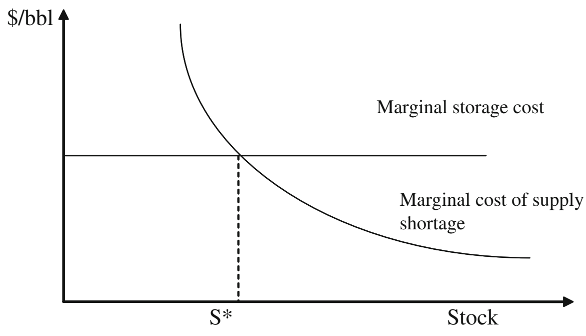


Fig. 20.7 Desired level of strategic stock. *Source* Razavi (1997)

Although strategic reserves are used as a policy option, its costs are not often reflected in the pricing of energy. Taylor and Van Doren (2005) question the economic rationale for maintaining stocks as well for the following reasons:

(a) The cost for maintaining the reserve in the USA was found to be quite high compared to the oil price. They estimate that each barrel of strategic reserve costs the taxpayer between $65 and $80 and maintaining such high cost oil for shortage mitigation does not make economic sense.
(b) The amount of oil stocked is just a fraction of the global oil demand and would not be able to influence the international oil price to any significant level.
(c) The reserves have been used only three times so far in the US history and the timing and volume of stock release did not provide much comfort to the affected population.

20.6.2 International Policy Co-ordination

Security of energy supply has an international public good dimension. This is because measures taken by any country independently would also benefit (or impose costs on) others.

International policy coordination helps avoid free-riding and limit opportunistic behaviour of countries. The crisis-response provisions of the IEA form the essential mechanism for such co-ordination in industrial countries. At a regional level, ASEAN has adopted an Emergency Petroleum Sharing Scheme during shortage and oversupply to assist both importers and exporters of the region (Bielecki 2002).

Any such international mechanism would have to ensure provision of the public good in a fair, cost-sharing programme. Normally larger benefits are expected to accrue to bigger economies. This requires some sort of 'common but differentiated' responsibility approach [adopted for the Climate Change policy coordination] (APERC 2002). Similarly, it may not make sense for smaller countries to go for own strategic reserves due to adverse cost-benefit characteristics and a co-operative solution would be preferable. The possibility of economic and political policy coordination as a group could also be considered.

20.7 Trade-Off between Energy Security and Climate Change Protection

Concerns about the climate change in recent times have imposed an additional consideration in the energy security debate. The diversification of energy supply system to enhance energy security could have a bearing on the climate protection.

For example, if coal is locally available and to reduce dependence of imported oil or natural gas, if coal use is promoted, the carbon emission is going to increase. On the other hand, if nuclear power option is chosen, both energy security and the protection of the climate will be ensured. Given that a large number of technical options are available for abating greenhouse gas emissions with different potentials for enhancing energy security (See Fig. 20.8), there is room for a trade-off.

In Fig. 20.8, the origin represents the reference scenario based on the business-as-usual assumptions. Two policy objectives are considered from this point: enhancing energy security (along the vertical axis) and abating greenhouse gas emission for climate protection (along the horizontal axis). The figure indicates a number of alternative options—some of which predominantly offer the security benefits (such as the Strategic Petroleum Reserves (SPR) or corn-based ethanol) while some others offer predominantly climate benefits (nuclear or renewable options). There are other options in between.

To determine the optimal policy combination, Brown and Huntington (2008) suggest the following simple optimization:

Assume that there are n technologies (including energy conservation options) x_i (for x_1, x_2…, x_n) for protecting the climate and enhancing the security of supply, each costing c_i. Assume that the security enhancement obtained from each technology is s_i, and that the GHG abatement obtained is q_i. Then the total provision of energy security, S, is the sum of the contribution of each technology.

$$S = \sum_{i=1}^{n} s_i(x_i) \tag{20.6}$$

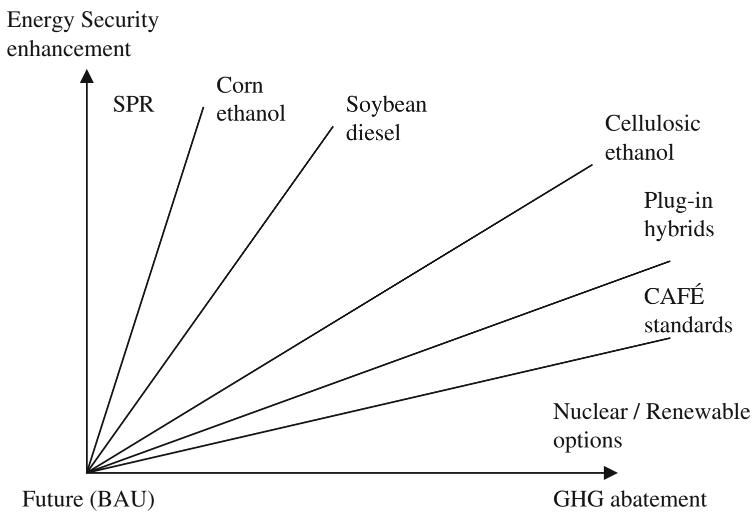


Fig. 20.8 Technology options for protection the climate and enhancing energy security. *Source* Brown and Huntington (2008)

Similarly, the total reduction in emission, Q, is given by sum of individual GHG reduction.

$$Q = \sum_{i=1}^{n} q_i(x_i) \tag{20.7}$$

The total cost of the programme, C, is given by

$$C = \sum_{i=1}^{n} c_i(x_i) \tag{20.8}$$

The problem then is to minimize the cost of the programme subject to the constraints of achieving a given level of supply security and GHG abatement. The Lagrangian can be written as

$$\hat{\lambda} = C - \lambda_s \sum s_i(x_i) - \lambda_q \sum q_i(x_i) \tag{20.9}$$

By setting the first derivatives with respect to x_i to zero the first order condition for optimality is obtained.

$$\frac{\partial C}{\partial x_i} = \lambda_s \frac{\partial s_i}{\partial x_i} + \lambda_q \frac{\partial q_i}{\partial x_i} \quad \text{for each } i \tag{20.10}$$

λ_s and λ_q represent the incremental value of security enhancement and greenhouse gas abatement respectively.

The optimality condition suggests that each technology is used to the point where the marginal cost of the technology is equal to the value of additional energy security and GHG abatement it provides. Given that the right hand side contains two factors, a cost effective solution could still be obtained if one of the factors outweighs the other factor working in an opposite direction. For example, a technology that produces a large, positive ($\delta s_i/\delta x_i$) but a small negative ($\delta q_i/\delta x_i$) could still be part of the optimal policy solution.

If it is assumed that the policymaker is not interested in climate protection, the second term of the right hand side of Eq. 20.10 can be assigned a zero value. This leads to

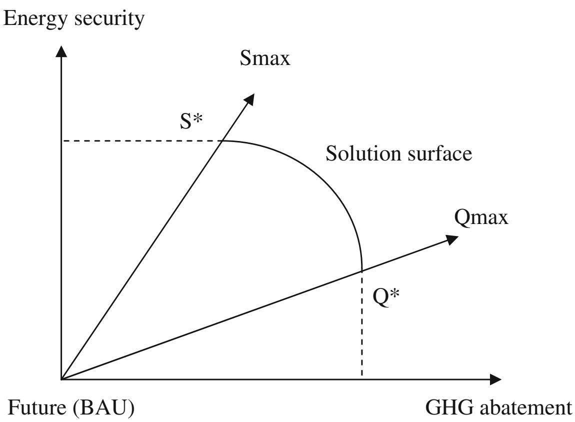
$$\frac{\partial C}{\partial s_i} = \lambda_s \quad \text{for each } i \tag{20.11}$$

Similarly, if the policymaker is not interested in energy security, the first term of the right hand side of Eq. 20.10 can be ignored. This leads to the other condition

$$\frac{\partial C}{\partial q_i} = \lambda_q \quad \text{for each } i \tag{20.12}$$

These two equations indicate that when only one attribute is considered, each technology has to be used so that the marginal cost of additional benefit under consideration (security or climate protection as the case may be) is equal across all

Fig. 20.9 Trade-off between climate protection and energy security objectives. *Source* Brown and Huntington (2008)



technologies. Technologies offering the largest gains at the lowest cost will be preferred in such cases. These two outcomes effectively set the upper limits of the solution surface from the perspective of each objective (see Fig. 20.9). Thus for a given cost a trade-off arises in choosing the combination of technologies through which the two objectives will be pursued.

20.8 Conclusions

This chapter has provided an overview of the energy security problem and analysed various aspects of it using simple economic principles. The chapter has presented the concepts related to the external cost of fuel imports, and the cost of supply disruption. Various options for mitigating the energy security issue are also discussed. The main message here is that a variety of options could be used but ultimately the cost of the policy and the benefits derived from it remain important. Any policy that imposes disproportionate burden on consumers is unlikely to find favour in the end.

References

APERC (2002) Energy security initiative: Emergency oil stocks as an option to respond to oil supply disruption, an APERC background report, Institute of Energy Economics, Japan (see http://www.ieej.or.jp/aperc/2002pdf/OilStocks2002.pdf)

Bhattacharyya SC (2009) Fossil-fuel dependence and vulnerability of electricity generation: case of selected European countries. Energy Policy 37:2411–2420

Bielecki J (2002) Energy security: is the wolf at the door? Q Rev Econ Finance 42:235–250

Brown SPA, Huntington H (2008) Energy security and climate change protection: complementarity or trade-off. Energy Policy 36(9):3510–3513

Huntington HG (2009) The oil security problem, chapter 16. In: Evans J, Hunt LC (eds) International handbook on the economics of energy. Edward Elgar, Cheltenham

IAEA (2005) Energy indicators for sustainable development: guidelines and methodologies. International Atomic Energy Agency, Vienna (see http://www-pub.iaea.org/MTCD/publications/PDF/Pub1222_web.pdf)

IEA (2002) Energy security. International Energy Agency, Paris (see http://www.iea.org/textbase/papers/2002/energy.pdf)

Leiby PN (2007) Estimating the energy security benefits of reduced US oil imports, ORNL/TM-2007/028. Oak Ridge National Laboratory, Tennessee

Leiby PN, Jones DW, Curlee TR, Lee R (1997) Oil imports: an assessment of benefits and costs. Oak Ridge National Laboratory, Oak Ridge (see http://pzl1.ed.ornl.gov/ORNL6851.pdf)

Markandya A, Hunt A (2004) The externalities of energy security, final report, Externe-Pol, Bath University, UK (see http://www.externe.info/expolwp3.pdf)

Owen AD (2004) Oil supply insecurity: control versus damage costs. Energy Policy 32(16):1879–1882

Parry IWH, Darmstader J (2003) The costs of US oil dependency, RFF discussion paper no. 03–59, Resources for the Future, Washington, DC (See http://www.rff.org/rff/Documents/RFF-DP-03-59.pdf)

Percebois J (1989) Economie de l’energie, Economica, Paris

Percebois J (2007) Energy vulnerability and its management. Int J Energy Sector Manage 1(1):51–62

Razavi H (1997) Economic, security and environmental aspects of energy supply: a conceptual framework for strategic analysis of fossil fuels, for Pacific Asia Regional Energy Security Project (see http://www.nautilus.org/archives/papers/energy/RazaviPARES.pdf)

Salameh M (2003) The new frontiers for the United States energy security in the 21st century. Appl Energy 76:135–144

Taylor J, Van Doren P (2005) The case against the strategic petroleum reserve, policy analysis, no. 555, Cato Institute (see http://www.cato.org/pubs/pas/pa555.pdf)

Toman MA (1993) The economics of energy security: theory, evidence and policy, chapter 25. In: Kneese AV, Aweeney JL (eds) Handbook of natural resources and energy economics, vol. 3. Elsevier Publishers

Toman MA (2002) International oil security: problems and policies, RFF issue briefs, resources for the future, Washington, DC, see (http://www.rff.org/rff/Documents/RFF-IB-02-04.pdf)