

THE COSTS OF ENERGY SUPPLY SECURITY
LES COÛTS DE LA SÉCURITÉ DES APPROVISIONNEMENTS ÉNERGÉTIQUES

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Abstract (English)

In general, increasing a country's energy supply security does not come for free. It costs money to build up a strategic reserve, to increase supply diversity or even to accelerate energy efficiency improvements. Nor are all investments in increasing energy supply security cost effective, even if the shocks they are designed to insure against can be predicted with 100% accuracy.

The first half of the paper surveys different definitions and strategies associated with the concept of energy supply security, and compares current initiatives to establish an 'assured supply of nuclear fuel' to the International Energy Agency's (IEA's) system of strategic national oil reserves. The second half of the paper presents results from several case studies of the costs and effectiveness of selected energy supply security policies. One case study examines alternative strategies for Lithuania following the scheduled closure of the Ignalina-2 nuclear reactor in 2009. The second case study examines, for countries with different energy resources and demand structures, the effectiveness of a policy to increase supply diversity by expanding renewable energy supplies.

Résumé (français)

En général, accroître la sécurité des approvisionnements énergétiques d'un pays a un coût. Constituer une réserve stratégique, diversifier les approvisionnements ou même accélérer les améliorations de l'efficacité énergétique coûte de l'argent. Or, les investissements consacrés à accroître la sécurité des approvisionnements énergétiques ne sont pas tous rentables, même si les chocs contre lesquels ils sont censés protéger sont prévisibles à 100 %.

La première moitié de l'article passe en revue différentes définitions et stratégies associées au concept de sécurité des approvisionnements énergétiques et compare les initiatives actuelles visant à mettre en place un 'approvisionnement assuré en combustible nucléaire' avec le système des réserves stratégiques nationales de pétrole de l'Agence internationale de l'énergie (AIE). La deuxième moitié présente les résultats de plusieurs études de cas sur les coûts et l'efficacité de certaines politiques de sécurité des approvisionnements énergétiques. Une étude de cas examine des stratégies de remplacement pour la Lituanie après l'arrêt de la centrale nucléaire Ignalina 2, prévu en 2009. Une deuxième analyse, pour les pays ayant des ressources énergétiques et des structures de la demande différentes, l'efficacité d'une politique de diversification des approvisionnements par un recours accru aux sources renouvelables.

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1. Definition of Energy Supply Security

In its broadest and most fundamental definition, national energy supply security means having enough energy to meet the basic needs of the population and to make possible a certain level of development aspirations. Depending on national or regional circumstances, supply security concerns might include several sometimes even divergent considerations, for example, import reduction and diversification of energy sources. An illustrative but not exhaustive list of possible energy security goals includes:

- secure energy supply
- fuel import reduction
- technology self sufficiency
- protection against supply disruptions
- protection against price volatility
- diversity of technologies and sources
- reducing threats to or from neighbouring states
- well-functioning energy markets
- environmental sustainability

Energy supply security is a growing rhetorical concern both as a matter of domestic policy and as a factor in international relations. Increased volatility of international prices, depletion of low cost resources, and anticipated long term and rapid growth in energy demand are often reflected in growing import dependence on a few suppliers coupled with growing competition for existing fuel resources. The availability of energy at desired quantities and prices can be neither taken for granted nor guaranteed. Perceived and real threats may be economic or logistical in nature, politically motivated or the result of war or of natural causes. They may be source, technology or transport related, specific to a facility or a function of system structure, due to sabotage or to inadequate investment or maintenance, or result from pricing or regulatory policies.

Nor is this a new or theoretical concern. Episodes where energy supply security has been threatened include periodic oil price hikes and collapses in the 1980s and 90s; disruptions of Mid-East and OPEC oil trade in 1973 and 1979, and of transit oil supplies through Latvia in 1998; disruption of gas deliveries in the Ukraine in 2005 and from Afghanistan in 1979; shortages of coal for power generation in China (due to insufficient transport infrastructure) and in the UK (due to a prolonged coal miners' strike); hydropower shortfalls in very dry times in California, Brazil and Fiji; the embargo imposed on South Africa in the 1970-90s; major blackouts in North America and Europe in 2003, 2004 and 2005; refinery shutdowns due to hurricane Katrina in the USA in 2005; and the dramatic pricing-related shortages of gas for interstate distribution in the US during the late 1970s. Such problems can be addressed by a variety of long and short term policies.

For most developing countries, security of supply means security of expanding supply in line with their economic development. The main energy security risks for developing countries are rooted in poor governance and economics: inefficient pricing, lack of access to capital for energy infrastructure investments or to pay for energy imports, and vulnerability to commodity price and exchange rate fluctuations. Physical security is also an issue where strikes or tribal disputes can threaten reliability of supply.

The current high level of world oil prices has caused particular hardship in low-income oil-importing countries because they are more energy-intensive and use

energy less efficiently. On average, oil-importing developing countries use more than twice as much oil to produce a unit of economic output than OECD countries. The potential impacts of this difference in energy intensity have been recently revealed. Following the oil price hike in 2000 the IEA in collaboration with the OECD Economics Department and with the assistance of the International Monetary Fund, conducted a quantitative analysis concluding that a sustained \$10/bbl increase in oil prices from \$25/bbl to \$35/bbl would reduce the GDP of OECD member countries by 0.4% in the first and second years, while the loss of GDP in Asia would be 0.8%, and 1.6% in poor, highly indebted countries (IEA, 2004). The effect on sub-Saharan Africa could be as high as 3% of GDP.

More recently, the World Bank concluded that, on average, the rise in oil prices between 2003 and 2005 had reduced real incomes in oil-importing economies by 3.6% and by as much as 10% for some low-income oil importers (World Bank, 2006). For example, India spent \$15 billion, equivalent to 3% of its GDP, on oil imports in 2003, which is 16% higher than its oil-import bill in 2001. Overall, the additional cost burden of high oil prices in oil-importing developing countries, some \$137 billion annually, exceeds by a large margin official development assistance and is about half of foreign direct investment (FDI) inflows (\$234 billion) (ibid.).

The IEA also notes that developing countries have difficulties to withstand the financial consequences inflicted by higher oil-import costs, such as fiscal deficits and monetary inflation (IEA, 2004). Similarly, the World Bank reports that some countries appear to be financing high-cost oil imports through an unsustainably rapid reduction in international reserves, and that in many African countries, utility firms, unable to pay mounting energy bills, have imposed rolling blackouts in an effort to ration energy (World Bank, 2006).

Supply security is also a concern for energy exporting countries. Supplier countries seek assured and sustained energy sales and hence sale revenues to finance further investment in energy producing and transmission facilities as well as in their own economic and social development. Uncertainty over future demand may translate into uncertainty about needed levels of long-term investment, and may ultimately affect long-term oil market stability.

Competitive markets are considered the best assurance of adequate supply and are least vulnerable to abuse or to political machinations. The reason lies in the characteristics of a competitive market. It requires a substantial number of buyers and sellers – all sufficiently well informed about the availability and price of available goods and services. Diversification of suppliers is thus an important step towards competitive energy markets. Each market participant has a choice whether or not to produce, sell or to buy under prevailing market conditions, but no one buyer, producer or seller can affect or control the supply or the market price of goods or services traded. By definition, no one controls a competitive market.

However, where competitive market conditions do not exist, or where governments are not happy with the market outcomes, then political interventions are likely to be considered. These can include market-based mechanisms as well as other policy approaches, such as:

- diversification of supply sources
- multiple fuel use capabilities
- inter-fuel substitution capabilities
- changes in regulatory or institutional mechanisms
- price reforms or price controls
- import fees or restrictions

- restrictions on foreign investment/ownership
- subsidies and taxes
- expanded integration of electricity grids
- development of new technologies or industries
- incentives targeted at changes in consumption or distribution patterns
- incentives for energy efficiency and reduced use
- investing in spare or strategic capacity; stockpiles.

None of these interventions is costless, though some are more cost-effective than others. Societies ultimately need to decide on the level of security they want and are willing to pay for. Seemingly high costs of specific security measures may appear relatively small compared to the benefits gained in the eyes of a nation. But such decisions should be based on at least some understanding of the relative costs involved. This is analogous at a societal level to establishing commercially the correct level of insurance premiums for a given level of risk. Finding the efficient level of security enhancing measures to implement requires weighing the options.

2. Energy Supply Security Response Strategies

Most security measures are defined and imposed at the national level: governments that choose to intervene in energy markets have a number of options. Poorer countries may have fewer available options for securing their energy supply, but they are not without possibilities. Especially one should not neglect the energy security benefits that can flow from collective energy security efforts secured through cooperation rather than protectionism. The interventions listed below have been implemented in different countries on different occasions, with varied success, and with a variety of side effects.

Producer subsidies and import fees may preserve inefficient production and effectively reallocate resources from the consumer to domestic producers, but this redistribution skews consumption, income and investment, incurs heavy transaction costs, imposes additional costs in industries using affected products as input or raw material, and has an inflationary effect. Import fees are generally used as a form of protection for high cost domestic producers, who would normally be priced out of the domestic market by lower cost but foreign producers. The imports fees artificially raise the domestic price of a product above the market price, allowing high cost domestic producers to continue operating and to sell their goods profitably at the higher price.

Nor are all producer protection measures in the form of monetary subsidies. Non-tariff barriers can be equally powerful. They include imposing higher technical standards for imports than for domestic production, and establishing portfolio requirements specifying a certain level of domestic content or a specific market share for a given fuel or technology.

Examples of monetary subsidies to domestic energy producers include Spain and Germany (to coal industries) and the USA (to the domestic oil industry); non-tariff barriers to trade include European Union specifications on the share of renewables in the generation mix.

Consumer subsidies are designed to keep prices for consumers below market levels. There are many different types of energy subsidies to consumers, such as grants, tax credits and price controls. Electricity is often priced below cost for rural, agricultural or other sets of customers, sometimes for political reasons and sometimes out of justifiable concern for affordability among the poor. There is a

strong social component to consumer subsidies in some countries, especially low income countries. But insulating consumers from actual market price signals does distort demand, and generates insufficient producer revenue to finance investment in continued supply. Governments that protect producers by absorbing the difference between prices and costs in such cases can incur massive debt to maintain the scheme.

Enhancing the affordability of available energy or electricity, and providing greater access for all to energy and electricity services, are both needed in developing countries, but require diametrically opposite policies and have contradictory results. A fine balance is needed between affordability and assuring investment for future supply.

Examples include LPG subsidies for poor households in India (where the companies receive revenues insufficient to cover supply costs) and the Low Income Home Energy Assistance Program in the USA (funded through general revenues). Consumer subsidies are widespread, especially in developing countries. Cross-subsidies among customer classes are another variant.

Diversification - of suppliers, of fuel and of technology mix – addresses both near term issues resulting from rapidly increasing dependence on a single fuel or supplier and longer term price increase issues due to global competition for energy resources. It provides alternatives in cases of supply interruption and for price negotiations, as well as opportunities for efficiency improvements, and can be optimised on a regional as well as national basis. Diversification can be an important step to increasing market competition.

Examples of diversification include mandated fuel switching in the USA, encouraging multi-fuel capabilities and greater use of Britain's North Sea gas production, and a commitment to nuclear power in France, China, India, Japan and the Republic of Korea. China, for example, attempting to diversify oil supply sources, now imports from more than 20 countries around the world (Dorlan et al., 2005).

R&D and technology diffusion in energy markets. In the longer term, investment in research and development in new energy technologies and their ultimate commercialisation may reduce the risk and/or cost of future energy supply disruptions. R&D may focus on either the supply or demand side of the energy market: new technologies in energy exploration, alternative processing technologies (e.g. coal to liquid synfuels), energy efficient appliance and manufacturing processes, multi-fuel technologies etc. (Pritchard and Hogan, 2005).

Examples include coal gasification and liquefaction in the USA, development of tar sands in Canada, oil shale in Estonia, extra heavy crude oil in Venezuela, synthetic fuels in South Africa, ethanol production and deep water drilling in Brazil, commercial hybrid car marketing of Japanese manufacturers, Generation IV nuclear reactor designs, and the Asian-Pacific Partnership on Clean Development and Climate.

Improved grid management and better interconnections effectively reduce the need for total generating and reserve capacity, permit better load management, e.g., through the wheeling of power, reduce the need for fuel substitution or imports, and may reduce investment and operating costs, even significantly.

Examples include the interconnections of the North American grid, European grid, the Baltic and Balkan grids, as well as the integration of the former Soviet Union electricity system.

Limiting foreign investment in the domestic energy sector reflects concerns that foreign investors will manipulate domestic energy markets for their own strategic interests. However, the threat to competition does not come from the nationality of the monopolist or the source of his investment funds. It comes rather from the market

arrangements in the economy where the investment is made. The problem lies when a government establishes, sanctions, or protects a non-competitive system (a sanctioned monopoly, for example) that is therefore susceptible to abuse. So long as such monopolies exist with government sanctions, governments have it within their power to alter the terms of that sanction, condition or end it, to reform the market structure, as public benefit demands. Banning foreigners from participating in the domestic economy may be simpler than market reform, but it is comparatively ineffective in curbing market abuse. However, if countries increasingly view long term access to energy resources as a crucial part of economic competition, interference in investment and in long term contractual agreements can become increasingly tempting.

Historically, foreign (direct inward) investment has been a beneficial and major factor in the growth of the developed world, and an important vehicle for inviting technology transfer. All industrialised and energy-producing countries have been, at different points in their histories, major recipients of investment by others and major investors in other countries; most recently, China is a prime example of negotiating mutually beneficial foreign investment patterns. The Russian Federation has proposed to host internationalised nuclear fuel cycle services for interested countries.

Examples of limits on foreign investment in the domestic energy sector include blocking energy company sales (France, the UK and the USA), constitutionally imposed exclusion of foreign investors in domestic industries (Venezuela and Mexico), and government retention of national shares in energy producing ventures (Russian Federation, Saudi Arabia and Libya).

Reducing energy demand includes measures to improve the technical efficiency of energy production and use, and some simply to reduce energy use, some focusing on achieving economic efficiency and some that impose lifestyle changes. Major gains in demand reduction have been made in the last few decades by improving energy intensities through economic or industrial restructuring towards less energy intensive production of goods and services.⁶

This decoupling of energy use and economic growth shows signs of re-coupling as, in the absence of more stringent policy measures, the easiest and cheapest efficiency improvement potentials appear to be exhausted in developed countries. In developing countries, efficiency improvements have limited potential for those in energy poverty. You cannot use less electricity if you have none to start with. And 'connecting the unconnected', a recognized priority for sustainable development, will necessarily increase their energy use. Hopefully, however, development can take advantage of technology leap-frogging opportunities (a non-energy example is cellular phone networks) such that developing countries can skip over many of the less-efficient technological stages experienced by today's industrialized countries, and take immediate advantage of modern efficient technologies, designs and possibilities for community and workplace planning.

Examples are the EU Directives on 'energy performance of buildings', 'energy labelling schemes of household appliances', the US EPA's State & Alternative Fuel Provider Program that requires certain fleets to acquire alternative fuel vehicles, and Brazil's ethanol programme.

International cooperation and commercial alliances among countries can result in a freer flow of trade and common investment, cooperative sharing of energy supplies in emergencies, collaboration on energy policy and investment decisions, and enhanced diversity of supplies and resources.

⁶ These intensity figures cannot be taken, however, as measures of actual technological improvements in energy use, since they are generally calculated on the basis of value added, and hence subject to world price and exchange rate fluctuations completely independent of changes in energy use.

Examples include cooperation on energy conservation in Asia; joint research on geological carbon storage among fossil fuel producers; development of the European Pressurised Water Reactor; and the signing of a basic agreement to build a \$5 billion gas pipeline linking Russia and Germany under the Baltic Sea. Energy-related but not energy-specific examples include the Kyoto Protocol's coordination of reduction targets and creation of carbon markets and the World Trade Organisation's rules to reduce trade barriers.

Strategic stocks may be amassed and used to counter extraordinary circumstances or extreme price rises. Conventional commercial stocks of almost any commodity are held by merchants and industry as part of normal operations, to provide flexibility in the face of circumstances that might delay supplies and hence disrupt downstream activities. Some countries, like Sweden, had a compulsory stock system for a number of vital (import) goods during the cold war.

In the oil industry, commercial enterprises handle some 125 million m³ of storage capacity, or some 10 % of the total world oil tank storage market. Commercial terminals handle about 10 % of the total global flow, an estimated 8-10 million barrels/per day (bbl/d) in comparison with 85 million bbl/d worldwide.

Strategic stocks by contrast are held by governments or at their behest to provide a buffer to domestic consumers in the case of a supply disruption or perhaps a temporary price hike. They are generally designed to extend supply for some 90-120 days.

Strategic stocks may be privately held or held under government control for allocation and sharing under specified crisis conditions. In such cases, the success of the intervention will be limited by the resources committed to the effort, the credibility of the intervention, by market expectations as to the duration of the relevant conditions, including the desire and opportunity for profit taking. Stockholding is a very costly proposition, and stock interventions are generally cumbersome operations requiring rapid response, knowledge of appropriate prices, marginal costs and market behaviour, proper timing and objective integrity, as well as a balancing of the interests of market players.

Examples of mandatory stockpiling of fuels include national reserves and the IEA- and EU-mandated strategic reserves.

3. Multilateral Cooperation for Supply Security – IEA Experience

The most well-known example of a multilateral approach to energy security is probably the International Energy Agency (IEA) and its energy security programmes. The IEA was established in 1974 in the wake of the Yom Kippur War and the 'first oil crisis', specifically to better prepare OECD countries for oil supply interruptions, and as a counterweight to OPEC.

The agreement whereby IEA was established is called the International Energy Program (IEP). Its principal focus was reducing import dependence by establishing compulsory oil buffer stocks⁷, demand restraint measures, developing alternative resources, and an Allocation Program between the member countries, to share the 'pain' of an oil shortfall equally among member countries). The system is tested regularly, but to date the system has been activated only in 1974, 1991 and 2005 as an IEA-coordinated action to bring stocks to market. It is therefore unclear how effective strategic stocks - designed for 90-day disruptions - would be at assuring

⁷ The EU also imposes stock obligations, with slightly different requirements, creating some overlap. The biggest difference is an EU requirement to stock 90 days of consumption vs. 90 days of net imports. The EU had strategic oil reserves starting in the 1960s (after Suez) even before the IEA in 1973.

supply security in the context of long term strong growth in demand (and hence growing competition) for increasingly scarce and costly oil.

Both the demand reduction and the fuel mix diversification are recommended for national implementation; the stockholding is mandatory, and presumes multilateral sharing of strategic stocks in IEA-declared emergencies. Stocks must be a minimum of 90 days of net imports of the previous calendar year, and can be released in times of crisis, as defined by agreement of IEA Member States. Current stocks held under the IEA programme are about 3 billion barrels of oil, i.e. about 45 days of world oil demand.

The interest in strategic oil stocks was anchored in several facts. Oil has become a highly political commodity. Current dominant players in the world oil market include producers who control some 50% of supply and whose supplies are considered vulnerable to disruption by political and non-political events. Against this risk the politically powerful consumers of the OECD have more or less entered into a mutual consumer protection pact with the aim to have a stronger influence on oil price and quantity. OECD accounts for some 60 % of the world oil demand. (The same kind of disproportion in fact applies to nuclear power, with the few suppliers of nuclear technology dominating the market.)

There are substantial costs involved in keeping oil stocks, the two main cost items being storage and financing. The total costs for storage, financing, and insurance of oil depend on the type of storage (underground storage for crude oil is the cheapest mode of storage, storage of gasoline in new built floating roof conventional tanks is the most expensive) and, needless to say, on the total volume stored. These costs also depend on the commodities stored, crude or refined products (gasoline, fuel, diesel oil, etc.), and also on the possibility for bilateral storage in another country, if this is cheaper. Crude oil, and the storage thereof, is normally cheaper than refined products.

Rough estimates vary considerably. IEA experts put typical costs for storage alone (for 2005) at around \$3-4 per m³ per year for crude oil stored underground, and around \$10-20 per m³ per year for refined product storage in conventional oil tanks. These actual storage costs are but a small fraction of the total. If other related costs (financing, insurance, operating costs, overhead, sample analysis, refreshing of the product, etc.), are included, then the estimated costs would be around \$18 per m³ per year for crude oil stored underground (or \$20 per tonne), and some \$27-35 per m³ per year for refined products (or \$30-40 per tonne). Neither set of estimates includes acquisition costs.

The IMF estimates that the cost of oil stocks is around \$1.5 billion for 100 million bbl (14 million tonnes). When this cost is levied on oil product consumers, the costs of stockholding seem to average out at about half a dollar cent or half a eurocent per litre.

The CATO Institute estimates costs to be much higher (Taylor et al., 2005). The cost of the national storage programme in the USA alone, estimated to be one of the cheapest, is some \$41-51 billion (2004\$), or some \$409-503 per m³ of oil stored. This figure includes the purchase of oil and is therefore not directly comparable to the IEA figure. The purchase of oil is about three-quarters of the total. These costs are also not per year but cumulative since the birth of the strategic petroleum reserve (SPR). As a result of the strategic petroleum reserve, fill orders may have increased oil prices by approximately \$5-8 per m³ through April of 2005⁸. According to the CATO Institute, if viewed historically and in the context of other market responses, the value of the programme as a hedge against supply disruption may be

⁸ This is equal to \$0.75-1.24 per bbl or \$0.018-0.03 per gallon or \$0.005 - 0.008 per litre

overestimated. Since some reserves have been replacements for and not supplementary to private industry reserves, they do not increase total stocks. Moreover, unless stocks have been released early and quickly, their price dampening effect has been very small; the USA has generally been slow to release its stocks. They conclude specifically that “the costs associated with the SPR have been larger than the benefits thus far”.

4. Multilateral Cooperation – a Nuclear Perspective

Nuclear power can play a positive role in assuring energy supply security, reducing vulnerability to fossil fuel price fluctuations, enhancing diversity of supply technologies and reducing demand for fuel imports. However, nuclear power does entail its own energy security concerns. In September 2006, in connection with its annual General Conference, the IAEA held a Special Event on a “*New Framework for the Utilization of Nuclear Energy in the 21st Century: Assurances of Supply and Non-Proliferation*”, to discuss two nuclear supply security objectives of current interest. The first is to reduce the risk of electricity shortfalls, and financial losses, created by the possibility of political interruptions of low enriched uranium (LEU) or fuel supplies. This is similar to the objectives motivating, for example, the IEA system of oil stocks. The second objective is specific to nuclear power and is driven by proliferation concerns. It is to reduce the incentives for building, as a hedge against such supply interruption risks, new national ‘proliferation-sensitive’ enrichment capabilities.

Recent calls for establishing an assurance of supply mechanism for LEU or nuclear fuel were made in an October 2003 essay by the IAEA Director General (DG) in *The Economist* (ElBaradei, 2003); in a December 2004 report to the UN Secretary-General from a High-level Panel on Threats, Challenges and Change (UN, 2004); and in a February 2005 report by an expert group established by the IAEA Director General on Multilateral Approaches to the Nuclear Fuel Cycle (IAEA, 2005). The *Economist* essay made three proposals, including limiting enrichment to multinational control “accompanied by proper rules of transparency and, above all, by an assurance that legitimate would-be users could get their supplies”. The High-level Panel’s report urged negotiations leading to the IAEA becoming “a guarantor for the supply of fissile material to civilian nuclear users”. The expert group’s report included as one of five suggested approaches “international supply guarantees... with the IAEA as a guarantor”.

Efforts to establish an assurance of supply mechanism through the IAEA have waxed and waned since the Agency’s founding in 1957. Such a role was envisioned already in the Statute, which allows the Agency: to establish its own stocks of special fissionable material for supply to Member States; to facilitate the supply of special fissionable material from one Member State directly to another; and also to facilitate the provision of enrichment and fuel fabrication services by one Member State to another or to the IAEA. The Agency has, on a number of occasions, facilitated the transfer of special fissionable material among Member States, but it has never been called upon to build its own stocks. In 1980, it established a Committee on Assurances of Supply that deliberated regularly for over a decade, but with no success. The question today is whether this is now an idea whose time has come. The essay and two reports cited above suggest the answer is, “yes”, and a number of countries have recently offered specific proposals.

In September 2005, the US announced it would establish a reserve of nuclear fuel and “would commit up to 17 metric tons of highly enriched uranium (HEU) to support assurances of reliable nuclear fuel supplies for states that forego enrichment and reprocessing”.

In January 2006, President Putin proposed a Global Nuclear Power Infrastructure (GNPI) that would include the “creation of a system of international centres providing nuclear fuel cycle services, including enrichment, on a non-discriminatory basis and under the control of the IAEA”.

In February 2006, President Bush proposed a Global Nuclear Energy Partnership, which includes as one of its “implementing elements” a “reliable fuel services program”.

Subsequently, more specific proposals were made.

In May 2006, the World Nuclear Association (WNA) offered a proposal in a report on “Ensuring Security of Supply in the International Nuclear Fuel Cycle”. The proposal has three levels of assurance. Level I is the existing market. Level II is commitments among the enrichment companies to cover for each other if one is politically forbidden from honouring a contract and if the IAEA says the request for coverage is legitimate. Level III is a final last-resort backup reserve or reserves. The WNA proposal, like the US reserve above and several other proposals, has a ‘no-enrichment requirement’: “To be eligible, a customer State must have made a commitment to forego the development of, or the building or operation of, enrichment facilities”.

In June 2006, at the IAEA Board meeting, six countries (France, Germany, Netherlands, Russia, UK, and USA) circulated a proposal titled “Concept for a Multilateral Mechanism for Reliable Access to Nuclear Fuel”. In this ‘6-country proposal’, if a country’s LEU supply were cut off for political reasons, it could first go to the IAEA as a sort of marriage broker to be matched up with another willing supplier. If that should fail, there would be a second-level appeal to physical last-resort reserves contributed by the six countries or by others. Like the WNA proposal there is a no-enrichment eligibility condition, although it is less strict: a country wanting to call on the reserve cannot be in the enrichment business at the time it makes the call. One last-resort reserve under this proposal could be based on the down-blended 17 tonnes of US HEU. In addition, during the Special Event in September 2006 the UK announced a proposal for a possible UK contribution to such reserves. They do not have excess material they could contribute, but are proposing enrichment bonds, a sort of virtual reserve – i.e. an agreement among the commercial enrichment States to provide enrichment services to eligible user States in the context of the 6-country proposal.

A brief informal discussion of the 6-country proposal took place for the first time on the margins of the IAEA Board of Governors meeting in June 2006. The no-enrichment requirement drew criticism from countries concerned about a possible entrenchment of global divides between nuclear technology haves and have-nots and the possible erosion of Article IV rights under the Non-proliferation Treaty (NPT).

On the opening day of the Special Event in September 2006 a US non-governmental entity called the Nuclear Threat Initiative (NTI) offered the IAEA a conditional \$50 million grant for establishing a last-resort reserve of LEU. There were only two conditions: that the Agency raise an additional \$100 million in a 2-to-1 match of NTI’s \$50 million, and that it raise the money and “take the necessary actions to approve the establishment of this reserve” within two years. Everything else – how to manage it, criteria for release, where to put it – would be entirely up to the Agency.

There are two further proposals that focus more on augmenting the existing enrichment business by establishing new multilateral enrichment companies, than on establishing last-resort reserves. One is a Russian proposal, in line with President Putin’s initiative, to create an enrichment company with international stockholders who have a claim on the product and the profits. The company would also sell on the global market to non-partners. The IAEA would have some role, which, according to

what is currently proposed, is rather minor beyond verifying that the facilities are operated within agreed safeguards constraints. One specific possibility under discussion involves using a facility at Angarsk, Russia and partnering with Kazakhstan. Early indications are that the Russian proposal includes a no-enrichment requirement – but this remains to be confirmed.

The second proposal to establish a new multinational enrichment company came from German Foreign Minister Steinmeier in a magazine interview that appeared shortly before the Special Event. It was for a new IAEA operated international enrichment facility on an unspecified extraterritorial site. There were very few details, and the German government has not yet announced it as a formal government proposal. However, the official German government statement in October 2006 at the First Committee of the UN General Assembly referred to such a possibility as part of new multilateral approaches to the nuclear fuel cycle

The Japanese government also made a proposal shortly before the Special Event that is different yet again. Its focus is on gathering and sharing information about capacities and plans for all the stages of the front end of the fuel cycle. It never mentions non-proliferation and has no no-enrichment requirement. It recognizes countries are at different stages in their front-end capabilities, and envisions countries with a small current enrichment capacity (like Japan) later expanding their capacity for an export market and eventually even having a large enough capacity to build up a reserve. But the emphasis is on information sharing during normal operation, not a last-resort reserve.

Comparing these recent proposals for nuclear supply assurances with arrangements discussed earlier for other supply reserves yields at least four notable differences.

First, most of the nuclear supply assurance proposals try to address two problems: (1) the risk of political interruptions of low enriched uranium (LEU) or fuel supplies, and (2) the risk that, as a hedge against such political interruptions, countries build their own proliferation-sensitive enrichment capabilities. Most other energy supply assurance arrangements address only one problem: the risk of interruptions. On the one hand, the additional problem in the case of nuclear supply assurances complicates negotiations to establish an assurance mechanism. On the other hand, it is a standard conclusion of negotiation theory that broadening a negotiation to include additional issues can, other things being equal, create new opportunities for logrolling and joint gains. Thus the additional problem in the case of nuclear supply assurances makes negotiations more complex: but it may simultaneously create new possibilities for mutual benefit and ultimate success.

Second, most of the nuclear supply assurance proposals have come from countries or firms that fall in the category of enrichment or fuel suppliers. These countries are also in the category of consumers, but not consumers at risk: their critical characteristic is that they control the 'means of production', as it were. Thus they are different from the countries in the IEA system of strategic oil stocks, whose distinctive characteristic is that they are consumers at risk. To gain support for their nuclear supply assurance proposals, the proposers need to make a good case that their proposals are also in the interests of non-supplier countries. Unlike the case of the IEA system, discussions of nuclear supply assurances have not been driven, at least initially, by a felt need on the part of consumers.

Third, most of the nuclear supply assurance proposals have focussed on LEU, which, like oil, is effectively a commodity. However, assurances of finished fuel assemblies may be equally important for reactor operators, and finished fuel assemblies are not a commodity. They are high-technology products, with a high degree of specialization for different reactors, based on intellectual property that is expensive to develop and tightly held. Given the variety of reactor designs and the

many variants of nuclear fuel they require, it would be impractical to have an actual bank of nuclear fuel. But, in addition to reserves of LEU, an assurance of supply mechanism might address this problem by including assurances (perhaps in the form of parallel binding commitments of fuel fabrication services) to convert and fabricate LEU held in a reserve into fuel assemblies ready for use in power reactors. The specifics of such an arrangement would be complex.

Fourth, most of the nuclear supply assurance proposals include a role for the IAEA, which is neither a consumer nor a supplier. The proposals generally call on the IAEA to decide when an appeal to the proposed assurance mechanism would be legitimate – e.g. whether the interruption is political and the customer's State is in compliance with its safeguards obligations. Various criteria for legitimacy are proposed. Nearly all proposals foresee that what might be called 'normal' commercial supply disruptions would not be a legitimate basis for triggering the assurance mechanism. These include such things as bad planning by suppliers, breakdowns in supplier equipment or the upstream supply chain, fires, labour disputes, commercial disputes and lawsuits, transportation accidents, and various acts of God. Beyond that, there is more divergence. And while most proposals foresee a role for the Agency, there are few explicit suggestions at this stage about specific decision making procedures, guidelines or criteria.

All of these points featured in the discussions at the IAEA Special Event. With respect to the first and second points, however, the presentations and discussion were dominated by those more motivated by the second of the driving concerns (hedging by building new national enrichment capabilities) than by the first (assuring against supply interruptions). But the focus on hedging through new enrichment capacity did not dominate exclusively. For the proposals with no-enrichment clauses, concerns were again expressed about the possible erosion of NPT Article IV rights and entrenchment of a divide between nuclear technology haves and have-nots.

There was also brief discussion of a potentially much more important possibility, spent fuel take-back, especially from the perspective of a newcomer to nuclear power, but also from the perspective of those focussed on non-proliferation. The argument was that uncertainties about eventual waste disposal may be a bigger deterrent to nuclear power investment than uncertainties about political interruptions to LEU or fuel supplies. Thus a proposal that can include an offer of spent fuel take-back and eliminate waste disposal uncertainties once and for all would likely attract more attention among customers than simply offers of assurances against political supply interruptions. The possibility of spent fuel take-back is hinted at in both President Putin's proposed "system of international centres providing nuclear fuel cycle services" and President Bush's Global Nuclear Energy Partnership. But, at the moment, no firm offer is on the table.

The discussions at the Special Event were summarized in a report by the event's chairman to the IAEA General Conference. The key points in the report, which is available through the IAEA web site⁹, are the following:

- In general, all the proposals are mutually compatible.
- Assurance of supply is a first phase in developing a multilateral framework that is equitable and accessible to all users of nuclear energy.
- Establishing such an assurance of supply is a complex endeavour.
- Progress would be step by step, requiring the IAEA Secretariat to consult and develop proposals for the DG to present for Board consideration in the course

⁹ <http://www.iaea.org/About/Policy/GC/GC50/SideEvent/report220906.pdf>

of 2007, as the proposals 'mature' and as policy, legal and technical issues are worked out.

- No one had suggested altering States' rights, and concerns had been expressed about implied or intended conditions for access to assured supplies, and about disrupting a smoothly functioning nuclear fuel market.
- A number of issues required further elaboration.
 - Why is an assurance of supply mechanism needed?
 - What is to be assured?
 - What are the modalities of assurance mechanisms?
 - What objective criteria would be required?
 - Possible role(s) of the Agency?
 - Possible roles(s) of the nuclear industry?
 - Others (e.g. sustainable financing).

The expectation was left that the Agency would begin to work on the step-by-step progress described in the fourth bullet.

5. The Cost of Security – Some Case Studies

5.1. National vs. regional security measures: “Analyses of Energy Supply Options and Security of Energy Supply in the Baltic States”

A joint modelling exercise by the three Baltic States, the Agency and NATO made a comparative assessment of the costs and efficacy of a number of energy security measures implemented at the national vs. a regional level. The study was triggered by a desire among the Baltic States to reduce energy imports of Russian gas and oil, coal and electricity, especially in light of closing the Ignalina nuclear power plant pursuant to Lithuania's accession agreements with the European Union.

5.1.1. The issues

Several factors highlight the vulnerability of natural gas supplies to the Baltic countries, and so argue strongly against a heavy dependence on growing natural gas imports:

- The aging Russian gas supply infrastructure is reportedly not being maintained and refurbished on an adequate basis, raising questions of long term reliability.
- Ownership by a Russian firm of the region's sole refinery at Mazeikiai in Lithuania potentially reduces its intended effectiveness as an alternative source of supply if natural gas exports from Russia are disrupted.
- Gazprom has raised gas prices to Latvia closer to international levels, and in 1998 Russia cut off transit supplies of oil through Latvia, moves taken as indicative in the Baltic Region of a willingness on the part of Russian authorities to use energy supply as a foreign policy tool.
- The relatively small Baltic market may not be able to compete for Russian gas supplies with larger economies.
- The construction by GazProm of a natural gas pipeline from Russia directly to Germany under the Baltic Sea, by-passes the Baltic Region and the current transit countries.

The Ignalina nuclear power plant historically supplied some 80-85% of Lithuania's, and some 40% of the region's, electricity before closure of Ignalina-1. The issue of

energy supply and energy security in Lithuania after Ignalina-2 closes is not resolved by a simple replacement (or not) of Ignalina by a more modern reactor. Decisions on future generation choices and transmission options cannot be made in a vacuum; import considerations and compliance with relevant European Union directives on the use of renewables must also be factored in.

The measures being considered by the Baltic States to deal with these concerns include: better grid integration, developing alternative but higher cost domestic energy resources (oil shale and coal/peat), efficiency improvements and coal plant rehabilitation, dispersed combined heat and power production (CHP), developing better strategic stocks of gas and oil, limiting foreign (Russian) investment in the Baltic refinery sector and in small CHP, and enhanced regional cooperation.

The study compared future energy sector developments for each individual country and for the region as a whole, assuming the implementation of different measures through a series of scenarios, and modelling the consequences of each under different assumed conditions. The study divided policy and investment measures into two broad categories: those whose primary purpose is supply to meet growth or replacement needs (e.g., power plants, grid extensions, renewable energy projects), and those whose primary purpose is to mitigate the damages of supply interruption (e.g., storage facilities, replacement nuclear power plant).

5.1.2. The findings

Regional Cooperation

The main finding of this study is that addressing energy and energy security issues on a coordinated integrated regional basis reduces the energy system cost over the period 2005-2025 for the Baltic countries by €727 million (discounted), benefiting the economies of all three countries. The savings from establishing a common Baltic electricity market would be more than €760 million. The study shows a strong congruence between energy supply and security measures that are less expensive and those that are regionally planned and implemented. Coordinated regional measures can also maximize supply, investment and security efficiencies without duplication among isolated entities within national boundaries, for example through a better utilisation of existing infrastructure. Cases for regional cooperation include investment in a regional 120-day gas storage facility and inter-ties with Sweden, Finland and Poland (and in the longer term, with NORDEL / UCTE), to integrate the Baltic electricity grids with neighbouring states.

Rationalisation of the electricity system

From a purely economic point of view, the most rational option for the Baltic electricity system would be continued operation of the second unit of the Ignalina nuclear power plants until the end of its technical lifetime in 2017 with existing fuel channels and, if necessary, with their subsequent replacement. In principle, this option has been foreclosed by the accession agreement with the EU, but the net economic benefit (i.e. difference in total system cost compared to base case) thus foregone to the Baltic region would be on the order of €440 million (discounted) in a future with low energy prices and some 50% higher still if current international market prices prevailed over the duration of the study period. If the additional costs to form and maintain the necessary fuel reserves are taken into account, the total saving will increase up to €446 million.

Moreover, studies to date show that the shutdown of the Ignalina Nuclear Power Plant Units 1 and 2 has a strong negative impact on energy security in the Baltic region by increasing the demand for imported natural gas. The impact of the supply loss of Unit 1 in the Baltic States is not great, since output is excess to Baltic demands and has been exported to Belarus, Kaliningrad and Russia. But the impact of shutting down Unit 2 will require increased imports of natural gas, orimulsion, coal

and electricity or the construction of a new nuclear power plant. This is because most alternative Baltic sources of primary energy will either be already utilised by 2010 or be hampered by cost considerations or long lead times, or both. The use of renewables in the Baltic over the study period will already be stretched beyond their economic potential by the degrees of deployment mandated by EU directives.

5.1.3. Trade-offs

Besides estimating the additional system costs imposed by different measures, the study identifies trade-offs between different fuel and technology choices, as well as different policy and investment measures, with regard to their consequences on the structure of energy supply. For example, when evaluating alternative replacement capacity for the Ignalina nuclear plant, the option of constructing new combined cycle gas turbine (CCGT) units and modernizing Lithuania's existing 300 MW thermal power units have similar economics, but CCGT units significantly increase dependence on natural gas, although they have lower levels of atmospheric emissions than the thermal plants. The scenario of building a new nuclear power plant would alter supply patterns by reducing imports of orimulsion and to a lesser extent gas, utilization of Lithuania's thermal plants, and capacity requirements for new CHP and CCGT. It would also shift production of decentralized heat supply from CHPs to boilers. A contrasting scenario of importing potentially cheap electricity from Russia would reduce utilization of existing power plants, and reduce the need for new CCGT and especially for a new nuclear plant. But in this case the vulnerability of supply from a single Russian source would be even greater, whereas regional plants always have the potential to diversify their fuel procurement.

Figure 1 shows the changes in the capacity mix between the national and regional optimal scenarios.

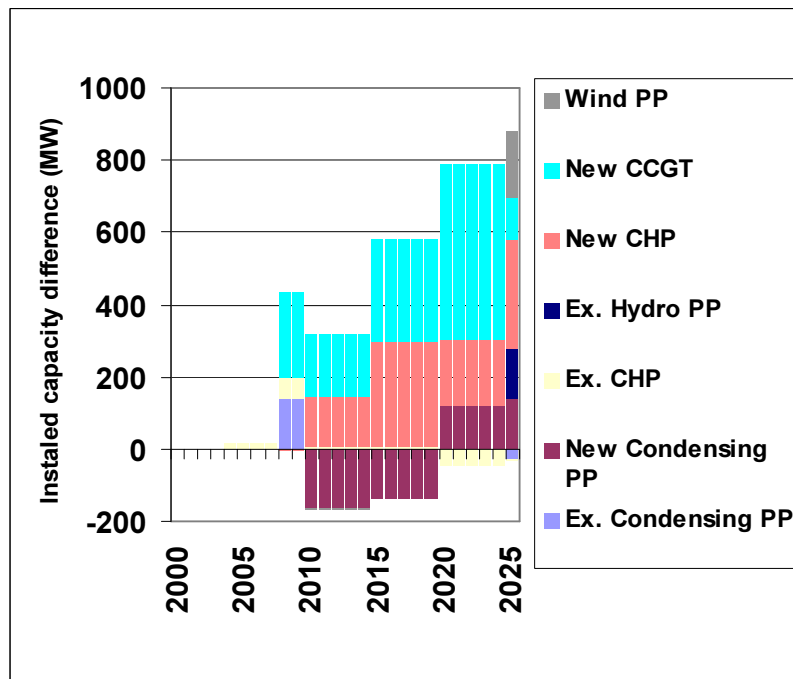


Figure 1. Differences in installed capacities of power plants in the Baltic region for the National Scenario compared to the Regional Scenario.

5.2. Diversification as a way to reduce import price vulnerability and to minimise the impact of a carbon tax: Three country types.

In this section, we estimate the cost of responding to energy related security challenges for three different kinds of countries. This is done for two possible security challenges, higher fossil fuel prices and the forced implementation of a carbon tax. These two challenges represent aspects of price volatility as well as concerns for environmental sustainability, which are tested against a business-as-usual case, a case that promotes renewable energy technologies and another, that responds in anticipation of those challenges. The envelope of cases defines a range of responses, between inaction in the face of the security challenge and adopting the most effective action¹⁰. The MESSAGE¹¹ optimization tool was used to calculate how best to build and operate an electricity system, in order to explore in detail what least-cost options pertain and how effective specific measures can be under different energy system conditions.

5.2.1. The modelling

The electricity systems of three different 'country types' (see table below) are modelled. Although the models are deliberately artificial, they are calibrated using actual country data (indicated in bold) in order to mimic a realistic energy system infrastructure. 'Country types' are chosen so that the analysis is detached from current or future country specific policy contexts. The models extend to 2030, and assume a 7% discount rate, as well as containing country specific load, resource and technology availabilities.

In this exercise three security scenarios are investigated:

- No security challenge
- Higher sustained international fossil fuel prices (a doubling of the assumed price from 2007 onwards)
- Introduction of a carbon tax (from 2007 a tax of \$30/tonne of CO₂ is imposed)

Each security scenario is assessed for each country type (CT) against three cases. However, this is done with the following logic:

1. The *reference case* for each country type is based on business-as-usual conditions and calculates a 'least-cost' expansion of the electricity supply industry - assuming no security challenge¹². The *reference case* is then

¹⁰ In reality, the course of action followed may be between these two extremes. As the market does not have perfect foresight, it is unlikely that it will respond as well as in the Optimal Response Scenarios. However, it is likely that at least marginal investments with short lead times will respond rapidly to the imposition of the mentioned security challenges. It is with this in mind that governments adopt policies, such as renewable energy targets, which may help hedge against such challenges when and if they occur.

¹¹ MESSAGE (Model of Energy Supply Systems and their General Environmental Impacts) is a systems engineering optimization model which can be used for medium- to long-term energy system planning, energy policy analysis, and scenario development. The model provides a framework for representing an energy system with all its interdependencies. Scenarios are developed by MESSAGE through minimizing the total systems costs under the constraints imposed on the energy system using mathematical techniques such as linear programming, mixed-integer programming and non-linear programming. The degree of technological detail in the representation of an energy system is flexible and depends on the geographical and temporal scope of the problem being analyzed, but could be anything from the global energy system to a multi-regional, national or local energy system.

MESSAGE can account for environmental (and other) effects of meeting energy needs. It can also include environmental costs or taxes within its optimization, to help quantify the most sustainable energy scenarios in a given context and under various constraints. MESSAGE belongs to the same family of models as MARKAL and MERGE and has been widely used both by international organisations, such as the United Nations and World Energy Council, by utility companies, as well as by individual countries and even down to the municipal level.

¹² The calculations for each country are based on domestic technology and resource assumptions (Winkler et. al 2006, UN-Energy 2006 and IAEA 2006).

exposed to the carbon tax and the higher international fuel prices but maintains its portfolio of generating capacities (i.e. there is no optimisation in the sizing of capacities - the capacity structure is constant; the analysis only optimises the operation and dispatch of existing power plants).

Table 1: Country types

Country type (CT)	Code	Examples
High fossil fuels dependency with relatively low levels of electricity imports	CT1	South Africa , Australia, USA and others
Underdeveloped Electricity Supply Industry (ESI), with large development needs. Distributed generation is allowed to meet the energy needs of rural consumers as an alternative to national electricity grid extension.	CT2	Ghana , other Less Developed Countries (LDCs)
Developed country with few domestic energy resources with limited potential for regional electricity grid interconnections.	CT3	South Korea , Japan and others

2. The 'renewable energy target case' (RET) assumes the same framework conditions and data input as the *reference case* (with no security challenge) but forces the system to provide 10% of the electricity supply from renewable energy sources by 2013¹³. Similarly to the sequence above, the *renewable energy target case* is then exposed to the carbon tax and the higher international fuel prices but maintains its portfolio of generating capacities.
3. The 'optimal response cases' expose the *reference case* and the *renewable energy target case* to higher fuel prices and a carbon tax. But here their capacities are not fixed, but allowed to respond/optimize to the energy security challenges in the most cost optimal way. These cases therefore represent cases in which investments are made in knowledge/anticipation of future energy security challenges. Please note that there is no *optimal response case* where no security challenge exists since it is identical to the *reference case*.

In view of the above, we get eight cases (see Table 2) that are compared in terms of their total system costs. This sheds light on three issues:

- The cost of inaction when no investment changes take place in the face of high fossil fuel prices and carbon taxes (i.e. the *reference cases*)
- The cost of implementing a renewable energy target as the only course of action in the face of the three security scenarios
- The most cost effective or optimal response to high fossil fuel prices and carbon taxes

¹³ For comparability, a generic renewable wind technology is available for the model to utilize in each country type to help meet this constraint. The generic technology is therefore used when cheaper local renewable options – used to calibrate the country type models – are exhausted. Further the costs of renewable energy technologies are assumed to decline over time. By 2025, the capital cost of wind is expected to decline to 636\$/kW; a capacity factor of 25% is assumed. Note that these favourable assumptions amplify the conclusions reached later.

Table 2: Security threat scenarios and electricity expansion cases

Security scenarios	Cases		
No security challenge	Reference case	Renewable energy target case (RET)	
High fossil fuel prices	Reference case under high fossil fuel prices	RET case under high fossil fuel prices	Optimal Response (OR) Case to high fossil fuel prices.
Carbon tax	Reference case under a carbon tax	RET case under a carbon tax	OR Scenario under a carbon tax.

5.2.2 Results

The results of this short analysis are as follows.¹⁴ The approach used here defines the cost of inaction¹⁵ in the *reference cases* and the best possible action (with perfect foresight) in the *optimal response cases*. This allows a consideration of the 'envelope' of options for each energy security challenge in isolation. It is not meant as a tool to derive optimal hedging strategies.

For country type 1 (CT1), Figure 2 shows the total installed capacity of the electricity system for three different least-cost scenarios (reference, high fossil fuel prices and a carbon tax) as well as the *renewable energy target case*¹⁶. Coal fired generating systems are the most cost effective for this country, and under the *reference case* remain the generating option of choice over the entire period. Coal prices are even too low for high fossil fuel price assumptions to affect the structure of new generating capacity¹⁷. Therefore the optimal response to price fluctuations within the range assumed for the high fossil fuel price scenario does not require significant changes in capital expenditure. As investment in new coal power stations remains the optimal response, changes to diversify electricity supply away from coal would be less cost-effective than doing nothing – no matter what electricity generation technology is being invested in. However, in the carbon tax scenario, new coal power stations are displaced by new nuclear power plants. In the case of the *renewable energy target case* (and this result is common to each country type) note that capacity increases are relatively high due the lower load factors of renewable energy (RE) technologies.

Cost results for country type 1 (CT1) are shown in Figure 3. The figure shows the cost (broken down into investment, operation and maintenance, fuel and carbon tax) for each case. The upper part of the figure shows the overall costs for each, while the lower part shows the difference in costs between cases compared to the corresponding *reference case*. In the *reference* and *renewable energy target cases* recall that the investment structure is fixed and based on the business-as-usual assumptions.

¹⁴ It should be noted that many permutations of analysis of this sort are available. Other approaches for example range from developing detailed hedging strategies in the face of multiple uncertain changes in the future, as described by Heinrich et al. (in Press) or as in portfolio theory, see for example, Awerbuch & Berger (2003), to relatively simple approaches.

¹⁵ For each case, we just apply the high prices or a carbon tax to the system as it was optimized under business as usual prices in the Reference and RET scenarios. Some flexibility is allowed; although the investment structure is not allowed to change, operation of power stations is.

¹⁶ Note that the renewable energy target case is also a least-cost solution with the constraint that 10% of electricity production must come from renewable sources.

¹⁷ All cost data and assumptions are taken from NER 2004 and supplemented by Winkler et al. 2006.

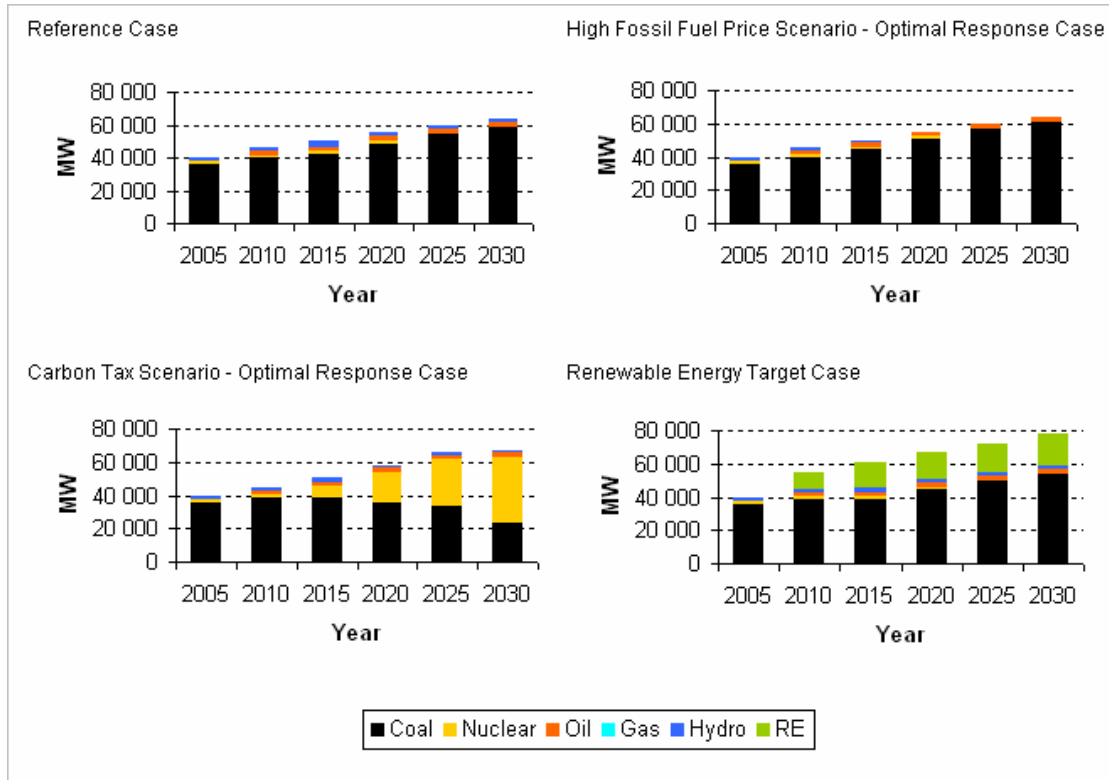


Figure 2. Total installed capacity for the least-cost case in each security scenario for country type 1 (CT1)

System-wide cost increases for CT1 are relatively large. Diversification to the *renewable energy target case* is close to 20% more expensive than the cost optimal *reference case*. Note that the *renewable energy target cases* are more expensive than the *reference cases* for all energy security scenarios tested here. Thus adopting a policy of diversifying to (relatively low cost) renewables is more expensive than doing nothing for the risks examined. Under higher fossil fuel prices, system cost increases and is nearly 25% higher than under business as usual conditions in the *reference case*. However, these cost increases are due mostly to increases in fuel prices. The structure of the *optimal response case* under higher fossil fuel prices is similar to the *reference case*. For CT1, the cheapest configuration to address higher fuel prices is *not* to diversify. As CT1 is characterised by low cost coal, the effects of implementing a carbon tax results in a switch to new nuclear from coal investments. It can also be noted that there is a significant difference between the cost of the system under high fossil fuel prices and the carbon tax. This is because the system is based on very low cost, carbon intensive coal¹⁸.

¹⁸ In this case, the cost of coal is around \$10 per tonne (NER 2004), and coal accounts for over 90% of generation. In very approximate terms, only for illustration, three tonnes of CO₂ is emitted for each tonne of this low CV coal consumed. With a carbon tax of \$30 per tonne applied here (IEA 2006) the carbon tax costs are close to nine times the fuel cost of the system.

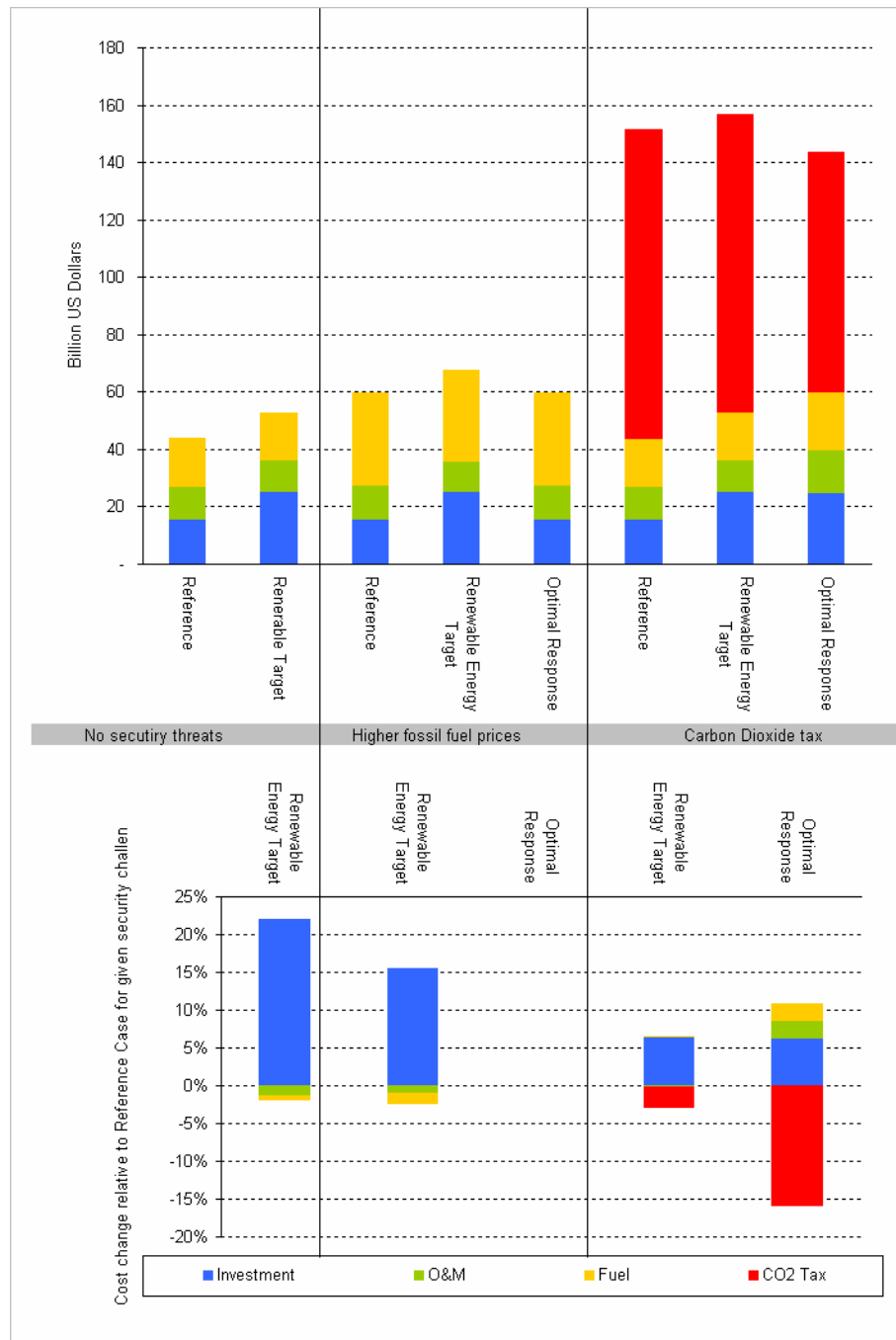


Figure 3: Change in Cost between the Reference case with no security challenge and all other cases for country type 1 (CT1)

In the case of country type 2 (CT2), rapidly growing energy demand requires significant new power supply investments (shown in Figure 4). Under the *reference* case, fossil fuels and hydro provide the least-cost option for capacity expansion in the medium term (till 2020). However, fossil fuel prices, based on more imports and only some local extraction, are more expensive than in the case of resource-rich CT1. Given these conditions for CT2, both relatively higher fossil fuel prices and carbon taxes affect the structure of new generating capacity; both result in the optimal system relying on more new nuclear power stations. Since absolute electricity demand in this case study is small, the level of nuclear that can be accommodated by the system is constrained by the unit size available for a new plant. For bulk supplies (i.e. not including distributed generation), nuclear's

contribution is important in the two *optimal response cases*. Renewables, especially hydropower, though limited by resource potential, are nonetheless important in all three least-cost scenarios in the short to medium term. Diesel generators supply some small part of electricity in rural areas especially at times of high marginal costs. However, in the carbon tax scenario, fossil fuel based diesel in remote areas is replaced with bio-diesel. In the longer term, 2025-2030, renewable energy plays a much more important role, supplying up to 20% of electricity requirements.

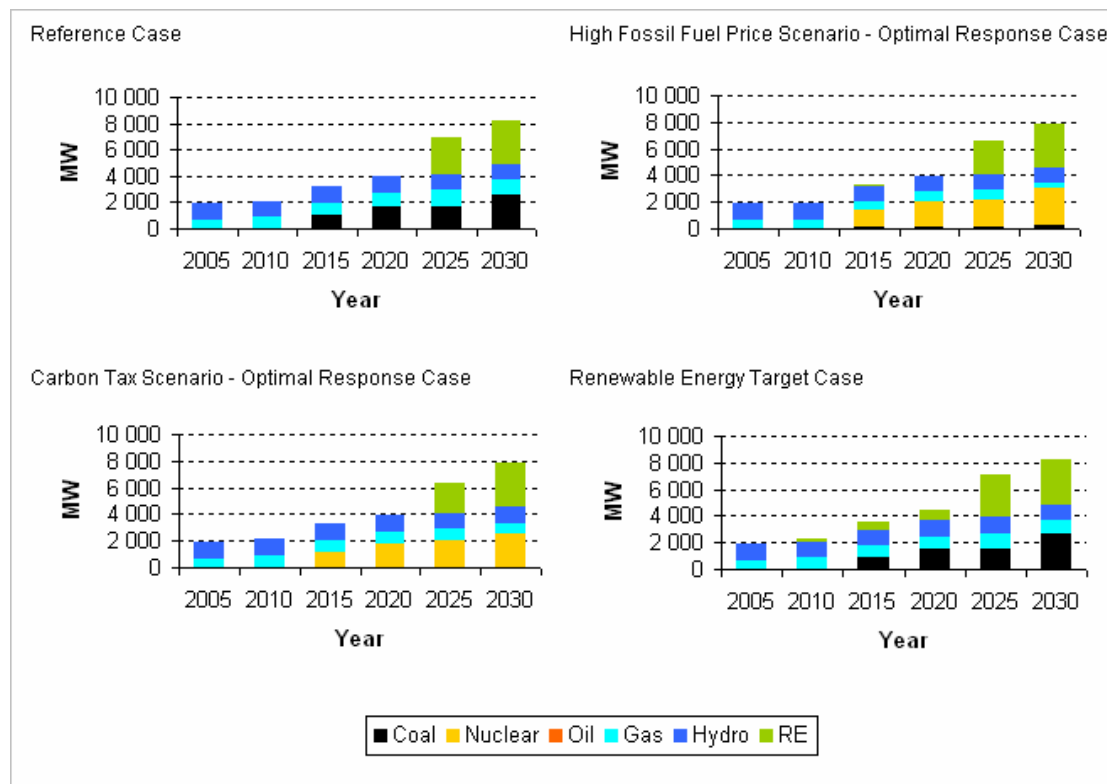


Figure 4: Total installed capacity for the least-cost case in each security scenario for country type 2 (CT2)

Optimal responses both to high fossil fuel prices and to a carbon tax involve diversification away from fossil fuels (see Figure 4). In the case of higher fossil fuel prices, coal generation is replaced by nuclear generation. In the case of the carbon tax, coal generation is replaced with nuclear and increased use of gas power plants. Figure 5 shows that increasing the share of renewable energy in the *renewable energy target case* with no security threat does not involve significant extra capital outlays. In fact, for higher fossil fuel prices and the carbon tax, the *renewable energy target case* is more economic than the corresponding *reference cases*. This indicates promise for the use of targeted renewable energy diversification measures for these security challenges. Unlike for a CT1 country, an anticipatory mandated diversification into renewables will actually 'pay off' if you then get hit by fossil price increases or a carbon tax.

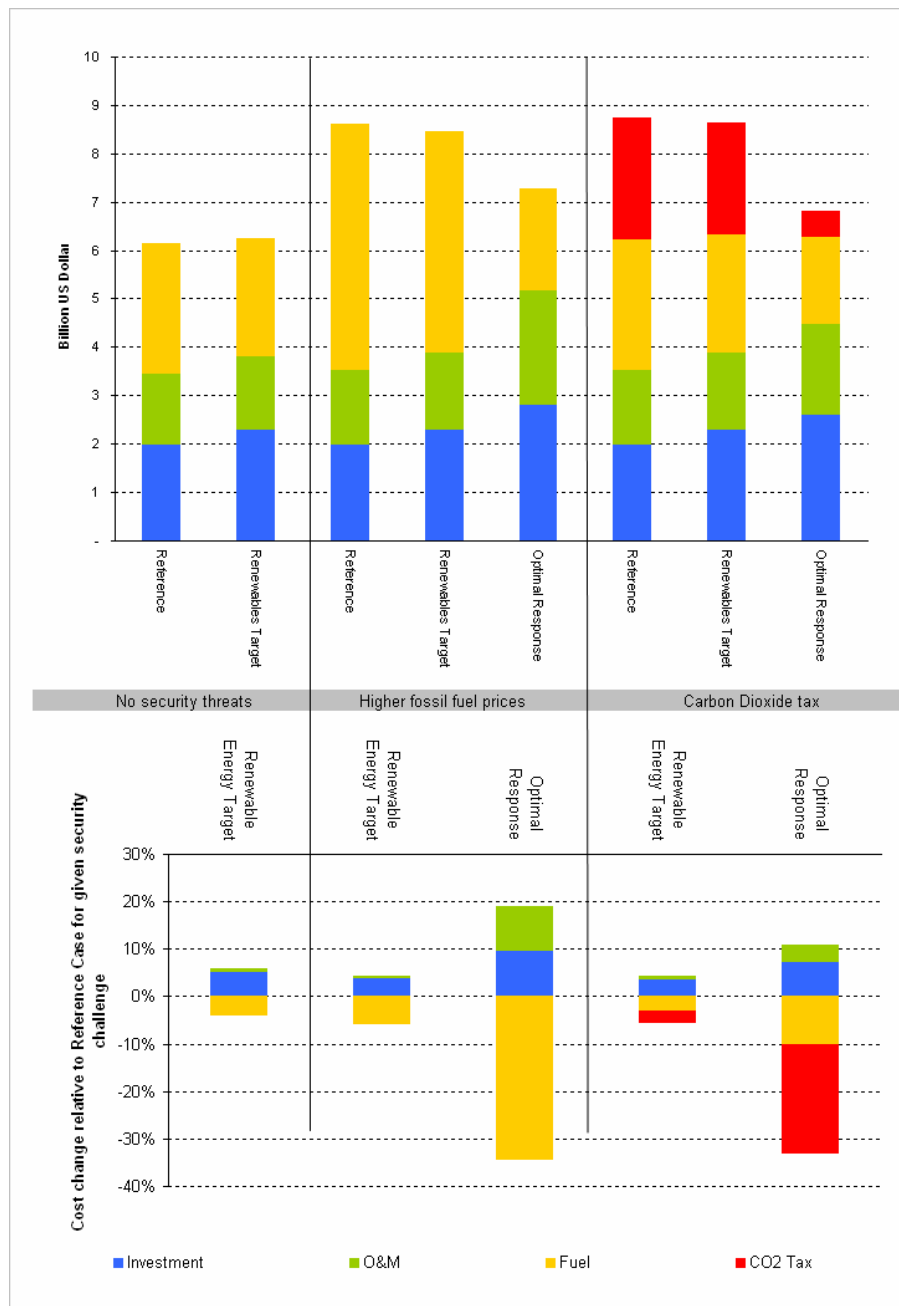


Figure 5: Change in Cost between the reference case with no security challenge and all other cases for country type 2 (CT2)

For country type 3 (CT3), nuclear is the most economic option in the *reference case* with no security challenge, and assuming higher fossil fuel prices or a carbon tax only makes nuclear relatively more economic. The imposition of a carbon tax does not alter the economic advantage of nuclear power over fossil fuel energy technologies, since nuclear is considered carbon free at the power plant level. (Capacity investment is summarised in Figure 6.) However, further penetration of nuclear is limited by technical aspects of the system (IAEA 2006).

Fuel costs for CT3 become dominated by coal and nuclear, as oil and gas are displaced over time (as shown in Figure 7). Though gas capacity is significant, due to higher fuel prices it is used to meet requirements only at peak times. The fuel costs for generating a unit of electricity from nuclear constitute a much smaller part of the

total unit cost than is the case for coal (12% compared to 64% in CT3). These unit fuel costs are also lower in absolute terms than the unit fuel costs of coal generation (by about 19%). As a result the cost of nuclear generated electricity is less sensitive to fuel price volatility, whereas coal-fired generation increases the system costs' sensitivity to higher fossil fuel prices.

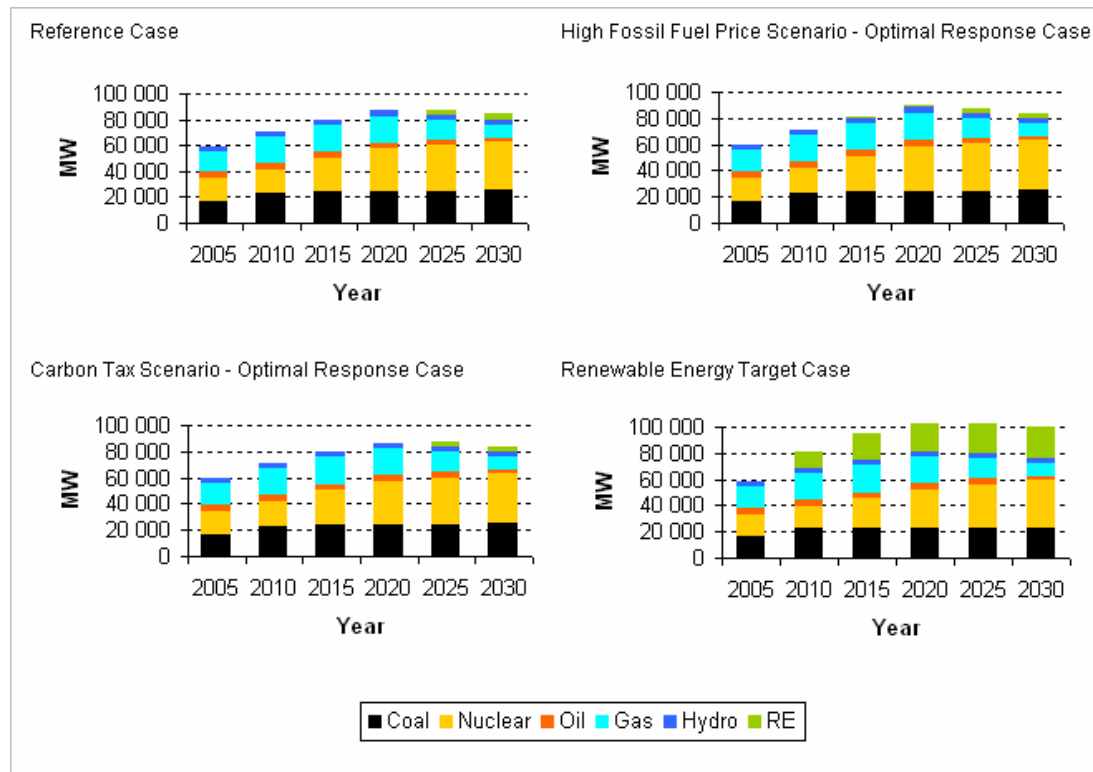


Figure 6: Total installed capacity for the least-cost case in each security scenario for country type 3 (CT3)

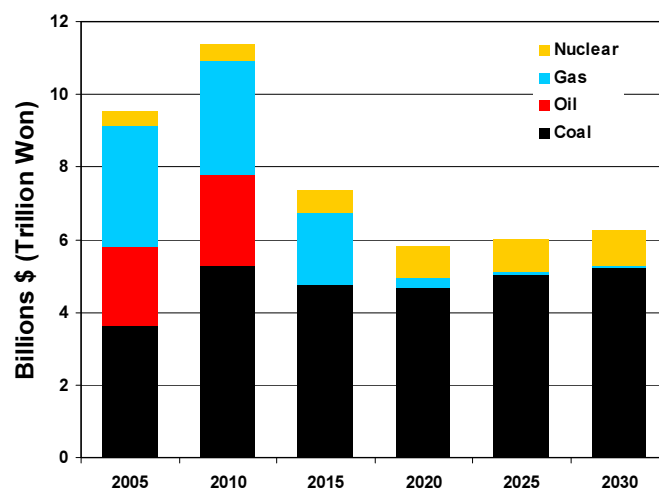


Figure 7: Fuel Cost Structure for the Reference Scenario of CT3

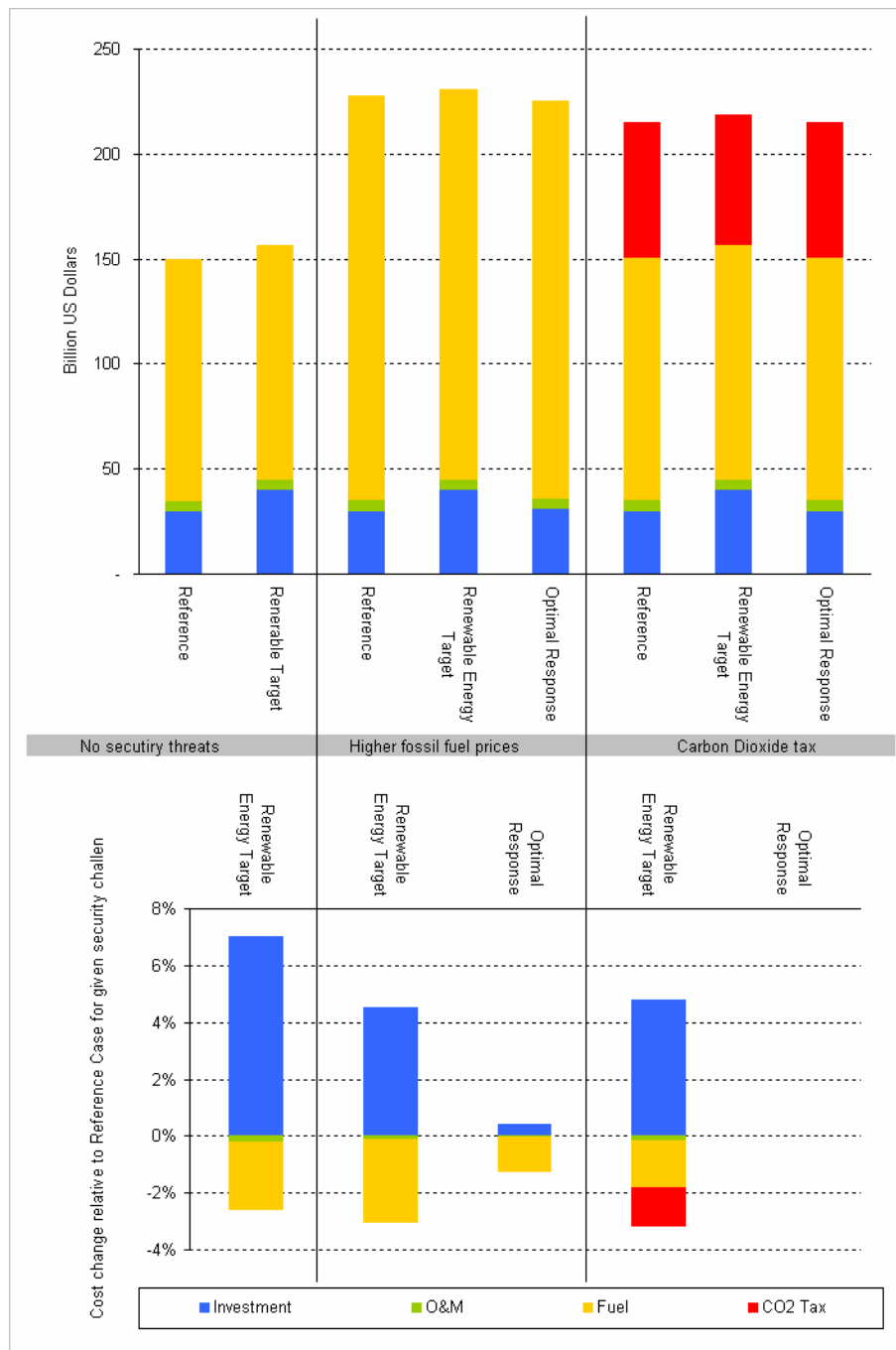


Figure 8: Change in cost between the Reference case with no security challenge and all other cases for country type (CT3)

It is again interesting to note in the case of CT3 that the optimal responses to the risks of higher prices and/or a carbon tax in this analysis do not involve significant changes in new power station investments (see Figure 8) compared to the *reference* case. Also of interest is the evolution of the fuel bill. While nuclear increases its contribution to generation, the cost of fuel and therefore imports decreases. The *renewable energy target* cases are more expensive than the corresponding *reference* cases. This implies that a targeted diversification to renewable electricity generation in response to these two challenges is not effective.

In this analysis we show that the costs to optimally respond to certain energy security risks can vary from significant (in the case of a carbon tax in CT1) to insignificant (in

the case of CT3). Similarly, adopting a renewable energy target may or may not be cost effective, depending on a country's resource base, demand growth and starting energy mix. In the case of CT1, there was no incentive to move away from a coal-dominated system, i.e. to diversify, to mitigate the risk of higher fuel prices, but large nuclear investments are required to displace cheap coal fired generation if a carbon tax is imposed. In CT3 the *reference case* proves most cost effective also for the high fossil fuel and carbon tax cases. Hence the optimal response involves no change to electricity system investments whatsoever and incurs minimal incremental capital costs. In the case of CT2 it was shown that a change to a more secure system involved high diversification from coal to nuclear, but this was done with relatively low extra cost. This is because in the case of CT2 the levelised cost of generating electricity from nuclear is not significantly higher than coal.

The efficacy of adopting a renewable energy target as a measure to cost effectively improve environmental sustainability and reduce exposure to fossil fuel price hikes varies across country types. For CT1 and CT3, adopting the targeted diversification to renewable energy in the *renewable energy target* cases is more expensive than doing nothing. This is the case even under higher fossil fuel prices and a carbon tax – in these situations it is ineffective. In the case of CT2, although not the optimal response, adopting the renewable energy target yields savings under both security challenges (relative to the *reference cases*), and the *renewable energy target* case is only mildly more expensive than the *reference case* when there is no security threat.

6. Conclusions

The quantitative results of the two case studies presented in Section 5 thus reinforce two points emphasized in the opening survey of energy supply security definitions and strategies.

- Measures to increase energy supply security are not costless.
- 'One size does not fit all'; different countries will find different strategies most cost effective, depending on their energy resources, their current energy systems, and projected growth in their energy use.

Beyond these two over-arching conclusions, the case studies also illustrate quantitatively several additional points made in the survey.

- Energy system integration is one way to reduce the costs of strengthening energy security. The Baltic study showed a strong congruence between lower costs and energy supply and security measures that are regionally planned and implemented. More specifically, addressing energy and energy security issues on a coordinated integrated regional basis reduced the energy system cost over the period 2005-2025 for the Baltic countries by €727 million, benefiting the economies of all three countries.
- Diversification is another possible strategy to increase energy security. But whether it is cost effective depends on the costs of diversification, the impacts of surprises in the absence of diversification, and the odds of the surprises occurring.
- More specifically, the CT1 and CT3 examples in Section 5.2 illustrate cases where a renewables diversification strategy would not be cost-effective even if future price and tax shocks were 100% certain.
- However, the CT2 example illustrates a case where a renewables diversification strategy would be cost-effective in the event of a price or tax

shock. In this case the wisdom of the strategy would then depend on the probabilities that policy makers assign to such shocks occurring.

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