Centre de Recherche en Economie et Droit de l'Energie

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Résumé

La planification énergétique peut être caractérisée comme un problème de décision d'investissement. Les investisseurs utilisent de nombreuses méthodes différentes pour traiter ces problèmes. L'une des méthodes la plus courante est basée sur la théorie du portefeuille de Markowitz par laquelle les investisseurs tentent de maîtriser les risques et de maximiser la performance du portefeuille en vertu de divers résultats économiques volatils. Ce travail explique les idées de la théorie du portefeuille et analyse leurs principales applications dans un pays producteur de pétrole et de gaz naturel. Nous allons illustrer comment le parc de production d'électricité en Iran peut être influencé par une addition supplémentaire de ressources nucléaires et renouvelables. En comparaison avec les mix électriques dominés par les ressources fossiles, des portefeuilles efficaces de production d'électricité peuvent réduire considérablement les coûts de production tout en incorporant une plus grande part d'énergies décarbonées dans le mix. Les résultats optimaux pour le mix électrique Iranien montrent que par rapport aux mix basés sur les ressources fossiles, il existe de nombreuses structures de production avec de plus grandes parts de non-fossiles (à la fois nucléaires et renouvelables) à des coûts et des risques égaux ou même inférieurs. D'ailleurs, si nous prenons également en considération les recettes d'exportation de combustibles fossiles libérés (coût d'opportunité des combustibles), cette conclusion devient encore plus évidente.

En outre, notre modèle d'analyse du portefeuille reflète l'interrelation des coûts (covariances) parmi les alternatives de production d'électricité et leur impact sur les coûts et les risques du portefeuille final. Les résultats montrent que le portefeuille typique de la génération d'électricité en Iran, basé sur des ressources fossiles, offre peu de diversification. Bien que cela puisse isoler le risque aléatoire, comme les enjeux entourant le développement de la filière nucléaire Iranienne, il fournit peu de couverture contre le risque systématique des mouvements du prix du pétrole et du gaz, qui historiquement ont été fortement corrélés.

Mots-clés: Portefeuille de la Production d'Electricité; Iran; Diversification

Abstract

Energy planning can be characterized as an investment-decision problem. Investors use many different methods for treating such problems. One of the most common methods is based on the Markowitz's portfolio theory by which investors try to manage risk and maximize their portfolio performance under variety of volatile economic outcomes. This work explains essential portfolio theory insights and analysis their application in an oil and gas producing country. We will illustrate how different electricity generation mixes can be influenced by additional share of nuclear and renewable sources. In comparison to the fossil dominated mixes, efficient power generation portfolios can dramatically reduce the generation costs while containing larger shares of decarbonized power units in the mix. The optimal results for the Iranian generation mix demonstrate that compared to the fossil-based mixes, there exist many generating mix structures with larger non-fossil shares (both nuclear and renewable) at equal or even lower expected costs and risks. Moreover, if we also take into consideration the export revenues of released fossil fuels (opportunity cost of fuels) this conclusion becomes even more affirmative.

Moreover, our portfolio model analysis reflects the cost inter-relationship (co-variances) among generating alternatives and their impact on the final portfolio costs and risks. The results illustrate that the typical Iranian gas and fuel generating portfolio offers little diversification. While it may insulate from random risk, such as Iranian nuclear issues, it provides little insulation from the systematic risk of oil and gas price movements, which have historically been highly correlated.

Keywords: Power Generation Portfolio; Iran; Diversification

Iran’s Economic Outlook and Recent Political Development

Currently Iran's economy is going through an extremely difficult period. GDP contracted in 2012 for the first time since the early 1990s, under the weight of US sanctions, which are supported by many other major economies. While sanctions have long been in place, they have become more severe since 2010 in response to Iran's alleged nuclear program. The sanctions are targeting Iran's energy sector in particular, as hydrocarbon products accounted for almost 80% of Iranian exports and government revenues in 2010. Furthermore, sanctions have become more effective because they are not only targeting Iran directly but also countries or companies that trade with Iran. For example, the EU placed a ban in 2012 on insurance for tankers carrying Iranian crude. The result has been that oil exports have more than halved in the past few years, a blow to Iran's fiscal position.

The imposition of sanctions and the collapse in exports are causing knock-on effects that will have serious repercussions in both short and long terms. The value of Iran's currency, the Rial, has depreciated by over 80% since late 2011, causing a sharp increase in the price that Iran must pay for imported goods. This has added to inflation that was already high following the progressive removal of energy subsidies that began in December 2010. As a result, inflation hit 37.5% in July 2013. Aside from stoking social unrest, high inflation levels reduced consumer purchasing power, thereby reducing domestic consumption and contributing to the short-term economic slowdown.

The surprise election of Dr. Hassan Rouhani as Iran's next president signals a possible change in the country's external relations and economic policies from recent years. Rouhani's moderate tone resonated with the majority of voters who turned out in record numbers (72.2% of an estimated 50 million voters) to reject the election of more conservative candidates.

The new political leadership will focus on tackling the country's economic crisis after Iran has suffered under crippling sanctions over the past two years, which pushed the inflation rate to 36%, increased youth unemployment to 28% and more than halved the value of the Iranian Rial against the dollar since July 2010. In order to revive the economy, Rohani will have to restart bilateral talks with the US on nuclear issues to get international sanctions removed and to mitigate their permanent damage to the country's industrial growth.

Iran Oil and Gas Sector

Iran is the second largest oil producer in the Middle East and plans to significantly increase output through developing a number of oil and gas fields in the Persian Gulf and through enhancing the recovery rate with gas injection technology. This is a very ambitious plan given that external investment is constrained under US and EU sanctions, unattractive buy-back contract conditions, ageing assets and chronic under-investment in petroleum infrastructure. The largest oil fields are Ahwaz, Gachsaran and Marun, which are located onshore and account for about one third of Iran's oil current production. Oil exploration, production, transportation and exports are managed and operated by various units of the National Iranian Oil Company (NIOC). The NIOC, through its affiliates, has a high degree of control over oil development projects. Buy-back contracts with Iranian oil companies must be signed by international oil companies to develop gas fields in Iran. This has tended to result in lengthy delays as Iranian companies struggle to find capital. To date, there have been twelve buy-back deals with foreign companies but only Asian NOCs remain in the existing field developments, given the exodus of IOCs from Iran. Oil and gas infrastructure of Iran is illustrated in figure 3-1.

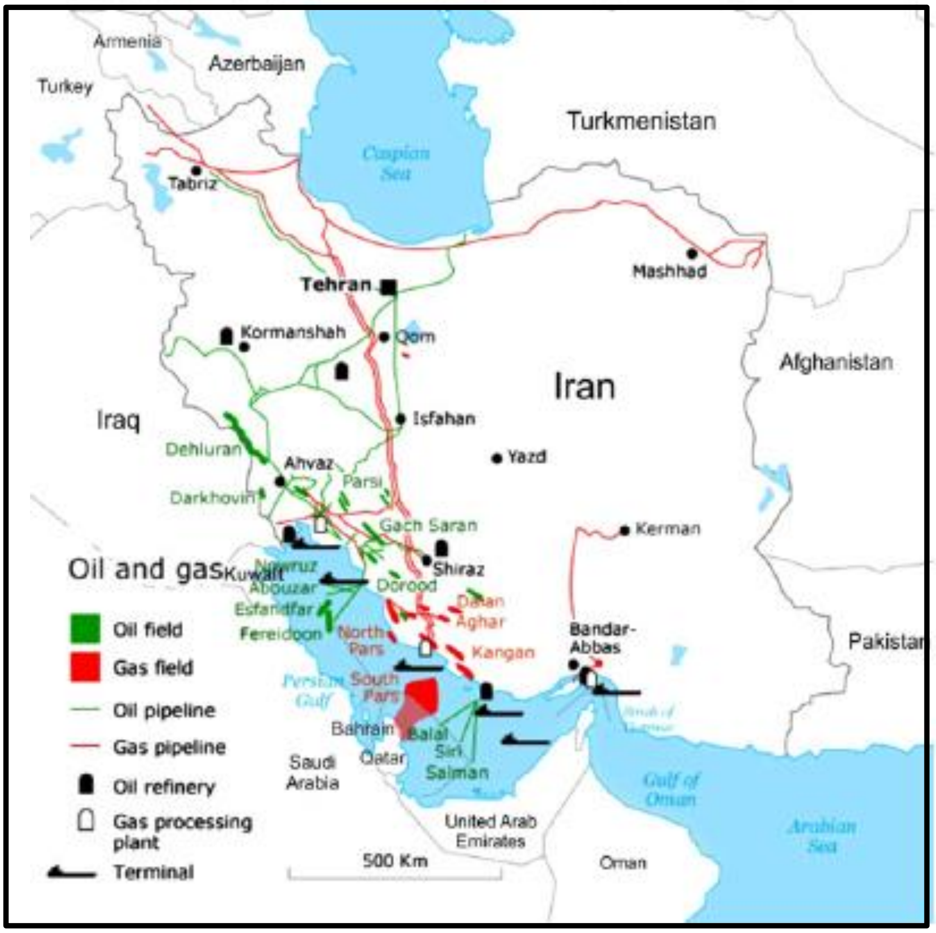


Figure 3-1

(Source: Fanack 2012)

Although Iran has the second largest gas reserves behind Russia, the country is expected to be challenged in exploiting these gas resources. Similar to the oil sector, external investment constraints will be the major impediment to the development of the gas sector. Iran's remaining commercial gas reserves are estimated to be 170 trillion cubic feet and are mainly found offshore in the giant South Pars gas field which is part of the same structure that Qatar has developed successfully (the Qatari side is called the North Field). Foreign companies must enter into buy-back contracts with NIOC (similar to the oil sector) to develop gas fields in Iran. A number of foreign companies had agreements for the development of South Pars including Phases 2&3 (Total, Petronas and Gazprom), Phases 4&5 (Agip and Petro Pars) and

Phases 6-8 (Statoil and Petro Pars). Although South Pars phases 11, 13 and 14 were due to be developed, the IOC participants have since been removed from gas production projects.

Current natural gas production is dominated by four onshore non-associated gas fields (Khangiran, Kangan, Nar and the Parsian group) and the first five phases of South Pars. Unlike Qatar's success in developing its gas reserves, Iran has been unable to support its plans to expand supply capacity and to become a major gas exporter. While sales gas production has increased from 56 bcm in 2000 to 138 bcm in 2010, Iran now faces some choices how to invest in the gas sector to maintain or increase production capacity.

Although Iran is a large gas producer, the country will continue to be a net importer over the next years. Iran imports gas via pipelines from Turkmenistan to supply Iran's northeast, which has no direct pipeline connection with Iran's producing fields in the South. While some imported gas is also going to Tehran, the densely populated area around Teheran in the country's centre is mainly supplied via pipelines from the South. Iran currently exports gas only to Turkey via long-term pipeline contracts, which will expire in 2025.

Iran’s Power Sector Overview

Gas is the dominant fuel for Iran's electricity generation as it provided 76% of total power generation in 2010, while oil and hydro supplied 20% and 4%, respectively (figure 3-2). Gas-fired generation grew at 7% per annum over 2000-10, spurred by low gas prices (figure 3-3). A severe drought caused hydro power generation to plummet in 2008-09 and electricity from hydro power to drop from 18 TWh in 2007 to 7 TWh in 2009. The shortage of hydro generation was offset by an increase in gas-fired power generation. Frequent power outages resulted from insufficient hydro power supply during the drought, which could not meet quickly rising power demand. Since then, a significant program of state investment has been implemented to boost installed power capacity in order to avoid power shortage in the future. Hydro power generation started to rise again in 2011 as water levels returned to normal.

Iran's electricity generation capacity reached 65 GW in 2011 and the country's generation plants are owned and operated by the company TAVANIR. Hydro generation capacity is owned and operated by then Iran Water and Power Resources Development Company or by Independent Power Producers (IPPs). Electricity production from TAVANIR supplies around

90% of Iran's total electricity generation. Any power produced by IPPs must be sold to TAVANIR under long-term contracts of around 25 years. The government does intend to establish a competitive wholesale market and allow direct sales to large end-users, but we believe it is highly unlikely that this will happen soon given the country's poor track record for privatization efforts over a number of years.

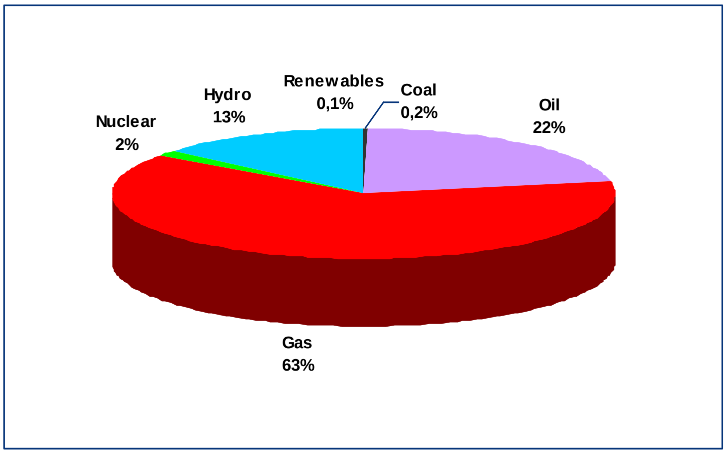


Figure 3-2: Electricity production composition in Iran in 2010

(Source: IEA & BP Statistics)

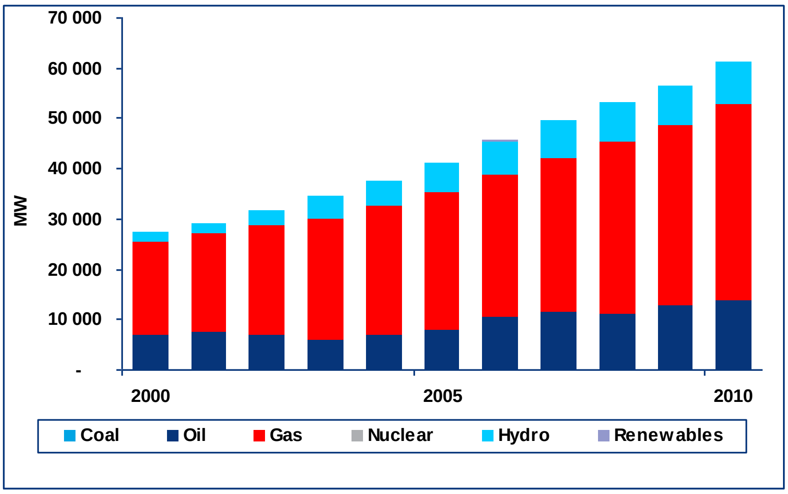


Figure 3-3: Fuel inputs to electricity generation from 2000 to 2010

(Source: IEA & BP Statistics)

Half of the total electricity demand in Iran goes for residential and commercial sectors, while industrial demand takes the second position with around 30% of the total domestic demand (figure 3-4). These shares remained almost intact for a decade between 2000 and 2010, whereas the total demand of the country increased by around 80% proportionally for all the sectors (figure 3-5).

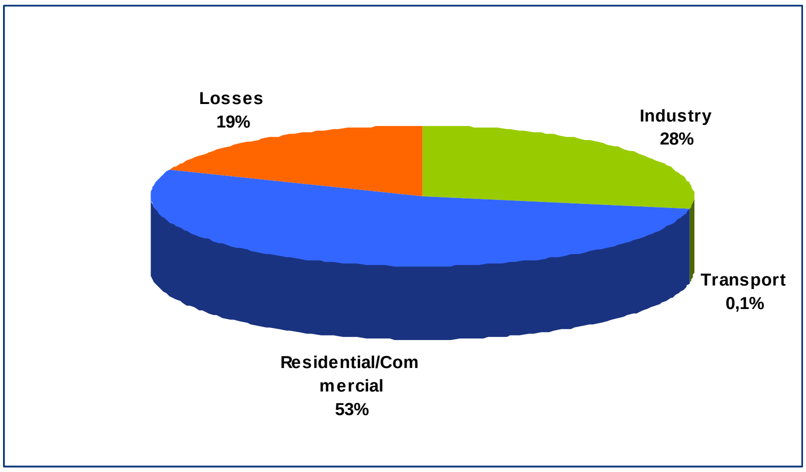


Figure 3-4: Electricity demand in 2010

(Source: IEA & BP Statistics)

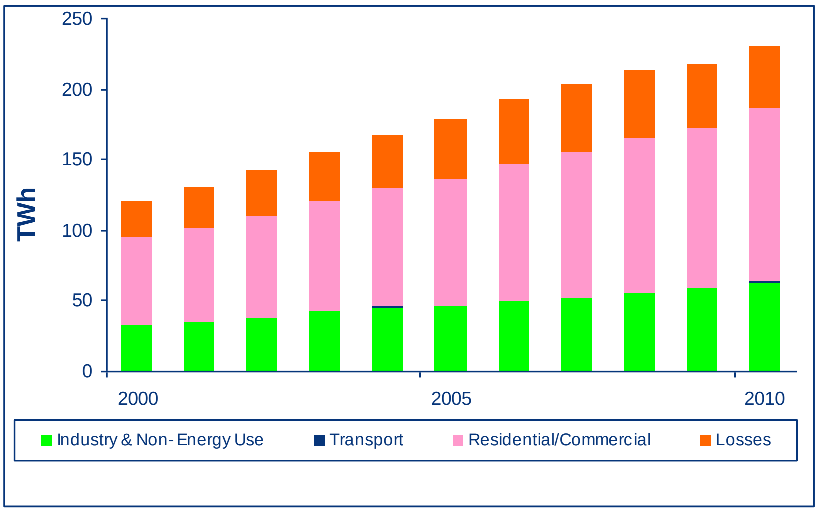


Figure 3-5: Electricity demand evolution from 2000 to 2010

(Source: IEA & BP Statistics)

Iran exports electricity to Armenia, Pakistan, Turkey, Iraq, and Afghanistan and the country's net electricity exports have increased noticeably over the past years. Although Iran's exports could be negatively impacted by rising domestic power prices when subsidies will be further removed, we expects the trend of rising electricity exports to continue over the forecast period as long as the domestic electricity generation and transmission infrastructure in neighbouring countries (Iraq, Pakistan, Afghanistan) remains underdeveloped.

The History of the Electric Power Industry in Iran

The history of electricity dates back to 1885 when the first dynamo came into service in Iran. This machine with the capacity of 3 KW was used to light the royal court of Tehran, the capital of the country. This occurred 3 years after the inauguration of the first commercial electric lighting entity by Edison in the New York City. 8 years later, a 12hp generator was installed in the Mashhad city (north east of Iran) by the private sector. Also at that time, the first license for establishing commercial electric lighting was granted (for lighting only during evening hours) and the first power plant inaugurated in 1906. Since that time, during around 40 years, electric power was considered as a luxury product used only for lighting with small number of consumers all around the country. The private sector became active in this business and supply facilities were installed by private institutions. After World War II, the government became actively involved in the electrification of the country and started to supply power with subsidized prices. Iran Power Generation & Transmission Company (TAVANIR) established and private sector gradually banned from investing in electricity business. Thereafter, the main objective of the government was to cover all potential electricity consumers and started to install large number of combined-cycles and hydraulic power plants.

Finally, since 90s, the government decided to gradually decentralize and privatize the electricity sector and persuading investment by private entities for bringing more competition into the sector, leading to possible reduction in the prices, and helping the electricity business to move toward financial self-reliance.

Moreover, according to the Article 44 of the Iran’s constitutional law, Ministry of Energy must release and transfer the ownership of its several power plants to the private sector and facilitate the liberalization process leading competitive electricity markets.

Electricity Market status in Iran

Iran’s power market was launched in 23 October 2003. It was based on a mandatory pool model and all producers and consumers should send their bids one day ahead, before 10am, to the market. In this market 32 generating entities and almost 43 distribution companies participate in wholesale energy trade each day. Once the power purchase and sale offers have been accepted, they will be matched by the market operator that administrates financial transactions and shares out production and demand among different parties involved in the auction. To provide a close and effective supervision on the electricity market of Iran, Electricity Market Regulatory Board has been established. This entity is independent of TAVANIR Company and includes seven expert persons of the power industry assigned every two years by the Energy Minister. Ancillary service markets in Iran’s electricity market are evolving gradually. Primary frequency control market was introduced on 22 May 2007 along with voltage support services (reactive power) and black start services.

Wind Energy Situation in Iran

Persians were the first people to construct the first wind mills around 200BC. Some of those historic mills are still on operation in rural areas of Khorasan province in North East of Iran. Iran is blessed with diversified and four season climate and besides having deserts; it is also a mountainous land with Caspian Sea on the North and Persian Golf & Oman Sea in the South. Due to this geographical position, the country benefits from various tropical wind flows coming from Central Asia during winters and Indian Ocean during summer seasons.

Iran's first experience in installing and using modern wind turbines backs to 1994. Two sets of 500KW NORD-TANK turbines were installed in Manjil and Roodbar sites (Alamdari et al. 2011).

Manjil and Binalood are major wind sites of Iran with installed capacity of 94MW (Mousavi et al. 2011). Almost all of the wind plants in the country are sate owned and private investors have not yet been involved in this technology. High investment costs, financing problems, lack of long-term governmental support and of course the low prices of electricity, due to heavily subsidized natural gas, are the most important barriers in front of private interventions. Evolution of wind capacity in Iran since 1997 is shown in figure 3-6.

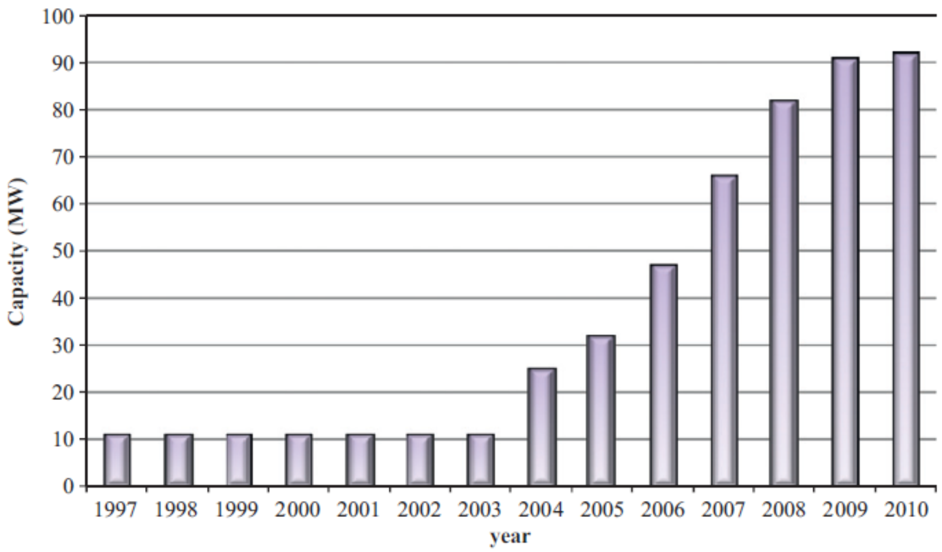


Figure 3-6: Iran wind installed power plants 1997-2010

(Source: Iran Renewable Energy Organization SUNA)

Looking at its potential, it is essential that Iran should absolutely not fall behind in the development of this technology. Nevertheless, it is a far journey so as to fill up the technology gaps and to utilize the large wind power potentials.

Hydropower Development in Iran

Iran is classified as an arid and semi-arid country because of its long-term average precipitation of around 250mm, which is nearly one-quarter of the world's average rate. Moreover, the precipitation is not evenly distributed all over the country. The total surface water is around 92bcm of which 27bcm flow into three major basins: Dez, Karkheh and Karoon rivers basins all located in the South-West of Iran over the Zagros mountain chains where the major hydroelectric projects are located. Northern and Northwestern regions have relevant precipitation and topography for developing small medium-sized hydro plants.

Currently, there are 42 hydroelectric plants on operation in Iran, with total installed capacity of around 8GW and many others with total capacity of almost 7GW are also under construction. Large hydro plants with capacity of more than 100MW cover more than 90% of the installed capacity.

Volume of hydropower is highly variable in Iran and depends on yearly water falls. For example, in 2007 more than 18TWh of power was fed to national grids while this amount was decreased by 72% in 2008 due to unexpected droughts (Ministry of Power Annual report 2008).

There are many water streams in Iran which either go waste or finish at rivers and finally into the sea. Therefore, many small and mini hydro systems can easily be installed to provide locally needed power or to be injected to grids. Unfortunately, these huge potentials of hydro power are not effectively utilized and are even deprived of any further extensive planning.

Solar Energy Status in Iran

Iran enjoys approximately 2800 sunny hours per year as it is located on the world's Sun Belt. Iran's average solar insulation rate is estimated to be around 2000 kwh/m². Figure 3-7 shows the average annual sum of this rate for different regions.

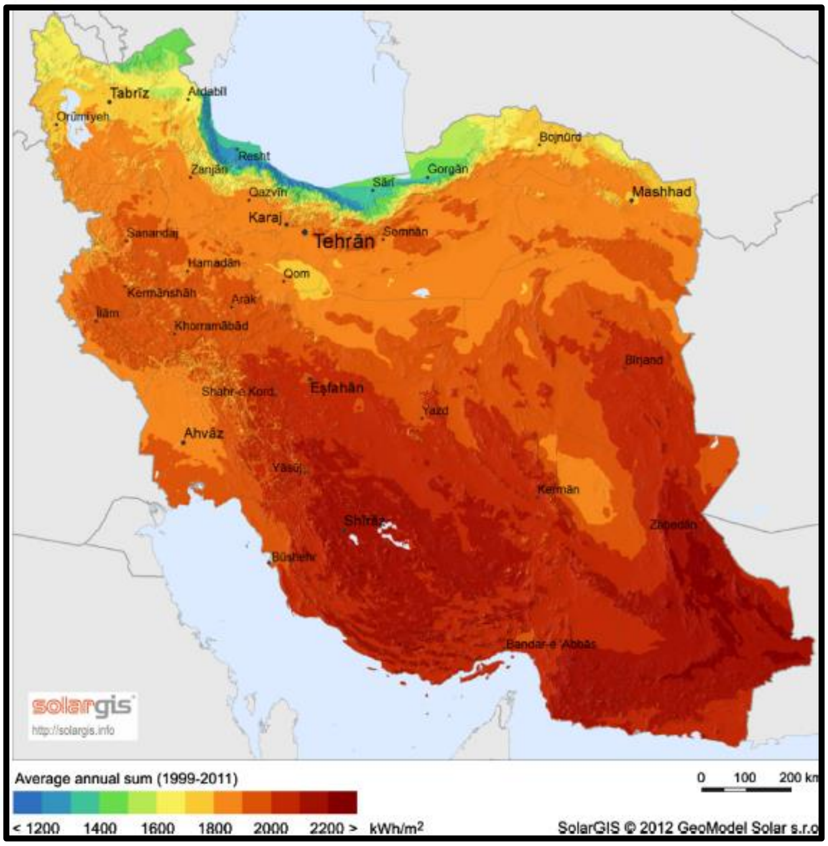


Figure 3-7: Iran solar energy map

(Source: Solar GIS)

The first in Iran and the largest in Middle East, Shiraz solar power plant will come to full operation by the end of 2015 according to Iran's Renewable Energy Organization.

Methodology

Hereby, we describe essential ideas related to portfolio theory and discuss their application in the analysis of the Iranian electricity generation mix. We adopted this methodology for the Iranian case as the electricity sector in Iran is a qausi-competitive system and more privatized than other oil and gas producing countries such as Saudi Arabia. Besides, energy diversity is the main focus of late between Iranian energy authorities and portfolio-based models are very much adapted to treat energy diversity issues.

Therefore stand-alone least cost approach does not necessarily provide the most optimal solution for the Iranian generation mix and we should adopt an optimization model based on both cost and risk minimization process.

By applying this approach we will illustrate how electric power generation mixes can benefit from additional shares of non-fossil generating units. In comparison to fossil dominated mixes, efficient portfolios could decrease the total generating cost while including greater non-fossil (nuclear and renewables) shares in the mix. This improves also energy security. Though counter-intuitive, this conclusion is completely consistent with fundamental finance theory. As a matter of fact, under dynamic and uncertain environments, the relative value of producing technologies should be determined not by evaluating alternative resources but alternative resource-portfolios.

Mean Variance Portfolio Approach

Markowitz' mean variance portfolio theory is a probabilistic approach which could be used to value and optimize fuel mix diversity. This theory defines portfolio risk as total risk (including both random and systematic fluctuations) measured by the standard deviation of periodic historic returns. An efficient portfolio includes the smallest risk for a given level of expected return or vice-versa, the biggest expected return for a given level of risk. The process contains making an optimal portfolio generally by using historical measures of risk, returns (costs) and of course the correlation coefficients between various assets to be considered in the portfolio.

By numerical (computer aided) processing the risk (standard deviation), return or cost and correlation coefficients data, it would be possible to produce a number of portfolios for varying amounts of return having the least risk level from asset classes consisted. They are called efficient/optimal portfolios, which situate on the so called efficient frontier. Efficient frontier of two risky assets and the set of optimal portfolios are shown in figure 3-8.

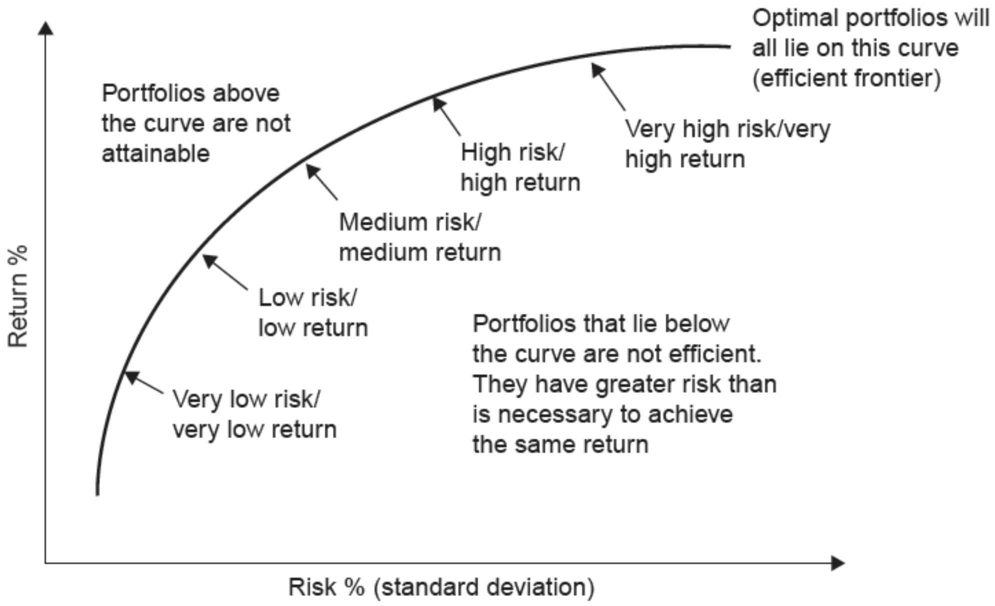


Figure 3-8

Then according to this efficient frontier, the investor simply needs to choose his desired level of risk. Actually, mean-variance portfolio theory suggests not a single efficient portfolio, but a range of optimal choices. Based on their risk aversion and preferences, investors will choose a risk-return combination.

Initially, mean-variance portfolio theory developed only for financial applications. But it can also be used for power generation assets to determine the efficient portfolio for a country or generation company, discussed in detail in Awerbuch & Berger (2003) and Roques et al. (2008). Awerbuch and Berger (2003) suggest that the relative value of producing assets should be determined not by evaluating alternative assets, but by evaluating alternative asset portfolios. Hence, energy planning entities need to focus less on stand-alone least cost alternative and more on building optimal power generating portfolios.

In 1976, Bar-Lev and Katz applied mean variance portfolio theory to fossil fuel supply for US electric utilities. By focusing on a regional approach, they constructed the theoretical efficient frontier of fossil fuel mix for various regulated utilities and compare it with the real experience of the power utilities. They found out that most of the utilities portfolios were situated on the efficient frontier but with very high level of risk and rate of return. They interpreted this as a consequence of the cost-plus regulatory frame work encouraging electric utilities to operate in a very risky manner.

Humphreys and McClain (1998) also used portfolio theory to propose the most optimal energy mix in the USA to reduce risks associated with unanticipated energy price shocks. They note that American electric utilities have approached more efficient points of generation since the 1980s, and that the switch toward natural gas took place in the 1990s were driven by strong wish for higher returns to investment.

Awerbuch (2000) analysis the US gas-coal generation mix and demonstrating that more wind, solar and other renewables with zero variable costs in the portfolio will lead to overall risk and cost reductions, even if their stand-alone costs might be higher.

Awerbuch and Berger (2003) attempt to determine the optimal European technology mix, taking into account not only fuel price risk but also construction period risks and operation and maintenance risks. They found that EU-2010 mix is coupled with higher rate of risk and return compare to EU-2000 generation mix.

Jansen et al. (2006) use portfolio approach for analysing the electricity generation mix of Netherlands. Their study concentrates on fuel price uncertainty and is based on generation costs. They conclude that more diverse production portfolios are generally associated with lower risks for the same amount of returns. Especially those which contain more fixed-cost renewables and nuclear which have a low covariance with the fossil-fuel technologies' costs.

More recent studies like Roques et al. (2008) focus more on a private investor prospective. They conclude that in the absence of long-term power purchase contracts in the UK efficient portfolios differ greatly from socially optimal ones. They found that there is a little motivation of diversification for private investors as there is a high correlation between electricity, gas and carbon prices. This kind of conclusion raises questions about how policy makers and regulators should adapt the market frame work to assure system diversity and security of supply.

Portfolio Theory Application in Power Generation Investment

Traditional power generation investment valuations approaches such as the famous levelized cost method, are mainly based on stand-alone analysis. But generation technologies have various risks and return patterns, as such that there are many valuable potential advantages in constructing a diversified portfolio of power plants. Mean variance portfolio theory applications provide more information for a country policy maker and utilities regarding many critical risks in liberalized and quasi-liberalized power systems.

Portfolio theory application is highly used by financial investors to construct high return and low-risk asset portfolios under different economic contexts. In one word, investors have learned that an optimal portfolio contains no unnecessary risk to its expected return-on-investment. Portfolio theory could be very suitable for planning and evaluating electric power portfolios and strategies as the process is too similar to one used by financial investors seeking to maximize their profit under minimization of the variety of unpredictable risks. In a similar way, it is essential to conceive of power generation not in terms of the levelized cost of a specific technology today, but in terms of its portfolio cost. In other words, when we apply portfolio theory to power generation planning and strategy, fossil and non-fossil alternatives are evaluated not on the bases of their stand-alone costs but on the basis of portfolio cost which is their contribution to total portfolio producing cost relative to their contribution to total portfolio risk.

If we look at the example of two assets from social planner view point (Iranian government in our case), the generating cost would be the relevant measure. As a matter of fact generating cost ($/KWh) is the inverse of a return (KWh/$); that is, a return in terms of physical output per unit of monetary input.

In this case, expected portfolio cost is the weighted average of the individual expected generating costs for the two technologies:

$$E(Cp) = X_1 \times E(C_1) + X_2 \times E(C_2)$$

Where X_1 and X_2 are fractional shares of the two technologies in the generating mix and $E(C_1)$ and $E(C_2)$ are respectively their expected levelized costs per KWh.

Expected portfolio risk, E(бp) is the expected year-to-year variation in generation cost. It is also a weighted average of the individual technology cost variances, as tempered by their covariance:

$$E(бp) = (X_1^2б_1^2 + X_2^2б_2^2 + 2X_1X_2\rho_{12}б_1б_2)^{0.5}$$

Where X_1 and X_2 are the fractional shares of the two technologies in the mix, $б_1$ and $б_2$ are the standard deviations of the holding period returns (HPRs) of the annual costs of technologies and ρ_{12} is their correlation coefficient.

Portfolio risk is estimated as the standard deviation of HPRs of the future cost of generation defined as:

$$HPR = (V_2 – V_1) / V_1$$

In which V_2 is the ending value and V_1 is the starting value of the costs. In case of fuel cost for example, V_2 can be considered as the cost of fuel in year (t + 1) and V_1 as the cost in year (t). In other words, HPR, measures the rate of change in the cost stream from one year to the next. A detailed discussion is given in Berger (2003).

The correlation ρ is an indicator of diversity in a sense that smaller ρ among portfolio components generates greater diversity, as measured by an absence of correlation between portfolio constituents. Adding a zero fuel cost technology to a risky generating mix, lowers expected portfolio cost at any level of risk, even if this technology costs more (Awerbuch 2006).

A fixed cost technology (with zero fuel cost) has бi=0, or very near to zero. This will decrease considering бp since two of three items in the E(бp) equation decrease to zero. And it is clear that бp reduces as ρ_{ij} falls below one. For example again in case of pure fuel-less, fixed-cost renewable technologies, fuel risk is zero and its correlation with fossil fuel costs is also zero.

Modelling Tool and Process

For the modelling purpose we have used OptQuest and Crystal Ball tools developed by Oracle Enterprise Performance Management System. Firstly we go through the Crystal Ball simulator structure which we use for our cost estimation and modelling purpose and then

OptQuest modelling tool will be developed in details so as to reveal the in-depth structure of our portfolio optimization model and of course the results based on already modelled costs structures.

Crystal Ball is a forecasting and risk analysis tool for decision making under uncertainty. Through Monte Carlo simulation technique, Crystal Ball forecasts the entire range of results for a given situation. It also shows us confidence levels, so we can know the likelihood of any specific event taking place. For each uncertain variable in a simulation, we can define the possible values with a probability distribution. A simulation calculates numerous scenarios of a model by repeatedly picking values from the probability distribution for the uncertain variables and using those values for the cell. Distributions and associated scenario input values are called assumptions. After hundreds or thousands of trials, we can view sets of values, the statistics of the results (such as the mean forecast value), and the certainty of any particular value. Crystal Ball actually is a simulation model that prepares the ground for our optimization model defined in OptQuest.

Traditional search methods work well when finding local solutions around a given starting point with model data that are precisely known. These methods fail, however, when searching for global solutions to real world problems that contain significant amounts of uncertainty. Recent developments in optimization have produced efficient search methods capable of finding optimal solutions to complex problems involving elements of uncertainty. OptQuest incorporates meta-heuristics to guide its search algorithm toward better solutions. This approach uses a form of adaptive memory to remember which solutions worked well before and recombines them into new, better solutions. Since this technique doesn’t use the hill-climbing approach of ordinary solvers, it does not get trapped in local solutions, and it does not get thrown of course by noisy (uncertain) model data.

Once we describe an optimization problem (by selecting decision variables and the objective and possibly imposing constraints and requirements), OptQuest invokes Crystal Ball to evaluate the simulation model for different sets of decision variable values. It evaluates the statistical outputs from the simulation model, analyses and integrates them with outputs from previous simulation runs, and determines a new set of values to evaluate. This is an iterative process that successively generates new sets of values. Not all of these values improve the objective, but over time this process provides a highly efficient trajectory to the best solutions. As shown in the following flow chart, the search process continues until it reaches some termination criteria, either a limit on the amount of time devoted to the search or a maximum number of simulations.

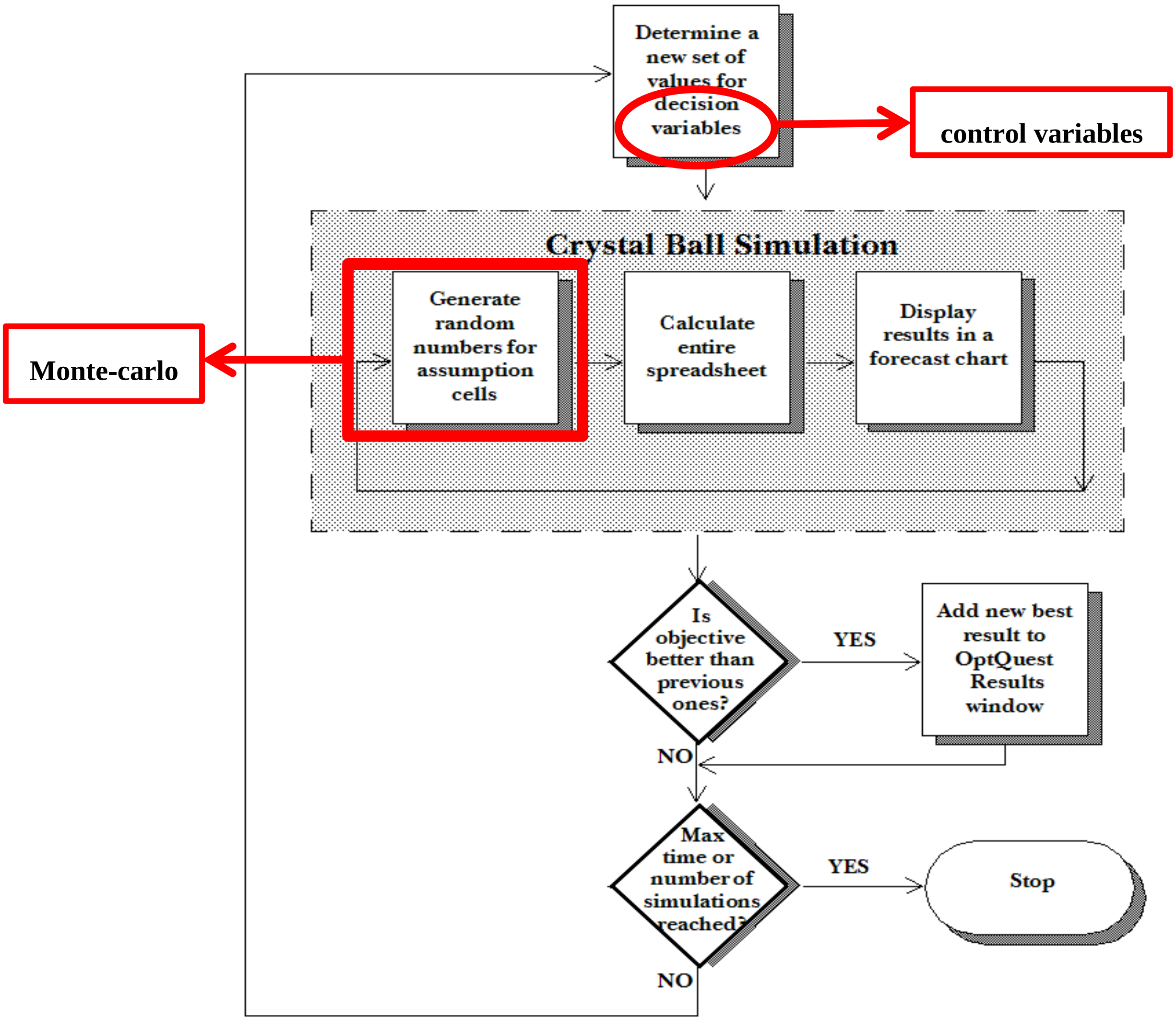


Figure 3-9

An OptQuest optimization model has four major elements: an objective, optional requirements, decision variables (already simulated by Crystal Ball) and optional constraints.

<u>Optimization Objectives</u>: Elements that represents the target goal of the optimization, such as maximizing profit or minimizing cost, based on a forecast and related decision variables.

<u>Requirements</u>: Optional restrictions placed on forecast statistics. All requirements must be satisfied before a solution can be considered feasible.

<u>Decision Variables</u>: Variables over which you have control; for example, the amount of product to make, the number of dollars to allocate among different investments, or which projects to select from among a limited set.

<u>Constraints</u>: Optional restrictions placed on decision variable values. For example, a constraint might ensure that the total amount of money allocated among various investments cannot exceed a specified amount, or at most one project from a certain group can be selected.

The whole stochastic simulation-optimization model to be constructed by Crystal Ball and OptQuest tools would be summarized in the following figure:

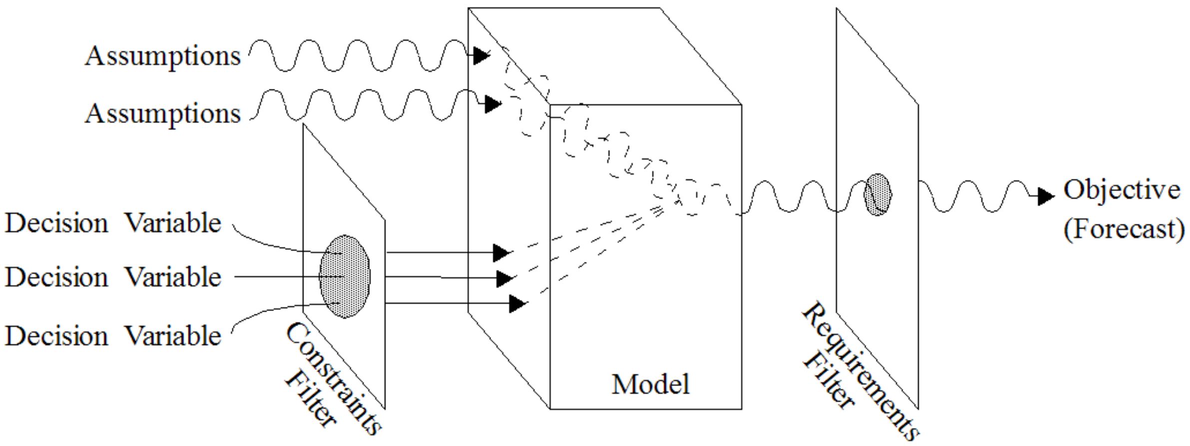


Figure 3-10

Iranian Power Generation Mix Model

As already mentioned at the beginning of this chapter both renewable and fossil fuel power plants are to be considered for the national electricity generation of Iran. Hence, coal, fuel-oil and natural gas power plants introduced to our model as fossil-based power units. In addition, nuclear power units and renewables (hydro, wind and solar) were also added to the generation mix. Geothermal units were not considered in our modelling because of the non-existence of any influential policy in the ministry agenda.

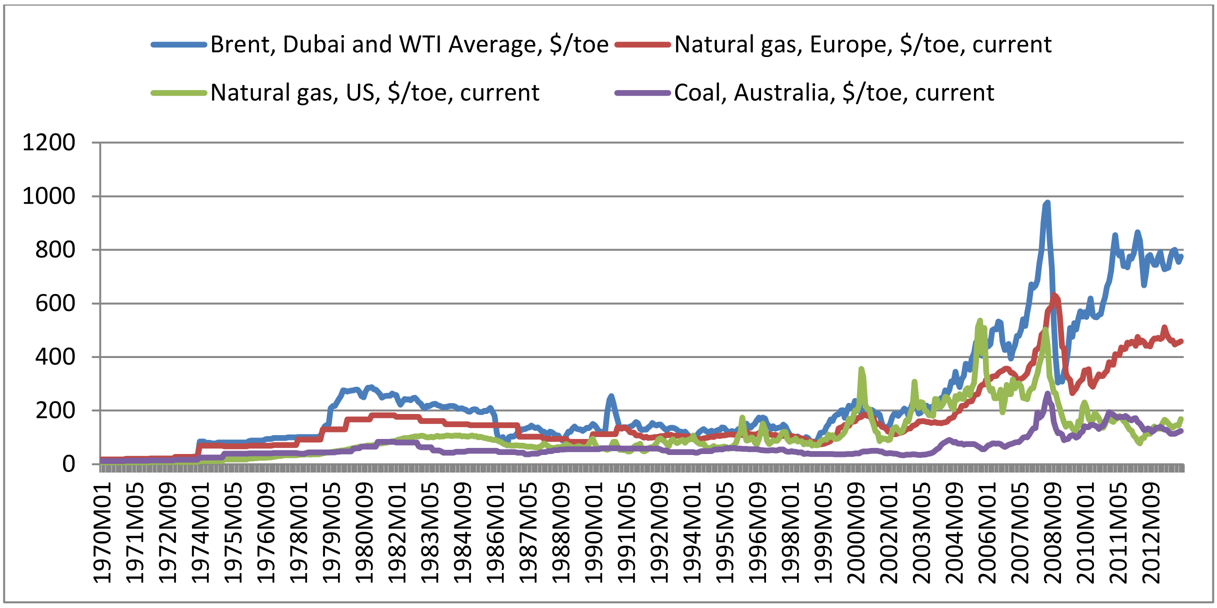
Therefore the total expected portfolio cost of the Iranian mix is given by:

$$E(C_{IranP}) = X_{oil}E(C_{oil}) + X_{gas}E(C_{gas}) + X_{coal}E(C_{coal}) + X_{nuc}E(C_{nuc}) + X_{hydro}E(C_{hydro}) + X_{solar}E(C_{solar}) + X_{wind}E(C_{wind})$$

And the total expected standard deviation (risk) of the portfolio is:

$$E(\sigma_{IranP}) = [\ X_{oil}^2\sigma_{oil}^2 + X_{gas}^2\sigma_{gas}^2 + X_{coal}^2\sigma_{coal}^2 + X_{nuc}^2\sigma_{nuc}^2 + X_{hydro}^2\sigma_{hydro}^2 + X_{solar}^2\sigma_{solar}^2 + X_{wind}^2\sigma_{wind}^2 + 2X_{oil}X_{coal}\rho_{oil,coal}\sigma_{oil}\sigma_{oal} + 2X_{oil}X_{gas}\rho_{oil,gas}\sigma_{oil}\sigma_{gas} + 2X_{oil}X_{nuc}\rho_{oil,nuc}\sigma_{oil}\sigma_{nuc} + 2X_{oil}X_{hydro}\rho_{oil,hydro}\sigma_{oil}\sigma_{hydro} + 2X_{oil}X_{solar}\rho_{oil,solar}\sigma_{oil}\sigma_{solar} + 2X_{oil}X_{wind}\rho_{oil,wind}\sigma_{oil}\sigma_{wind} + 2X_{gas}X_{coal}\rho_{coal,gas}\sigma_{gas}\sigma_{coal} + 2X_{gas}X_{nuc}\rho_{nuc,gas}\sigma_{nuc}\sigma_{gas} + 2X_{gas}X_{hydro}\rho_{hydro,gas}\sigma_{gas}\sigma_{hydro} + 2X_{gas}X_{solar}\rho_{solar,gas}\sigma_{gas}\sigma_{solar} + 2X_{gas}X_{wind}\rho_{wind,gas}\sigma_{gas}\sigma_{wind} + 2X_{nuc}X_{coal}\rho_{coal,nuc}\sigma_{nuc}\sigma_{coal} + 2X_{hydro}X_{coal}\rho_{coal,hydro}\sigma_{coal}\sigma_{hydro} + 2X_{solar}X_{coal}\rho_{coal,solar}\sigma_{coal}\sigma_{solar} + 2X_{wind}X_{coal}\rho_{wind,coal}\sigma_{wind}\sigma_{coal} + 2X_{nuc}X_{hydro}\rho_{nuc,hydro}\sigma_{hydro}\sigma_{nuc} + 2X_{nuc}X_{solar}\rho_{nuc,solar}\sigma_{nuc}\sigma_{solar} + 2X_{nuc}X_{wind}\rho_{nuc,wind}\sigma_{nuc}\sigma_{wind}\ 2X_{hydro}X_{solar}\rho_{hydro,solar}\sigma_{hydro}\sigma_{solar} + 2X_{hydro}X_{wind}\rho_{hydro,wind}\sigma_{hydro}\sigma_{wind} + 2X_{soalr}X_{wind}\rho_{solar,wind}\sigma_{solar}\sigma_{wind}\ ]^{0.5}$$

In which X_i and C_i are respectively the shares and costs of Iranian power generation technologies. The standard deviation associated with each technology is denoted by σ_i and ρ_i illustrates the correlation coefficients between various fuels used in related power units. For instance the correlations between fossil fuel prices, calculated based on the last decade monthly-averaged price of fossil commodities, are shown in the below figure.



Correlation analysis of fossil commodities used in the model

	Brent, Dubai and WTI Average, $/toe	*Natural gas, Europe, $/toe, current*	*Natural gas, US, $/toe, current*	*Coal, Australia, $/toe, current*
Brent, Dubai and WTI Average, $/toe	1			
Natural gas, Europe, $/toe, current	0,942016019	1		
Natural gas, US, $/toe, current	0,740124098	0,675343067	1	
Coal, Australia, $/toe, current	0,572281856	0,591320862	0,462094974	1

Figure 3-11

In case of nuclear fuel, we considered the annual average price of natural uranium over the last fifteen years and its correlation with other fossil resources prices. This resulted in a rather high correlation coefficient between coal and nuclear at around 0.4 while natural gas and oil have respectively 0.2 and 0.1 correlation coefficients with nuclear fuels (table 3-1B).

Consequently, the total generating portfolio cost has been constructed based on the weighted average cost distribution of each technology. Costs were defined with normal distributions and their associated means and estimated standard deviations. Details of standard deviation (risk) for each technology for its construction period, fuel cost and O&M costs and correlation coefficients between various technologies are summarized in tables 3-1A and 3-1B.

Technology Risk Estimates / Standard Deviation				
	Construction Period	Fuel[a]	Variable O&M	Fixed O&M
Nuclear	0,2	0,15	0,2	0,08
Coal	0,18	0,05	0,2	0,08
Oil	0,1	0,3	0,2	0,08
Gas	0,15	0,3	0,2	0,08
Wind	0,05	0	0,2	0,08
Solar	0,09	0	0,2	0,08
Hydro	0,2	0	0,2	0,08

a. Estimation based on empirical data 2005-2012

Table 3-1A

Correlations Coefficients between Technologies					
	Gas	Coal	Nuclear	Oil	Renewable
Gas	1	0,5	0,2	0,8	0
Coal	0,5	1	0,4	0,5	0
Nuclear	0,2	0,4	1	0,1	0
Oil	0,8	0,5	0,2	1	0
Renewable	0	0	0	0	1

Table 3-1B

Source: TAVANIR, Awerbuch et al. (2010) & Author's estimations

As you can see in the table the standard deviation for fuel costs are all equal to zero for renewable technologies. As there is no requirement for any sort of fossil fuel. Construction period risks vary by unit type and are mainly related to complexity and length of construction period[1]. Fixed cost implies an annual obligation that will be undertaken by an investor as long as sufficient income exists, which make this risk somehow similar to the risk of payments on the company's debt.

As explained previously, the correlation coefficient ρ is an indicator of diversity. Lower correlation among portfolio components creates greater diversity, which serves to reduce

[1] Nuclear construction period and its related standard deviation is based on the normal situation and contractual relations, even if it was not really the case of the first nuclear power plant (Booshehr) constructed in Iran. The construction period of Booshehr plant took almost 30 years due to political reasons.

portfolio risk. In general, portfolio risk falls with increasing diversity, as measured by an absence of correlation between portfolio elements. Adding a fixed-cost technology to a risky generating mix serves to lower expected portfolio cost at any level of risk, even if the fixed-cost technology costs more (Awerbuch 2005). In the case of fuel-less renewables, fuel risk is equal to zero and its correlation with fossil fuel costs is also taken as zero.

For each power unit, risk is equal to the year-to-year standard deviation of the holding period returns for main generating cost: capital or construction period risk, fixed and fuel. Fossil fuel standard deviations are estimated from historical data already explained in previous chapters.

The portfolio analysis focuses on the risk of generating costs only. We ignore year-to-year fluctuations in electricity output from wind (or solar) plants, taking the approach that a properly managed wind resource can produce constant annual output.

Future fossil fuel costs and other generating outlays are random statistical variables. While their historic averages and standard deviations are known, they move unpredictably over time. No one knows for sure what the price of gas will be next month, just like nobody knows what the stock markets will do in finance theory. Estimating the generating cost of a particular portfolio presents the same problems as estimating the expected return to a financial portfolio. It involves estimating cost from the perspective of its market risk.

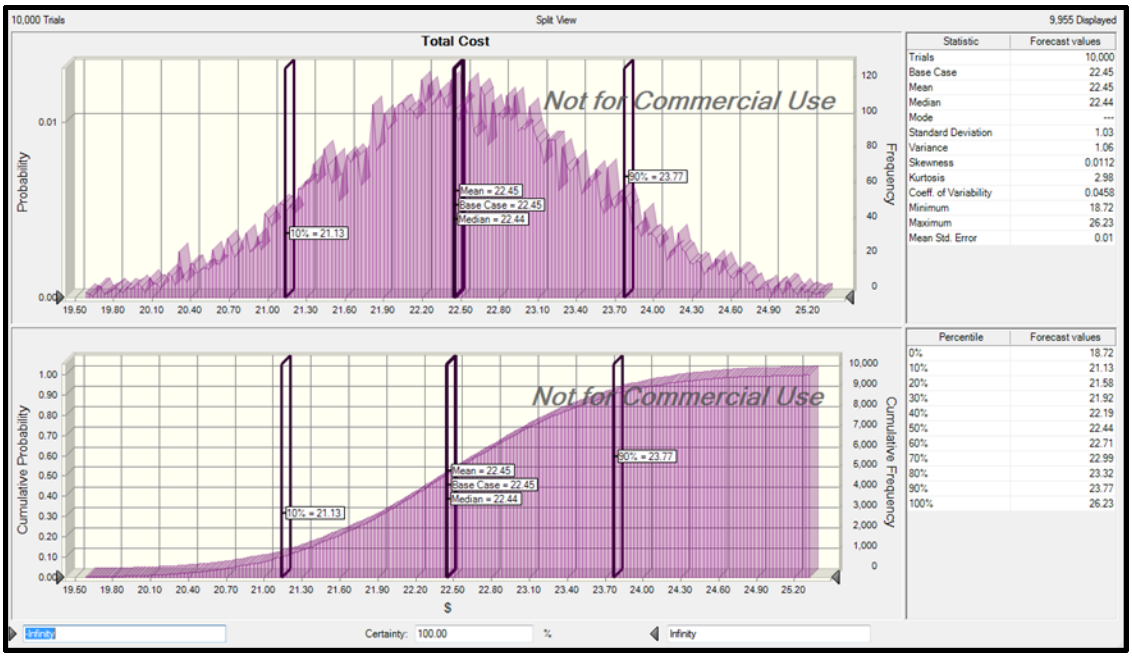
Current approaches for evaluating and planning national energy mixes consistently bias in favour of risky fossil alternatives. Whereas by understating the true value of wind, solar, and similar fixed-cost, low-risk, passive, capital-intensive technologies. The evidence indicates that such technologies offer a unique cost-risk menu along with other valuable attributes that traditional valuation models cannot (Awerbuch, 1995). The evidence further suggests that fixed-cost renewables cost-effectively hedge the fossil price risk as compared to standard financial hedging mechanisms (Bolinger et al. 2004).

The total cost of the portfolio is the sum of all the levelized costs distribution (specific for each technology). Crystal Ball simulation tool, generates the total cost of the portfolio as showed in the below figures.

As a matter of fact, the cost of each power generation unit is given to the model under the normal distribution assumption of the cost distribution with associated mean and variance.

Afterwards, we generate the total cost of the whole portfolio under Monte-Carlo process based on the percentage share of each unit in the portfolio. Details of this total cost modelling process are illustrated in figure 3-12.

Total generation cost of the portfolio



Cost distribution of each power generation unit

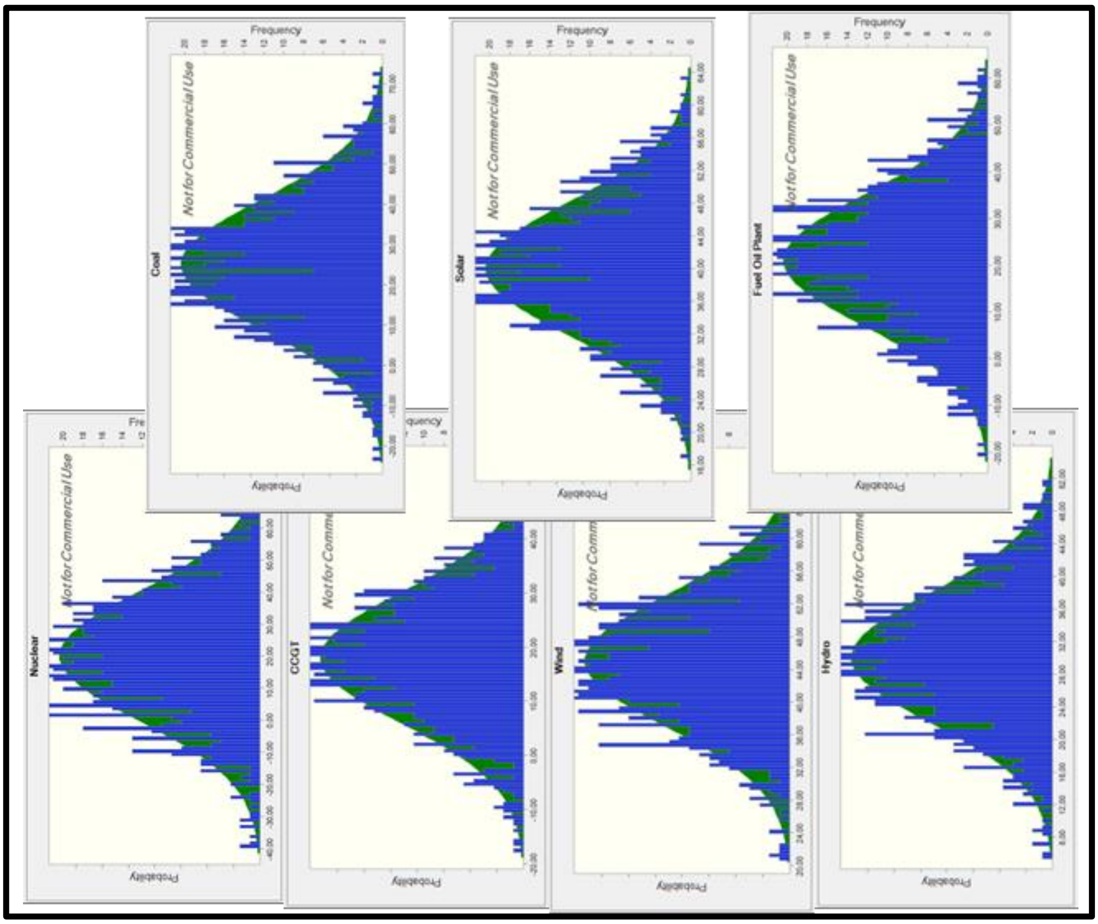


Figure 3-12

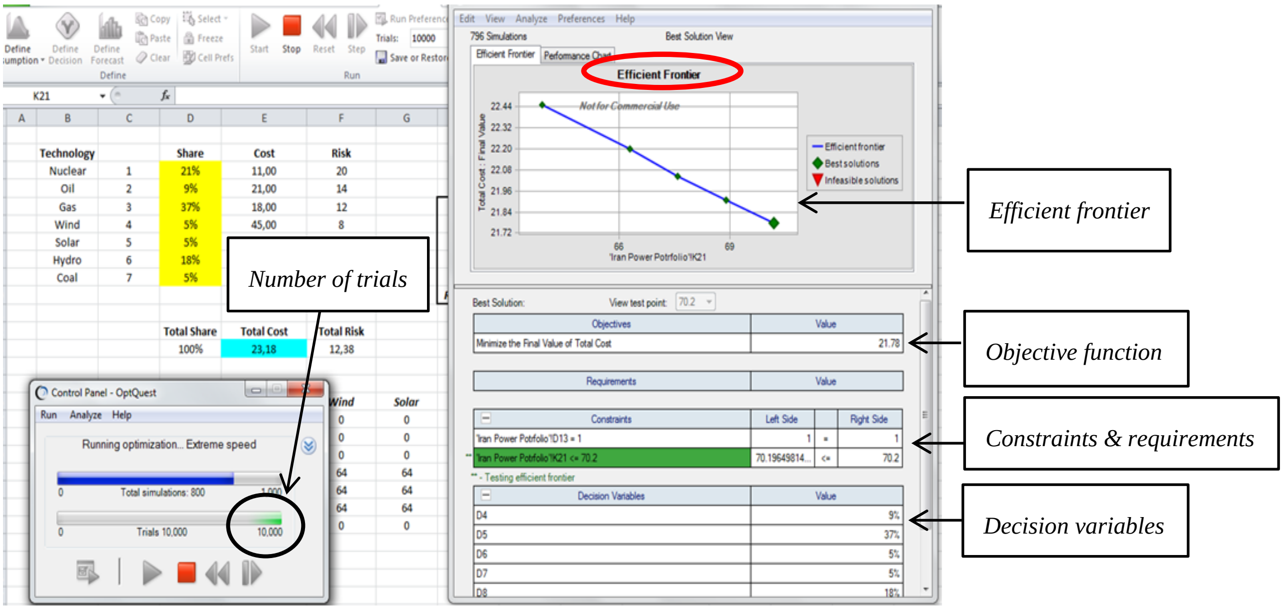
Feasible intervals for technologies' share are also introduced in the model. Intervals are defined according to the techno-economic feasibilities for each power unit. For example, the upper bound of hydroelectricity cannot go beyond 20% due to its saturation level in Iran. Technologies' share-bounds of all power units used in the model are given in table 3-2.

Decision Variable	Lower Bound	Base Case	Upper Bound
Coal	1%	5%	10%
Gas	30%	40%	80%
Hydro	10%	20%	20%
Nuclear	2%	15%	40%
Oil	10%	10%	40%
Solar	1%	5%	30%
Wind	1%	5%	50%

Table 3-2

Model's Result and Optimal Portfolios

After running the model for around 10,000 trials (iterations), we obtain the following efficient frontier (figures 3-13 and 3-14) for the various generation mix portfolios for the Iranian mix.



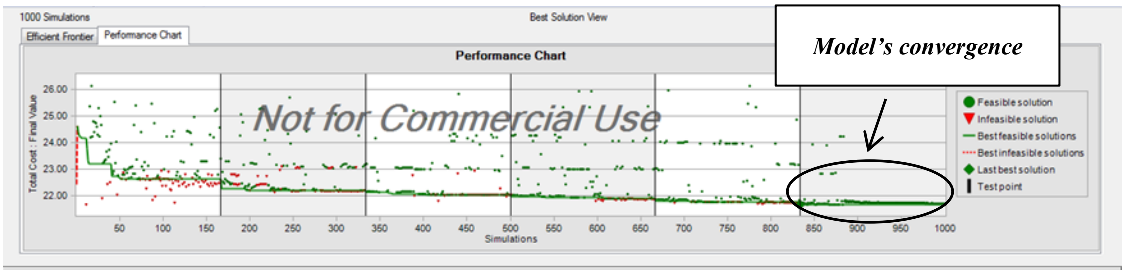


Figure 3-13

Each point on the efficient frontier represents an optimal generation mix scenario based on its related generation total cost and risks. Results show us that the least risky portfolio of power generation has the total cost of electricity generation equals to 26.35 USD/MWh. Least risky portfolio has the largest possible share of hydroelectricity and solar power units while fossil fuel technologies have the least possible shares. In this case, nuclear power share stays at 11%. On the contrary, in the least cost portfolio, at around 13.8 USD/MWh with two times riskier portfolio, nuclear and gas power plants shares are respectively equal to 35 and 36 per cents. Renewable resources, both wind and solar, are at their minimum levels. A comparative analysis of these two max and min costs portfolios, illustrates the impact of the non-fossil power units integration into the national generation mix. The more we decarbonize the mix (via renewables and of course up to the upper bound limit), the less risky portfolio we have.

However, strong penetration of non-fossil power units in the system can increase significantly the total cost of the power portfolio. Central planner can choose among all the possible portfolios on the efficient frontier according to its risk aversion.

In the second step we place the current portfolio of the Iranian power generation mix (data available in figures 3-2 and 3-3) on the cost-risk graph (figure 3-13).

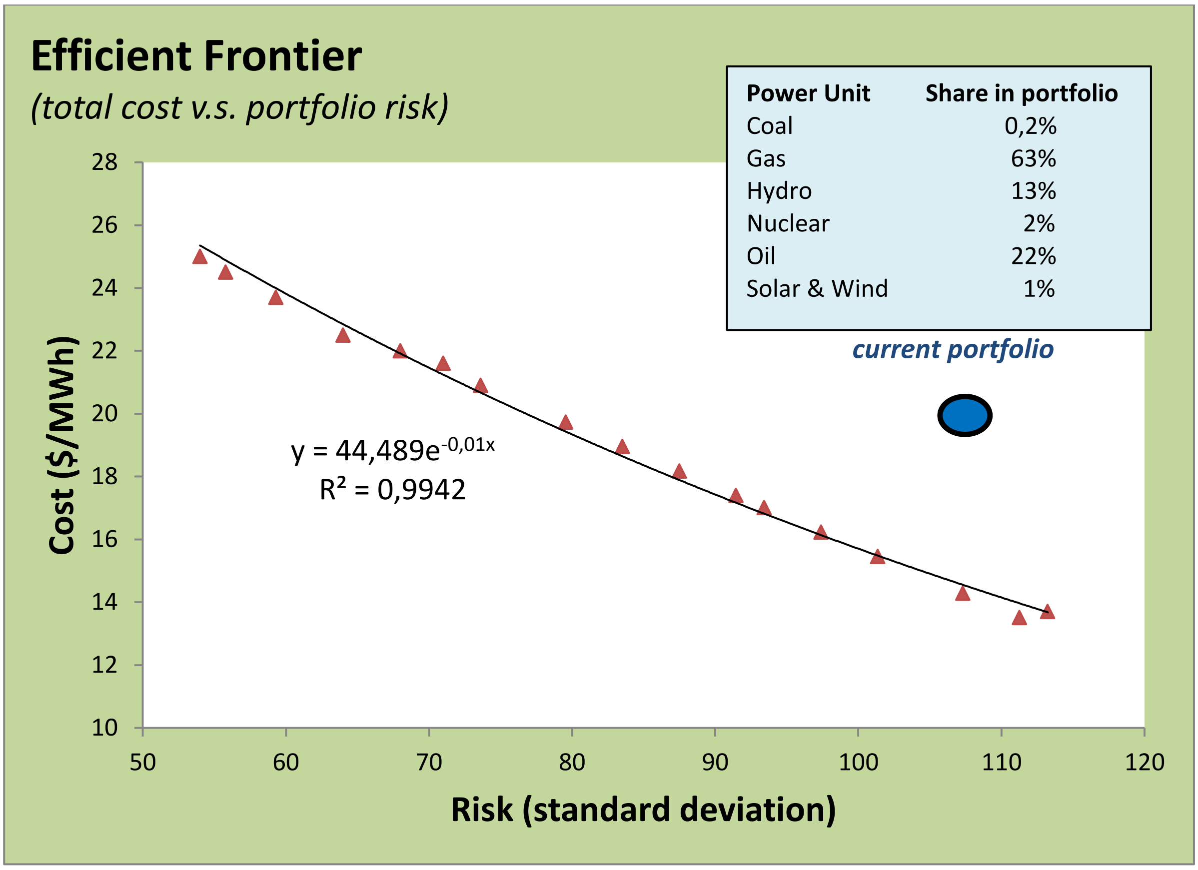


Figure 3-14

We can see that the current Iranian portfolio is not situated on the efficient frontier constructed by the model. Central planner can bring the portfolio to the efficient and optimal frontier by running a trade-off between risk and total cost. Iranian power portfolio could become at least 20% less risky under the current generation cost by following the constant-cost path (trajectory 1 on the figure 3-15) for reaching the efficient border.

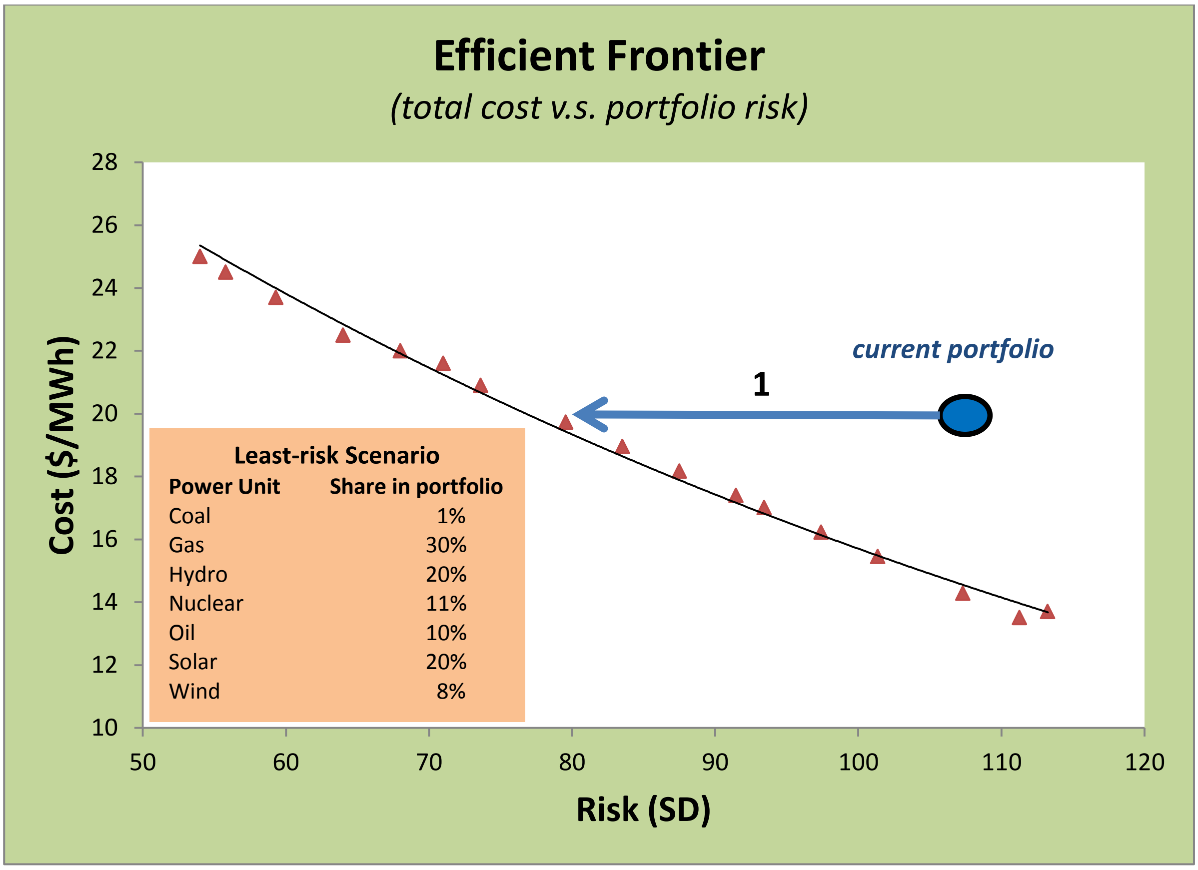


Figure 3-15

This action implies an increase of non-fossil power units share up to 30% in the generation mix (with at least 11% of electricity coming from nuclear). Fuel oil power plants share must be reduced up to 40%, half of their current share. And in case of coal power units, the situation is less dramatic as the model suggests even a small increase of its share up to 1% of the total mix which can be explained by the tendency of the model to raise the diversity of the portfolio and consequently reducing the total risk.

Trajectory 1, is the most risk-averse way of optimizing the Iranian portfolio while there are plenty other existing trade-offs among various risk and cost values. Trajectories 2 and 3 are other examples (figure 3-16). If the planner follows path 3, it will lead to the least cost scenario in which the share of nuclear energy should reach the maximum upper limit and the natural gas units take over just after. What we recommend as the most economic rational solution is the path 2 which is the median case and contains a fifty-fifty trade-off between risk and cost.

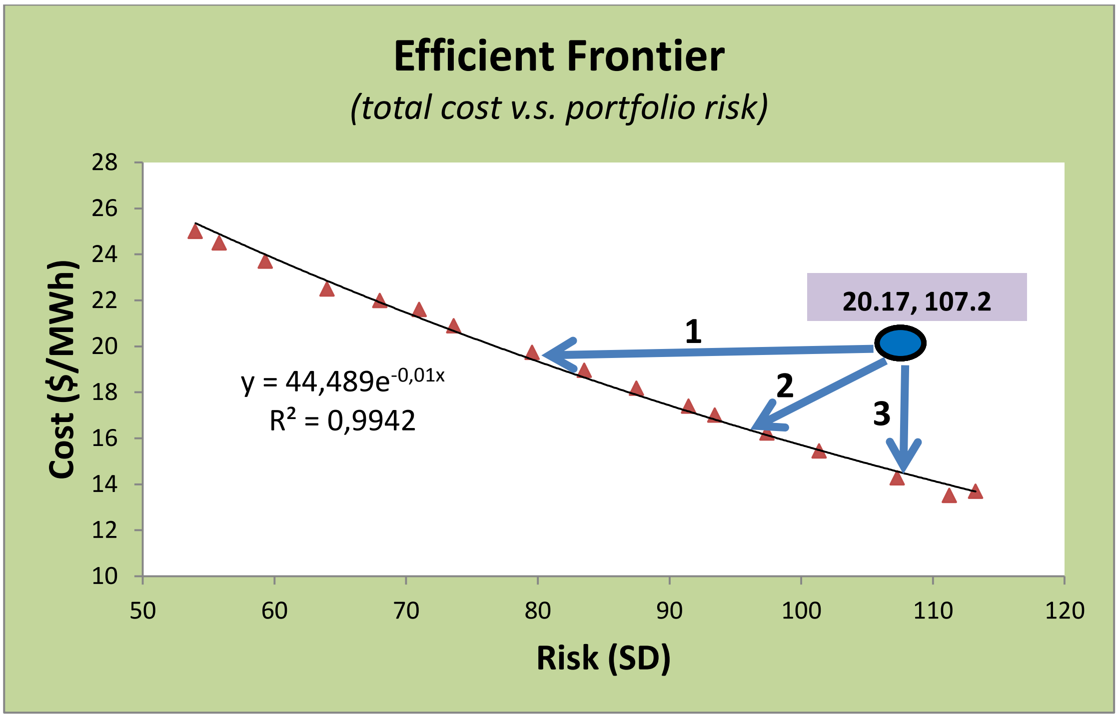


Figure 3-16

Summary of the power generation mix structure of three above-mentioned portfolio possibilities and the current one, are given in table 3-3.

Power Generation Units	Current Portfolio	Least-Cost Scenario	Median Case	Least-Risk Scenario
Coal	0.2%	3%	2%	1%
Gas	63%	36%	33%	30%
Hydro	13%	19%	19%	20%
Nuclear	2%	31%	19%	11%
Oil	22%	9%	10%	10%
Solar	0.05%	1%	12%	20%
Wind	0.05%	1%	5%	8%

Table 3-3

We also performed a sensitivity analysis over the fossil fuel price used in the energy system model. We did it for 30% of oil price variation in the international markets compare to our initial input. This will obviously impact the variable costs of power generation in our fossil based power units. As already analysed in the earlier sections of this paper, oil price variation will also influence the price of other fossil commodities. This in not only the case of natural gas price, which is mainly indexed on oil price, but also that of coal and natural uranium whose prices are in correlation with the oil price.

Fuel price sensitivity analysis was done for the whole portfolio and for every new price assumption. We run the simulation and optimization model so as to generate the new efficient frontiers of our power generation portfolio. For the same reasons explained above, we are mainly interested in the median case. Structures of each optimal electricity generation portfolio are given in table 3-4 under various oil price variation assumptions.

Power Units	Δ$ Oil (-30%)	Δ$ Oil (-15%)	Median	Δ$ Oil (+15%)	Δ$ Oil (+30%)
Coal	0.25%	1%	2%	1.5%	1%
Gas	60%	51%	33%	29.5%	20%
Hydro	16%	18%	19%	20%	20%
Nuclear	3%	9%	19%	22%	30%
Oil	20%	13%	10%	6%	2%
Solar	0.5%	6%	12%	14%	17%
Wind	0.25%	2%	5%	7%	10%

Table 3-4

The results show that the increase of oil price can highly promote the non-fossilisation of our power generation portfolio. For instance, in case of 30% increase in the oil price the shares of natural gas and fuel power units in the system can decrease respectively by 16 and 10 per cents. Nuclear and solar power units would be the most optimal and cost-risk efficient production means. Nevertheless, the model still recommends 2% of fuel power units as these units can provide energy diversity and reliable back-up power for intermittent renewables in the system.

On the contrary in case of oil price decrease, the model suggest significant amount of gas and fuel power stations. But still the share of the natural gas in the system is less than that of the current portfolio (63% of gas) which is situated very far from the efficient frontier. This also the case for the power units run by fuel. Finally in this case, we can observe a dramatically decrease of the nuclear and renewable shares. Still their shares are not equal to zero as the model has always the tendency to bring energy diversity and security in the system. To conclude, we can say that under the oil price decrease assumption, the optimal mix would be pushed toward more fossil-based structures consisting highly inter-connected fossil fuels (oil, natural gas and even to some extent coal).

Moreover, higher oil prices in the international markets (and consequently higher natural gas prices) brings more export opportunity for Iran and vice versa. This can also accelerate the impact of oil price variations on the electricity mix structure of Iran. However, we must add that the natural gas export has recently become a very strategic matter due to its geopolitical and technological perspectives. And Iranian energy authorities have always announced keeping this issue as a priority whatever the opportunity cost of natural gas monetization would be elsewhere in other domestic usages, except as feed for petrochemical units providing products also ready for export.

Lastly, we also integrated the CO_2 costs of 10, 15 and 20 €/MWH in the model. The results for each CO_2 cost integration compare to the median optimal scenario without carbon price are given in table 3-5.

Power Generation Units	No CO_2	CO_2 at 10 €/MWh	CO_2 at 15 €/MWh	CO_2 at 20 €/MWh
Coal	2%	1%	0.7%	0.2%
Gas	33%	26%	21%	17%
Hydro	19%	19.2%	19.5%	20%
Nuclear	19%	26%	31%	34%
Oil	10%	6%	4.5%	2%
Solar	12%	15%	16.3%	18%
Wind	5%	6.8%	7%	8.8%

Table 3-5

The results show that CO_2 cost reacts and influences the power system in the opposite direction of oil price variation. Except for the case of coal which is not recommended neither in case of oil price increase nor CO_2 high costs. We can conclude that a proper CO_2-cost integration in the system cannot only provide environmental benefits but also dampen the vulnerability of the electricity mix against oil price fluctuations. Yet, there is not still any solid CO_2 reduction policy concerning the power generation sector and for the time being the main focus of Iran in terms of environmental issues is rather on the transport sector than others.

Conclusion

Today's dynamic and uncertain energy environment of Iran needs planning procedures that accommodate risks and de-emphasize stand-alone electricity generating costs. Procedures that can reflect the cost inter-relationship among various generating alternatives. In this work we attempted to construct the efficient portfolio of national power generation for the Iranian electricity sector. This was done under Mean Variance Portfolio (MVP) approach of Markowitz theory, fully explained throughout the text.

Mean-variance portfolio theory that we applied in our analysis is well tested and ideally suited to evaluating national electricity strategies. The MVP framework offers solutions that enhance energy diversity and security and are therefore considerably more robust than arbitrarily mixing technology alternatives. MVP illustrates that the typical Iran gas and fuel generating portfolio offers little diversification. While it may insulate from random risk, such as Iranian nuclear issues, it provides little insulation from the systematic risk of oil and gas price movements, which have historically been highly correlated[2] and can dramatically impact the export revenue of the country and opportunity cost of electricity generation.

Given the high degree of uncertainty, the relative value of generating technologies must be determined not by evaluating alternative resources, but by evaluating alternative resource portfolios. Energy analysts and policy makers in oil producing countries face a future that is technologically, institutionally and politically complex and uncertain. In this environment,

[2] Increasing use of contracts may mitigate this historical relationship by pricing each fuel more on the basis of its costs. However, history suggests that when shortages for a particular fuel occur, the cost of alternative fossil fuels rises. This is also the case in hydrocarbon producing countries.

MVP techniques help establish renewables targets and portfolio standards that make economic and policy sense (Jansen, 2004). They also provide the analytic basis policy-makers need to devise efficient generating mixes that maximize not only the national revenue but also the system security and sustainability. MVP analysis shows that contrary to widespread belief, attaining these objectives need not increase cost. In the case of the Iranian national power generation mix, increasing the non-fossil share, even if it is believed to cost more on a stand-alone basis, reduces portfolio cost-risk and enhances very high energy security. The results revealed that the current Iranian generation mix is far from the optimality in terms of cost and diversity. In fact, according to our model's outputs, there is a huge potential of improvement in costs and risks reductions (respectively 15 and 10 per cent) by going toward more non-fossil fuel based portfolios of power generation.

However, any sort of aggressive strategy concerning both cost and risk reduction process, is not recommended as they are negatively correlated to each other. Massive investment in nuclear and other non-fossil resources would highly increase the portfolio's costs and can make the Iranian power sector very vulnerable against technological risks even if the impact on the energy security risk reduction could be very significant. Besides, relying on the current investment trend in the fossil power units can harm the Iranian power sector seriously by increasing the total risk of electricity generation portfolio. Moreover, this will also lead to substantial reduction of hydrocarbon export, as the domestic demand of oil and gas for power generation will continue to rise.

A compromise between fossil and non-fossil sources of power generation would be the most efficient solution for Iran. In the short and medium term Iran should continue to invest in both types of power units while gradually decrease the share of fossil units in the generation mix until reaching the optimal values. Both nuclear and renewable (wind and solar) power plants should gradually become more and more present in the national electricity portfolio of the country. However, this should happen under the condition that the nuclear power units' costs per MWh become at the normal and internationally acceptable rates. If the nuclear costs continue to stay at the same levels as of the first Iranian nuclear power plant in Booshehr (30 years of construction time and tripled investment costs), this conclusion would be totally irrelevant and inconsiderable from economic point of view. But under any circumstances, investment in solar power must become the priority of the Iranian authorities as Iran with its vast desert areas can benefit from very smooth and reliable solar firms.

Last but not the least, it should not be disremembered that this gradual non-fossilization of the Iran's generation portfolio must be fulfilled in parallel with a solid and efficient policy regarding the decrease and eventually total removal of fossil fuels subsidies.

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