An economic assessment of Sea and Pipeline transport of Natural Gas between the Russian Federation and South Korea

Abstract

Natural Gas consumption is increasing with the expansion of the global economy and greater awareness of alternative energy sources. However, compared to pipeline transport, the movement of Liquid Natural Gas (LNG) using dedicated LNG vessels has cost disadvantages over short and medium delivery distances, as the transport costs using ships over such distances is proportionally higher. While there has been research focused on analysing the economic and ecological feasibility of using pipelines for the transit of Natural Gas, most studies have concentrated on the advantages and benefits of using pipeline only. It is however important to consider other possible transport options, and the cost efficiency of using LNG shipping and pipeline combinations may offer significant economic benefits.

The objective of this paper is therefore to provide an analysis of transport costs for the alternative options available using sea transport and pipeline combinations to transport LNG. This paper assesses the comparative costs of a series of route combinations from Sakhalin in Russia to South Korea using sea transport and pipeline both separately and together. The research uses five empirical, data based case studies for an investment appraisal of each route to fulfil the research objective. Capital investments for the entire life of the transport assets are considered in order to take into account all cash inflows and outflows. In order to calculate and compare returns on investment, the indicators selected are discounted using cash flow analysis and net present value, being standard methods of investment appraisal.

Keywords: Pipeline, water freight transport, Natural Gas, investment appraisal.

1. Introduction

Traditional energy sources play a major role in economic activity (Kang 2009). However concerns regarding the negative effects of such energy sources, particularly environmental factors, place an increasingly significant constraint on economic activity (Mahlia et al., 2012) Further, as climate policy action has increased there has been an increase in the use of Natural Gas in the overall energy mix (International Energy Agency 2011). Natural Gas, when burned, generates only half of the CO_{2e} emissions in comparison to the CO_{2e} outputs of those produced by coal and oil (Schaffer 2008; Kargbo et al. 2010). This factor, and the further expansion of the global economy, are expected to result in significant increases in its consumption (Stopford 2009).

An important factor in the delivery of Natural Gas is the mode of transport used for its delivery, that is either by pipeline or by ship. The use of Liquid Natural Gas (LNG) carriers is generally known to have considerable cost disadvantages in the case of short- and medium-haul delivery distances compared to pipeline. However, there has been little research on pipeline transport as a feasible alternative to traditional freight transport modes. Some research has been undertaken to examine the efficiency of pipelines, in particular, to estimate the economic or ecological feasibility the transit of Natural Gas (Lidskog and Elander, 2011). Most researchers concentrate on the advantages and benefits of pipeline only, despite being able to compare the running cost efficiency of combinations of shipping and pipeline on a given corridor.

A number of research studies have been undertaken to estimate the impact of macroeconomic factors on transport prices. Jonkeren et al (2011) examine the relationships between trade flows, transport prices and schedules, showing that, for instance, trade imbalances increase transport prices by a significant amount. However, little research has been undertaken to compare different transport modes and route combinations including the strategic and policy aspects of international freight transport decision making, taking account of the long-term investment implications as well as the running costs throughout the life of assets. This aspect is very relevant to any initiative which involves a radical change in the shape of the infrastructure of any logistics network, including modal shift type of initiatives which have the purpose of reducing running cost and CO_{2e} emissions.

In this paper, a financial assessment of the effectiveness of pipeline transport in comparison to water freight transport is undertaken by including running cost efficiency as well as other more long-term economic indicators. This paper also aims to assess the different combinations of pipeline and shipping by applying a full economic costing approach. The Sakhalin (Russia) – Korea transport corridor in the Natural Gas sector has been selected for this purpose. The research considers five scenarios for the transport of Natural Gas that involve the movement of LNG by sea, pipeline Natural Gas (PNG) or a combination of both. The literature on multimodal transport and the trade and transport of Natural Gas worldwide provides the research foundation. Subsequently, the methodology adopted to undertake the research is justified. The paper concludes with a discussion on the theoretical contribution of the paper, the main findings and implications for theory and practice.

2. Multimodal Transport

It has long been recognised that transport forms a major part of logistics and that, in turn, successful transport operations can be critical to supply chain efficiency both for inbound freight, such as components supply, and outward finished products distribution. For short-distance transport, especially internal land-based transport, solutions are usually clear-cut and simple; but over medium to long hauls modal combinations can be varied and complex. Over long to very long distances a wide range of influences come into play in determining freight routeing, and mode, method and carrier choice (Beresford , 1999). The economies of the various transport modes: air, sea, waterway, rail road and pipeline, form the basic framework for freight carriage and for supply chain structure optimisation from a transport perspective (Stopford, 2009). Indeed, the ever decreasing pro rata unit costs over time of shipping, derived primarily from steadily increasing ship size and from parallel developments in cargo unitisation and containerisation, have been cited as decisive components in the globalisation of the world economy (Dicken, 2007).

Traditional literature has shown that transport systems facilitate the large-scale shipment of general cargo over long distances and the adoption of approaches which were entirely different from those which were previously dominant. Transport and logistics research has, in the recent past, focused on how modes can be best combined to produce, least-cost, least-distance or least-time solutions; more subtly, solutions could now also involve ‘packages’ that could be tailored to particular requirements. Despite revolutionary changes in transport the literature has often emphasised modal indifference (Baumol and Vinod, 1970). Blauwens and Van de Voorde (1988) looked at the underlying decision-making process in choosing between using road haulage or inland waterway in continental Europe, confirming that time savings were valued more highly than the role of working capital. Likewise, Kaatama (1990) highlighted key considerations in the movement of goods and showed that financial cost persists as the most important consideration, but speed, service reliability and in some cases damage can be almost as important. Baumol and Vinod (1970) developed a ‘modal indifference curve’ which enabled the attributes of different modes to be evaluated in a simple trade-off analysis.

In these conventional approaches to modal decision-making it is apparent that ‘trade-offs’ were treated in what would seem to be an over-simplistic way, for example volume against value or weight against volume. What traditional approaches did not consider in a sophisticated way was that other factors may also form an important consideration in any cargo routeing or transport decision made. In a related area, Jonkeren et al (2011) examined the relationships between trade flows, transport prices and schedules, showing that, for instance, trade imbalances increase transport prices by a significant amount. Although both are case study based, their findings are relevant to this paper as they demonstrate the sensitivity of trade to routeing and transport choices. A parallel thread of research has been the analysis of the carbon footprint of a particular transport solution, recently explored by, for example, Leonardi and Browne (2009, 2010). However, one of the factors which had a major influence on radical changes/modal shift to international transport infrastructure is the investment required in these types of changes. However, the vast majority of studies in the multimodal transport literature have not considered the investment cost which can be incurred in modal shift programmes which require radical changes to the transport infrastructure of a particular corridor. This paper aims to address these shortcomings.

3. Water versus Pipeline for Natural Gas Transport

In the trade of Natural Gas worldwide, most of the freight movements involve either pipeline or water freight transport. Water and pipeline are widely utilised for international and transcontinental Natural Gas cargo transport. However, in most of the Asian transport corridors, Natural Gas is transported by sea, in the form of LNG, rather than by pipeline.

For the transport of Natural Gas, Methane the main raw material of Natural Gas is condensed at a temperature of below -161.5˚C into a liquid, namely LNG. The volume of liquefied Methane reduces to 1/600th in comparison with Methane gas, and its specific gravity decreases to around half that of crude oil (see e.g. Clarkson, 2012). Due to such extreme conditions required to maintain Methane as a liquid it needs to be transported in refrigerated tanks and rapidly to its destination. Thus the main cost disadvantage of LNG is that it requires being stored at extremely low temperatures. Furthermore, typical modern LNG tankers with a steam turbine engine or diesel are sailing at approximately 19 knots. When LNG arrives at a port where there is re-gasification plant, the LNG is returned to its gaseous state, and is then supplied to a local pipeline or power utility system for customers. Thus, in the trade of LNG there is a need for the construction of infrastructure which has high investment cost implications, making the LNG trade an extremely capital-intensive industry. The LNG business has thus generally been executed with long-term contracts, fixed prices and contracted quantities (Shin et al. 2009; Stopford 2009).

According to British Petroleum (2012), almost two thirds of the trade movements of LNG in 2011 occurred in the Asia Pacific region (Table 1) and the LNG trade accounts for 28% of the world trade of Natural Gas. In 1989, only eight countries imported LNG, but by 2009 this had increased to 22. However in spite of the rise in importing countries the larger volumes remain with the traditional importers. The top four importing countries; Japan, South Korea, United Kingdom and Spain accounted for 62.2% of total rate of LNG movement. LNG exports have had a similar trend, with almost 70% of world exporting volume being accounted for by the top exporting countries including Qatar, Malaysia, Australia and Nigeria (British Petroleum, 2012). One of the main reasons why the LNG trade has been focused on a few countries is that those countries are easy to access by sea, while the Russian Federation and many European countries do not have the necessary port infrastructure (Bang, 2011). Further, exporting countries tend to prefer LNG transport, mainly because larger ships can lower the cost of transport and significantly increase the economies of scale for transport. Also, although typically there are long-term contracts between importers and exporters, sea based LNG transport has a considerable advantage due to the high degree of flexibility in routeing compared to that through fixed, and thus rigid pipeline systems (Jung et al., 1997; Bang, 2011). The significant degree of flexibility offered by LNG shipping is thus highly relevant in times of high demand fluctuations.

When Natural Gas is transported in its normal state (no need for liquefaction) from the point of production to the point of consumption through pipelines it is referred to as Pipeline Natural Gas (PNG) (Jang et al. 2005). The trade of PNG has grown considerably since the 1970s and as Table 1 shows, PNG accounted for approximately 70% of world gas trade in 2011 (British Petroleum, 2012). Although LNG ships currently carry a significant proportion of Natural Gas worldwide the main reason for the rise in PNG trade has been that the use of pipelines is more economically feasible in the long term,. In the Natural Gas supply chain, the transport process is of considerable importance, because Natural Gas resources are often located in less accessible locations. Hence, cross-border and transcontinental transport has accelerated with the increase in global trade (Bang 2011).

The trade of Natural Gas via pipeline is uneconomic over long distances, contrary to the LNG trade, and there are many PNG trades from the Middle East and the Russian Federation to Europe. Almost all European countries import Natural Gas produced in the Russian Federation, because their geographical location and the land accessibility of Europe in relation to the Russian Federation (Szul, 2011). A pipeline network has existed for many years supplying Europe with PNG produced in the Russian Federation (Bang 2011).

Table 1: Gas trade in 2011 (billion cubic metres)

World region	**Pipeline imports**	**LNG imports**	**Pipeline exports**	**LNG exports**
North America	128.8	17.4	128.8	2.0
South & Cent. America	15.6	10.9	15.6	24
Europe	368.7	90.7	180.9	5.3
Former Soviet Union	101.0	0.0	269.5	14.4
Middle East	31.6	4.6	28.3	130.4
Africa	5.7	0.0	42.7	56.9
Asia Pacific	43.2	207.3	29.0	360.8
Total exports	**694.6**	**330.8**	**694.6**	**330.8**

Source: Adapted from British Petroleum (2012)

In addition, in Europe, there are a large number of planned pipelines in comparison than the number of planned LNG port terminals (Szul 2011). This is a trend that should be considered for future decision making of selecting between PNG and LNG in other world regions.

On the other hand, in South and Central America, and Asia Pacific, the PNG-based trade is almost non-existent (British Petroleum, 2012). Furthermore, in the specific case of the Asia Pacific region, the construction of pipelines for Natural Gas trade between nations is less than Europe, since there are no major Natural Gas reserves (Bang, 2011). It expected that if Asian Pacific-based planned construction projects are executed, the demand for PNG would increase. For example, even though China has traditionally imported Natural Gas from Central Asia and the Russian Federation due to their large PNG demand, China has recently imported Natural Gas from less traditional sources, such as Turkmenistan. Moreover, they have entered into an import contract of PNG and commissioned the construction of a pipeline from Myanmar to Kunming (Hutapea, 2010). Even though there are several construction projects between the Russian Federation and Asia Pacific countries, there has been little academic research on the comparison of pipeline and shipping alternatives in the multimodal transport literature.

4. Methodology

This research takes a case study approach. As Yin (2009) states, case studies can be used to assess the relationship of two or more variables and throw light on complex problems. In this paper, the core problem is the complex decision-making process of selecting the most financially viable option for the transport of Natural Gas in the Russia Federation - Korea corridor. There are a number of valid reasons why the Russian Federation - Korea corridor was selected. Firstly, Natural Gas pipelines represent a significant proportion of the total commodities traded and transported via pipeline worldwide. Second, as has been already been discussed, Russia is a major exporter of PNG and the Asia-Pacific region is the major importing region for LNG. Third, there has been little research focusing on economic assessments of corridors where both shipping and pipeline are available as viable modes of transport. Hence, a quantitative assessment of a representative Natural Gas corridor is needed in order to clarify the main economic drivers involved in the decision-making process for choosing the most financially feasible option. A further reason why the Russian Federation - Korea corridor was selected is that it is one of the ten pipelines planned between the Russian and the Asia-Pacific region. As Table 2 depicts, this particular pipeline project is the second biggest in distance terms and the largest in terms in terms of volume.

This paper assesses the full economic cost of the corridor. According to the World Bank (1996) the factors used for determining the competitiveness of PNG relative to LNG are capital expenditure and operating expenditure. On the cost side, the main decision-making factors are distance and the volumes transported from origin to destination (Table 3). If Natural Gas is transported over short distances, PNG movement offers significant advantages over LNG movement. On the other hand, LNG is generally selected for long distances, because there are more transport-based economies of scale, in particular in the process of liquefaction of Natural Gas to LNG and all the associated investment and operating costs involved in this process (Cornot-Gandolphe et al., 2003). According to the World Bank (1996), transport costs via pipeline were $3.41/mmbtu over 3,800km of distance and volumes of five million tonnes, $2.51/mmbtu for ten million tonnes and $1.75/mmbtu for 20 million tonnes. The transport cost for LNG decreases from $3.62 to $2.72 for the same distances and volumes. The breakeven point where LNG transport becomes more financially viable than PNG transport is approximately 4,500 Km when the volume transported is 5 million cubic metres; nevertheless, if the volume transported per year is larger, the breakeven distance can be much greater.

Table 2. Natural Gas Pipeline Construction: Russia Federation – Asia-Pacific corridors

Departure	**Destination**	**Gas field**	**Distance (Km)**	**Volume (Mscfd)**	**Operation Year**
Iran	Pakistan	South Pars	750	2,118	2018
Pakistan	India	South Pars	760	1,059	After 2020
Malaysia	Philippine	Sabah	500	350	After 2015
Myanmar	China(Kunming)	A-1, A-3 blocks	1,308	1,161	After 2012
Russia	Japan	Sakhalin-1	1,950	1,000	After 2020
Russia	China(Beijing)	Sakhalin-1	2,200	1,000	After 2015
Russia	China(Shanghai)	West Siberia	6,500	3,200	After 2015
Russia	**South Korea**	**Sakhalin-3**	**2,957**	**10bmc/y**	**After 2015**
Turkmenistan	China	Bagtyyarlyk	1,833	967	2012
Turkmenistan	India/Pakistan	Daulatebad	1,700	1,500	After 2015

Source: Adapted from Bang (2011)

The research was conducted by undertaking five scenarios based on an investment appraisal assessment. These five scenarios are described in Table 4. Initially, all the capital costs and running costs were calculated based on data provided by the companies involved in the project. The main contributor to the research project was the Korea Gas Corporation. The company provided reports from 2011 and several interviews were conducted with the managers in charge of developing the Russian Federation - Korean pipelines. Table 5 depicts the capital costs of the five scenarios. In the calculation of these capital costs, for scenarios 4 and 5 in particular, it is assumed that there is no need for an additional pipeline-related investment cost due to the existence of a pipeline in the Russian Federation. Table 6 shows the running costs for scenarios 1, 2, 4 and 5 and Table 7 depicts the running costs incurred in scenario 3.

Table 3: Comparison of transport cost ($US) per unit volume

Volume (million cubic metres)	**Method**	**Distance (km)**		
		1,200	**3,800**	**7,600**
5	LNG	23.05	3.62	4.26
	Pipeline	0.99	3.41	7.80
10	LNG	2.58	**3.16**	4.01
	Pipeline	0.74	**2.52**	5.65
20	LNG	2.21	2.78	3.55
	Pipeline	0.54	1.75	3.89

Source ; World Bank 1996

Table 4: Description of the five scenarios included in the assessment

Scenario	**Route**	**Route**	**Transport mode**
1	Sakhalin - Pyeongtaek	Water	LNG tanker
2	Sakhalin - Tongyeong	Water	LNG tanker
3	Sakhalin - Vladivostok - North Korea - Pyeongtaek	Pipeline	Pipeline
4	Sakhalin - Vladivostok - Pyeongtaek	Water and Pipeline	LNG tanker and Pipeline
5	Sakhalin - Vladivostok - Tongyeong	Water and Pipeline	LNG tanker and Pipeline

In terms of the calculation, the capital investment of the entire life of the assets acquired has been considered to take into account all cash inflows and outflows. In order to calculate and compare returns on the investment required in the five scenarios, two investment appraisal criteria were chosen. The investment appraisal techniques adopted in this study were Discounted Cash Flow (DCF) analysis and the Net Present Value (NPV), since they are the most straightforward method of investment appraisal since a capital project should only be commissioned if the cash invested in the capital project exceeds the opportunity cost of the investment (Lumby and Jones 2002; Bhimani et al. 2008).

Table 5: Summary of the capital costs of the five scenarios (US$)

		Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**
Initial capital	**Ship**	215,600,000	215,600,000		215,600,000	215,600,000
	LNG plant	10,000,000,000	10,000,000,000		10,000,000,000	10,000,000,000
	Pipeline			3,273,000,000		
Equity	**Ship**	43,120,000	43,120,000		43,120,000	43,120,000
	LNG plant	4,000,000,000	4,000,000,000		4,000,000,000	4,000,000,000
	Pipeline			1,309,200,000		
Loan	**Ship**	172,480,000	172,480,000		172,480,000	172,480,000
	LNG plant	6,000,000,000	6,000,000,000		6,000,000,000	6,000,000,000
	Pipeline			1,963,800,000		
Interest	**Ship**	137,983,997	137,983,997		137,983,997	137,983,997
	LNG plant	2,640,000,000	2,640,000,000		2,640,000,000	2,640,000,000
	Pipeline			864,072,00		
Total		12,993,583,997	12,993,583,997		12,993,583,997	12,993,583,997

Table 6: Running costs for scenarios 1, 2, 4 and 5 ($US)

	Item	Scenario 1	Scenario 2	Scenario 4	Scenario 5
Fuel		33,365,487	23,636,741	21,056,112	11,233,751
Port charge	**Prigorodnoye**	7,139,000	7,139,000	7,139,000	7,139,000
	Pyeongtaek	6,050,000	8,470,000	6,050,000	7,080,000
Administration	**Spares**	160,000	160,000	160,000	160,000
	Consumables	34,670	34,670	34,670	34,670
	Lubricant	32,000	32,000	32,000	32,000
	Sundries	166,000	166,000	166,000	166,000
	Repairs	100,000	100,000	100,000	100,000
Crew wage		2,797,232	2,797,232	2,797,232	2,797,232
Total		49,844,389	42,535,643	63,189,096	30,003,653

Table 7: Running costs for scenarios 3 ($US)

	Cost
Pipeline	65,460,000
Compressor station	114,555,000
Royalties	145,090,413
Total	325,105,413

Moreover, the time value of money should reflect any capital budgeting decisions, because the life of a project is longer than one accounting period. Hence, the capital investments, which are incurred during the entire life of the project, have been included in the study to consider all cash inflows and outflows incurred throughout the life of the assets. With reference to the DCF analysis, the time value of money is taken into consideration through the discounting process. The time value of money depends on several key factors: (1) the principal amounts, that is the investment or amount of money borrowed (2) the number of periods, that is the length of time and (3) the interest rate, that is the annual percentage charge on the investment (Lumby and Jones 2002; Bhimani et al. 2008).

For the calculation, the equations used for compound interest calculation are as follow:

(1) $S = P(1+r)^n$

Where S = final amounts,

P = principal amounts,

r = rate of interest,

and n = period of investment.

$(1+r)^{-n}$ = the discount factor

(2) $P = \frac{S}{(1+r)^n} = S(1+r)^{-n}$ f

Subsequently, in order to calculate exact future cash flows, both the rate of interest and the rate of inflation must be taken into account for estimating the discount factor. The discount factor then becomes:

(3) $DF = [(1+r)(1+rp)]^{-n}$

rp = rate of inflation

n = time in years

For the estimation of the NPV, the objective is to estimate the present value of all future and present costs and revenues in order to estimate whether the project generates a surplus or deficit. In other words, using the given rate of return, the NPV estimates the expected financial gains or losses in a project through discounting all expected cash inflows and outflows from the point in year 0 when the investment was made. When the NPV in a project is positive, the investment required is more likely to be approved, because monetary returns exceed the cost of capital (Bhimani et al. 2008). The equations which were used for calculating NPV are given by:

(4) $NPV = A_1(1+r)^{-1} + A_2(1+r)^{-2} + \cdots + A_n(1+r)^{-i} - C_0,$

(5) $NPV = \sum_{i=1}^{n} A_i(l+r)^{-i} - C_0,$

(6) $NPV = GPV - C_0$

(7) $GPV = \sum_{t=0}^{n} A_t (l + r)^{-t}$

Where A_i = annual cash flow in year i,

r = rate of discount,

C_0 = initial capital cost,

GPV = gross present value

5. Results

In this section, the results obtained from the five scenarios are presented and the factors which influence the transport costs discussed. In this study, cost categories have been considered, namely capital, operation, and voyage cost or royalty. The literature recommends a number of cost categories in regards to shipping operations (Dykstra, 2005; Gorton et al., 2009; Stopford, 2009). These cost categories cover the running costs for a ship which involve bunker charges, port charges, and operational costs. On the other hand, the running costs incurred from operating a pipeline are related to pipeline and compressor station costs and royalties (Jung et al., 1997; Lee et al., 2003; Bang, 2011). These cost categories have been included in the study.

In this study, there is a need to analyse the transport costs over the long term. This is mainly because the future value needs to be converted into the present value at the time an investment decision is evaluated. Through the investment appraisal technique stated in previous section, the calculations of the NPV have been run for a period of 25 years. In order to estimate the present value of the five scenarios, the appropriate discount factors has to be decided with an annual inflation rate, that is normally 3% in Korea. The discount factor related to LNG methods was assumed to been 10% (taken as the standard for LNG transport projects as recommended by the Korean Gas Corporation). In contrast, there is a 12% discount factor for PNG transport project, which again is the value suggested by the Korean Gas Corporation. In practice this could of course vary but the figures are both realistic and have been used widely. The total cash flows calculated in all cost categories are multiplied by the given discount factors.

The present value without equity resulting from running the five scenarios, is illustrated in Table 8. According to the findings, there are strong similarities in the present values (PVs) of the transport combinations involving shipping. However, the PVs of the scenarios linked to an LNG ship are three times higher than scenario 3 (PNG pipeline project) where the total present value of PNG methods are estimated to be about $4.8 billion including $1.3 billion of equity. Scenarios 1 and 2, which involve traditional shipping methods, and scenarios 4 and 5, which involve pipeline and short sea shipping, all have similar results of over $8 billion. According to the results of case studies, scenario 3, the PNG option, would be the most economically feasible scenario for the transport of Natural Gas from the Russian Federation to Korea. It should be noted that this summary is focused entirely on financial measures and omits other elements, such as the level of certainty, which are potentially very important for such a key cargo.

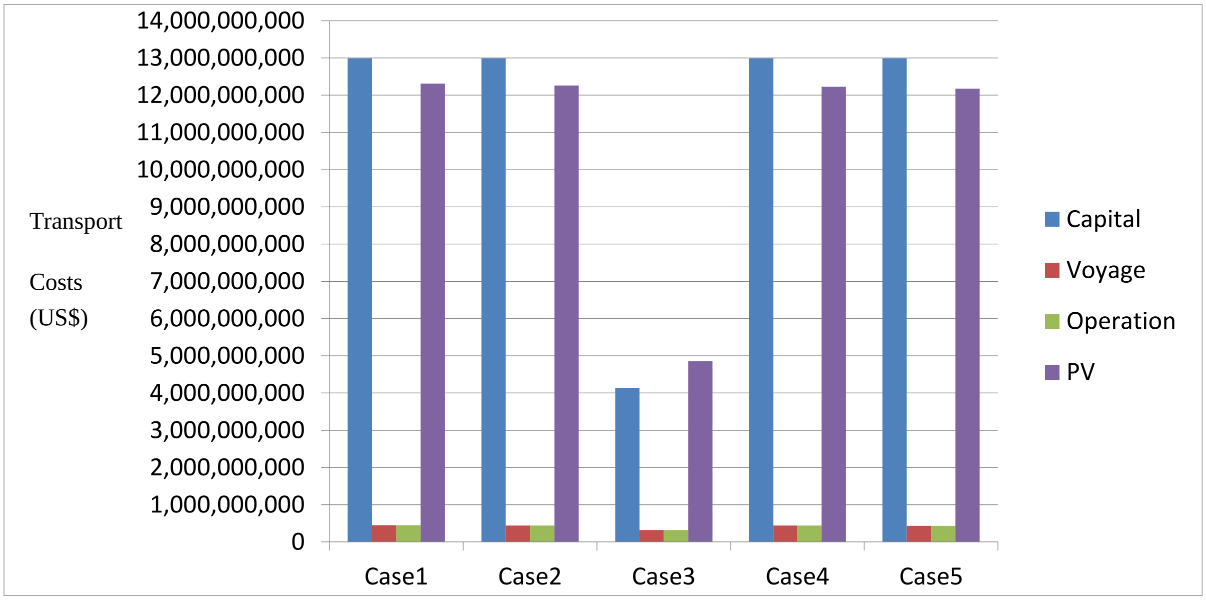
Table 8: Summary of Present Value ($US)

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**
	Shipping	**Shipping**	**Pipeline**	**Ship & Pipeline**	**Ship & Pipeline**
PV	8,272,050,433	8,219,519,845	3,545,771,617	8,183,578,517	8,129,447,918
Total PV (including equity)	12,315,170,433	12,262,639,845	4,854,971,617	12,226,698,517	12,172,567,918

In the literature review, the various factors that affect the transport cost of movements that include shipping and pipeline alternatives throughout a Natural Gas corridor were detailed. According to the scenarios run, as Figure 1 shows, it shown that the initial investment costs generated by the construction of the infrastructure required in the five scenarios account for the largest proportion of the total cost. The newly-built infrastructure required for LNG methods (in particular, the costs incurred to build LNG plants) requires higher levels of investment than the PNG scenarios. Furthermore, from the results of this study, it is shown that, for the shipping option, the voyage and operation costs are not high and they should not therefore strongly influence the decision-making process. However, this particular finding applies to the corridor study, which has a distance of just under 3,000 Km, which is lower than the breakeven distance of 4,500 Km suggested by the World Bank (1996). In the case of the Russian Federation - Korea Natural Gas corridor, the voyage and operation costs only represent about 3.5% in the case of LNG and about 8% in the case of PNG.

Considering the overall analysis above, the most efficient way with regard to the economic cost is transport using pipelines. Over a long-term period, the total present value of PNG movement is estimated at around $4 billion, even though a very high investment cost for initial infrastructure is expected to be required. In contrast, the result of LNG movements or mixed movements between LNG and PNG exceed $12 billion. Hence, it is shown that a pure PNG corridor is the most economically feasible option for the trade of Natural Gas between the Russia Federation and Korea.

Figure 1: Summary of the findings from the five scenarios in US$



Source: Authors

Regarding Natural Gas trades, current major pipelines yield not only lower operational costs per unit volume but also more reliable supply and longer asset life expectancy. According Clarkson (2012), the consumption of Natural Gas is expected to continue to increase; and for such market conditions, PNG is technically and economically feasible. This is the case for the contract of Natural Gas supply in the Russian Federation - Korea corridor, where an annual volume supply of 10 billion cubic metres has been agreed for the next 25 years. Moreover, the lifespan of the pipeline is expected to be at least 20 years after construction, but a ship is normally demolished after 25 years. Furthermore, if the present value is taken into account in the calculation of the total transport cost, the PNG alternative considered in scenario 3 is clearly the most economically feasible option.

6. Conclusions

This study contributes to both the academic and commercial understanding of the trade-offs involved in sea versus pipeline transport as it is the first attempt to assess the economic feasibility of maritime and pipeline transport modes. From a theoretical perspective, this research contributes to the multimodal transport literature in several ways. Firstly, pipeline has been included as an alternative transport mode. Secondly, a full economic cost approach has been applied in the assessment as opposed to previous multimodal transport studies. Thirdly, the study includes a commodity (Natural Gas) that has not traditionally been included in previous studies on multimodal transport. This research reveals the feasibility of Natural Gas supply to South Korea in the five scenarios considered. Previous research has focused on the advantages and disadvantages of pipeline and water transport from a conceptual perspective. This research measures the economic feasibility of each scenario based on empirical data gathered in the case study. From a practical perspective, there are still doubts relating to the cost benefits of pipelines, since North Korea has historically required a high transit fee. Nevertheless, the findings from the case study suggest that the pipeline option would be the cheaper option overall over a 25-year time period.

It is important to highlight that several assumptions have been made for running the five scenarios presented in the paper. Therefore, the findings from the study could have been different if different assumptions were applied, even though the assumptions are made based on the actual data operated by a shipping company and the Korean Gas Corporation involved in the research. For example, the voyage costs of a ship, such as bunker and port charges, were presumed as fixed during a given period, though in reality these costs are frequently changed.

In addition, in a construction project for PNG, there are various factors, other than economic feasibility – demand variability, institutional costs and funding requirements, which were not considered here. The institutional cost relates to the transit fee considered in the five scenarios studied, in particular, the tax system of resource development and the pipeline business. As well as these factors, there are considerations such as the cost of the right of way charged by North Korea that could affect the findings. Moreover, due to the fact that the construction of a pipeline requires extensive up-front funds, the state of the economy of the countries involved is key.

Thus, an obvious area of future research would be the role that uncertainty, or security, plays in the final decision concerning whether shipping or pipeline is the preferred solution for the transport of LNG into Korea given that its role in the economy is so important. Other issues which potentially could seriously affect the transport of LNG in the pipeline scenario relate to the security of supply for pipelines crossing North Korea. South Korea are unlikely to be willing to allow North Korea to have any influence on its LNG imports and to do so would be a major political decision.

Finally, it is recognised that LNG shipping primarily has advantages only over long distances and in the scenarios studied shipping is only used for parts of the distance. With the investment in liquefying/de-liquefying facilities being so large and the transport costs only being lower for shipping over longer distances, the mixed alternatives shown are more expensive than pure pipeline or shipping alternatives.

In future appraisals of pipeline viability, other important appraisal indicators can be considered, e.g. development conditions and the relationships of the countries directly involved, and factors that might be harder to measure.

References

BANG, S. (2011), A study on the Natural Gas Transit via Cross-border Pipeline and the Tariffs imposed by Transit Countries. PhD Thesis, Korea Polytechnic University.

BAUMOL WJ, VINOD HD (1970) An inventory-theoretic model of freight transport demand. Management Science 1 (6), 71 – 89.

BERESFORD AKC (1999), Modelling Freight Transport Costs: A Case Study of the UK - Greece Corridor. International Journal of Logistics: Research and Applications. 2(3), 229 – 246

BHIMANI, A. et al. (2008), Management and Cost Accounting. Essex: Pearson Education Limited.

BLAUWENS G and VAN DE VOORDE E (1988), The valuation of time savings in commodity transport, International Journal of Transport Economics 11 (1) February 1988, 25 – 42.

BRITISH PETROLEUM (2012), BP Statistical Review of World Energy for 2012, Statistical Review of World Energy.

CLARKSON. (2012), The Clarkson Shipping Review and Outlook, Spring 2012. London: Clarkson Research Studies.

DICKEN, P (2007), Global Shift: mapping the changing contours of the world economy, Guildford Press, New York, 599 pp.

DYKSTRA, D. L. 2005. *Commercial Management in Shipping.* London: The Nautical institute.

GORTON, L. *et al.* 2009. *Shipbroking and Chartering Practice.* London: Informa business.

HUTAPEA, M. (2010), Myanmar-China Brotherhood: Securing the Energy for China [Online]. Indonesia: Institute for Essential Services Reform. Available at: http://www.iesr.or.id/wp content/uploads/china-myanmar_papers.pdf [Accessed: 1st August 2012].

INTERNATIONAL ENERGY AGENCY. 2010. *World Energy Outlook 2010.* UK: International Energy Agency.

JANG, S. et al. (2005), Natural Gas storing Device and trend analysis relating to sea transport system. Seoul: Ministry of Science and Technology and Korea Institute of Science and Technology Information.

JONKEREN O, DEMIREL E, VAN OMMEREN J, RIETVEL D P (2011), Endogenous Transport Prices and Trade Imbalances, Journal of Economic Geography 11 (2011) 509 - 527.

JUNG, Y. et al. (1997), Economic Analysis of Natural Gas pipelines in the Northeast Asia. Gyeonggi: Korea Energy Economics Institute.

KAATAMA M (1990), Effect of services and security on choice of transport, for Confederation of Finnish Industries. In: Proceedings of INTRA Conference, Paris, 171 – 175.

KANG, J. 2009. *Low-carbon green growth and industry of natural gas, Spring 2009.* Gyeonggi: Korea Gas Corporation.

KARGBO, D. M. *et al.* 2010. Natural gas plays in the Marcellus shale: Challenges and potential opportunities. *Environmental Science and Technology Feature.* Vol. 44. No. 15. 5679 - 5684.

KOREA GAS CORPORATION. Supply Natural Gas [Online]. Korea: Korea Gas Corporation. Available at: http://www.kogas.or.kr/kogas_kr/html/about/about_11.jsp [Accessed: 7th January 2011].

KOREA GAS CORPORATION. Overseas business [Online]. Korea: Korea Gas Corporation. Available at: http://www.kogas.or.kr/kogas_kr/html/about/about_15.jsp [Accessed: 7th January 2011].

LEE, E. et al. 2003. Comparison of economic feasibility in terms of main gas projects in the Russian Federation. Korea: Korea Energy Economics Institute.

LEONARDI J, BROWNE M (2009), Method for assessing the carbon footprint of maritime freight transport: European case study and results, Proceedings of the 14th Logistics Research Network Conference 2009, Cardiff.

LEONARDI J, BROWNE M (2010), Allocation and calculation rules for GHG emissions in complex logistics and freight transport services, Proceedings of the 15th Logistics Research Network Conference 2010, Leeds.

LIDSKOGH, R. and ELANDER, I. 2011. Sweden and the Baltic Sea pipeline: Between ecology and economy. *Marine Policy*. Vol. 36. No. 2. 333 - 338.

LOWE, D (2005), Intermodal Freight Transport, Elsevier, Oxford, 276pp.

LUMBY, S. and JONES, C. (2002), Investment Appraisal & Financial Decisions. 6th ed. London: Thomson.

MAHLIA, T. M. I. *et al*. 2012. History and current status of the motor vehicle energy labeling and its implementation possibilities in Malaysia. *Renewable and Sustainable Energy Reviews*. Vol.16. No. 4. 1828 - 1844.

SCHAFFER M B (2008) The great gas pipeline game: monopolistic expansion of Russia`s Gasprom into European markets. *Foresight*. Vol. 10.No. 5. pp. 11 - 23

SHIN. Y. et al. (2009), Boil-off gas reliquefaction system for LNG carrier with BOG-BOG heat exchange. Journal of the Society of Naval Architects of Korea. Vol. 46. No. 4. pp. 444 - 451.

STOPFORD, M (2009), Maritime Economics 3rd Edition, Routledge, London, 815 pp.

SZUL, R. (2011), Geopolitics of Natural Gas supply in Europe-Poland between the EU and Russia. European Spatial Research and Policy. Vol. 18. No. 2. pp. 47 - 67.

YIN, R. K. 2003. *Case Study Research: Design and Methods.* 3rd ed. London: Sage Publications, Inc.