Proceedings
16th IAMU Annual General Assembly
Opatija, Croatia, 2015

Sveučilište u Rijeci
Pomorski fakultet Rijeka
University of Rijeka
Faculty of Maritime
Studies Rijeka
IAMU
International Association of Maritime Universities

TECHNICAL AND ECONOMIC STUDY OF LNG DIESEL POWER (DUAL FUEL) SHIP

Ge, Jiawei*; Li, Shengyan

Shanghai Maritime University
China

***Corresponding author**
Phone: 13564715311
e-mail: 646435645@qq.com

Abstract. LNG (Liquefied Natural Gas), a substitution of crude oil, is a clean energy and has witnessed a rapid development since its first application in shipping industry at the beginning of this century. Generally, fuel costs account for nearly 20-50% of the operation cost in a particular shipping company. Due to IMO's regulation on reduction of emissions of sulphur oxides, the required sulphur maximum content in fuel needs to drop from 4.5% at present to 0.5% by 2020 and from 1% down to 0.1% at present in Emission Control Areas (ECAs) for example Baltic and North sea. It's an urgent issue for shipping companies to cut emission and fuel consumption by using a cleaner fuel—mostly LNG to replace. Although major roadblocks still exists as lack of bunkering supply system and loss of cargo space occupied by LNG tanks, LNG as a ship fuel has great potential: Clean burning which meets all current and future emission standards, lower cost than diesel fuel and manageable vessel regulatory issues. Since pure LNG power ships are expensive in building which most carriers cannot afford, many new-buildings are LNG and diesel hybrid technology, so called dual fuel. This article mainly proposed three technically effective alternatives to satisfy the current and future emission control regulations and laws in shipping. LNG-diesel dual fuel power technology was introduced through feasibility study on several aspects including research development, retrofitting methods, vessel type, safety issues and other technical characteristics. Based on sample ship and route, I conducted economic evaluation on these three alternatives. Cost-effectiveness of each project was detailed in the calculation of net present value(NPV) and payback time via discount cash flow method. The findings show that LNG-diesel dual fuel power technology performs best among three alternatives. Due to the impact of fuel price on the conclusion, two scenarios were carried out in sensitivity analysis which witnessed a variation of NPV with the fluctuation of fuel price. 29.31% oil fuel slump and 35% LNG fuel rise are the turning point between project I and project III, left project II the least cost-effective method in three alternatives. And further study is recommended for the deficits of this article.

Key words: LNG, dual fuel, net present value

1 INTRODUCTION

Recent years has witnessed a growing attention on environment protection. Governments formulated several measures to reduce air pollution. In shipping industry, particularly, there are EN 2005/33/EC from EU Directive, MARPAL(Marine Agreement Regarding Oil Pollution And Reliability) convention made by IMO(International Maritime Organization) and CARB Title 13/17 in California USA, all of which stipulated a detailed schedule and technical guide for emission control of shipping. (See table 1)

From the picture above, we can see that this year a stricter emission control on Sulfur Oxides(SOx) has come into effect in the so called ECA(Emission Control Area) area where the sulfur content will be restricted in 0.1%, while 0.5% is allowed worldwide until 2020. What's on the way is the limitation on Nitrous Oxides(NOx) with the operation of IMO Tier III from next year, see Figure 1 below.

Under this circumstance, companies and shipowners usually have three alternative choices to overcome the environment regulations. Firstly, remain current ship state and reduce SOx and NOx emission respectively through technical means like add a scrubber and SCR(Selective Catalytic Reduction) system. Secondly, change the bunker fuel refined to lower sulfur content and add SCR system. Thirdly, using new energy like liquefied natural gas(LNG) as ship fuel. All these three alternatives are proved to meet the requirements of emission regulations and laws.[2]

North Europe is the cradle of LNG technology on board the ship. Det Norsk Veritas(DNV) ship classification society, now merge with Germanischer Lloyd(GL) as DNV·GL, is the pioneer to classify LNG fueled ships and enjoy a large share of its world fleet. However, LNG fueled ships are still a regional product due to many reasons such as lack of bunkering supply system and loss of cargo space. Most studies mainly focus on environmental, technical and economic issues.

Environmentally, LNG is acknowledged as a clean fuel with no SOx and little NOx emission that complies with all the current and future regulations. But problem occurs when applied to a normal diesel engine. The so called CH4 'slip' will increase the pollution of greenhouse gases. Only the slip controlled in 2% or less can highlight the advantage of LNG in environment protection.[2]

Technically, about the physical and chemical characteristics of LNG, Jerzy Herdzik's research found that the burning speed is too slow to use in a diesel engine directly, instead, a spark ignition engine don't have such problems.[10] However, with the increment of engine load, risk of energy loss and self-burning may rise and the jet system need to make a retrofit accordingly.

Table 1 Emission Control Regulations & Conventions

Regulations/convention	S%	Date into execution	area
MARPOL VI	3.5	2012.1.1	Out of ECA
	0.5	2020.1.1	
	1	2010.7.1	In ECA
	0.1	2015.1.1	
EU	0.1	2010.1.1	EU ports
CARB	1.5	2009.7.1	24 nm off California coast and within ports
	0.5		
	1	2012.8.1	
	0.5		
	0.1	2014.1.1	
	0.1		
S% of 1.5 and 0.5 aim at MDO and MGO respectively			

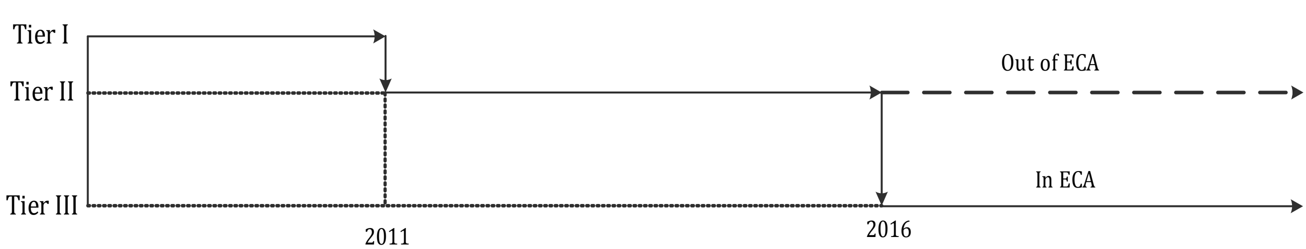

Figure 1 Time Schedule of IMO Regulation for NOx

Economically, compared with traditional bunker fuel, LNG has a lower price at most scenario and the operation cost of a ship, either. Quantitative analysis show that the annual fuel and maintenance cost may decrease by 39% and 40% with LNG instead of diesel oil.[1]In contrast with the high fluctuation of heavy fuel oil(HFO) affected by many factors like political and regional issues, LNG price is more stable from a historic view which implies LNG as a good alternative for traditional fuel.[10]

Meanwhile, Transport Research Board(TRB)'s report about LNG as ship fuel made an elaborate of the ship type, propulsion options, LNG fuel system and bunkering, operation and design of LNG fueled container ships.[3] It indicates that suitable ship types for LNG power are restricted in tug, ferry and other short route or coast sailing ships. Further, construction and equipment costs as economic analysis factors were compared between two container ships around 1000TEU, one in LNG fuel and the other in marine gas oil(MGO). Statistics show the construction cost of LNG powered ship is 20% higher than its counterpart but will be covered by its fuel cost savings and other environmental value, for example, LNG don't have to pay the carbon tax and have tax concession in some ports as an incentive.

GL ship classification society and MAN the engine builder jointly conducted a cost-effectiveness analysis of LNG as fuel on container ships with a size range from 2500TEU to 18,000TEU.[7] Four technical solution were proposed as Scrubber, Scrubber and Waste Heat Recovery(WHR) System, LNG system and LNG with WHR system. The findings shew that sailing time in ECA, price spread between LNG and oil and retrofitting cost were the main factors affecting shipowners' decision making. And when the price of LNG comes lower or equals HFO(Heavy Fuel Oil), 2500TEU container ship is in a better economic scenario.

On the other hand, the world crude oil price experienced a big slump since the latter half of year 2014 that gave breath to the depressed shipping market. The drop of crude oil price directly led to a decrease of bunker fuel taking up more than 50% of the operation cost of a liner shipping company. So price of bunker fuel immediately affects the profit of a shipping company. But there is a small probability that the fuel price stay low after this period due to the diversification of effect factors of oil price from production process to geopolitics resulting in intense price fluctuation. Companies have to find another way out to lock their cost for risk control. Then comes the application of new energies as wind, solar, fuel cell, LNG and so on. Most of which are under construction and feasibility studies that do not adapted to modern merchant shipping except LNG. Comparatively, LNG is in a more mature market as LNG carriers have existed for decades. Although major roadblocks still exists as lack of bunkering supply system and loss of cargo space occupied by LNG tanks, the application of LNG as a hybrid fuel on board is on its way in non-LNG carriers and excepted to have a prosperity in the near future.

Above all, researches about LNG as ship fuel have made progress. LNG-diesel dual fuel was accepted by the industry and expounded and proved in reality which shew better environment protection and cost-efficiency. Nevertheless, thanks to low price of oil fuel at present, environmental regulation under formulation and extra cost for new technology, LNG is only a regional solution especially in north Europe. At the same time, little studies focused on the effect of price fluctuation on cost efficiency of LNG diesel fuel ship, nor did on bigger ships. Based on these situations, this article try to make a further step on the techno-economic study about ocean transportation LNG diesel dual fuel power ships and other technical alternatives complying with present and future emission regulations and the effect price factor in these alternatives.

2 METHOD

In order to highlight the cost-efficiency of new technologies, three common alternatives complying with current and future emission control regulations talked above are introduced hereunder:

(i) IFO+Scrubber+SCR

(ii) Diesel+SCR

(iii) LNG-diesel dual fuel

For (i), it means remaining current ship state in Intermediate Fuel Oil(IFO) and reducing SOx and NOx emission respectively through technical proposals by retrofitting a scrubber and SCR(Selective Catalytic Reduction) system. (ii) suggests to change the bunker fuel refined to lower sulfur content here called diesel, Marine Gas Oil(MGO, 0.1%S) or Marine Diesel Oil(MDO, 0.5%S), then retrofit a SCR system. (iii) uses liquefied natural gas(LNG) as main power fuel and diesel as auxiliary fuel in a dual fuel engine like Wärtsilä X92DF. [13]

We selected a real vessel operating on Asia-Europe route as our sample ship, COSCO VIETNAM, to conduct the cost-efficiency analysis. COSCO VIETNAM is a 8501TEU container ship operated by COSCO(China Ocean Shipping Group Company) on its Line NE6 start from port of QINGDAO to Port of HAMBURG at north Europe via the Suez canal with a round voyage in 77 days. Particular parameters see Table 2 & 3 below. [5, 14]

Table 2 Voyage Schedule

Port of call	ETA	Time	ETD	Time
QINGDAO	Sat	0	Sun	1
GWANGYANG	Tue	3	Thu	3
PUSAN	Wed	4	Tue	5
SHANGHAI	Fri	6	Sat	7
YANTIAN	Mon	9	Tue	10
SINGAPORE	Fri	13	Sat	14
ALGECIRAS	Wed	32	Thu	33
HAMBURG	Mon	37	Wed	39
ROTERDAM	Thu	40	Sat	42
LE HAVRE	Sun	43	Mon	44
ALGECIRAS	Thu	47	Fri	48
SINGAPORE	Thu	68	Thu	68
YANTIAN	Tue	73	Tue	73
QINGDAO	周六	77		
ETA/ETD:: Estimated time of arrival/Departure				

Source: www.cosco.com

Table 3 Ship Parameters

Capacity	8501 TEU
LOA	334 m
Lpp	319 m
B	42.8 m
D	14.61
Main engine output (Total)	68,530 mkW (97 rpm)
Auxiliary output (Total)	11,000ekW (60 Hz)
Fuel consumption	250 t/day (24.5 knot)
Chartering rate of sister ships	24,000 $/day

Source: Clarkson

Table 4 lists the engine output, fuel consumption rate and switch of fuel of each project. (i) and (ii) remain the diesel engine while (iii) is retrofitted to a two stroke dual fuel(DF) engine with a load decline to 58,400kw according to Masaki Adachi's research.[12] Given a ten years' evaluation time, the operation program is divided into two phases, five years each, mainly on the different fuel decision out of ECA due to the upcoming emission regulation in 2020. The first phase is shown as 'out of ECA (1)' which represent year 2015 to 2020 and 2021 to 2025 as 'out of ECA (2)' in Table 4. As described above, project (i) still use the bunker fuel of current quality, most IFO380 in practice, what so ever, in or out of ECA during the whole time schedule. For (ii) and (iii), IFO will be applied out of ECA in first phase and MDO with 0.5% S will replace as one of the dual fuel while MGO with 0.1% S is accepted in ECA during both two phases.

Table 4 Engine Parameter and Fuel Choice

Project	(i)	(ii)	(iii)
Main engine			
Type	**Two-stroke diesel**	**Two-stroke diesel**	**Two-stroke DF**
Total output	68,530 KW	68,530 KW	58,400 KW
Fuel rate (g/kwh)	152	152	174
Auxiliary			
Type	Diesel	Diesel	Dual fuel
Units	4	4	4
Per output	2750KW	2750KW	2700KW
Fuel rate (g/kwh)	197	197	217
Fuel			
In ECA	IFO	MGO (0.1% S)	LNG+MGO
Out of ECA (1)	IFO380	IFO380	LNG+IFO380
Out of ECA (2)	IFO380	MDO (0.5% S)	LNG+MDO

Source: Author and asaki Adachi etc.

Moreover, we have to notice that LNG as ship fuel has special requirement for storage. As per IMO's regualtion, Type C storage tank should be used to reduce the percolation of heat and thus vaporization of LNG. Due to the fact of inevitable vaporization when LNG bunkering, 100% bunkering cannot be promised, so here we see a ratio of bunkering at 93.6% according to asaki Adachi's study. So the capacity of the tank should be 14,583 cubic meter at least convert from the equation, 1.2 cubic meter LNG = 1 kg oil fuel, and depending on statistics of Figure 3 & 4.

In order to simplify the calculation, the Boil off Gas are completely and nicely used in working of boiler and SCR burning system.

3 COST-EFFICIENCY ANALYSIS

Cost-efficiency analysis are adapted to measure the difference among three alternatives and divided into three parts: retrofitting cost, operation situation and fuel cost. There are some assumptions in this article:

1. Time in calculation is 10 years, that means depreciation expense are divided into ten equivalent parts in each year and the scrap value of each alternative will be 0 $ after 10 years.

2. Unit price to retrofit main engines, auxiliaries and accessories, as per market price, 0.5 $/w in (ii) and 0.55 $/w in (iii) [12]

3. Unit cost of SCR system is 50 $/kw [4]

4. Cost of LNG and Scrubber system refer to Triality's study of a VLCC [8]

5. Discount rate i = 10%

6. Ignore the consumption of igniting fuel (only 1% of total consumption)

7. Mixing ratio of gas and fuel is 7:3 and apply to the whole voyage.

3.1 Retrofitting cost

Based on the statistics of Figure 3 & 4 and assumptions above, the retrofitting cost of main engines, auxiliaries, Scrubber, SCR and LNG systems are calculated below, in Table 5, the price spread between project (i) and (ii) is 440 m$ and 1131.6 m$ between (ii) and (iii). The retrofitting cost of LNG system seems to be far more higher than the other two alternatives.

3.2 Operation situation

Operation situation in this article including annual revenue and operation cost of emission control system. With regard to liner shipping practice, income mainly comes from the freight revenue while the cost contains shipping maintenance, harbor dues, crew fee, insurance, so on so forth. For the reason given above that his article focus on project evaluation, so we hereby ignore these costs and take the operation cost of the retrofitting systems into account only.

As freight revenue equals freight rate times freight volume (in TEU), we need to know freight rate and volume on the Asia-Europe route. The latest report of UNCTAD[6] and Clarkson [5], the annual container freight rate from Shanghai to north Europe are listed in Table hereunder. (2015 is the first quarter of this year) Excluding the unusual value in 2010 and 2011, taking average of left 5 years, the average annual freight revenue is 1212 $/TEU. And we set the rate from north Europe to Shanghai is two-thirds of it, approximately 800 $/TEU based on market experience.

$/TEU	2009	2010	2011	2012	2013	2014	2015
SH-NE	1395	1789	881	1353	1084	1172	1056

What's more, we choose the findings of Masaki Adachi in the handbook of Ocean Commerce that the loading factor of our sample ship is 76% from Asia to Europe and 34% conversely.

Depending on the study of MAN Diesel & Turbo, SCR system has a 0.3% capacity loss.[7] When it comes to project (iii), the LNG tank may occupy the cargo capacity directly by 471TEU converting from 14,583 cubic meter. And we can find the capacity loss on the annual revenue, see Figure 2.

Table 5 Retrofitting Cost of Each Project

Million $	IFO+Scrubber+SCR	MGO+SCR	LNG+MGO
Main engine	34.265	34.265	32.120
Auxiliary	1.375	1.375	2.700
Scrubber	4.400	0.000	0.000
SCR system	3.564	3.564	0.000
LNG system	0.000	0.000	15.700
Total	43.604	39.204	50.520

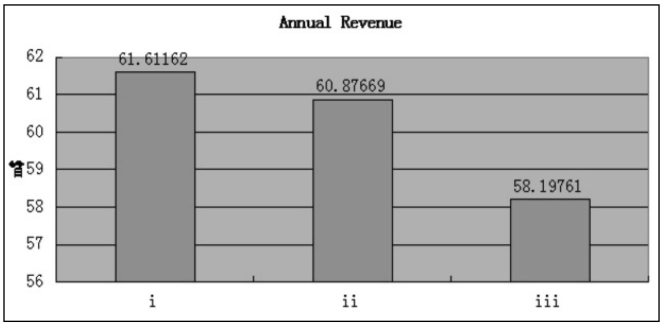

Figure 2 Annual Revenue

With respect to the operation cost including the consumption of material and maintenance, each system has its own factors need to be considered.

A Scrubber is used to filtrate the sulfur in the exhaust gas. The operation rely on the sodium hydroxide consumption, pumping and water consumption. Unit all in cost of its operation are 6 $/ mkwh, said by Wärtsilä. [13] Considering its working hour in ECA, this article set the starting point at port of Algeciras and end at the same port after its voyage back from port of hamburger. Refer to Table ?, its about 42.66 days in ECA, thus the annual cost of Scrubber system is 437,876 $.

The International Association for Catalytic Control of Ship Emissions to Air (IACCSEA) has lucubrated the efficiency and cost of SCR system, according to its report, the unit cost of the material, mainly urea, and maintenance are:

(1) Urea consumption: 0.063 $/kwh

(2) Maintenance: 0.01 $/kwh

So as the calculation of Scrubber system, the annual cost of SCR system is 5,327,490 $. Here we don't count the cost of LNG system. As Meike Baumgart said in their study [9], the LNG diesel dual fuel engine has a longer life time than other ordinary diesel engines which have a potential benefit for future utility, this may exceed the maintenance cost of all years.

3.3 Fuel cost

Given the fact shipping companies always always choose Singapore and Rotterdam as port of bunkering because of the comparatively low fuel price in Asia and Europe. To simplify the problem, we suppose shipping companies have fuel hedging to lock their fuel cost, so in this chapter, the fuel price is the average price in December, 2014. From the report of Bunkerworld [11] and Clarkson [5], we found the price of Singapore of different kinds of fuel: IFO380 = 366 $/t, MDO = 592.5$/t, MGO = 602.5$/t. And Rotterdam: IFO380 = 322.5$/t, MDO = 548.5$/t, MGO = 558.3$/t.

The price of LNG is estimated from the local market of Rotterdam who have realized the construction of LNG bunkering system invested by Shell last year and Singapore on Jurong island in 2013. As per ICIC's report, the corresponding price of LNG in those two ports are 332.8 $ and 249.6 $ per cubic meter respectively.

Above all, we got the annual cost of each alternative in Table 6.

4 NET PRESENT VALUE

Net Present Value (NPV) is defined as the sum of the present values (PVs) of incoming and outgoing cash flows over a period of time. Incoming and outgoing cash flows can also be described as benefit and cost cash flows, respectively.[15] We use NPV as a financial indicator to make comparison with each project so as to decide which one is the best for shipowners. The formula is:

$$NPV = \sum_{j=o}^{n} \frac{C_j}{(1+i)^j} = \sum_{j=1}^{n} A_j \left(P/\mathrm{A}, i, j\right) + R\left(P/F, i, n\right) - P \quad (1)$$

j is the number of year; A_j and C_j stand for the revenue and net cash flow respectively in year j; n is its life time, set as 10 years in this article; i represent the discount rate, 10%; R as scrap value, 0 at year 10 and P is initial investment of each project.

Table 6 Annual cost

Cost/$	Fuel	Scrubber	SCR	Total
		Annual cost 2015-2020		
(i)	26517309.25	437876	5327490	32282675.25
(ii)	29035987.01	0	5327490	34363477.01
(iii)	21967462.91	0	0	21967462.91
		Annual cost 2021-2025		
(i)	26517309.25	3746477.73	5327490	35591276.98
(ii)	44050759.74	0	5327490	49378249.74
(iii)	22917712.91	0	0	22917712.91

After calculating via Excel, we find that the project (iii) is the highest, either in NPV or NPV rate, see Table below:

Project	NPV	NPV rate
(i)	145.63 m$	3.34
(ii)	103.48 m$	2.64
(iii)	189.34 m$	3.75

The value seems to be high due to excluding of construction cost and other operating cost. It is obvious that Project (iii) performs best among these alternatives while (ii) beyond our expectation which indicate that changing fuel is not a good idea in the game between cost efficiency and emission control. In details, year by year, from Figure 3, the curve of project (i) is smooth while the other two have a drop after 5 years because of switching of fuel. That means project (ii) and (iii) are more vulnerable to the fluctuation of fuel price.

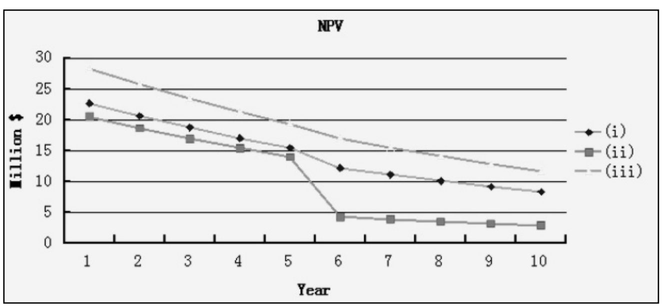

Figure 3 NPV year by year

In addition, pay back time(PBT) of each alternative, depending on the formula indicate the risk of projects:

$$PBP = \frac{\lg \dfrac{A}{A - Pi}}{\lg(1+i)} \tag{2}$$

A is annual revenue; P, i is the same in the formula above. So PBT of (i), (ii), (iii) are 2.07, 2.06, 2.01 respectively, which means project (iii) have the lowest risk in three alternatives.

5 SENSITIVITY ANALYSIS

In the last eight years since 2008, the fuel price fluctuated between 250-664.1 $/t (IFO380) and 479.5-958.3 $/t (MGO) which left a big space for sensitivity analysis. Our analysis concentrate on the rise of LNG price and slump of oil. Rate of change were set by 10%, 15%, 20%, 25% and 30%. Figure 4 is the situation that oil price drop while LNG price keep steady. The intersection of curve (i) and (iii) is at nearly 30%, precisely 29.31%, where (i) catch up (iii) becoming the most profitable project. And Figure 5 shows the scenario of rising LNG price and steady oil. The intersection also express that when LNG price rise by 35%, (i) will be the best performer.

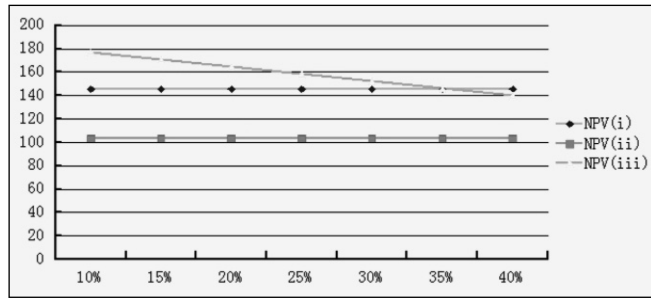

Figure 4

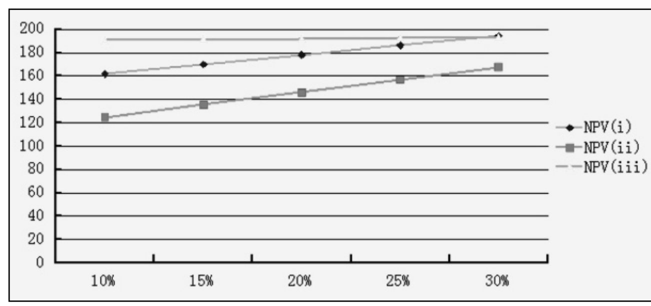

Figure 5

6 CONCLUSION

This article mainly proposed three technically effective alternatives to satisfy the current and future emission control regulations and laws in shipping. The findings show that LNG-diesel dual fuel power technology performs best among three alternatives. Due to the impact of fuel price on the conclusion, two scenarios were carried out in sensitivity analysis which witnessed a variation of NPV with the fluctuation of fuel price. 29.31% oil fuel slump and 35% LNG fuel rise are the turning point between project (i) and project (iii), left project (ii) the least cost-effective method in three alternatives. However, factors like ship size, load distance, route choice, stricter regulation, technology breakthrough, will have an impact on the outcome and further affect the decision of shipowners. So future study is recommended on these factors.

Acknowlegements

We are grateful to the help of library staff for providing the access to some information platform. And many thanks to our tutor, Professor Wang who gave us technical instruction.

REFERENCES

[1] A. A. Banawan, M M El Gohary and I S Sadek. Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment 2010,224: 103.

[2] S. Brynolf. M. Magnusson. E. Fridell. K. Andersson. Compliance possibilities for the future ECA regulations through the use of abatement technologies or change of fuels. Transportation Research. 2014. Part D(28): 6–18.

[3] http://www.lngbunkering.org/sites/default/files/2013%20HEC%20lng%20effect%20on%20ship%20design.pdf.

[4] http://www.iaccsea.com/scr-cost-model/.

[5] https://sin.clarksons.net/.

[6] UNCTAD (2009, 2014), Review of maritime transport.

[7] MAN Diesel & Turbo, 2012, Germanischer lloyd and MAN(2012). Costs and Benefits of LNG as Ship Fuel for Container Vessels: Key results from a GL and MAN Joint study. http://www.gl-group.com/pdf/GL_MAN_LNG_study_web.pdf.

[8] DNV (2010) Triality Taking the environmental and economic performance of VLCCs a great forward, Tanker Update No. 2, 2010 special edition.

[9] Meike Baumgart and Jon Halvard Bolstad Olsen. LNG-fueled vessels in the Norwegian short-sea market: a cost-effective response to environmental regulation. NORGES HANDELSHØYSKOLE, Bergen, Spring 2010.

[10] Jerzy Herdzik. LNG AS A .MARINE FUEL-POSSIBILITIES AND PROBLEMS. Journal of KONES Powertrain and Transport, Vol. 18, No. 2 2011.

[11] www.bunkerworld.com.

[12] Masaki Adachi, Hiroyuki Kosaka, Tetsugo Fukuda, Shota Ohashi, Kazuyoshi Harumi. Economic analysis of trans-ocean LNG-fueled container ship. J Mar Sci Technol (2014) 19:470–478.

[13] www. wartsila.com.

[14] www.cosco.com.

[15] http://en.wikipedia.org/wiki/NPV.