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Impact of the Shale Gas Revolution on a Portfolio of Alternative Fuel Vehicles and Water Usage: Case Study on the Polish Market

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Abstract. Alternative Fuel Vehicles (AFVs) are slowly influencing the energy portfolio mix in many countries due to their increased popularity. Shale gas revolution has already changed the shape of the energy mix in the U.S. and it is also a promising option for other countries to diversify their energy portfolio. However, questions have been raised about the water security in the area of shale gas extraction. There have been no studies, which analyze the impact of shale gas revolution on AFV's portfolio and its implications. This study was conducted based on the integration of optimization model and life cycle assessment analysis. Numerical results suggest that shale gas revolution impacts the portfolio of AFVs substantially due to the significant decrease of gas price. Moreover, the data concerning the usage of water were provided as well. In conclusion, this paper demonstrates the impact of a feasible shale gas revolution on a portfolio of AFVs and water consumption, and it provides numerical findings for multiple stakeholders such as lawmakers, energy, and automotive companies.

Keywords: shale gas, water, alternative fuel vehicles, portfolio

1. Introduction

The past decade has seen the rapid development of Alternative Fuel Vehicles (AFVs). AFVs are vehicles operating on an alternative fuel such as hydrogen, electricity, etc. [1]. The scarcity of resources, the climate change by GHG emissions, energy security and so forth have triggered the interest among lawmakers, automakers and researchers on AFVs and their implementation of sustainable transportation systems. Technologies using hydrogen and batteries will become increasingly popular due to the price drop and broader availability in the market [2].

Governments of EU countries are slowly attempting to shift from fossil fuels to renewable energy, not only for environmental benefits, but also for energy security reasons, but these are still minor sources of global energy production. Recent developments within the field of natural gas extraction from shale rock have changed the US energy mix dramatically [3]. The shale gas revolution is also a promising option for countries like Poland and China to diversify their coal-based economies and additionally improve the energy security of many countries [3].

Due to the decrease of prices of oil on global markets, the pace of popularization of AFVs is impeded and the extraction of shale gas has noted a significant slowdown as well. However, according to the energy outlook for 22nd February 2016 by the IEA, the prices of oil will sharply increase before 2020, due to the insufficient investment in new production [4]. Indisputably, with the increase in oil price, the government will push the extraction of shale gas, also in Europe [5].

The research to date has tended to focus on GHG emission, oil depletion or policy measures for introducing AFVs [6]–[9]. However, there have been no studies, which analyze the impact of the shale gas revolution on AFV's portfolio and its implications. It is of utmost importance to treat this topic in a

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systematic way and provide a broader view of the consequences of using shale gas in an economy. Therefore, the objectives of this research are to determine the implication of the shale gas revolution on a portfolio of AFVs and water usage in an example of the Polish economy. The scenario of a low-priced natural gas is being presented. This study would be beneficial for the government, as well as automakers and potential shale gas investors as it would provide numerical results on water usage and vehicle portfolio as a consequence of implementing shale gas into a sustainable transportation system.

Section 2 outlines quantitative methods to the study. The originality of this method is the integration of Life cycle analysis and optimization model. Water consumption is generated as an aftermath of shale gas used to supply energy for vehicles investigated in this study hence two methods are integrated in order to provide analysis of this phenomenon. The scenario of low-priced natural gas and petroleum is described in the section mentioned above. The numerical results and findings are presented in Section 3. Section 4 concludes the research and identifies the future work.

2. Methods

The qualitative part of this study integrates an optimization model and life cycle analysis. The optimization model contains multiple energy preconditions and transportation variables, whereas a life cycle analysis includes water consumption of shale gas on different stages of production (extraction, processing, transportation and power generation). The outline of the optimization and Life Cycle Analysis process are presented in Fig. 1.

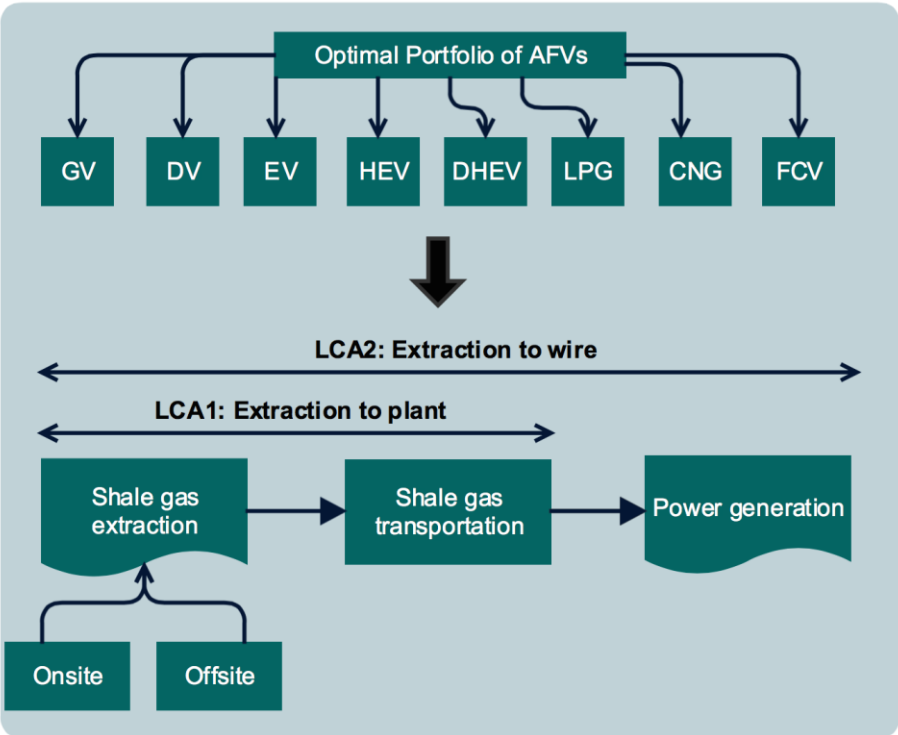

Fig. 1: Outline of methods

2.1. Life Cycle Analysis

The outline of the Life Cycle Analysis process is presented in Fig. 1 above. We are considering 2 scenarios, LCA1: Extraction to plant, which includes extraction and transportation of shale gas, LCA2: Extraction to wire, which includes extraction, transportation and power generation coming from shale gas. The focus of the study is on the production of the shale gas hence water consumption during vehicle usage is not taken into consideration.

2.2. Shale Gas Extraction and Transportation

Shale gas extraction is relatively new to Polish economy, in line with this; the data on shale gas extraction, e.g. rate, size and cost are taken from the most reliable source - the US. The average lifespan of the shale gas well is set to 30 years [10], [11]. The average gas production of one well over six months for shale gas plays in the U.S. varies depending on the site size and resources, in Barnett play it amounted to 30000m ^{3}per day, in Haynesville to 15000m ^{3}per day, in Fayetteville to 50000m ^{3}per day and Marcellus to 100000m ^{3}per day [12].

The initial production is considerably higher than the above values, but the decline rate of shale gas is also significant. That is why the average production rate of the well is 60,000 m3 per day per well from the conventional studies [12], [13].

Water usage for production of shale gas consists of direct (onsite) consumption during extraction of shale gas and indirect (offsite) consumption during supply chain production.

The heavy direct consumption of water, connected to the shale gas production, is associated with fracturing and drilling processes [10]. The rate of water consumption is also highly variable and depends on the geology and drilling techniques and rate of the flowback water recycling. The flowback water can be recycled, in Marcellus region, 95% of the flowback water is recycled, in other regions, the amount is significantly lower, e.g. 20% in Barnett and 0% in Haynesville [10]. In Marcellus play, 4,5 million gallons of water are used per well yearly for fraccing, drilling and construction activities (around 12,300 gallons per day). In Barnett it amounts to around 3,0 million gallons for fraccing and 270,000 gallons for drilling and construction [10], [14]. The average amount of the US shale gas plays is set to 4Mbarells, which states to 15,141MT yearly, around 0.685 l/ per m3 of shale gas (taking into consideration that daily production is 60 000m3). Those numbers are higher in China, and according to Chang [15], water consumption amounts to around 25MT of water per shale gas well. The substantial difference corresponds to more advanced technologies, reuse of flowback water and favorable geological conditions in the U.S. in comparison with China. It is probable, that American companies will deliver the technology to the country used in the case study, which is why we have decided that the average direct use of water for m3 of shale gas is 0.685l/m3.

Indirect consumption of water is linked mainly to forestry and agriculture industry, steel rolling and distribution and production of water [16]. According to benchmark, around 34% of entire water consumption results from direct water usage, and 65% originates from indirect use [16].

All things considered, total water consumption during shale gas production is set is 2,0l per 1m3 of shale gas. Table I presents data connected to water consumption during shale gas production and transportation.

Table I: Water consumption during shale gas transportation is minimal and amounts to 0.01l per 1m^3 of shale gas

Stage	Unit	Primary Energy(KJ)	Water consumption(1)
Extraction	1m^3	4,800.00	2.00
	1MJ	134.00	0.056
Transportation	1m^3	200.00	0.10
	1MJ	5.60	0.003

2.2.1. Power generation from shale gas

Estimates for water consumption in power generations were based on a combined-cycle power plant since the GHG emissions are lower than in the combustion turbine power plant. The estimated value of water consumption is set to 0.8l/kWh [16], [17], while primary energy use amounts to 7.06 MJ/kWh [16].

The average price of natural gas extracted from shale gas has been set to 0.12$/m3 (without taxes), which is an average industrial price of gas in the U.S. in 2016 [18], [19] The price of natural gas that is nowadays imported from Russia was around 0.37$ per m3 between 2014-2016 [20]. The high-price results from long-term agreements signed between Poland and Russia. The price should decrease significantly within the next years due to the launch of LNG terminal and resources' cooperation with other countries.

Therefore, the average price of a m3 of natural gas has been set to 0,25 $ per m3. All other parameters and data concerning LCA and shale gas were gathered in Table II.

Table II: Parameters concerning LCA and shale gas production

	Unit	Amount	Data source
Natural gas price	$/m ³	0.25	[18], [19]
Shale gas price	$/m ³	0.12	[15]
Shale gas well lifespan	year	30	[10], [11]
Shale gas well average production	m ³/well/day	60,000	[12], [13]
Shale gas fracturing water consumption	m ³(ton)	15,141	[10], [14]
Water consumption of power generation	l/kWh	0.80	[16], [17]

2.3. Optimization Model

This part of the study employs the optimization model that is based on the research done by Romejko and Nakano [8]. The new model covers only personal vehicles, restrictions rate are updated, and vehicle characteristics are revised as well. The model calculates the optimal vehicle portfolio while taking into account energy security issues. It includes seven types of engine platforms:

LPG – Liquefied Petroleum Vehicle,

CNG – Compressed Natural Gas Vehicle,

GV – Gasoline Vehicle,

DV – Diesel Vehicle,

HEV – Hybrid Electric Vehicle,

DHEV – Diesel Hybrid Electric Vehicle,

EV –Electric Vehicle,

FCV – Fuel Cell Vehicle,

The mathematical model incorporates three costs, i.e. vehicle, fuel and infrastructure. The objective is minimizing the cost of implementing AFVs. The previous study elucidates the model and optimization methods profoundly [8].

3. Quantitative Results and Discussion

In this section of the research, Poland is taken as a case study.

3.1. Vehicle Portfolio

In this model, six energy sources are considered (LPG, CNG, diesel, petrol, electricity and hydrogen). A detailed description of the function of the model, vehicle characteristics and assumptions, energy prices, power configuration, and other data and a full set of preconditions are described in [8]. Scenario for low-price natural gas and petroleum is being investigated. The low price of the natural gas is associated with the development of shale gas on the case study’s market.

The energy security restriction of petroleum has been set to 10%, while gas spending is minimized. In this study, the term ‘AFV’ is used to describe five types of vehicles: EV, CNG, HEV, DHEV and FCV. GV, DV and LPG are not considered to be AFVs.

The first set of analyses examined the impact of the introduction of cheap natural gas and petroleum, as a response to shale gas revolution, on vehicle portfolio. The numerical results are shown in Fig. 2-Fig. 4.

In Fig. 2, EV gains the most within AFVs. EV has surged substantially in the given time period. This result may be explained by the fact that around 13,7% (2016) and 14.5 % (2030) of electricity in Poland come from gas. 50% of hydrogen is produced from gas as well, however, the high prices of FCV and hydrogen price make it less favorable than EV. The combination of electricity and gas use is the most advantageous in AFVs in terms of energy security and price mix. There was no significant increase in HEV, DHEV due to petroleum restrictions. CNGs are using natural gas, however, their spread is not so high as it would be expected, due to the price of CNG fuel. In Poland, the price of CNG fuel is calculated according to petroleum benchmark and not natural gas price.

The transition of total vehicle portfolio between 2016 and 2030 is presented in the Fig. 3 below. The Figure shows that there has been a gradual decrease of GV and DV, slight increase of FCV, CNG, DHEV and HEV and a steady rise of EV and LPG.

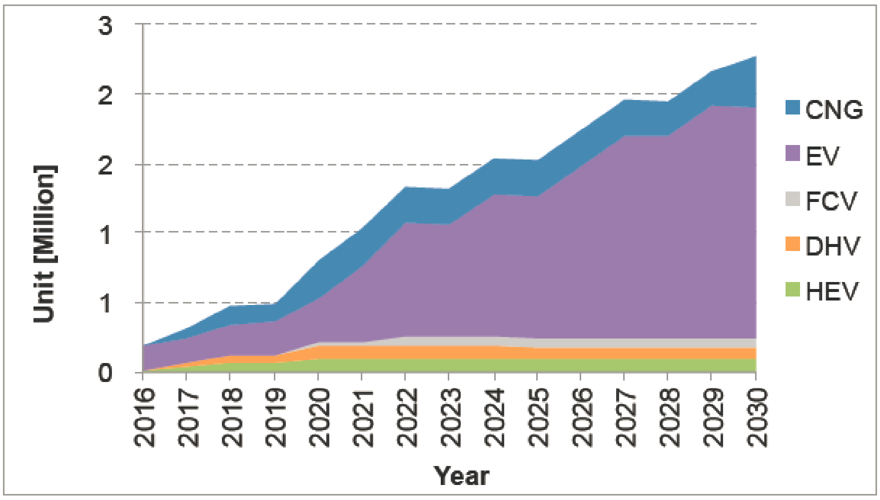

Fig. 2: Total vehicle possession of the AFVs.

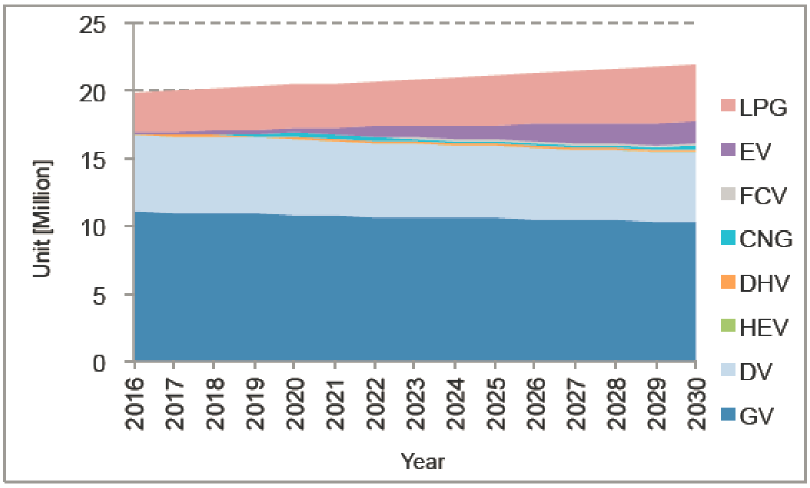

Fig. 3: Changes in total vehicle portfolio between 2016 and 2030

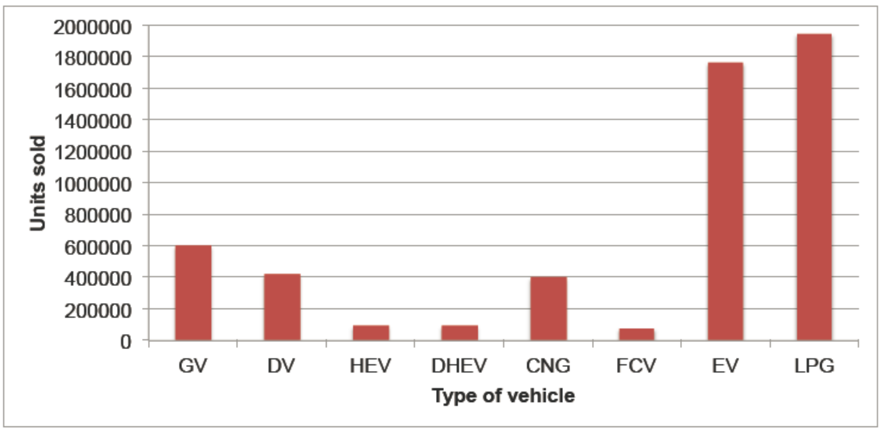

Fig. 4: Total sum of units sold between 2016 and 2030 by type of vehicle

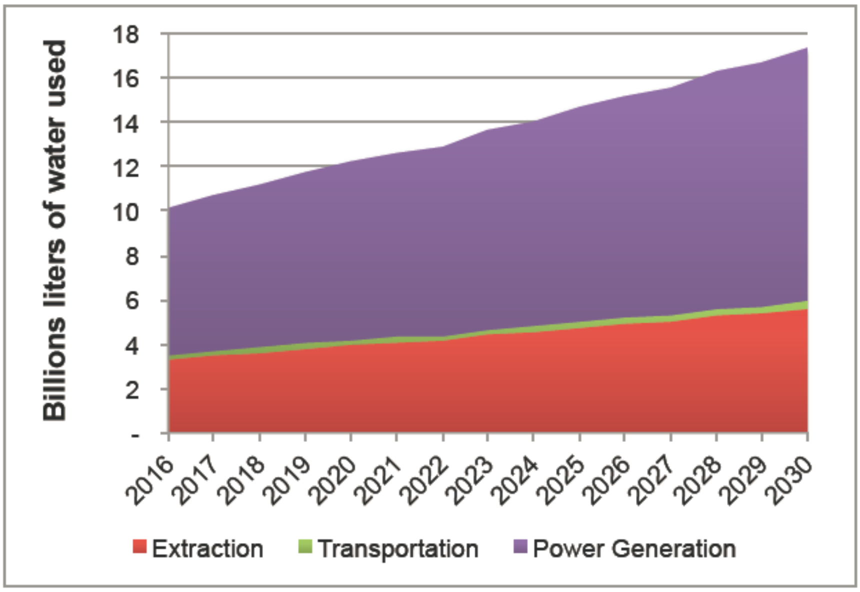

Fig. 5: LCA1 and LCA2 - water consumption of shale gas in billions of liters between 2016 and 2030

Fig. 4 presents the data for total units sold between the time period. In total, the vehicle, which recorded the most sales between 2016 and 2030, is LPG, followed closely by EV, while GV and DV sales remain low.

3.2. Water Usage

The total water consumption is calculated as the sum of natural gas used to supply LPG, CNG, EV and FCV.

Fig. 5 illustrates water consumption of shale gas for LCA1: Extraction to plant (red and green) and LCA2: Extraction to wire (red, green and violet)

In LCA1 around 71 billions of liters of water are used in this stage of shale gas production in order to provide natural gas supplies for passenger vehicles. It is projected, that totally 67 billions of water are consumed during extraction, which amounts to 95% of the whole extraction to plant consumption. Only 5% comes from the transportation process, which is 4 billions of water.

In LCA2, the rate of total extraction to wire amounted to around 205 billions of liters of water between 2016 and 2030. 65.79% comes from power generation, 32.4% from extraction and 1.7% from transportation.

In comparison, the yearly water supply to the city of Warsaw in 2014 reached around 120 million liters [21]. By contrast, annual consumption of water in extraction to the wire has amounted to around 10 billion in 2016 and 17 billion in 2030. Moreover, there has been a myriad of questions raised regarding the water quality, wastewater and its disposal, spills and groundwater disturbance in the area of shale gas extraction [22]. Significant increase in the use of water for shale gas production could affect the availability of water for residents within the area [22]. Those threads have to be minimized, for instance, technologies such as wastewater recycling, storage and disposal; non-toxic hydraulic fracturing fluids or additives like guar gum are being adopted during shale gas production [22].

4. Conclusion

In conclusion, this research examined the impact of a feasible shale gas revolution on a portfolio of AFVs and water usage and provides findings for multiple stakeholders. Conventional studies revealed that there are opportunities to explore shale gas in Poland [23], [24]. Results of this qualitative analysis suggest that the shale gas revolution substantially impacts the portfolio of AFVs due to the significant decrease of gas prices. The results of this study indicate that due to shale gas revolution, the portfolio of vehicles positively on behalf of AFVs. The most important finding to emerge from this study is that the drop of GV and DHV is recorded in favor of EV and LPG. Moreover, the results for LCA1 and LCA2 cases show that increased use of shale gas engenders the high consumption of water. Those findings suggest that, if the shale gas is introduced in Poland, minimization of water-oriented issues is crucial.

Further research should be extended and could investigate the sensitivity analysis of factors such as: the production rate, the recycling rate of the flowback water, the decline rate of shale gas price, technological improvements over time, etc.

5. Acknowledgments

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