

THEORETICAL ANALYSIS OF THE EFFICIENCIES OF THE ENERGY CHAIN ELEMENTS IN THE CASE OF THE TRANSITION TO ELECTRIC VEHICLES

Assoc. Prof, PhD, Eng. Florin Gabriel POPESCU, University of Petrosani, Petrosani, ROMANIA, floringabriel82@yahoo.com

Assoc. Prof, PhD, Eng. Dragos PASCULESCU, University of Petrosani, Petrosani, ROMANIA, pdragos_74@yahoo.com

Lecturer, PhD, Eng. Răzvan SLUSARIUC, University of Petrosani, Petrosani, ROMANIA, RazvanSlusariuc@upet.ro

Assoc. Prof. Phd Adina TATAR, Constantin Brancuși University, Târgu-Jiu, ROMANIA, adynatatar@gmail.com

Assist, PhD, Eng. Teodora LAZAR, University of Petrosani, Petrosani, ROMANIA, teomititica@yahoo.com

Abstract: *This paper aims to prove that the subject of transition to electric vehicles being a bad decision concerning efficiency, is not founded on clear grounds. So it was shown in a theoretical approach, how efficiencies for the elements in the chain of extraction, processing and distribution of different energies add up to a more clearer image of this transition that is already taking place.*

Key words: efficiency, fuel, energy, electric vehicle, power plant.

1. Introduction

Romania aims to make an equitable contribution to achieving the European Union's decarbonisation target and will follow best environmental practices [1], [10].

The implementation of the EU-ETS scheme and compliance with the annual emission targets for non-ETS sectors are the main commitments for achieving the targets. For the sectors that are the target of the EU-ETS scheme, Romania's overall target for reducing emissions is around 44% by 2030 compared to 2005 [2], [9], [12].

In April 2011, new policies were adopted to promote clean and efficient road transport vehicles - (hybrid and electric) [5], [7]. These have been implemented in two ways:

1. Subsidies for the purchase of EVs (up to 20% of the price, but not more than € 3,700) - at the end of 2011 the regulations for the application of this provision were published but stipulated only in certain intervals. So far, these periods have not been specified. They can be granted to individuals, public institutions and public administrations.

2. A scrap program for public administrations and institutions, individuals, NGOs and small and medium-sized enterprises, through which a voucher (€ 3,600, four times the grant for 1 vehicle) is awarded for purchase of new cars that can be used for EVs.

2. The opportunity of the transition from the analysis of energy yields

Developing countries face the highest rate of increase in energy consumption for transport. In order to understand the energy efficiency of the vehicle and to compare the efficiency of different vehicle models, the efficiency of the WTW (well to wheel –

from primary energy source to car wheel) should be recognized.

The WTW examination was widely applied to assess the energy consumption of the vehicle. WTW refers to the efficiency of the energy chain of vehicles from cradle to grave or from source (energy) to end. The purpose of this analysis is to compare the WTW efficiency of conventional internal combustion vehicles (petrol, diesel and natural gas) with electric vehicles. The WTW efficiency of the electric car indicates that the optimal use of power plants combined with natural gas will improve the overall efficiency of electric cars.

The results indicate that the efficiency of the electric drive (47.06%) is three times higher than for liquid fuel engines (15.32%). This research led to a comprehensive assessment of the overall energy chain in order to obtain an accurate estimate of energy performance. The examination of the energy efficiency of electric vehicles, CO₂ emissions and costs, taking into account the impact of EV on the need for electricity and the stability of the electricity grid, showed the significance of including all energy chain (WTW) processes in assessing the performance of electric vehicles.

3. Methodology

Efficiency of energy conversion or transmission was found first to calculate overall energy efficiency by multiplying all obtained efficiencies [3], [11].

Low efficiency components reduce overall efficiency with multiplier effect. We use WTW approach, dividing into tank and wheel tank efficiency and multiplying all component efficiencies for the overall efficiency [6], [16].

Efficiency of η_{TTW} wheeled tank for liquid fuels, natural gas compressors, and electricity is defined as following next step:

$$\eta_{LF} = \eta_{OE} \cdot \eta_{FC} \cdot \eta_D \quad (1)$$

$$\eta_{NGC} = \eta_{GE} \cdot \eta_{FC} \cdot \eta_C \quad (2)$$

$$\eta_{EI} = \eta_{RE} \cdot \eta_P \cdot \eta_{T\&D} \cdot \eta_{Ch} \quad (3)$$

Where:

η_{OE} - Crude oil extraction - the efficiency of the extraction process;

η_{GE} - Natural gas extraction - extraction process efficiency;

η_{FC} - Crude oil refinery fuel conversion efficiency;

η_D - Transportation of fuel to the oil station;

η_C - Efficiency of the natural gas compressor / compressors at the filling station;

η_{EI} - Efficiency of power plants for electricity generation;

$\eta_{T\&D}$ - The efficiency of the transmission and distribution of the electricity network;

η_{Ch} - Charging efficiency of electricity transfer to EV in the station;

η_{RE} - Extraction efficiency of primary energy resources;

η_P - Plant efficiency.

4. Plant efficiency, efficiency in extraction, processing and distribution

The energy chain starts with extracting crude oil, refining it, then distributing to a power plant or gas station [8]. Table 1 details the efficiency of each stage. To find the TTW efficiency, the average efficiency of each stage was taken.

Table 1. Extraction, processing, and distribution of primary energy

Fuel	Extraction	Processing	Distribution
Natural Gas	96-99%	96-99%	96-98%
Coal	97%	97%	98%
Oil:			
Petrol	95%	88%	99%
Diesel	93%	95%	

Most power plants rely on coal and natural gas as fuel to generate electricity. Coal-fired and natural gas-fired power plants account for almost 40% and 20% of world electricity production, respectively [13], [15].

Natural gas is considered an efficient fossil fuel to generate electricity, with an efficiency of about 34% in the single cycle turbine, and up to 50.1% in the combined cycle plant. In comparison, coal-fired power plants offer an overall efficiency of between 32 and 42%. Diesel power plants, high-capacity industrial engines, have an efficiency of 35% to 42%, as shown in Table 2. The plant is of significant importance in determining the efficiency of electric vehicles; electricity being the main source of energy for an electric vehicle [4], [14].

To this end, the performance of the fossil fuel power plant has been extensively reviewed and is summarized in Table 2. In this research, the efficiency ranges shown in Table 2 were used, taking into account that part of the energy used comes from inside the power plant.

Table 2. Efficiency of power plant

Fuel type	Technology	Efficiency margin
Natural Gas	Simple cycle turbines	
Coal	Combined cycle	34-50%
Natural Gas		32-42%
Diesel generators		32-40%

Efficiency of Tank to Wheel (TTW). Analyzed each component of the electric vehicle should be to determine its TTW efficiency [3].

Table 3. Efficiency of the EV's electrical components

VE component	Efficiency margin
AC/DC Converter	90-96 %
Battery charging	90-99 %
Battery consumption	93-98 %
DC/AC Converter	96-98 %
Electric motor	81-95 %
Generator	82-95%
Mechanical transmission	89-98%

Table 3 shows the efficiency of EV components, with the range of TTW efficiency of the EV taken from 50% to 80% based on values from revised literature.

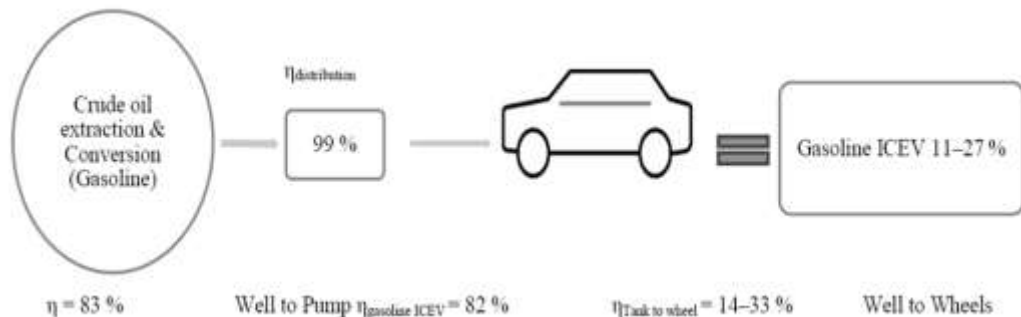


Figure 1. WTW efficiency of ICEV petrol

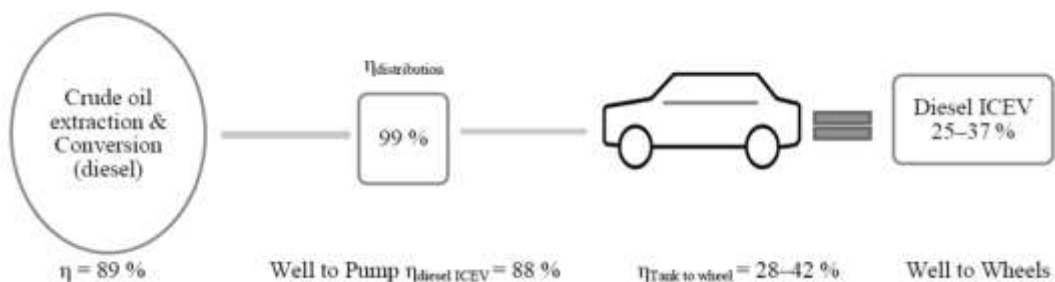


Figure 2. WTW efficiency of ICEV diesel

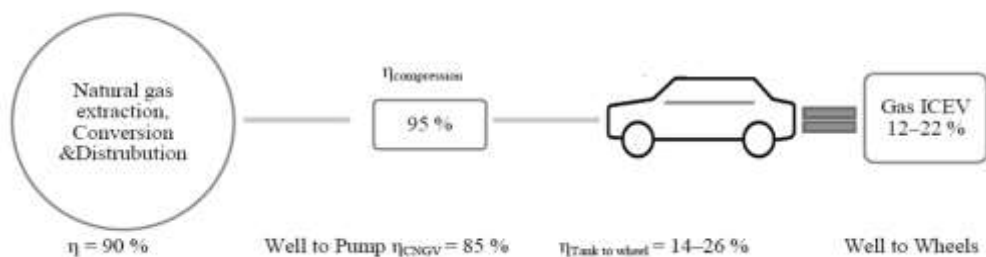


Figure 3. WTW efficiency of Gas ICEV (compressed natural gas)

By using electricity generated from solar or wind systems, the WTW efficiency of electric vehicles is significantly increased. Between 39% and 67%, the efficiency of electric vehicles charged from solar or wind farms varies. The overall efficiency is increased by the use of a roof photovoltaic system, reducing transmission losses and resulting in a WTW efficiency range of 42% to 72% shown in Figure 5. Figure 6 displays the overall efficiency for different vehicles, with renewable energy sources having the highest, followed by diesel engines, electric cars, and gasoline cars with the lowest efficiency [14].

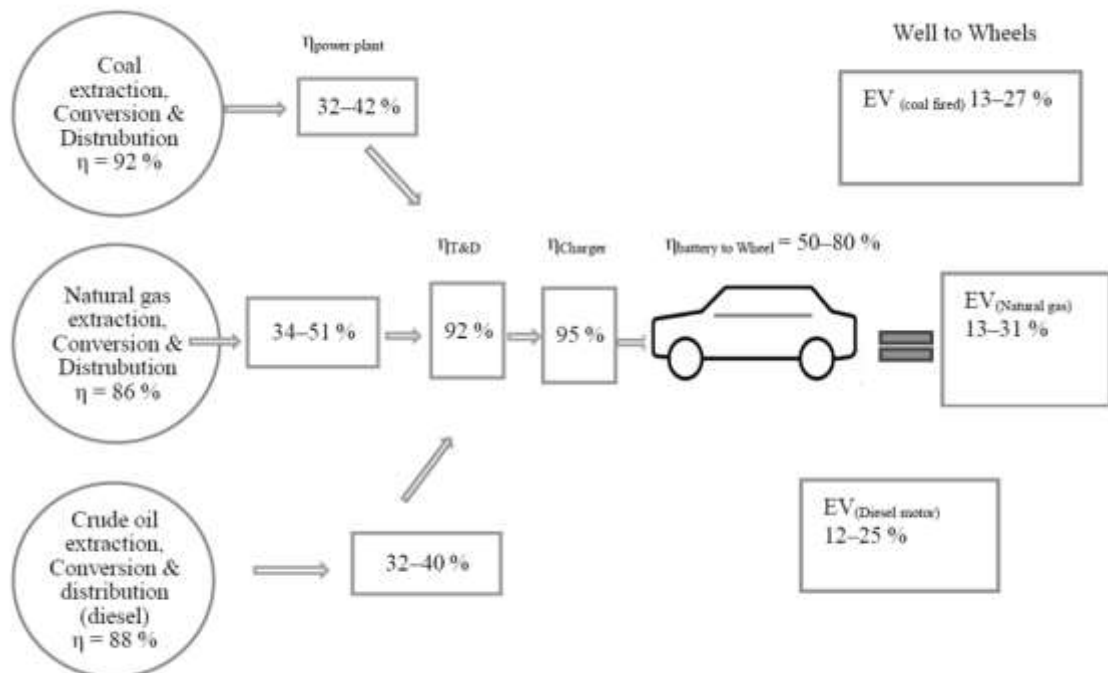


Figure 4. WTW efficiency of electric vehicles powered by fossil fuel power plants

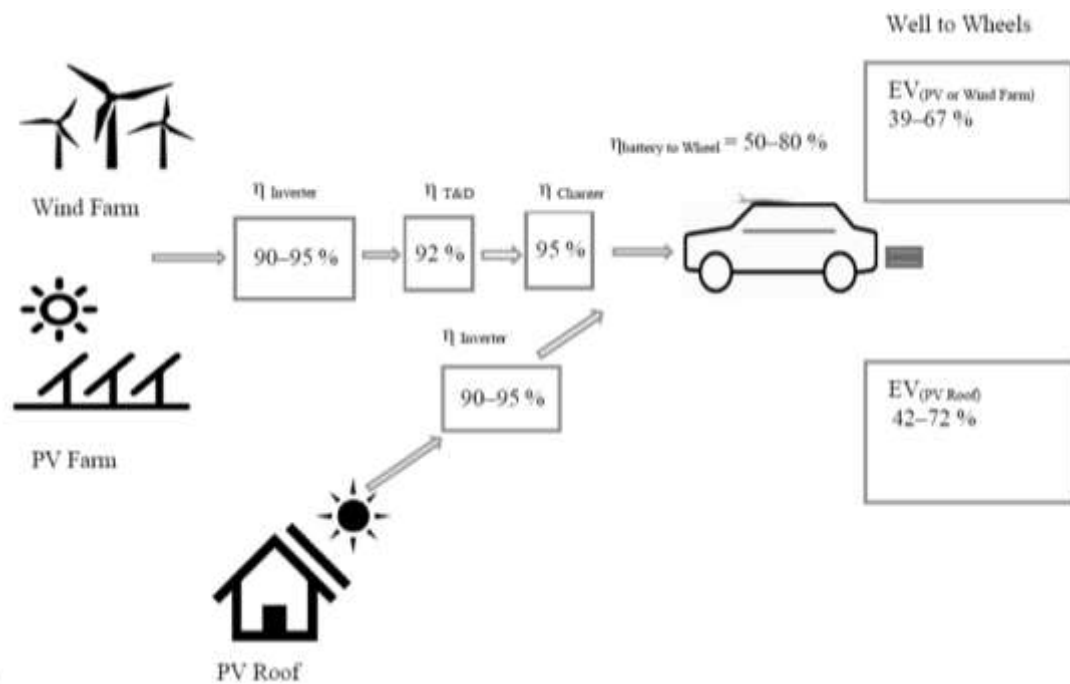


Figure 5. WTW efficiency of renewable energy EVs

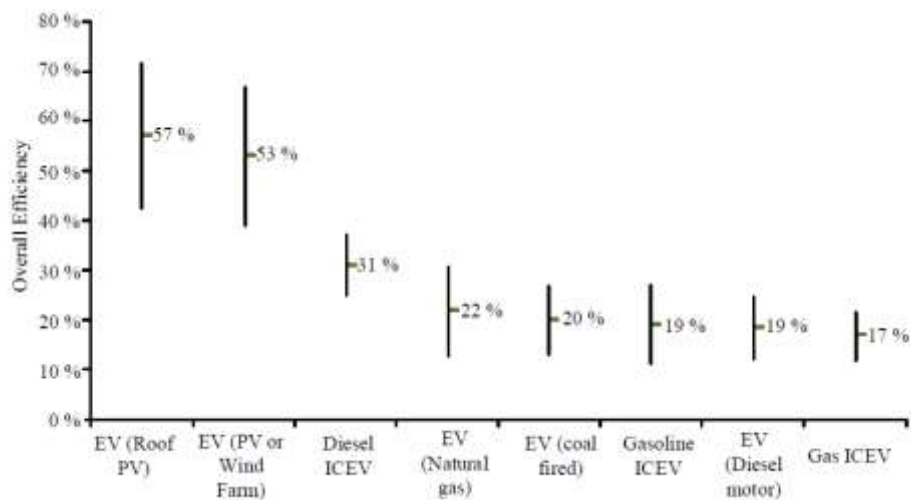


Figure 6. Overall efficiency for each type of primary energy pair – consumer

3. Conclusions

The efficiency of the wheel tank of liquid ICEV (petrol and diesel) and GAS ICEV determines the WTW efficiency breakdown as shown in Equations (1) and (2).

Table 1 displays the average values of extraction, refinery, and distribution fuel efficiency. Figures 1 and 2 illustrate the process where liquid fuel from oil stations is pumped to the vehicle for petrol and diesel cases.

The WTW efficiency of ICEV on petrol ranges from 11-27% and diesel ICEV from 25% to 37%. In the case of CNGV, natural gas is compressed by a compressor and supplied to the vehicle, shown in Figure 2. The WTW efficiency of GAS ICEV is between 12% and 22%.

For electric vehicles, fuel is extracted, processed, and supplied to the power plant, with the efficiency of power generation impacting the WTW efficiency. The electricity reaches the EV after transfer from the distribution network and charging station, as described and explained in Figure 4.

EV powered by a natural gas power plant has the highest WTW efficiency, ranging from 13% to 31%, while EV supplied by coal and diesel thermal power plants have similar WTW efficiencies, between 13% and 27% and 12% to 25%, respectively.

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