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# Strategic Analysis of EV's electrical energy storage using PEST analysis and Analytical Network Process for Technology Adoption

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*Abstract*— **In the last recent years, the interest on electric vehicle has been increased more and more due to environmental issues and oil's price dependency. The purpose of this study is to select the best energy storage source for Electric Vehicle in the future In light of this purpose, firstly, specific criteria has been proposed as main f actors influencing on energy storage technology adoption using PEST analysis and the results calculated by Analytical Network Process tools select battery technology as the best energy storage source for Electric Vehicle regard to the maturity of this technology and its various advantages such as cost, charging facilities, efficiency...etc.**

*Index Terms*— **Electric Vehicle, Energy storage, PEST, ANP.**

## I. INTRODUCTION

Electric vehicle is a vehicle that use electrical energy for propulsion, that energy can be stored in various sources such as batteries, super capacitors, fuel cell..etc. energy storage source technology is the most important success key on electric vehicle. Nowadays, for the sack of increasing EV market and attracting the public interest, governments support the automakers and researchers to develop the autonomy range and reduce the production cost by improving the available technologies and exploring new alternatives whose can be the best energy storage source for EV. This study attempt to give new dimensions aspects to compare energy storage technologies of EV. Whereas, Section 2 presents the different available technologies. Section 3 present the different describe PEST analysis to define criteria and Analytical Network Process to establish comparison between alternatives and calculate priorities. While Section 4 discusses the results, finally conclusion is drawing in Section 5.

## II. BACK GROUND INFORMATION

This section explains the energy sources to electric vehicle and focus on energy storage technologies with giving examples of each technology's applications should *not* be selected.

### A. Analysis of Energy Source to Electric Vehicles

Energy sources of electric vehicles can be classified in two main categories [1]:

- Energy generation unit: including photovoltaic cell (PV), adapted as a sunroof options by automakers such as Toyota Prius 2010, Mazda 929 and Audi A8, Automotive thermoelectric generator that converts heat energy into electricity tested by Nissan, 2006 BMW 530i and GM Chevy Suburban, and Regenerative braking.
- Energy storage unit: using some devices to store energy in various form to be used to power the vehicle as primary or secondary sources the storage devices could be batteries, super capacitor, flywheel, and fuel cell….etc..
- *Batteries for Electric Vehicles*

Batteries is the most common energy storage device used in the hybrid and electric vehicles, it has been used for lighting, starting and ignition batteries in either hybrid/electric vehicle or internal combustion engine [2] the table below show some batteries adapted in electric vehicle.

Lead Acid Battery is the oldest and cheapest battery involved in internal combustion engine and electric vehicle, it's preferable when the weight is least importance because its low energy density requires a heavy weight and massive volume to can support a long distance which lead to increase the price. Lead Acid battery have been used in the first mass produced electric vehicle which called "EV 1" produced by GM in 1996 as the main energy source with 70 miles of range.

*Nickel-Metal Battery*

From the early hybrid electric Vehicle (HEV) Nickel-Metal battery became popular due to their light weight, greater energy density and smaller volume compared to lead acid batteries. The name of Nickel-Metal hybrid battery has attached with the success of the first commercial hybrid electric vehicle "Prius" launched by Toyota in 1997. That inspires General motor after two years later in 1999 to change the battery of EV1 from lead acid battery to metal hybrid battery.

*Sodium Nickel-Chloride (ZEBRA)*

The Zero Emissions Batteries Research Activity ZEBRA batteries has several advantages make it favorable for electric vehicle application compared to same others types of batteries such as typical ZEBRA battery offer a high energy density (120 wh/kg) 2-3 times higher than nickel-metal hybrid and 3-4 times more than lead-acid battery, higher life cycle ( almost 3500 name plate cycle) 7 to 8 times higher than lead acid battery, zero self-discharge unaffected by ambient temperatures, maintenance free operation, no gassing.

The ZEBRA Battery has been in many electric vehicles prototypes, such as all-electric smart car which is a brand of Daimler Chrysler, Mercedes-Benz 'A'-class, BMW E1 as well as hybrid/electric public transportation buses in Italy and California. In addition, Rolls Royce has decided to replace Lead Acid by ZEBRA battery technology in military, rescue surface and submersible ship application [3].

*Lithium-Ion*

Lithium-Ion is one of the promising energy source hybrid/electric vehicle due to high energy density, high

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specific power, light weight which draw attention of automakers to replace he Nickel-Metal hybrid and Lead Acid battery to lithium-Ion. Modec first adopted lithium ion phosphate in 2007, then tesla used lithium cobat oxide for an electric vehicle in 2008. One year later, MUTSIBISHI involved lithium manganese oxide in the electric vehicle Outlander.

The researches and manufacturers of lithium ion battery are tending to reducing the manufacturing cost and improving energy density and power density.

- *Super Capacitor for Electric Vehicles*

The applications of super capacitor in the vehicle has been started from the late of 1980[4], the automakers of electric vehicle including hybrid/pluging/battery electric vehicle had adopted super capacitor in those type vehicle increase the power during acceleration, improve the fuel economy (the case of hybrid vehicle), extend the life cycle of the batteries, recovering the energy lost during braking. The use of super capacitor as subsystem combining or without batteries in the following application [5]:

*-Stop-Start system in hybrid vehicles:*

When the vehicle stops, the engine is turned off and on, so the electric energy storage must provide the accessory loads. The super capacitor have been used to assure the stop-go application by storing unit 10-25 Wh until up to 50 Wh with motor assist capability.

*Charge sustaining mild hybrids:*

In this application the super capacitor can be used instead of batteries, when the power demand is less than power capability of the electric motor, the hybrid vehicle operate only with electric drive is the case of low speed or urban driving, then the engine is operated to power the vehicle and recharge the super capacitor when the power demand is much higher than the capacity of electric motor.

*Hybrid transit Buses:*

Hybrid Transit buses operating in china using a packs of super capacitors of 3000 f Carbon/ Carbon cells from Maxwell Techn which lead to a signification improvement on fuel economy about 30-50% the most city driving (with natural gas engine), in addition for very low speed driving with frequent stops, the improvement was much higher (200-300).whoever the fuel economy decrease and energy consumption increase with air conditioning operating.

Fuel cell vehicles:

The super capacitor can be utilized in fuel cell vehicle by combining super capacitor with fuel cell too provide the peak power demand and/or when the power demand is much higher than the set maximum level of fuel cell.

*Plug-in Electric Vehicle ( PEVs)*

The key principle of use the super capacitor in plug-in electric vehicle is to cover the insufficient of the power requirement of the vehicle using batteries, whoever the average power needed by the vehicle is provided by battery and additional power during the acceleration is provided by super capacitor which also recovered the energy during regenerative braking and recharged when engine is operated by the engine power. The acceleration time of vehicle using super capacitor were lower than for batteries alone, it was 2.7 sec for 0-30 mph and 6.9 for 0-60 mph with super capacitor, in contrast with batteries the acceleration times varied from 2.9-3.2 for 0-30 mph and 8.6 to 9.8 sec for 0-60 mph.in the case of using super capacitor the peak power and average current from batteries are reduced by a factor of 2-3, the voltage flacuation decreased and the minimum voltage of the battery become higher. Then the resultant heating and the stress on battery are much reduced. As a result, without super capacitor the battery in both Ev's and PHEVs have to be increased volume, weight and cost to satisfy the maximum power rather than the range/ energy requirement.

Examples of using super capacitor in electric automotive industry:

-Toyota racing TS030 Hybrid established as a pioneer in the field of hybrid powertrains for motorsport. The car featured a Kinetic Energy Recovery System to charge a Nisshinbo super capacitor.

-TS040 Hybrid use a V8 engine and at the core of the system a Nisshinbo super capacitor mounted on the rear axle.

-The company NanoFlowCell presented the QUANT e-Sport limousine : Flow battery and super capacitors in an electric sports car in 2014.

- BMW launched a super capacitor hybrid sports car with Toyota.

-Peugeot 308 with a super capacitor based stop-start system.

-Volvo develops structural battery with super capacitor for car.

The big success of using the super capacitor for the Electric automotive was realized in China by the Chinese company Sunwin, which is a joint venture between Volvo and China's largest automaker SAIC had already made a big publicity stunt in 2010 by providing 61 electric buses using super capacitors to serve the World Expo 2010 of Shanghai.

Buses with super capacitors of Sunwin brought in their 2010 version an autonomy from 3 to 6 km. Super capacitors are then charged on each bus stop with a pantograph (like a tram). 30 seconds are enough to charge the bus to 50% and it takes 80 seconds to charge to 100%.

That success attracts more Chinese companies to follow this technology for example Higer super-capacitor buses have made their way to Bulgaria, Italy, Austria, and Serbia.

- *Other technologies for Electric Vehicles*

Other technologies are considerate as a research efforts and prototype concerning electric vehicles energy sources are ongoing on such as fuel cell, flywheel

The basic principle of flywheel technology is to recover the kinetic energy that used to be lost during braking as heat and store it in the spinning wheel, then release that energy upon acceleration. This technology has been tested by some car manufacturer such as Porsche "911 GT3 RS Hybrid", Audi "R18-tron Quattro", Jaguar "Prototype flywheel hybrid XF". They claim that it can provide a 25% of fuel economy improvement [6].

Fuel cell technology generates electricity using a chemical reaction between compressed hydrogen stored in tanks and the oxygen available from air. This technology is classified as zero emission and considerate as one of the promising technology and actual topic interest that drive to increase researches development enhanced by automakers experiments which achieve as result a several prototypes were leased such as: Honda FC X-V4, Nissan X-trail FCV, Ford focus FCV, GM hydrogen Gen4 and Mercedes Benz F-cell[7].

## III. METHODS

Several factors have been defined to characterize the performance of energy storage system suitable for electric vehicle such as external factor depend on the macroeconomic of the industry or the technical characteristic related to batteries and super capacitor and other storage technologies. The following factors cited below are the technical factors [8]:

-Ampere-hour capacity (Ah): is the total charge that can be provided (discharged) from a fully charged under specified conditions.

-Rated AH Capacity: is the nominal capacity of a fully charged device under predefined condition by the manufacturer.

-C-rate : is the discharge or charge rate equal to the capacity o the ES device in one hour.

-Internal Resistance: is the overall equivalent resistance within the ES device which is different or discharging and charging and may vary with change of operating conditions.

-Specific Energy : expressed in W/Kg is the quantity of energy that can be stored per unit mass.

Specific Power = rated peak power/ device mass in Kg.

-Power density : is the peak power per unit volume of ES device (W/L).

Energy density: is the nominal ES energy per unit volume (Wh/L).

-Power Peak: is defined at the condition when he terminal voltage is 2/3 of the open circuit voltage expressed by: $P= 2Voc^2/9R$ where : Voc: open circuit voltage and R: internal resistance of device.

-State of Charge (SOS): is the remaining capacity of the ES device and affected by the operating conditions such as temperature and load current.

SOC= Remaining Capacity/ Rated Capacity.

-Cut-off Voltage: is the minimum voltage allowable defined by the manufacturer.

- State of health (SOH) it can be expressed as the maximum charge capacity of an aged ES device over the maximum charge capacity where the device was new, which has a significant importance to indicate the degree of degradation of device and to can estimate the remaining lifetime.

-Deepth of Charge (DoD): is the percentage that indicate the total ES device capacity that has been discharged. DoD=1-SOC.

- Cycle life : is the number of charge-discharge cycles that the device can handle at a specific DoD before it can't meet specific performance criteria.

-Calender life: is the expected life span of the ES device under periodic cycling conditions which is related to SoC during storage and temperature.

The technical factors influencing the identification of energy source can be defined as the most imported for all type of electric vehicles including (hybrid vehicle, PHV, EV) are the specific energy (Wh/kg), specific power (w/kg), life cycle, energy efficiency (%) and the cost ($ /kwh). The table1 shows the comparison of energy storage system that can be applicated in EV.

### *A. PEST Analysis-based Influencing Factor Identification*

PEST analysis is an analytical tool to define the (Political, Economic, Socio-Cultural and Technological) factors used in the environmental scanning components of strategic management which help to minimize the threat and take advantages of opportunities [10][11].

This section used PEST Analysis to define the influencing factor on identifications of EV energy storage system.

-Political factors:

The political factor can be expressed by the act of governments on an industry or activity by applying such as laws, tax policy, trade restrictions, environmental laws and tariffs. In this context, governments and regional parliaments (such as European parliament) plays an important role on forcing the automotive industry to follow the regulatory requirements in term of greenhouses gas emission, fuel economy and safety by setting standards such as the national greenhouse gases standards setted by Environmental Protection Agency in US which requires that emission level of new passenger cars should be 225 gram of Co2 per mile in model 2016, in addition providing a financial and non-financial intensive as its cited in the table below in some countries. -Economic factors:

Economic factors can be defined by the factors which affect the purchasing power of potential customers and firm's cost of capital such as: interest rates, economic growth, inflation rate……etc. The selection of energy storage source of electric vehicle can be affected in this context by the raw material prices which control the rising and decreasing the production cost and maintenance cost whose considerate as very important variables in the financial equations established by the customer, also the rolling cost can be added as third variable. Figure 1 shows the historical and forecasted of some raw material prices $/mt.

-Social factors:

The social factors include cultural and demographic aspects that affect customer needs.in this context, automakers and statistical agency used to make a survey about customers main interest aspects in buying a car, the results are intuitive such as: cost, comfort, prestige, reliability…etc. the case of electric vehicle is quietly different whereas the customer should focus in some special aspects which related to electric vehicle such as autonomy range and charging facilities, in addition, the rising of environmental awareness in recent years lead people to feel more responsibility and act to protect the environment by making the CO2 emissions one the important side to choose the friendly environmental vehicle and take on consideration the following aspects: fuel economy, autonomy range, cost, safety, charging facilities, recharging time, reliability ( technical performance) whose are critical criteria in selecting the convenient electric vehicle cited in as survey established in US[12].

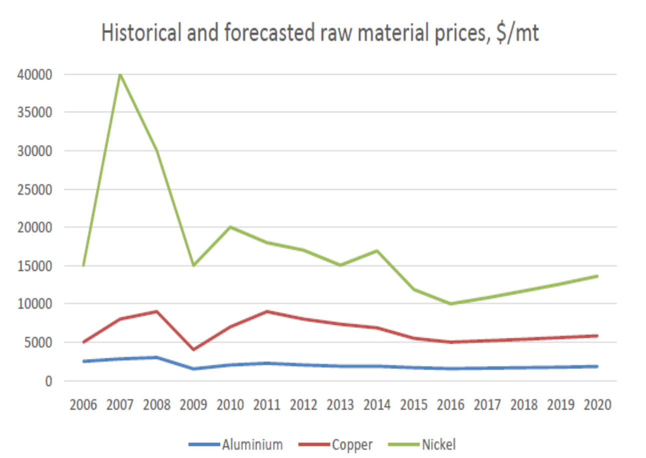



Figure 1: Historical and forecasted raw material prices [11].

**Table1**Comparison of energy storage systems that can be applicated in EV[9].

| Energy storage type | Specific energy (Wh/kg) | Energy density (Wh/L) | Specific power (W/kg) | Life cycle | Energy efficiency(%) | Production cost ($/kWh) |
|---|---|---|---|---|---|---|
| Lead acid | 35 | 100 | 180 | 1000 | >80 | 60 |
| Advance leadacid | 45 | - | 250 | 1500 | - | 200 |
| Valve regulated Lead Acid (VRLA) | 50 | - | 150 | 700 | - | 150 |
| Metal Foil Lead Acid | 30 | - | 900 | 500 | - | - |
| Nickel-iron | 50-60 | 60 | 100-150 | 2000 | 75 | 150-200 |
| Nickel-zinc | 75 | 140 | 170-260 | 300 | 76 | 100-200 |
| Nickel-cadmium | 50-80 | 300 | 200 | 2000 | 75 | 250-300 |
| Nickel-Metal hybrid | 70-95 | 180-220 | 200-300 | <3000 | 70 | 200-250 |
| Sodium-sulfur | 150-240 | - | 150-230 | 800 | 80 | 250-450 |
| Sodium-nickel chloride | 90-120 | 160 | 155 | 1200 | 80 | 220-345 |
| Lithium-iron sulphide (FeS) | 150 | - | 300 | 1000 | 80 | 110 |
| Lithium-iron phostphate (lifePO4) | 120 | 220 | 2000-4500 | >2000 | - | 350 |
| Lithium-ion polymer (LiPo) | 130-225 | 200-250 | 260-450 | >1200 | - | 150 |
| Lithium-ion | 118-250 | 200-400 | 200-430 | 2000 | >95 | 150 |
| Lithium-titanate (LiTio/NiMnO2) | 80-100 | - | 4000 | 18000 | - | 2000 |
| Aluminum-air | 220 | - | 60 | - | - | - |
| Zinc-Air | 460 | 1400 | 80-140 | 200 | 60 | 90-120 |
| Lithium-Air | 1,800 | - | - | - | - | - |
| **Ultracapacitor** | | | | | | |
| Electric double-layer capacitor (EDLC) | 05-Jul | - | 1-2M | 40 years | >95 | - |
| Pseudo-capacitor | Oct-15 | - | 1-2M | 40 years | >95 | - |
| Hybrid caapacitor | Oct-15 | - | 1-2M | 40 years | >95 | - |

**Table 2 :** Governments intensives for Electric Vehicles [11].

| | **China** | **US** | **The Netherland** | **Norway** |
|---|---|---|---|---|
| **Financial** | National subsidies $5600-$9500 Local subsidies up to $9500 Free licence plates $12000 | ATVM loans maximum of $75000 Federal income tax credit. | Exemption from registration tax BPM (private motor vehicle tax), annual circulation tax. | Exemptions from purchase Tax 25% VAT. |
| **Non Financial** | - | Free parking access to high occupancy vehicle lane. | Parking lots reserved for EV's, free charging in public spaces. | Free parking lot of EV's with charging stations, use of public transport lane. |

*-Technological Factors:*

Technological factors help to lower the barriers to entry, influence outsourcing decisions such as: automation, R&D Activity and technology incentives. In last recent years, technology advancement succeeds to reformulate the automotive industry and change the customer behavior by providing more facilities, raising the safety, increasing the environmental protection measures and others advantages that are presented in electric vehicle as a new generation of automotive industry. However, the high cost and lower autonomy range are the most barriers for electric vehicle to can compete the combustion engine vehicle. As a result; the automakers and researchers invest and increase efforts on those two aspects: decreasing the raw material cost and improving autonomy range.

*A. ANP-based Forecasting of Technology Adoption*

In order to select the best energy storage technology for electric vehicle, the analytical network process has been chosen to provide the best alternatives because it can model complex decision making problem and allows loops and feedback connections, using the criteria and aspects designed by PEST analysis and technical characteristics that allowed the comparison between the alternatives.

First of all, to can model a complex decision making problem should follow the steps of analytical network process using " Super decision " software which is the best and up to-date ANP program to form each step of the process until get the final synthetize priorities for the best alternatives.

**-Step 1:** Determine the criteria, sub-criteria and alternatives.

-According to the previous section, the structure of the model includes the following criteria:

Political, Economic, Social and Technological which have been defined by PEST analysis in addition of the technical criteria as the main factors influencing the energy storage identification as it shown in the following figure:

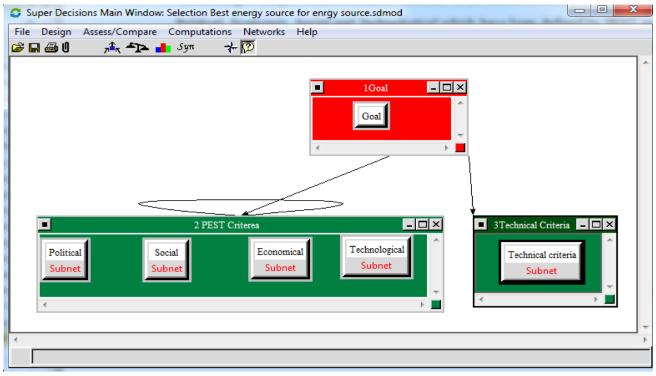



Figure 2: Influencing factors for energy storage identification

The complexity of the model force each criteria to have a sub-criteria as a sub-network with the same alternatives for all sub-network which are the main energy storage source for electric vehicle (battery, super capacitor, fuel cell).

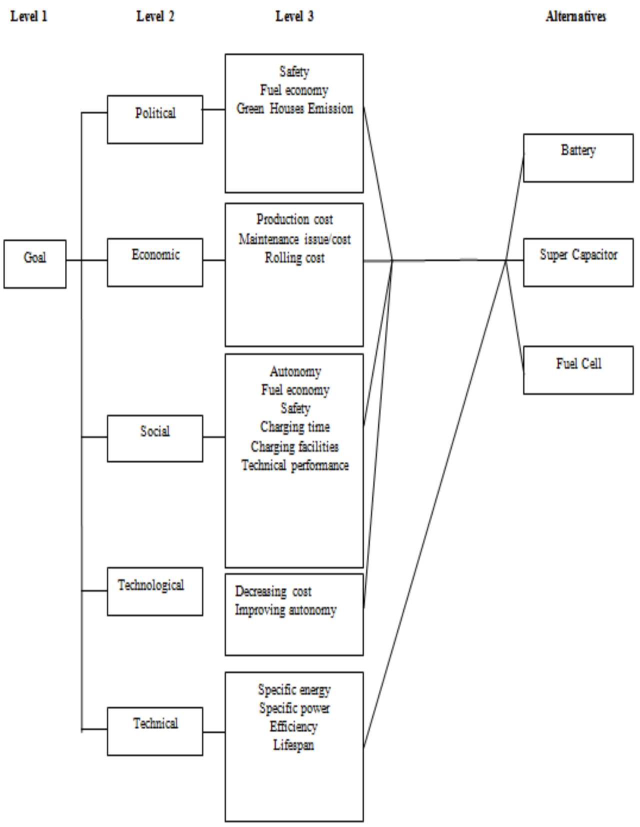



Figure 3: The whole model conception.

-Step 2: Establishment of pair-wise comparison matrix

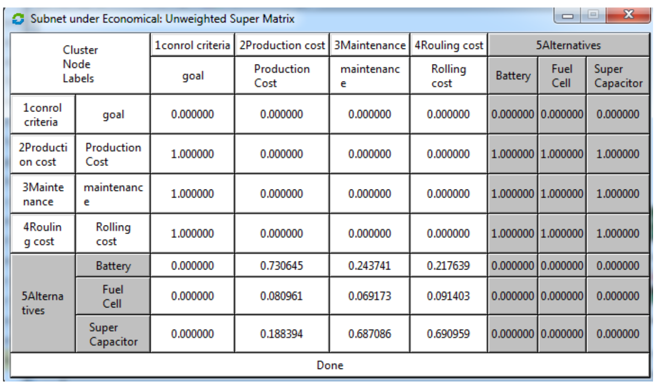
In this step, the pair wise comparison has been done according to two sources: the first one, are the several survey results has been done in different countries such as the studies cited in [12][13][14] where they studied the consumer concern in electric vehicle ( autonomy, fuel economy, recharging time….) which provide data to measure the weight of criteria, the second source is the technical comparison between the alternatives as it cited in the table below.

Table 3: comparison between alternatives

| Alternatives | Battery | Super Capacitor | Fuel Cell |
|---|---|---|---|
| **Specific Energy (wh/kg)** | 200 | 8-10 (130 typical graphen lab ) | 1300 |
| **Specific Power (W/kg)** | 2000-3000 | 10000 | 400-500 |
| **Energy Efficiency** (%) | 75-9 | Up to 95 | 50-80 |
| **Life span (years)** | 5-10 | 10-15 | 8-10 |
| **Safety** | Less safe | Safe | dangerous |
| **Co2 emission (g/mi)** [8] | 214 | 60-80 | 260-364 |
| **Recharging facilities** | lack | lack | rarely |
| **Fuel economy (average mpge)** | 84-119 | 31-85 | 50-67 |
| **Production cost ($per kwh** | Lithium battery 500$-1000 $ | 2400$-6000$ | 5000$-8000 $ |
| **Rouling cost ($ per mile)** | 0.004 | 0.018 | 0.09 |
| **Maintenance issue** | Low | Very low | Higher |
| **autonomy (mi)** | 110 | 1.86-3.11mi | 289 mi |
| **Decreasing raw material cost** | Extremly important | Very important | Important |
| **Improving autonomy** | Important | Extremely important | Important |
| **Time to refuel** | 3.5h-12h | Few seconds-1min | 5-30 min |

-Step 3: getting the Un-weighted super matrix

The Un-weighted super matrix contains the local priorities divided from the pairwise comparison through the network as shown in figure bellow. For example: the priorities of elements production cost and rolling cost, with respect to battery are shown as 0.614411 and 0.210920 respectively. This statement can be interpreted with, "the production cost of battery is moderately to strongly important than rolling cost". All the local priority information can be read directly at its shown from the un-weighted super matrix.


Subnet under Economical: Unweighted Super Matrix

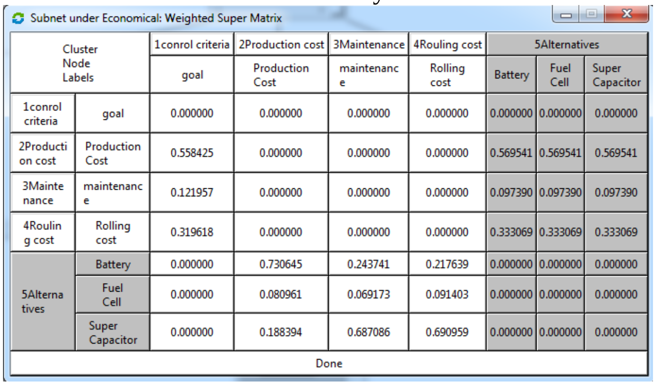
| Cluster Node Labels | | 1conrol criteria | 2Production cost | 3Maintenance | 4Rouling cost | 5Alternatives | | |
|---|---|---|---|---|---|---|---|---|
| | | goal | Production Cost | maintenance | Rolling cost | Battery | Fuel Cell | Super Capacitor |
| 1conrol criteria | goal | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 2Production cost | Production Cost | 1.000000 | 0.000000 | 0.000000 | 0.000000 | 1.000000 | 1.000000 | 1.000000 |
| 3Maintenance | maintenance | 1.000000 | 0.000000 | 0.000000 | 0.000000 | 1.000000 | 1.000000 | 1.000000 |
| 4Rouling cost | Rolling cost | 1.000000 | 0.000000 | 0.000000 | 0.000000 | 1.000000 | 1.000000 | 1.000000 |
| 5Alternatives | Battery | 0.000000 | 0.730645 | 0.243741 | 0.217639 | 0.000000 | 0.000000 | 0.000000 |
| | Fuel Cell | 0.000000 | 0.080961 | 0.069173 | 0.091403 | 0.000000 | 0.000000 | 0.000000 |
| | Super Capacitor | 0.000000 | 0.188394 | 0.687086 | 0.690959 | 0.000000 | 0.000000 | 0.000000 |

Done

Figure 4: Un-weighted Matrix

-Step 4: Getting the Weighted Super Matrix.

The Weighted super matrix is obtained by multiplying all the elements in a component of the un-weighted Super-matrix by the corresponding cluster weighted. In some cases; the weighted and un-weighted super matrix are the same since there are only two cluster in each network including the sub-network, so there is no cluster comparison because it cannot be made when there are only two cluster.


Subnet under Economical: Weighted Super Matrix

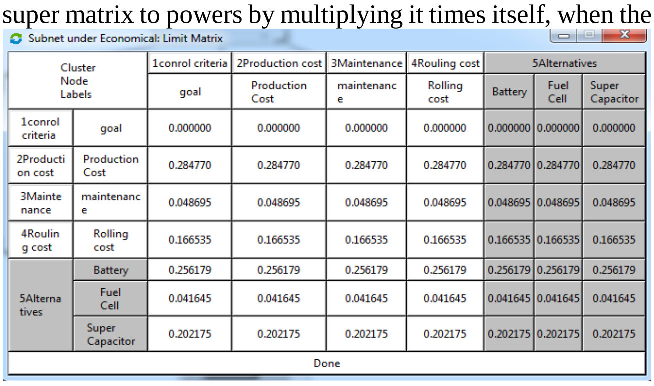
| Cluster | Node Labels | 1conrol criteria: goal | 2Production cost: Production Cost | 3Maintenance: maintenance | 4Rouling cost: Rolling cost | 5Alternatives: Battery | 5Alternatives: Fuel Cell | 5Alternatives: Super Capacitor |
|---|---|---|---|---|---|---|---|---|
| 1conrol criteria | goal | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 2Production cost | Production Cost | 0.558425 | 0.000000 | 0.000000 | 0.000000 | 0.569541 | 0.569541 | 0.569541 |
| 3Maintenance | maintenance | 0.121957 | 0.000000 | 0.000000 | 0.000000 | 0.097390 | 0.097390 | 0.097390 |
| 4Rouling cost | Rolling cost | 0.319618 | 0.000000 | 0.000000 | 0.000000 | 0.333069 | 0.333069 | 0.333069 |
| 5Alternatives | Battery | 0.000000 | 0.730645 | 0.243741 | 0.217639 | 0.000000 | 0.000000 | 0.000000 |
| | Fuel Cell | 0.000000 | 0.080961 | 0.069173 | 0.091403 | 0.000000 | 0.000000 | 0.000000 |
| | Super Capacitor | 0.000000 | 0.188394 | 0.687086 | 0.690959 | 0.000000 | 0.000000 | 0.000000 |

Done

Figure 5: Weighted matrix

- Step 5: the limit super matrix

The limit super matrix is obtained by raising the weighted super matrix to powers by multiplying it times itself, when the


Subnet under Economical: Limit Matrix

| Cluster | Node Labels | 1conrol criteria: goal | 2Production cost: Production Cost | 3Maintenance: maintenance | 4Rouling cost: Rolling cost | 5Alternatives: Battery | 5Alternatives: Fuel Cell | 5Alternatives: Super Capacitor |
|---|---|---|---|---|---|---|---|---|
| 1conrol criteria | goal | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 2Production cost | Production Cost | 0.284770 | 0.284770 | 0.284770 | 0.284770 | 0.284770 | 0.284770 | 0.284770 |
| 3Maintenance | maintenance | 0.048695 | 0.048695 | 0.048695 | 0.048695 | 0.048695 | 0.048695 | 0.048695 |
| 4Rouling cost | Rolling cost | 0.166535 | 0.166535 | 0.166535 | 0.166535 | 0.166535 | 0.166535 | 0.166535 |
| 5Alternatives | Battery | 0.256179 | 0.256179 | 0.256179 | 0.256179 | 0.256179 | 0.256179 | 0.256179 |
| | Fuel Cell | 0.041645 | 0.041645 | 0.041645 | 0.041645 | 0.041645 | 0.041645 | 0.041645 |
| | Super Capacitor | 0.202175 | 0.202175 | 0.202175 | 0.202175 | 0.202175 | 0.202175 | 0.202175 |

Done

Figure 6: Limit Matrix of Economic Subnet

column of numbers is the same for every column, the limit matrix has been reached and the matrix multiplication process is halted. As it shown following figure 6 the super matrix of economic sub-network.

-Step 6: Analyze and final decision using ANP.

In this step, "Super Decision" synthesis results of each sub-network and the whole model according to given weight and pair-wise comparison.

## IV. RESULTS DISCUSSION

The Political subnet:

- As it's shown in the following figure, the battery is the preference choice with a slightly difference from the super capacitor due to the advantage of battery on charging facilities and fuel economy. Where, the fuel cell is the last choice.

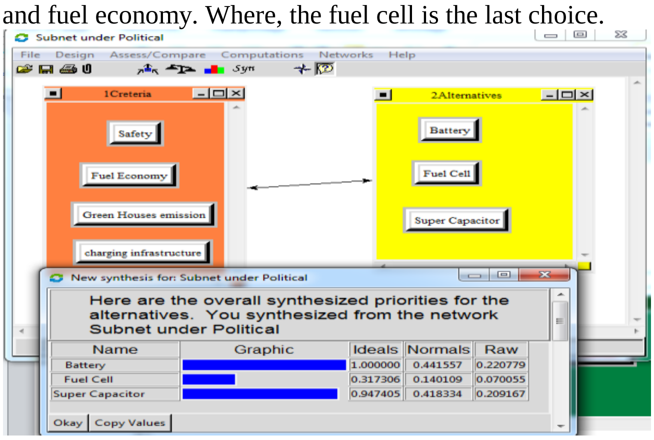



Figure 7: Political Subnet results

-Economic Subnet: The results shown that battery is the best alternative because its cheaper production cost which is the most important criteria in this aspect, whoever super capacitor take advantage in rolling cost and maintenance cost because the maintenance issues are fewer almost rare compare to other alternatives, in the other side, the high production cost and complexity of hydrogen system involved in fuel cell technology lead to more maintenance issues which make it as worst alternative in economic aspect.

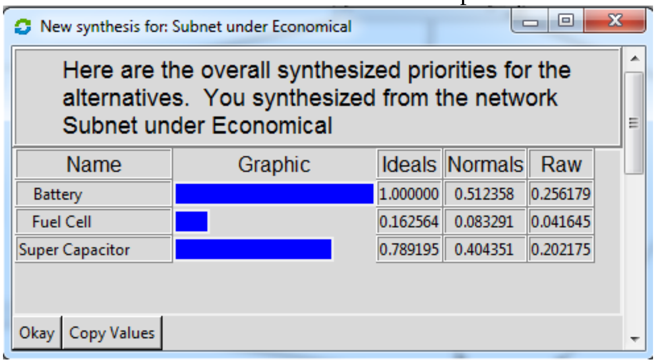



Figure 8: Economic Subnet results

-Social Subnet

The result shows that battery and Super capacitor have almost the same priority with light advantage to battery because they have almost the same advantages on criteria such as CO2 emission, safety, fuel economy…etc. in another hand the high cost, lack of safety and charging facilities make the fuel cell as the latest priority.

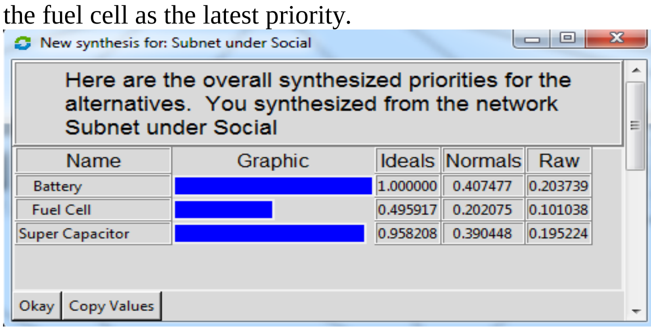



Figure 9: Social Subnet results

-Technological Subnet

The widespread of battery technology attract more researchers' efforts to carry on that leadership by improving the autonomy range and reducing production cost which explain the results shown in the following figure that battery have more development march than the others alternatives.

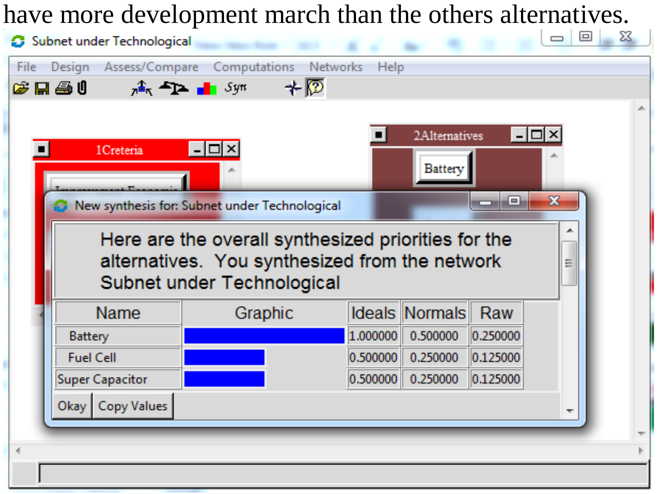



Figure 10 : Technological Sub-network results

-Technical Subnet

The result shows that Super capacitor is the first choice due to its high power densities, long life cycle and more efficiency than fuel cell and battery which are second and third choice respectively.

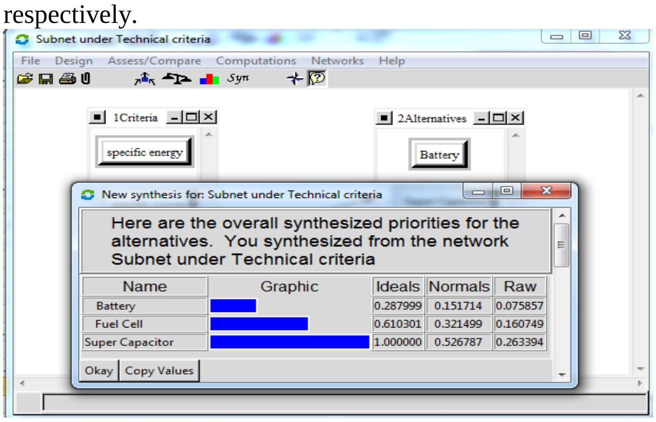



Figure 11 : Technical Sub-network results

The whole Model Synthesis

As it's noticed in the previous figures that battery has been elected as the best choice in all PEST analysis sub-network criteria (Political, Economic, Social and Technological) where super capacitor was the first alternative in Technical criteria, the figure bellow shows the final synthesis for the whole model.

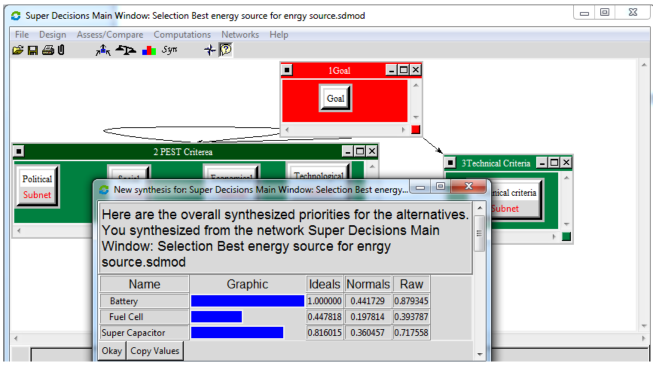



Figure 3. : The whole model results

-The final results generated by Super decision software select Battery as the best energy storage source for electric vehicle according to Analytical Network Process, and the others alternatives : Super capacitor and fuel cell as the second and third, respectively.

## V. Conclusion

The final results presented by the model characterized on the following highlight:

-Firstly, battery technology is still dominate the market as the best energy storage source for EV which satisfied all requirements defined by PEST analysis as macroeconomic dimension and from customers' needs such as cost, charging facilities, autonomy…etc. That choice is a logical result due to the maturity of this technology that keep on the leadership since appearance of EV till next decades looked at the enormous number of on-going researches and development on this technology in terms improving autonomy range, efficiency, prolonging life span and reducing recharging time and production cost.

- Secondly, super capacitor technology is a promising which can compete battery technology in the future because it has a several advantages such as high power density, long life cycle, high efficiency...etc. however, the main obstacle is the low energy density which considerate faraway from vehicle's requirement that make it impractical solution in current time, even that exception tested in super capacitor buses in china, can't be applicated to EV because the frequent load ( recharge) need for super capacitor bank each short distance ( few miles/less than 4 miles) that can be only practical with frequent stops of bus. Thus, super capacitor is typical for hybrid energy storage system with battery or fuel cell to provide the power need during acceleration, recovering braking energy, stop and star system and prolonging battery's life span, waiting the day that research succeed to reduce the production cost and improve the energy density of super capacity as much as vehicle's requirement to can replace battery technology.

-Thirdly, fuel cell technology was the last choice in the comparison established although the researches and manufacturer efforts to make it the future EV, enthused by its high energy density which assure more autonomy range and the short refueling time expressed just a few minutes compare to several hours with battery technology, but the lack of charging infrastructure for supplying a pure hydrogen to refuel hydrogen tanks, in addition, the high cost of fuel cell are the main obstacles to consumer's acceptance and practibility. Furthermore, the complexity of fuel cell system require more control of pressure and cooling systems are others technical issues underdevelopment.

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