Investigation of the Hybrid Renewable Power Plants and Financial Analysis of Tidal-wave-Solar Power Plant

Anupama Kanchustambam(1225758846), Lalith Sai Madhav Rayala(1226017093), Surys Sudarsan Naveen Ravula(1225834027), Masters in Mechanical Engineering, Arizona State University, Tempe, Arizona, United States, 85281

***Abstract* — Renewable energy power plants offer a green and sustainable solution for generating electricity, but they also have limitations, including low efficiency, low-capacity factor, and infrastructure requirements. Hybrid renewable energy power plants can address these limitations by combining two or more renewable sources to achieve greater efficiency and reliability. In this paper, we examine the advantages and disadvantages of renewable energy and explore the design and implementation stages of hybrid renewable energy power plants. We analyze several existing renewable energy power plants and discuss the key features of award-winning hybrid renewable energy power plants. We also propose a new concept for a tidal wave solar hybrid power plant and evaluate its economic feasibility by estimating key metrics such as the levelized cost of electricity and payback period. This paper provides insights into the benefits of hybrid renewable energy power plants and their potential to overcome the limitations of individual renewable sources.**

Keywords—renewable energy, hybrid renewable energy, improved efficiency, carbon footprint, Wind – solar, tidal-wave-solar.

I. INTRODUCTION (*HEADING 1*)

Energy is an essential part of the world that powers everything from our homes to transportation and communication devices. The statistics show that the exponential growth of energy demand is increasing rapidly. However, traditional energy sources such as fossil fuels are finite and as a negative effect on our environment. Therefore, renewable energy sources are becoming essential to meet the current energy demands. Although some developed countries contribute their share of renewable energy sources, they are not significant in the energy sector. It is necessary to note that many studies are on individual renewable sources without considering them as one. Our study focuses on hybrid renewable energy sources that combine multiple renewable energies to provide the required output. This report investigates various hybrid renewable energy power plants and their contribution to the energy sector.

II. ADVANTAGES OF RENEWABLE ENERGY

Renewable energy sources are becoming significant, especially in generating electricity to meet energy needs. Using natural and unlimited resources without damaging the environment gives renewable energy sources various advantages compared to traditional energy sources like fossil fuels. If the overall life cycle of the power plant is considered, the greenhouse gas emissions expressed in carbon dioxide equivalents are negligible for renewable sources. Fig ---- shows the greenhouse gas emissions by different energy sources in CO2 equivalent over their life cycle. It can be observed that the emissions from renewable energy sources like hydro and wind energies are significantly less when compared to traditional energies like natural gas, oil, and industrial gas.

Although each type of renewable energy has its characteristics, they all have the same life cycle phases, including research and design, development and manufacturing, construction and installation, maintenance, and dismantling. Moreover, implementing renewable energy sources promotes growth in the energy sector, leading to economic development. In addition, this sector's technological change and innovation require skilled workers, thus boosting employment opportunities. Also, as renewable energies are utilized as an additional energy source, the energy produced directly relates to the reduced consumption of fossil fuels that would otherwise be used to produce electricity.

But why hybrid comes into the picture is because of the disadvantages of renewable energy plants.

III. DISADVANTAGES OF RENEWABLE ENERGY

In addition to the numerous advantages of renewable energy sources, they have a few limitations and drawbacks. Its primary drawback is that it largely depends on geographic location and weather conditions, making them highly unpredictable. They also have a low capacity to generate electricity, meaning they do not produce large amounts of electricity compared to traditional energy sources. This can be because of the irregular availability of energy sources, fewer renewable energy power plants, and the available technologies in the renewable sector. Another concern in using renewable energy power plants is their efficiency in generating electricity. Therefore, more significant investments must be made in this sector to improve the existing technologies and efficiency. Furthermore, renewable energy power plants require a larger area to generate the same amount of electricity as traditional sources, thus increasing the initial cost of the plant. Because of these factors, the cost of electricity production using renewable energy sources is relatively high compared to traditional energy sources.

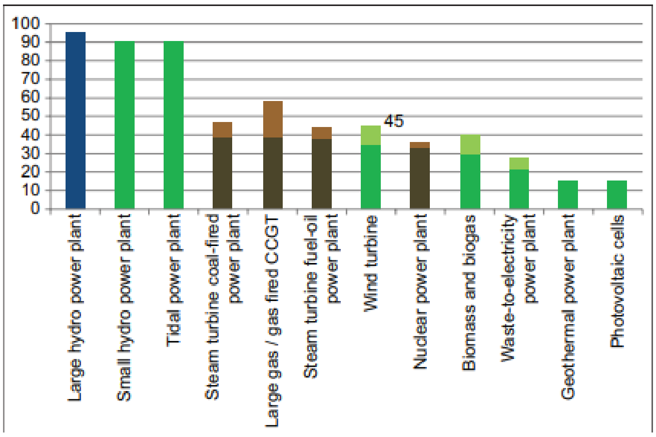

Fig. Efficiency of different technologies in electricity generation (%)

Source: Dario Maradin – Advantages and Disadvantages of Renewable energy sources

The figure shows that the efficiencies of the renewable power plants are low except for hydro and wind energies. In addition, biomass and biogas have efficiencies in the range of 30-40%, while PV and geothermal have the lowest energy efficiency of about 15%. In contrast, the large hydropower plants have the highest efficiency with over 90%, followed by small hydropower and tidal plants with efficiency close to 90%.

So, one solution to overcome the above disadvantages of renewable energy power plants is implementing hybrid renewable energy power plants.

IV. WHAT IS A HYBRID?

A hybrid renewable energy power plant is a facility that generates electricity by combining two or more renewable energy technologies, typically solar, wind, and/or hydropower. Hybrid power plants are designed to provide a more stable and reliable supply of electricity than a single renewable energy source can provide alone. By combining different renewable energy sources, hybrid power plants can maximize the benefits of each energy source while minimizing their drawbacks. For example, solar power can be used during the daytime, wind power can be used during the night, and hydropower can be used during periods of peak demand. The result is a more cost-effective and sustainable energy solution that can help reduce greenhouse gas emissions and combat climate change.

V. POSSIBLE CONFIGURATIONS OF HYBRID RENEWABLE POWER PLANTS

A. *Wind-Hydro Power Plant:*

In this type of system, the wind turbines and hydro turbines are connected to the same grid to generate electricity simultaneously. With high wind speeds, the wind turbines generate more power; when there are low wind speeds, the hydro turbines generate more power ensuring that the electricity is generated continuously.

B. *Solar-Hydro Power Plant:*

This hybrid power plant combines solar and hydropower to generate electricity. During the daytime, it uses solar panels to generate electricity, while the excess energy generated is used in pumping water into a higher reservoir. Then, during low solar radiation or nights, water is stored in a higher reservoir and released to generate electricity using hydropower turbines by using the potential energy of the water.

C. *Wind - Solar Power Plant:*

This power plant combines wind and solar power to generate electricity. Wind turbines and solar panels are used to generate electricity by connecting them to a single grid. During the day, with high wind speeds, wind turbines, and solar panels generate more electricity together. The excess energy generated is stored in energy storage systems like batteries. During low solar energy and wind speeds, the excess energy stored is used to meet the high energy demand.

D. *Biomass - Solar Power Plant:*

This hybrid power plant simultaneously uses biomass and solar power to generate electricity. When solar energy is high, the solar panels generate more electricity, but biomass supplements the energy production when there is low solar energy available. This system can also be used to fire biomass using solar energy without the use of additional fossil fuels.

E. *Geothermal - Solar Power Plant:*

In this type of hybrid power plant, geothermal and solar power are used simultaneously to generate electricity. Solar panels generate more electricity during high solar radiation, but geothermal power is used at night to supplement energy production. In addition, this hybrid power plant can relate to energy storage devices such as batteries, which can be charged using excess energy generated during high solar radiation or geothermal power periods.

VI. Design and Implementation of Hybrid Renewable Energy Systems

A. *Renewable energy resources:*

Renewable energy sources are a key component in the design and implementation of hybrid renewable energy systems (HRES). HRES combines two or more renewable energy sources to optimize energy generation and improve overall efficiency. A wide range of renewable energy sources can be used in HRES, including solar panels, wind turbines, hydroelectric generators, biomass generators, and geothermal systems. The choice of energy sources will depend on factors such as location, available resources, and energy demand. For example, a location with ample sunlight might prioritize solar panels, while a location with high wind speeds might prioritize wind turbines.

B. *Energy Storage*

One critical component of hybrid renewable energy systems (HRES) is energy storage. Energy storage systems, such as battery storage systems or hydrogen fuel cells, can be used to store excess energy generated by renewable sources. This stored energy can be used during periods when renewable sources are not generating enough power, such as during the night or on cloudy days. The use of energy storage systems allows for greater energy reliability and improved energy efficiency. Additionally, energy storage systems can help to reduce the need for additional power generation capacity during peak energy demand periods. Battery storage systems are a popular choice for energy storage due to their low maintenance requirements and high efficiency, while hydrogen fuel cells offer the advantage of high energy density and long-term storage capabilities. The selection of an appropriate energy storage system will depend on several factors, including energy demand, system size, and available resources.

C. *Backup Power*

In certain instances, hybrid renewable energy systems (HRES) may require a backup power source to ensure an uninterrupted power supply. The backup power source can be a fossil fuel generator or a battery backup system. The choice of backup power source will depend on several factors, including energy demand, system size, and available resources. A fossil fuel generator can provide reliable backup power but comes with the disadvantages of high carbon emissions and high maintenance costs. Alternatively, a battery backup system can provide a reliable backup power source with the added benefit of low carbon emissions and minimal maintenance requirements.

D. *Control and monitoring*

Control and monitoring systems are essential components of hybrid renewable energy systems (HRES) as they ensure the efficient use of energy sources and storage. These systems can optimize the use of renewable sources, manage energy storage, and control backup power systems. Advanced control and monitoring systems are required for the effective operation of HRES, particularly for complex systems that incorporate multiple energy sources and storage technologies. Control systems can provide real-time data on energy production and consumption, allowing for the optimization of energy flows and the minimization of energy waste. Monitoring systems can provide data on system performance, allowing for the detection of potential issues and the implementation of corrective actions. These systems can be automated, enabling the HRES to adjust to changing energy demands and fluctuations in the energy supply.

E. *Integration and optimization*

The optimization of hybrid renewable energy systems (HRES) is crucial for ensuring their efficient and reliable operation. The integration of renewable energy sources, energy storage systems, and control and monitoring systems must be carefully designed to maximize energy efficiency, minimize energy waste, and ensure system reliability. The size and placement of energy sources must be carefully considered to ensure the optimal use of available resources and to minimize the environmental impact of the system. Energy storage capacity must be designed to match the energy demands of the system, ensuring that energy can be stored when it is abundant and used when it is needed. Control and monitoring systems must be integrated to manage energy flows and ensure that the system operates at optimal efficiency. The optimization of HRES requires a thorough understanding of the energy demands of the system, available resources, and the environmental impact of the system. The use of advanced modeling and simulation techniques can help to optimize the design and operation of HRES, enabling the system to meet energy demands efficiently and reliably.

VII. Few Award-Winning Hybrid Renewable Power Plants

A. *El Hierro Renewable Power Energy Plant, Spain*

The El Hierro Renewable Energy Plant serves as a remarkable example of sustainable energy generation and storage. It is located on the island of El Hierro in the Canary Islands, Spain, and has been recognized internationally for its innovative approach. The plant employs a hybrid system, utilizing a combination of wind and hydroelectric power to generate electricity and meet the island's energy needs. The wind farm comprises of five wind turbines, with a total capacity of 11.5 MW, and a pumping capacity of 6MW. Since the peak demand of the island is 7.5 MW, the plant can provide completely sustainable energy without having to depend on backup in certain circumstances. The plant has a pumped hydroelectric storage facility that uses excess wind energy to pump water from a lower to a higher reservoir. The water is then released to generate hydroelectric power when electricity demand is high. The plant has a significant impact on the environment, avoiding over 20,000 tons of CO2 emissions per year and reducing diesel consumption by 7,000 tons per year. The wind has enabled the Canary Island of El Hierro to cover all its electricity demand with renewable energy from 13 July to 7 August and has thus reached the milestone of covering its electricity needs for more than 24 days using 100% clean generation, exceeding the previous record that was set between 15 July and 2 August 2018. The plant currently covers approximately 60% of the island's electricity demand, reducing the island's dependence on fossil fuels and contributing to the global effort to lower greenhouse gas emissions.

B. *Coober Pedy hybrid renewable power project, Australia*

The renewable energy project located in Coober Pedy, South Australia, is an impressive example of the potential of renewable energy to reduce greenhouse gas emissions, lower electricity costs, and increase energy security and reliability. The project includes 1.6 MW of solar panels, 2 MW/0.5 MWh battery storage, and 4 diesel generators with a total capacity of 1.5 MW. The system is designed to meet up to 70% of the town's electricity demand with renewable energy, maximizing the use of solar power during the day and storing excess energy in batteries for use at night. The benefits of this renewable energy project are significant. By reducing reliance on diesel generators, the project lowers the town's annual diesel consumption by 400,000 liters and reduces greenhouse gas emissions by around 1,000 tons per year. In addition, the project provides job opportunities and economic development in the town, which could have a positive impact on the local community. The site record of 97 continuous hours of 100% renewable energy supply in December 2019 is a testament to the effectiveness of the project's design and implementation. Overall, the Coober Pedy renewable energy project serves as an excellent example of the potential of renewable energy to provide sustainable and reliable energy to remote areas while also reducing greenhouse gas emissions and supporting local economic development.

C. *Wind Solar hybrid plant, Rajasthan, India*

The Jaisalmer Wind Park is an impressive wind-solar hybrid power plant located in Jaisalmer, Rajasthan, India. With a total capacity of 1.06 GW, it consists of 750 MW of wind power and 310 MW of solar power. The project has 528 wind turbines, each with a capacity of 1.42 MW, spread across an area of approximately 220 square kilometers, and 130 MW of solar photovoltaic panels, spread across an area of approximately 1300 acres. The integration of wind and solar power components into a single grid is a significant achievement, and the use of advanced technologies to manage the variability and intermittency of wind and solar power is commendable. The project's 25-year Power Purchase Agreement (PPA) with SECI at Rs. 2.69 per kWh (3.3 cents per kWh) is also impressive, as it demonstrates the economic viability of renewable energy. The Jaisalmer Wind Park project is an excellent example of how renewable energy can help to reduce greenhouse gas emissions, promote sustainable development, and increase the share of renewable energy in the region's electricity mix. It is also aligned with India's ambitious vision of achieving a 45 GW capacity by 2030, which is a significant step towards a greener and more sustainable future. Overall, the Jaisalmer Wind Park is a remarkable project that showcases the potential of renewable energy to provide clean, reliable, and affordable energy while also addressing climate change and promoting sustainable development. It serves as an inspiration for other countries and regions looking to transition to a low-carbon economy. The project includes 1.6 MW of solar panels, 2 MW/0.5 MWh battery storage, and 4 diesel generators with a total capacity of 1.5 MW.

E. King Island Hybrid renewable energy power plant, Australia

The King Island Hybrid Renewable Energy Project is an exciting sustainable energy initiative that demonstrates the potential of integrating multiple renewable energy sources. The project is being led by Hydro Tasmania in partnership with the King Island community in Tasmania, Australia. The project includes the integration of wind, solar, and energy storage technologies. The wind farm has three turbines with a total capacity of 3 MW, while the solar farm consists of approximately 2,800 panels with a capacity of 0.75 MW. The energy storage system has a capacity of 1 MW/4 MWh. This combination of renewable energy sources and energy storage enables the system to operate entirely off-grid and transition from diesel power to 100% renewables and back again as needed., and 130 MW of solar photovoltaic panels, spread across an area of approximately 1300 acres. The automated transition from diesel power to 100% renewables, and back again as needed, is a remarkable achievement of the King Island Hybrid Renewable Energy Project. This automation is critical because it allows the system to operate unstaffed and ensures that the power supply remains uninterrupted during rapid and unpredictable changes in sun or wind conditions. The integration of multiple renewable energy sources, along with an energy storage system, enables the system to be more reliable and resilient. By automating the system's operation, the project can achieve significant diesel savings, which is an essential factor in reducing greenhouse gas emissions and promoting sustainable development. The project's success demonstrates the importance of technological innovation and collaboration between communities and energy companies in achieving sustainable development goals.

E. Biomass – solar hybrid Plant, Spain:

The combination of biomass and solar power to generate electricity is a promising solution for achieving a sustainable and renewable energy system. This hybrid system can provide stable and reliable electricity, using renewable energy sources, and reduce greenhouse gas emissions. The plant can be operated in three modes, namely solar, mixed, and biomass, allowing flexibility in power generation based on the availability of biomass and solar resources. The use of forestry residue and other biomass waste for the biomass system, and high-efficiency solar panels for the solar system, helps to maximize electricity output and improve the plant's overall efficiency. The levelized cost of electricity (LCOE) for biomass power and solar power is estimated to be EUR 0.17/kWh and EUR 0.19/kWh, respectively. The estimated carbon emissions reduction of more than 30,000 tons per year is a significant achievement for the plant and demonstrates the potential of hybrid systems to reduce greenhouse gas emissions. The overall efficiency of the hybrid system can range from 30% to 50%, depending on the specific design and operating conditions. A higher capacity ratio of biomass to solar can result in higher overall efficiency, with a well-designed and optimized hybrid system achieving 40% or higher efficiency. In summary, the hybrid biomass and solar power plant is an innovative and sustainable approach to generating electricity. The plant's flexibility, high efficiency, and low carbon emissions make it a promising solution for meeting energy demands while addressing climate change.

VIII. Analysis of a Model of a Tidal-Wave-Solar Hybrid Power Plant

The location chosen for the model is East Banks Strait Islands, Australia. Typically, a hybrid tidal wave solar energy plant harnesses the energy from both tidal waves and solar energy to generate electricity. The tidal wave portion of the plant consists of turbines that are placed in areas where there is significant tidal activity, such as in coastal areas. These turbines are driven by the force of the incoming and outgoing tides, which rotate the turbines and generate electricity.

The solar energy portion of the plant consists of solar panels that are placed in areas with high levels of solar radiation, such as in deserts or sunny regions. The solar panels convert the energy from the sun into electricity, which is then fed into the power grid.

In a hybrid tidal wave solar energy plant, the electricity generated by both the tidal wave and solar energy components is combined and fed into the power grid. The combination of these two energy sources provides a more consistent and reliable supply of electricity, as tidal energy is more predictable than solar energy, which can be affected by weather conditions.

IX. Calculation of LCOE

Here are the calculation steps to determine the LCOE of your hybrid tidal wave solar energy plant, including the incentives from RECs:

I. Calculate the total revenue generated from selling RECs over the lifetime of the project.

Total RECs generated = 25 years * 175,000 MWh/year = 4,375,000 MWh

Total revenue from selling RECs = Total RECs generated * price per REC

= 4,375,000 * AUD 45/REC

= AUD 196,875,000

II. *Calculate the total present value of cash flows over the lifetime of the project.*

Total present value of cash flows = (Annual revenue - Annual operating cost - Annual capital cost) / (1 + Discount rate) ^{Year}

Where,
Annual revenue = Annual energy output * (PPA price + REC price)

Annual operating cost = AUD 3.5 million

Annual capital cost = AUD 8 million

PPA price = AUD 80/MWh

REC price = AUD 45/REC

Year = year of operation (1-25)

Using the above formula and data, the total present value of cash flows is AUD 214,059,147.

III. *Subtract the revenue generated from selling RECs from the total present value of cash flows.*

Total present value of cash flows after REC revenue = AUD 214,059,147 - AUD 196,875,000 = AUD 17,184,147.

IV. *Calculate the levelized cost of energy (LCOE).*

LCOE = Total present value of cash flows / Total energy output over the lifetime of the project

LCOE = AUD 17,184,147 / (175,000 MWh/year * 25 years)

LCOE = AUD 0.0564/kWh

Therefore, the LCOE of your hybrid tidal wave solar energy plant with a capacity of 40MW, including the incentives from RECs, is AUD 0.0564/kWh.
To calculate the return on investment (ROI), we need to determine the total revenue generated over the lifetime of the plant and compare it to the total cost of the plant.

The total revenue generated can be calculated as follows:

Total Revenue = Annual Energy Output x Price per MWh x Lifetime

Substituting the values from our earlier calculation, we get:

Total Revenue = 175,000 MWh x AUD 70/MWh x 25 years = AUD 306,250,000

The total cost of the plant, including the tax credit and grant, is AUD 180 million, calculated as follows:

Total Cost = Initial Investment - Tax Credit + Grant
Total Cost = AUD 200 million - (10% x AUD 200 million) + AUD 50 million
Total Cost = AUD 180 million

Therefore, the ROI can be calculated as follows:

ROI = (Total Revenue - Total Cost) / Total Cost x 100%
ROI = (AUD 306,250,000 - AUD 180,000,000) / AUD 180,000,000 x 100%
ROI = 70.14%

The payback period can be calculated as the length of time it takes for the total revenue generated to equal the total cost of the plant. We can calculate the annual revenue generated by dividing the total revenue by the lifetime of the plant:

Annual Revenue = Total Revenue / Lifetime
Annual Revenue = AUD 306,250,000 / 25 years
Annual Revenue = AUD 12,250,000

The payback period can be calculated as follows:

Payback Period = Total Cost / Annual Revenue
Payback Period = AUD 180,000,000 / AUD 12,250,000 per year
Payback Period = 14.7 years

Therefore, the return on investment is 70.14%, and the payback period is 14.7 years.
These are the results of our analysis of a hybrid tidal wave solar renewable energy plant. The calculations are based on rough estimates and assumptions as not much data is available regarding the above-mentioned parameters and factors considered in the calculations.

X. Summary of the Calculations

Here is a summary of the calculation steps for the LCOE of your hybrid tidal wave solar energy plant with a capacity of 40MW:

1. The total cost of the plant is AUD 200 million, including operational and maintenance costs for 25 years of life expectancy.
2. The expected lifetime of the plant is 25 years.
3. The expected annual energy output of the plant is 175,000 MWh.
4. The discount rate used to calculate the present value of future cash flows is 8%.
5. The Australian government provides a 10% tax credit, and a scheme called ARENA can provide up to AUD 50 million to large-scale renewable projects. Moreover, in the RET scheme, each MW generated gives us one REC. The average price of one REC in Australia is AUD 45.
6.

References

[1] https://www.theguardian.com/business/2017/jun/28/china-floating-solar-power-farm-renewable-energy

[2] International Energy Agency. "Spain's Bioenergy Future: The Potential of Biomass for Heating and Electricity." https://www.iea.org/reports/spains-bioenergy-future

[3] https://tethys.pnnl.gov/project-sites/west-islay-tidal-project-energy-park

[4] https://www.insider.co.uk/news/meygen-tidal-project-awarded-176m-9869209

[5] http://euanmearns.com/a-first-look-at-the-king-island-tasmania-renewable-energy-integration-project/

[6] https://www.irena.org/

[7] https://www.nrel.gov/

[8] https://www.renewableenergyworld.com/

[9] https://www.investopedia.com/terms/r/renewable-energy-project-finance.asp

[10] https://www.indiatvnews.com/business/news/adani-green-switches-on-india-first-hybrid-power-plant-latest-business-news-updates-2022-05-28-780041

[11] https://www.researchgate.net/publication/350801317_Advantages_and_Disadvantages_of_Renewable_Energy_Sources_Utilization

[12] https://renewablesnow.com/news/spains-el-hierro-island-finishes-2019-with-54-renewables-share-683388/

[13] https://www.idom.com/en/project/el-hierro-hydrowind-power-plant-2/

[14] https://fedarene.org/best-practice/wind-pumped-hydro-power-station-of-el-hierro/

[15] https://www.pv-magazine-australia.com/2019/09/05/edls-coober-pedy-hybrid-renewable-project-wins-at-2019-asia-power-awards/

[16] https://edlenergy.com/project/coober-pedy/

[17] https://www.drishtiias.com/state-pcs-current-affairs/india-s-first-hybrid-power-plant-started-in-jaisalmer#:~:text=Jain%2C%20MD%20and%20CEO%20of,generation%20plant%20in%20the%20country

[18] https://www.energymining.sa.gov.au/industry/modern-energy/off-grid-energy/off-grid-projects#:~:text=Energy%20Developments%20Limited%20(EDL)%20has,uses%20approximately%2070%25%20renewable%20energy

[19] https://edlenergy.com/news/edls-coober-pedy-hybrid-renewable-project-wins-at-2019-asia-power-awards/

[20] https://www.indiatvnews.com/business/news/adani-green-switches-on-india-first-hybrid-power-plant-latest-business-news-updates-2022-05-28-780041

[21] https://www.energy.gov/lpo/loan-programs-office

[22] Advantages and Disadvantages of Renewable Energy Sources UtilizationDario Maradin*University of Rijeka, Faculty of Economics and Business, Rijeka, Croatia. *Email: dario.maradin@efri.hr , https://doi.org/10.32479/ijeep.11027