

## An integrated ANP-ELECTRE III decision model applied to eco-friendly car selection

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### ABSTRACT

The number of green energy options in different fields is growing because of the need for reducing energy consumption and eliminating gas emission. One of these options is the use of eco-friendly cars produced by various manufacturers. Given the many available options and conflicting evaluation criteria, evaluation of such options becomes complex, and different multi-criteria decision-making (MCDM) approaches have been used to select the most suitable car in terms of eco-friendly car selection. Previous research has been somewhat limited with respect to consideration of interdependencies between evaluation criteria and multi-levels of preference. This paper proposes a new integrated MCDM approach with the capability for considering interdependent criteria for eco-friendly car evaluation and different levels of preference. An analytic network process (ANP) will be used to evaluate the levels of importance of interdependent criteria, and ELECTRE III will be modeled to include thresholds of preference. The introduced model, based on twenty-eight evaluation criteria, was demonstrated in a case study dealing with five alternative electric and hybrid cars. The results from this model were compared to a traditional decision-making method and better results were obtained from the model. The model can help users make proper decisions regarding their future car options in a comprehensive manner. Sensitivity analysis showed the robustness of the model under different setups.

Key words: ANP; ELECTRE III; Green cars; MCDM; Selection

## INTRODUCTION

Eco-friendly cars have recently come into wide use and have received great acceptance from a variety of cultures and governments (Paulino Mendoza, 2018). An intention to buy this sort of car may differ from country to country and customer to customer (Yim & Chong, 2018), but the adoption of such cars may generally be explained by their capability for saving energy and significantly reduce gas emissions (Chowdhury, Salam, & Tay, 2016), (Sultana, Khairuddin, Rasheed, Qazi, & Mokhtar, 2018) and (Rihab, Naourez, Mohamed, & Rafik, 2021). The greater acceptance of such cars also comes in response to increased costs of regular fuel sources, especially in energy-poor countries. Other causes can be related to environmental and political issues, especially in industrially-based countries. Many companies have begun producing electric and hybrid versions of their brands with different styles and capabilities, with the result that a variety of cars of this kind, with a wide range of technical specifications and prices, are now available to users in different countries. Rooted in the fact that preferences may differ widely with respect to basic needs, characteristics, and perceptions, a user should choose a car which fulfills his/her requirements and preferences. Accordingly, technical specifications, preferences and financial aspects should all be considered when selecting an eco-friendly car.

The process of selecting an option can be performed using simple ranking methods when a simple selection choice is encountered, but systematic decision-making approaches are needed for dealing with complicated problems. In the context of eco-friendly car selection, given potential interdependencies among performance measures and uncertainties related to evaluation of alternatives, a systematic decision-making approach is required, so the decision-making process is likely to be even more complicated. Many decision-making methods have been applied to the

selection of suitable cars with a particular focus on eco-friendly cars. However, the interdependencies among performance measures have often been only superficially considered in eco-friendly car selection, minimizing their importance in real case situations. In addition, little effort has been directed toward handling the uncertainties associated with eco-friendly car evaluation. Accordingly, there is a need to introduce a model, which is easily understood with capabilities to consider the complexities associated with interdependent selection criteria and uncertainties.

This paper seeks to introduce a realistic decision-making framework to aid in making good decisions regarding eco-friendly cars. The framework is composed of two integrated main stages; an analytic network process (ANP) method, and ELimination and Choice Expressing REality (ELECTRE) III. The first stage will be structured to allow consideration of interdependencies between performance measures and provide limiting priorities for them. These weights of importance will then be used by ELECTRE III to perform consecutive outranking stages that seek to rank alternative cars based on specified preference thresholds.

This paper is organized as follows: Section 2 will provide a background of related work and previously-used decision-making methods. Section 3 describes the methodology used and demonstrates its use in a real case study. Discussion, conclusions, and future work will be presented in Sections 4 and 5.

## BACKGROUND

This section introduces previous work related to car selection and presents the decision-making method and evaluation measures used. ANP and ELECTRE III methods will also be briefly described.

### Related Work

Modern lifestyles necessitate the use of cars and people have naturally become increasingly dependent on them. Car aesthetics also play a major role in framing consumers' perceptions, as stated by Ranscombe et al. (2011) who conducted a web-based study to evaluate preferences with respect to aesthetic features of cars and their influence on consumer perceptions. A study conducted on undergraduate students showed that cultural factors in developing countries can affect needs for new car possession (Belgiawan, Schmöcker, & Fujii, 2013). On the other hand, considerable effort has been directed toward reducing the effects of an increase in the number of cars. For example, Ishak, Malingam, and Mansor (2016) proposed a Fuzzy-VIKOR method to aid in selection of a proper natural material used in a car's front hood to reduce car weight, improve fuel efficiency, and reduce emissions.

The problem of car selection has attracted researchers from the automobile industry, marketing, and decision-making fields. Previous research has focused on vehicle, material-handling equipment, and car selection based on a combination of performance measures and user perceptions. An integrated decision model was introduced based on Fuzzy set theory and TOPSIS and applied to the problem of crane selection (Amir Mohamadghasemi, Hadi-Vencheh, & Hosseinzadeh Lotfi, 2020). A MCDM framework was also developed by integrating fuzzy set theory and ELECTRE III, the resulted framework was applied to the material handling equipment

evaluation and selection (A. Mohamadghasemi, Hadi-Vencheh, Lotfi, & Khalilzadeh, 2020). To enhance understanding of user preferences with respect to luxury cars, an AHP model embodying various evaluation criteria was configured. The criteria in that model were weighted using AHP to allow comparisons between alternative cars (Apak, Göğüş, & Karakadılar, 2012). In addition, Chand and Avikal (2016) introduced an AHP model for selecting the most suitable hatchback car from the Indian market. Sri Yogi (2018) used AHP and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to improve understanding of customer intention with respect to purchasing a two-wheeler India automobile. Singh, Singh, and Sandhu (2018) also introduced a decision-making framework for scooter selection based on a combined TOPSIS-AHP model structured from various evaluation criteria, and Biswas and Saha (2019) introduced a Fuzzy-AHP Based model integrated with a new MCDM method for selecting scooters. The results of that model were compared to other MCDM methods, with model attaining greater simplicity.

As another example, Yıldız and Ergül (2014) introduced a Fuzzy-TOPSIS decision-making framework for automobile selection, with Fuzzy AHP also utilized to structure the problem of car selection and determine relative weights of importance of the evaluation criteria. Subsequently, hierarchical gray relation analysis (GRA) and the Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) were used to rank car alternatives (Sakthivel et al., 2013). Yousefi and Hadi-Vencheh (2010) combined scores of AHP and TOPSIS to rank aspects of automobiles to help Iranian automobile industries further understand consumer needs, with the scores validated using a data-envelopment analysis technique. The results demonstrated the superiority of the proposed model over individual AHP and TOPSIS models. Criteria for selecting sport-utility vehicles were examined using AHP with results showing the importance of safety, comfort, and quality to SUV users (Tumuju, Lopian, & Tumbuan, 2017) and (Mangindaan, Saerang, & Tumiwa 2017). Criteria for selecting off-road double cabins in terms of

their importance were also determined using AHP. Singh and Avikal (2019) also introduced an integrated MCDM model composed of two main stages of weight determination criteria and subcriteria and ranking alternatives. A fuzzy AHP model was built to determine the relative weights of importance, while a TOPSIS-based model was built to rank car alternatives.

An AHP-based model was also proposed to help make car purchase decisions based on many criteria and sub-criteria and structured in a hierarchy, and the results of the model were validated with market-share information about three cars (Byun, 2001). Kele (2019) introduced a decision-making framework composed of integrated Entropy and ELECTRE III, with the Entropy method used to weight evaluation criteria importance after which ELECTRE III used these weights to proceed through its outranking stages to rank car alternative. To allow consideration of interdependencies between evaluation criteria, a fuzzy-ANP model with capabilities for dealing with interdependent linguistic decision criteria has been developed, with criteria and sub-criteria arranged in clusters, forming a network of interdependent criteria (Yayla, A & Yildiz, 2013).

Multiple linear regression has also been used to determine the main factors affecting consumer preferences in Chennai toward small cars, with consumer preferences shown to be affected by factors of value, need, comfort, efficiency, accessibility, and ambition. For each factor, sub-factors were shown and examined (Anandh & Sundar, 2014). To enhance understanding of the needs of car consumers in India, factors with potential influences on the preferences of baby boomers toward car brands were investigated through a questionnaire-based study (Davey & Balakrishnan, Principal, 2017).

Advances in automotive technology and the increased consumption of fuel and associated emissions have motivated automobile manufacturers to produce eco-friendly cars, and the result has been plenty of available options with various specifications and prices for consumers in different countries, making the process of car selection a multi-criteria decision-making (MCDM)

problem. To systematically deal with this problem, researchers began to propose MCDM models for facilitating the selection process. For example, Hamurcu and Eren (2018) introduced an integrated MCDM model that used AHP, TOPSIS, and Goal programming for electric car selection. Another MCDM model was introduced for selecting hybrid cars with the capability to handle different categories of customers (Fenwick & Daim, 2011). Prakash and Mohanty (2017) introduced an integrated DEA and Monte-Carlo simulation framework for use in green car selection. In that framework, historical data were used to classify green cars based on their performance. An AHP model was structured to seek understanding of intention toward using eco-friendly cars, considering both electric and hybrid car alternatives to demonstrate the model (Jamil & Aminuddin, 2019). In addition, Tampatty, Kindangen, and Tumbuan (2017) conducted a study that used AHP to explore factors affecting the adoption of low-cost green cars in Indonesia, with results showing factors of safety, quality, and price to be of higher importance than other factors. To motivate usage of electric cars, Mendoza (2018) introduced an AHP model seeking to better understand user preferences and intentions to use electric cars. Shariff et al. (2019) also built a Fuzzy-AHP model for better recognizing uncertainties associated with user decisions and intentions to buy eco-friendly cars, and the results of the that model were confirmed using a simple AHP model.

An integrated model was also introduced to aid in selecting among electrical cars. In that model, values of performance measures of hybrid electrical cars were determined using an operating-window method, after which a TOPSIS model was built using these values to rank car alternatives (İç & Şimşek, 2019). An entropy-based multi-attributive border approximation area comparison (MABAC)-based model was also introduced to select hybrid cars based on performance measures of interest. In that model, an entropy method was used to determine relative weights of importance of evaluation criteria, while MABAC was used to evaluate performances of alternatives (Biswas

& Das, 2018). Mohamadabadi, Tichkowsky, and Kumar (2009) also introduced an MCDM model based on PROMETHEE to select among fuel-based cars, including a hybrid-car option. Fuzzy-AHP was also used in selecting the most appropriate technology for electric-car battery development (Lee, Chen, Chan, & Hung, 2015). The integration between ANP and ELECTRE III has not been introduced in the previous literature within the context of car selection. Table 1 summarizes previous work related to car selection.

**Table 1:** Summary of relevant research.

Reference	Method	Application	Evaluation Criteria
(Paulino, 2018)	AHP	Electric car selection	Demographics, consumers' personality, performance, financial aspects, and government policies.
(Ishak et al., 2016)	Fuzzy-VIKOR	Select natural material for car front	Weight, fuel efficiency, and emissions.
(Tampatty et al., 2017)	AHP	Adoption of low cost green cars	Safety, quality, price, interior, comfortability, and advertisement
(Prakash & Mohanty, 2017)	DEA-Monte-Carlo	Green cars evaluation	Emission, braking, ride quality, acceleration, turning circle, luggage capacity, miles per gallon MPG, and torque
(Apak et al., 2012)	AHP	Preferences toward luxury cars	Quality, reliability, flexibility, technology, brand image, performance, and price
(Chand & Avikal, 2016)	AHP	Selection of suitable hatchback car	Cost, Brand name, fuel efficiency, interior and exterior design, after sale service, and maintenance cost
(Sri Yogi, 2018)	AHP- TOPSIS	Preferences toward two-wheeler automobile	Operational, performance, economics, brand, and maintenance beam light, ability climb, ease of changing gear, vibration, fuel saving, spare parts price, trade value, uniqueness, colour, accessories installation, service time, easy to service at any station.
(Singh et al., 2018)	TOPSIS-AHP	Scooter selection	Safety, quality, cost, style, comforts, and after sale service.
(Biswas & Saha, 2019)	Fuzzy-AHP	Scooter selection	Mileage, Top speed, kerb weight, fuel tank capacity, Price
(Hamurcu, & Eren 2018)	AHP, TOPSIS, nad Goal programming	Electric car selection	Economic, Political, Social, Ecological
(Fenwick & Daim, 2011)	MCDM	Hybrid car selection	Seating capacity, Horsepower, mile per gallon, and base price
(Anandh & Sundar, 2014)	Multiple linear regression	Preferences toward small cars	value, need, comfortability, efficiency, accessibility, and ambition, Less emission, Prestige value, Safety, Entertainment Superior quality, price, Compactness, design, Range of colors, Fashion, fuel consumption, maintenance, After sales service, Availability of spare parts, Availability of service center, Brand image, Family use, Attractiveness
(Yıldız & Ergül, 2014)	Fuzzy-TOPSIS	Automobile car selection	Engine power, fuel consumption, after sale servuce, cylindrical volume, sale price, aisthetic, and comfort
(Sakthivel et al., 2013)	Fuzzy-AHP, hierarchy grey relation and PROMETHEE	Car selection	safety (Seat belt, Body alarm, ABS, airbag, impact), performance (speed, tourque, braking, noise, comfort), economics (price, resale, fuel, insurance), exterior (model, style, color, decoration, length, dealer), convenience (loading, inside width, visibility, audio), warranty (spare parts, service, repaire, satisfaction) and emmision (NOx, CO, HC, Smoke)
(Yousefi & Hadi-Vencheh, 2010)	AHP, TOPSIS, and Data envelopment analysis	Consumers preference toward automobile cars	Technical features (engine feature, safety, speed, comftrbleness), beuty (internal and external design, color variaty), manufacturers (country, company, brand), tools avialability ( spare parts, consumption tools), economical aspects ( price, fuel consumption, and payment flexibility), and social aspects ( satisfaction, advertisement, social atmosphere).
(Gerald Fandy Tumuju, S.L.H.V.Joyce Lapijan, 2017)	AHP	Sport utility veichle selection	Safety, comfortability, quality price, interior and advertising
(Mangindaan, Saerang, & Tumiwa 2017)	AHP	Selection of off road douple cabins car	Product quality, price, interior, and comfort
(Singh, & Avikal2019)	Fuzzy-AHP and TOPSIS	Selection of Sedan Car	Criteria of Economy, Performance, After sale service, Safety, and Comfort were used with their subcriteria to evaluate alternative cars.



(Byun, 2001)	AHP	Car selection	Exterior ( model, style, length, decoration, color, instrument cluster), convenience ( inside width, loading, operating, fitting, audio system), performance ( tourque , speed, fuel tank, braking, noise, comfort) , safety ( trunk, Seat belt, Body alarm, ABS, airbag, impact ) , economic ( price, resale, fuel, insurance), dealer, warranty ( spare parts, service station, repaire time, satisfaction)
(Jamil & Aminuddin, 2019)	AHP	Eco-friendly cars selection	Service, price, fule economy, safety, design, peformance , and emmission.
(Kele, 2019)	ELECTRE III	Car selection	Price and technical specifications
(Yayla, A & Yildiz, 2013)	Fuzzy-ANP	Car selection	Performaance ( engine cylander, engine power, acceleration), safety (road holding, material used,safety system), economy ( sale price, fuel consumption, taxes, maintenance cost), comfort ( sielent, width, vibration), and after sale services ( spare part supplies, insurance service, technical support)
(Shariff et al., 2019)	Fuzzy-AHP	Eco-friendly cars selection	Affordable price, Fuel economy, Safety, Services, Design, Performance, Emission
(İç & Şimşek, 2019)	Operating windo-TOPSIS	Eco-friendly cars selection	Cubic motor capacity, Fuel consumbtio, body type, CO2 emmission, number of point sale, warranty, price, second hand price, Tourque
(Biswas & Das, 2018)	MABAC	Hybrid car selection	Tank size, Tailpipe Emissions, Passenger volume, Vehicle cost, fuel economy
(Mohamadabadi et al., 2009)	PROMETHEE	Car selectiojn	Vehicle cost, fuel cost, distance between refueling stations, number of vehicle options available to the consumer, and greenhouse gas (GHG) emissions per unit distance traveled

### Analytic Network Process Methodology

Multiple evaluation measures are usually used in proper decision-making, and, depending on the decision-making problem, these measures may be interdependent, and ignoring such interdependencies may lead to a deficient decision-making process. ANP is a decision-making method that can deal with situations in which different types of interdependencies are to be considered. This method has been proven to have the capability to deal with complex decision-making problems associated with interdependencies among evaluation criteria. For example, Saaty and Vargas (2006) introduced ANP as a decision-making tool for dealing with complex economic, social, and technological decisions with different interdependencies among evaluation criteria. Al-Hawari, Mumani, and Momani (2014) also built an ANP model to select among alternative facility layouts while considering interdependent quantitative and qualitative measures. Yayla, A and Yildiz (2013) also applied a Fuzzy-ANP models to car selection.

Other researchers have used ANP along with ELECTRE to achieve advantages. For example, Banar, Özkan and Kulaç (2015) proposed an approach for selecting the best site treatment technology for metal-contaminated soils. In that model both ANP and ELECTRE II were utilized,

and similar results were obtained from both methods. Banar, Özkan, and Kulaç (2010) also applied ANP and ELECTRE III to select the most appropriate recycling scenario, and again results of both methods produced similar conclusions with respect to the best recycling scenario. The problem of supplier selection was also tackled by integrating modified ANP and ELECTRE III methods (Wan, Xu, & Dong, 2017). In that study, a modified -ANP method was used to determine sub-criteria weights, and modified ELECTRE III was used to rank the alternatives. To our knowledge, integration of ANP and ELECTRE III has not been applied to eco-friendly car selection.

The ANP method can be summarized into consecutive stages, beginning with identification of evaluation criteria and alternatives of interest. The resulting elements should then be arranged into clusters, and interdependencies among the clusters should be identified, after which the decision-making problem can be structured into a network of interdependent elements. The influence of interdependent elements should then be quantified using a proper scale. Mathematical procedures and required pairwise comparisons should then be performed to achieve limit priorities of these elements. More details on the ANP procedure and algorithm are available in (Saaty, 1999; Saaty & Vargas, 2006), with the main stages listed below.

- 1- Define the decision-making problem.
- 2- Identify decision criteria of relevance.
- 3- Arrange the decision criteria into clusters.
- 4- Identify interdependencies among decision criteria.
- 5- Evaluate the relative influence of interrelated criteria on one another.
- 6- Build an un-weighted super matrix.
- 7- Evaluate the overall influence of interdependent clusters and obtain a cluster matrix.
- 8- Use the un-weighted super matrix and the cluster matrix to obtain a weighted super matrix.

9- Raise the weighted super matrix to a high power.

10- A limit matrix with similar rows can then be produced to reflect limit priorities.

### **ELECTRE III Methodology**

One of the ELECTRE decision-making family is ELECTRE III, known to be an outranking-based decision-making tool with capability to rank alternatives (Figueira, J. R., Greco, S., Roy, B., Słowiński, 2013). ELECTRE III has many applications in different fields, e.g., Fancello, Carta, and Fadda (2014) proposed an evaluation method based on ELECTRE III to aid in evaluating road-safety conditions, and the model helped in creating an efficient resource-allocation plan that ensures proper infrastructure improvement. ELECTRE III was also applied to solve transportation problems by ranking alternative scenarios (Richter, 2018). El Mazouri et al. (2018) also proposed an MCDM model based on ELECTRE III to determining priority for providing electricity services to villages in Morocco. A modified version of ELECTREIII, integrating ELECTRE III with the Kano quality model, was proposed and applied a cell-phone selection problem (I. F. Chen, Tsaur, & Chen, 2018). ELECTRE III was also used along with historical data to aid in making proper decisions regarding portfolio selection (Chanvarasuth, Boongasame, & Boonjing, 2019). ELECTRE III was also integrated with the method of quality-function deployment to select the best alternative sustainable building material in consideration of stakeholder requirements (Z.-S. Chen et al., 2019). An MCDM model based on ELECTRE III was also used to help evaluate renewable-energy options (Peng, Shen, He, Zhang, & Wang, 2019).

ELECTRE III is known to have capability of dealing with fuzzy decision criteria as it constructs fuzzy outranking relationships (Lizbeth, Sa, Carlos, & Lo, 2008) by producing concordance and discordance indices for evaluating alternative options using three thresholds (Milani, Shanian, & El-Lahham, 2006). It requires knowledge of weight of importance ( $w$ ) and thresholds of indifference ( $q$ ), preference, and veto ( $v$ ) for each criterion. The thresholds can be selected such

that  $q \leq p \leq v$  (Marzouk, 2011). The following sections will describe ELECTRE III methodology, including its stages of identifying outranking relationships and ranking alternatives (Rogers, Bruen, & Maystre, 2000).

*Outranking Relationships*

Concordance and discordance indices infer the degree of agreement or disagreement with assertions like “a outranks b”. In fact, the outranking relationships are built based on these indices, as shown below.

*The Concordance Index C (a, b).* The concordance index represents the proportion of criteria weights that agree with “a outranks b”.  $C (a, b) \in [0 1]$  and can be calculated as follows.

$$C (a, b) = \frac{1}{w} \sum_{j=1}^n w_j c_j(a, b) \dots\dots\dots (1)$$

Where;  $w = \sum_{j=1}^n w_j$

$$C_j(a, b) = \begin{cases} 1, & g_j(a) + q_j(g_j(a)) \geq g_j(b) \\ 0, & g_j(a) + p_j(g_j(a)) < g_j(b) \\ \frac{g_j(a) - g_j(b) + p_j(g_j(a))}{p_j(q_j(a)) - q_j(g_j(a))}, & \text{Otherwise} \end{cases} \dots\dots\dots (2)$$

where

- $p_j$ : is the strict threshold of criterion j.
- $q_j$ : is the indifference threshold of criterion j.
- $g_j(a)$ : the performance of a on criterion j.
- $g_j(b)$  : the performance of a on criterion j.
- $q_j(g_j(a))$ : j’s indifference threshold with respect to a.
- $p_j(g_j(a))$ : j’s preference threshold with respect to a.

The discordance index  $D(a, b)$ . The discordance index for a criteria  $D_j(a, b) \in [0, 1]$  can be calculated as follows.

$$D_j(a, b) = \begin{cases} 0 & \text{if } g_j(a) + p_j(g_j(a)) \geq g_j(b) \\ 1, & g_j(a) + v_j(g_j(a)) < g_j(b) \\ \frac{g_j(b) - g_j(a) - p_j(g_j(a))}{v_j(g_j(a)) - P_j(g_j(a))}, & \text{Otherwise} \end{cases} \dots\dots\dots (3)$$

where  $v_j(g_j(a))$  is the  $j$ th criterion veto threshold with respect to  $a$ .

*Credibility Score.* To combine  $C_j(a, b)$  and  $D_j(a, b)$  into a single measure, ELECTRE III generates what is called a credibility score  $S(a, b)$ . In general, if the discordance indices are less than the concordance index, the concordance index will remain the same. However, if this is not the case, the concordance index value will be diminished. This score measures overall conformance with “ $a$  outranks  $b$ ” and can be calculated as follows.

$$S(a, b) = \begin{cases} C(a, b), & D_j(a, b) \leq C(a, b), \text{ for all } j \\ C(a, b) \prod_{j \in J(a, b)} \frac{(1 - D_j(a, b))}{1 - C(a, b)}, & \text{Otherwise} \end{cases} \dots\dots\dots (4)$$

*Utilizing the outranking relations.* The identified outranking relationships can then be utilized to rank the alternatives under evaluation, and the ranking process can be described as a sequential distillation process leading to ranked alternatives. Downward and upward distillation methods are performed to obtain alternative rankings, and to that end a qualification score should be identified for each option. The detailed steps of the ranking process can be described as follows.

*Step 1: Identification of  $\lambda_0$*

$$\lambda_0 = \max \{S(a, b)\} \forall a, b \in A \dots\dots\dots (5)$$

*Step 2: Identification of the cutoff value  $\lambda_1$*

$$\lambda_1 = \lambda_0 - S(\lambda_0)$$

where  $S(\lambda_0)$  is the threshold value that can discriminate between alternatives.

Accordingly, it can be stated that a outranks b at  $\lambda_1$  such that

$$a S_{\lambda_1} b \text{ Iff } S(a, b) > \lambda_1 \text{ and } S(a, b) - S(b, a) > S(s(a, b))$$

$$\text{Where, } S(\lambda) = \alpha\lambda - \beta$$

*Step 3: The qualification score*

To determine the qualification score of an option ( $q_A^{\lambda_1}(a)$ ), its strength  $P_A^{\lambda_1}(a)$  and weakness  $f_A^{\lambda_1}(a)$  must be evaluated as follows:

$$(q_A^{\lambda_1}(a)) = P_A^{\lambda_1}(a) - f_A^{\lambda_1}(a) \dots\dots\dots (6)$$

Where

$$P_A^{\lambda_1}(a) = |\{b \in A / a S_A^{\lambda_1} b\}|$$

$$f_A^{\lambda_1}(a) = |\{b \in A / b S_A^{\lambda_1} a\}|$$

*Step 4: Downward Method*

A subset of the best options with highest qualification scores is then created and can be described as follows.

$$\overline{D1} = \{a \in A / q_A^{\lambda_1}\} = \text{Max } q_A^{\lambda_1}(x), x \in A \dots\dots\dots (7)$$

For alternatives in  $\overline{D1}$ , the process of distillation is repeated with a reduced cutoff value. The distillation process proceeds until only either one option remains in  $D1$  or the cutoff value approaches 0. In case of two alternatives resulting from a distillation process, they are considered

to have the same rank. The cutoff value for each distillation step can be determined using the following equation.

$$\lambda_{k+1} = \text{Max} ( S(a,b) < \lambda_k - S(\lambda_k) ; a,b \in D_k) \dots\dots\dots (8)$$

The next step of distillation continues with the remaining unranked alternatives, and  $\lambda_0$  can be calculated based on them. The distillation process continues until all alternatives are ranked.

*Step 5: Upward Method*

The subset D1 of the worst options, those having the lowest qualification scores, can be determined as follows

$$\underline{D1} = \{a \in A / q_A^{\lambda_1}\} = \text{Min } q_A^{\lambda_1} , x \in A \dots\dots\dots (9)$$

Alternatives with minimum qualification scores are drawn each distillation step, and the process continues until either only one option remains in D1 or the cut-off value approaches 0. A similar procedure will be followed as in the Downward method.

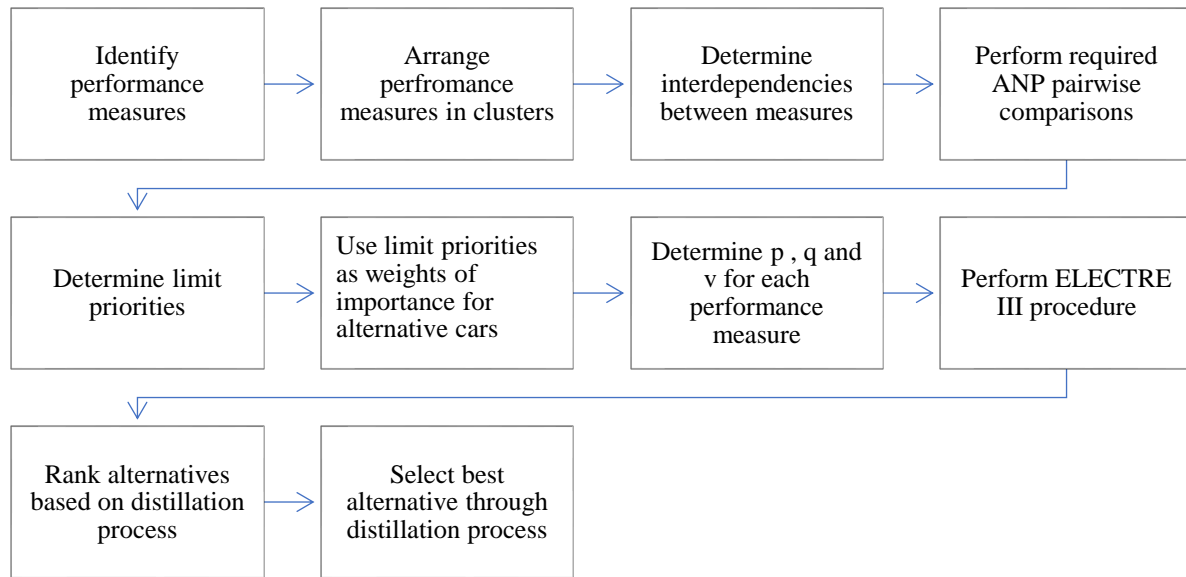
*Step 6: Final ranking*

The alternative ranking resulting from both downward and upward methods is then combined to produce a final ranking.

**METHODOLOGY**

The integrated decision-making framework is comprised of ANP and ELECTRE III. Since performance measures of green-friendly cars are to be identified and categorized into homogeneous clusters, previous related research can be surveyed, and proper evaluation measures selected and further categorized. Interdependencies between these measures should then be determined and evaluated in terms of weights of influence on one another. A network structure of performance measures arranged in clusters and connected through influence arrows can be built and required pairwise comparisons performed to allow determining limit priorities to be used to represent steady-state priorities of performance measures. Alternative cars should then be

identified and evaluated based on these evaluation measures, and thresholds of preferences identified to produce outranking relationships. The ELECTRE III procedure is followed to rank car alternatives. Figure 1 is a flow chart of the methodology.



**Figure 1:** Methodology flow chart

## CASE STUDY

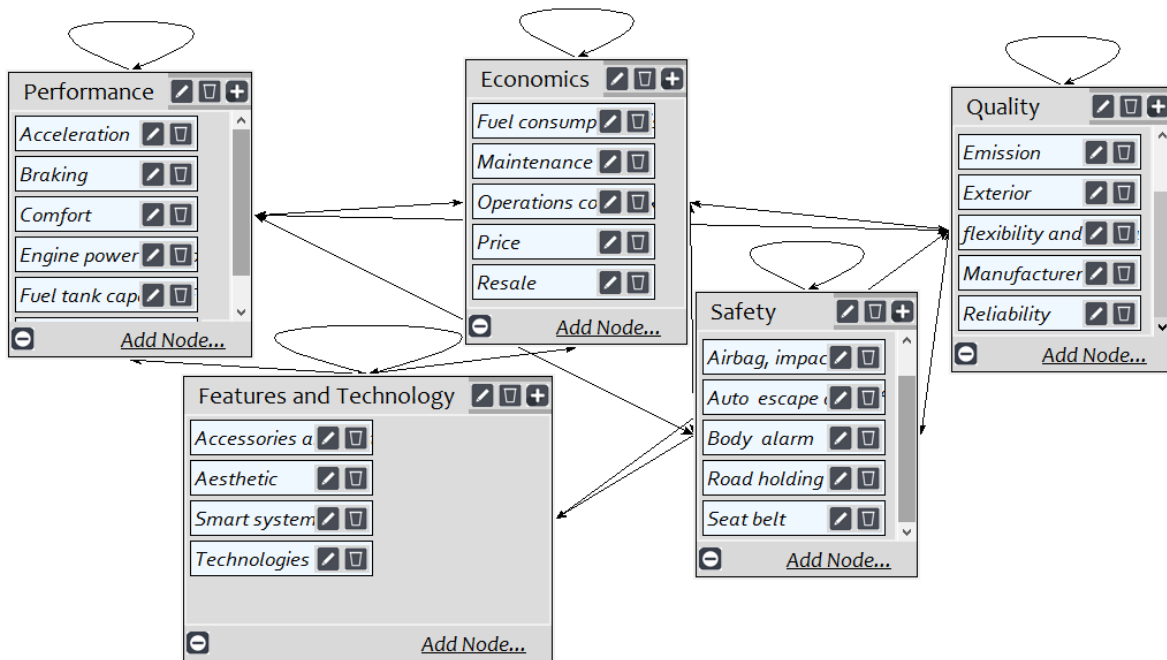
To demonstrate the model, a case study of selecting an eco-friendly car among five alternatives is presented, with hybrid Toyota Prius, hybrid Ford Fusion, hybrid Hyundai Sonata, electrical Nissan Leaf, and electrical BMW i3 considered as alternatives that are well known to customers and available in the market. An expert extracted twenty-eight decision criteria from the literature (Table 1) and verified them to ensure their suitability for the case under study. Homogenous criteria were then categorized into the five clusters shown in Table 2. Interdependencies between decision criteria were identified along with their influences to produce the ANP structure shown in Figure 2. The process of clustering and identifying interdependencies was performed in consecutive



sessions. Required pairwise comparisons were then performed by the expert to obtain limit priorities from the ANP model as shown in Table 2.

**Table 2:** Decision criteria arranged in clusters

Cluster	Decision Criteria	Limit priorities
Economics	Fuel consumption\distance per full charge battery	0.1559
	Maintenance cost	0.0190
	Operations cost: Taxes & insurance	0.0126
	Price	0.2848
	Resale	0.0047
Features and Technology	Accessories and features	0.0152
	Aesthetic	0.0036
	Smart systems	0.0131
	Technologies	0.0417
Performance	Acceleration	0.0171
	Braking	0.0155
	Comfort	0.0195
	Engine power and torque	0.0667
	Fuel tank capacity/Full battery charge	0.0066
	Speed	0.0538
Quality	Accessibility and Efficiency	0.0071
	Convenience	0.0228
	Emission	0.0065
	Exterior	0.0137
	Flexibility and warranty	0.0306
	Manufacturers	0.0630
	Reliability	0.0672
Safety	ABS	0.0132
	Airbag	0.0056
	Auto escape and Life-Saving Tool	0.0049
	Body alarm	0.0057
	Road holding	0.0242
	Seat belt	0.0057



**Figure 2:** A network structure of the selection problem

Limit priorities obtained from ANP then can be used as ELECTRE III inputs ( $w_j$ ). Because of variability among car dealers and selling used cars in most cases, subjective measures were used to evaluate alternative cars. Alternative cars were evaluated with insights on car specifications, available data on the internet, consumer reviews, car rate by ownerships, and general service centers (general car repair shops). A swing-weighting method (Kenneth Chelst, 2011) was used to evaluate alternative cars with respect to evaluation criteria. For each performance measure, the alternatives were ranked, with the best alternative ranked first and assigned a score of 100, with following alternatives assigned lower scores. For each decision criteria, indifference and preference values were identified as shown in Table 3.

The data presented in Tables 2 and 3 were used to perform ELECTRE III using J-Electre-v2.0 software, and ELECTRE III produced an upward and downward ranking through a distillation process, with average rankings shown in Table 4 then calculated. These results state that Toyota

Prius, Ford Fusion, and Nissan Leaf were ranked first based on the used decision criteria, weights of importance and preference, and indifference values, while BMW i3 and Hyundai Sonata were respectively ranked second and third. When a veto value equal to the preference value for each decision criteria is considered, ELECTRE III produced more distinguishable results in which the Toyota Prius was ranked first, followed by Nissan Leaf, Hyundai Sonata, Ford Fusion, and BMW i3.

The alternatives were ranked based on the ANP method in which limit priorities of evaluation criteria were multiplied by their corresponding alternative's performance, and the summation of these multiplications resulted in an overall alternative score for each alternative car. These scores were then used to rank the alternatives. Nissan Leaf was ranked first, followed by BMW i3, Toyota Prius, Ford Fusion, and Hyundai Sonata, as shown in Table 4.

**Table 3:** Performance of alternative eco-friendly cars.

Decision Criteria	Indifference(q)	Preference(p)	Toyota Prius	Ford Fusion	Hyundai Sonata	Nissan Leaf	BMW i3
Fuel consumption\distance per full charge battery	5	16	84	91	86	100	97
Maintenance cost	10	31	83	88	85	100	94
Operations cost: Taxes & insurance	25	75	63	50	50	100	88
Price	1	3	94	89	90	100	91
Resale	4	12	92	100	90	96	94
Accessories and features	19	58	96	100	100	96	92
Aesthetic	26	78	81	100	100	74	78
Smart systems	42	83	100	92	92	83	92
Technologies	31	92	92	77	85	77	100
Acceleration	8	24	100	95	100	74	74
Braking	8	24	100	100	100	100	100
Comfort	25	75	80	78	75	100	100
Engine power and torque	13	40	89	100	93	78	82
Fuel tank capacity/Full battery charge	7	22	100	96	93	78	74
Speed	4	11	93	100	96	74	78
Accessibility and Efficiency	11	32	100	97	97	84	82
Convenience	28	56	72	94	100	94	83
Emission	25	75	75	75	75	100	100
Exterior	14	29	89	100	100	86	89
flexibility and warranty	24	48	98	95	93	100	95
Manufacturers	7	21	100	93	79	93	97
Reliability	24	48	98	95	93	100	95
ABS	5	8	100	100	100	100	100
Airbag	25	50	100	100	100	100	100
Auto escape and Life-Saving Tool	30	40	100	100	100	100	100
Body alarm	50	83	83	67	100	50	67
Road holding	11	32	96	100	93	96	96
Seat belt	17	50	100	100	100	100	100

**Table 4:** Alternatives' Ranking using ELECTRE III and ANP

Alternative	ELECTRE III Without Veto			ELECTRE III With veto=Preference			ANP	
	Upward	Downward	Average	Upward	Downward	Average	Score	Rank
Toyota Prius	1.0	1.0	1.0	1.0	1.0	1.0	0.916656	3
Ford Fusion	1.0	1.0	1.0	2.0	3.0	2.5	0.915606	4
Hyundai Sonata	3.0	2.0	2.5	2.0	2.0	2.0	0.896993	5
Nissan Leaf	1.0	1.0	1.0	1.0	2.0	1.5	0.939237	1
BMW i3	2.0	2.0	2.0	3.0	4.0	3.5	0.917402	2

### Sensitivity Analysis

The priorities obtained from the ANP model are highly dependent on subjective judgments, which may be associated with uncertainties. Such uncertainties are also associated with the used thresholds. Accordingly, there is a need to observe the robustness of the resulting ranking when these priorities and thresholds change. To that end, sensitivity analysis was conducted on the criteria with the highest priorities resulting from the ANP model and on the thresholds used in the ELECTRE III model. The priorities have been manipulated by increasing and decreasing the original values by 10%, 20%, 30%, and 40%. The priority of each criterion was manipulated separately, while the deviations from original values were distributed to the remaining criteria based on their relative priorities to ensure that the weights add to one. The sensitivity analysis resulted in eight different setups in addition to the original one as shown in Table 5. Under each setup, alternatives' ranking was reported to determine the robustness of those ranking.

The thresholds used in ELECTRE III were also manipulated for the criteria with the highest priorities by increasing and decreasing the original thresholds of a criterion by 10%, 20%, 30%, and 40%. While manipulating the thresholds for a criterion, other thresholds used for the remaining criteria were fixed. Under each setup, the ranking of the alternatives was reported with a summary of the results shown in Table 6. The results obtained from the sensitivity analysis

showed the robustness of the model, in which the alternatives' ranking showed no noticeable changes under the setups under study.

**Table 5:** Sensitivity analysis with average ranking under different priorities when applying a veto.

Criteria	Alternatives	Original	-10%	10%	-20%	20%	-30%	30%	-40%	40%
Fuel consumption\distance per full charge battery	Toyota Prius	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Ford Fusion	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
	Hyundai Sonata	2.0	2.0	2.0	2.0	2.5	2.0	2.5	2.0	2.5
	Nissan Leaf	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	BMW i3	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Price	Toyota Prius	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Ford Fusion	2.5	2.0	2.5	2.0	2.5	2.0	2.5	2.0	2.5
	Hyundai Sonata	2	2.0	2.0	2.0	2.0	2.5	2.0	2.5	2.0
	Nissan Leaf	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	BMW i3	3.5	3.0	3.5	3.0	3.5	3.5	3.5	3.5	3.5

**Table 6:** Sensitivity analysis with average ranking under different thresholds when applying a veto.

	Alternatives	Original	-10%	10%	-20%	20%	-30%	30%	-40%	40%
Fuel consumption\distance per full charge battery	Toyota Prius	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Ford Fusion	2.5	2.5	2.5	2.5	2.0	2.5	2.0	2.5	2.0
	Hyundai Sonata	2.0	2.5	2.0	2.5	2.0	2.5	2.0	3.0	2.0
	Nissan Leaf	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	BMW i3	3.5	3.5	3.5	3.5	3.0	3.5	3.0	3.5	3.0
	Price	Toyota Prius	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Ford Fusion		2.5	3.0	2.0	3.0	2.0	2.5	2.0	3.0	2.0
Hyundai Sonata		2.0	2.5	2.0	2.5	2.0	2.5	2.0	2.5	2.0
Nissan Leaf		1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
BMW i3		3.5	4.0	3.0	4.0	3.0	3.5	3.0	3.5	3.0

## DISCUSSION

The proposed integrated model was presented and applied to a case study focused on selecting an alternative eco-friendly car among five alternatives. ANP was initially applied to determine the relative weights of importance of the decision criteria, and these weights were then used with required thresholds to perform ELECTRE III. The results produced by the model were presented in terms of an alternative ranking in which the best alternative was ranked first

Based on the ANP model, selling price and fuel consumption \distance per full charge battery were assigned the highest level of priority compared to the rest of the evaluation criteria. In fact, this result represented the market in which the fuel prices are high compared to individual income, and where cars are sold at high prices. Accordingly, while consumers are usually looking for an affordable car with efficient fuel consumption, criteria importance may differ depending on the case under evaluation. For example, fuel prices may not be of as much concern as selling price in another country.

To perform ELECTRE III, weights of importance should be determined along with appropriate thresholds of preference. ANP limit priorities were used to represent weights of relative importance of the evaluation criteria, while other preferences were determined for each evaluation criteria. ELECTRE III was performed both with no veto assigned for any evaluation criteria and with a veto value for each criterion. With no veto values considered, the model results reflected the superiority of the Toyota Prius-Ford Fusion and Nissan Leaf, ranked first, over BMW i3 and Hyundai Sonata, ranked last. When applying a veto value to each performance measure, the model resulted in a distinguishable ranking for each alternative, with the Toyota Prius ranked first and the BMW i3 ranked last, as shown in Table 3. In fact, the veto value was able to produce a

comparable result since it produced a distinct ranking for each alternative. Sensitivity analysis showed the robustness of the model under different setups when applying a veto value.

To evaluate the performance of ELECTRE III, results obtained from ANP and Idealized values of alternative performances were presented. Overall alternative performances were very close to one another, with only tiny differences, making these alternatives virtually indistinguishable, so this ranking would not help users make a decision regarding their future car. In fact, given the similarities between the alternative cars, this result would be expected to happen. However, in the case of using ELECTRE III with veto thresholds, the alternatives were distinguishable even in this situation. It is worth mentioning that ANP resulted in an alternative ranking differing from that of ELECTRE III, in which Nissan Leaf was ranked first, followed by BMW i3, Toyota Prius, Ford Fusion, and Hyundai Sonata, an unreasonable result in the context of the market.

The case study presented is taken from a market that has experienced a noticeable increase in the number of eco-friendly cars, especially the five alternatives of this study. The model presented can be implemented to select any type of cars with a modified set of decision criteria and alternatives. The preferences presented in the model are relevant only to the market under study and may be subject to change if based on other cases. Even with the advantages associated with the use of ANP, an increase in the number of evaluation criteria is usually associated with more complexities in terms of identifying interdependencies and the weights of influence.



## CONCLUSIONS

In this paper an integration of ANP and ELECTRE III has been introduced as a decision-making framework that aids in assessing eco-friendly cars. The decision-making problem was structured into a network of interdependent evaluation criteria that allowed consideration of types of interdependencies among decision criteria and results reflecting more realistic evaluation. The ANP model was applied to obtain limit priorities that were then used to perform ELECTRE III. ELECTRE III had the advantage of ranking alternatives based on indifference, preference, and veto thresholds, with capabilities for handling uncertainties. This integration between ANP and ELECTRE III assured the benefits of evaluating alternative cars based on interdependent decision criteria including thresholds of preferences. In fact, this study is the first to provide a comprehensive framework for selecting eco-friendly cars.

The model presented can help users make proper decisions regarding car purchase options. The model is comprehensive with a wide range of evaluation criteria that should be considered during the selection process. In addition, consideration of interdependencies among criteria handled complexities associated with car evaluation. Both manufacturers and dealers can benefit from the use of the ANP model to determine the most important factors that affect user-purchase decisions. In addition, the integration between ANP and ELECTRE III seems promising in solving complex decision-making problem.

As future work, eco-friendly cars could be evaluated using other outranking methods such as preference-selection index, grey rational methods, and fuzzy-set theory. Agent-based modeling can also be used to help understand the behavior of eco-friendly users, given scenarios related to the surrounding environment. Logistic regression can also be proposed for use in understanding

the preferences of users with respect to eco-friendly cars. In addition, a decision tree will be structured to help users select proper eco-friendly cars in an environment of uncertainties. Monte-Carlo simulation will also be integrated with a decision tree to cope with uncertainties experienced in the market

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