Sustainability **2015**, *7*, 11570-11594; doi:10.3390/su70911570

OPEN ACCESS

sustainability

ISSN 2071-1050

www.mdpi.com/journal/sustainability

Article

Evaluation Framework for Alternative Fuel Vehicles: Sustainable Development Perspective

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Academic Editor: Bin Yu

Received: 22 March 2015 / Accepted: 13 August 2015 / Published: 25 August 2015

Abstract: Road transport accounts for 72.06% of total transport CO_2, which is considered a cause of climate change. At present, the use of alternative fuels has become a pressing issue and a significant number of automakers and scholars have devoted themselves to the study and subsequent development of alternative fuel vehicles (AFVs). The evaluation of AFVs should consider not only air pollution reduction and fuel efficiency but also AFV sustainability. In general, the field of sustainable development is subdivided into three areas: economic, environmental, and social. On the basis of the sustainable development perspective, this study presents an evaluation framework for AFVs by using the DEMATEL-based analytical network process. The results reveal that the five most important criteria are price, added value, user acceptance, reduction of hazardous substances, and dematerialization. Price is the most important criterion because it can improve the popularity of AFVs and affect other criteria, including user acceptance. Additional, the energy usage criterion is expected to significantly affect the sustainable development of AFVs. These results should be seriously considered by automakers and governments in developing AFVs.

Keywords: sustainable development; alternative fuel vehicle; DEMATEL; ANP

1. Introduction

World transport energy use is projected to increase at a rate of approximately 2% per year, with emerging economies accounting for the highest growth rate. Total transport energy use and carbon emissions are projected to be approximately 80% higher than current levels by 2030. In 2010, the transport sector produced 7.0 Gt CO_2 emissions, accounting for 14% of world CO_2 emissions [1]. The growth rate of world transport energy use ranks the highest among the end-user sectors.

Road transport currently accounts for 72.06% of total transport CO_2 emissions [1], which is the leading cause of global warming. As confirmed by the Intergovernmental Panel on Climate Change, CO_2 emissions spur temperature change and climate change (Figure 1).

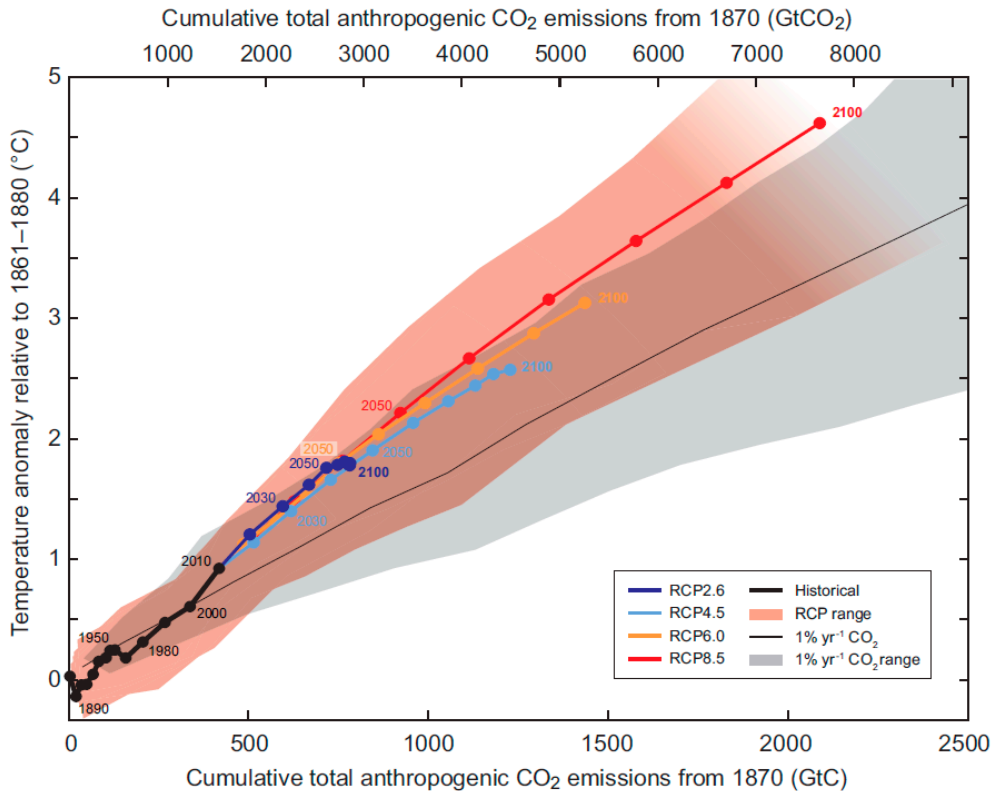

Figure 1. Temperature change and CO_2 emission. Source: Assessment Report of the Intergovernmental Panel on Climate Change, 2013 [2].

In view of curbing CO_2 and greenhouse gas emissions, alternative fuel vehicles (AFVs) have become the focus of research in recent years. The urgent need to address climate change has resulted in significant progress in AFV development. To date, various types of AFVs are available in the market, including biodiesel, electric/hybrid electric, fuel cell/hydrogen, natural gas, methanol, and ethanol. Alternative fuels possess different characteristics and compositions that merit considerable attention [3]. Abundant research discussions on AFVs have been conducted with views on sustainable development focusing on sustainable mobility [4], life-cycle cost [5,6], alternative fuel and clean vehicle development [7], sustainable development of energy and transport [8,9], renewable energy strategies [10], transport project assessment [11], vehicle-to-grid systems [12], investment strategies for energy and transport infrastructures[13–15], and safety [16,17]. However, discussions on AFV evaluation itself are minimal.

Many automakers are currently devoted to developing and producing AFVs, such as Toyota, Ford, GM, Fiat, Tesla, and BMW. Furthermore, the concept of sustainable development has resulted in significant attention and gradual acceptance being given by the public and government bodies to AFVs. Automakers must consider sustainable development in AFV development to expand the market diffusion of AFVs. Sustainable development was introduced in a report entitled *Our Common Future* published by the World Commission on Environment and Development in 1987. In general, the field of sustainable development is subdivided into three elements: economic, environmental, and social [18]. Hence, this study intends to construct an evaluation hierarchy for AFVs from the perspective of sustainable development comprising economic, environmental, and social elements. Market diffusion is expanded by determining the most important criterion in developing AFVs.

Several criteria and aspects should be considered to determine the most critical criterion in developing AFVs, which is a typical multiple criteria decision-making (MCDM) problem. Sustainable development involving professional judgement should also be considered. Thus, this study applies an MCDM approach to evaluate the AFVs with experts' choice by constructing a hierarchical framework. Some studies used the analytic hierarchy process (AHP) [19,20] and analytic network process (ANP) [21,22] to construct an evaluation hierarchy introduced by Saaty [23]. AHP assumes criteria are independent that do not meet with reality and ANP can overcome the AHP assumption of independence [24]. However, ANP has an equal weight assumption problem in each cluster, which is not irrational in the real world because there are different degrees of influence among the clusters of criteria [25]. To overcome the shortcomings of ANP, this study uses the decision-making trial and evaluation laboratory (DEMATEL) technique [26–30] to assess the causal relationships among the evaluation criteria. The causal relationships indicate that each dimension (criterion) has total direct and indirect influences on other dimensions (criteria). Furthermore, each dimension (criterion) can receive and give influence by or to other dimensions (criteria). DEMATEL was developed by the Science and Human Affairs Program of the Battelle Memorial Institute of Geneva between 1972 and 1976 to research and solve complex interrelated problems. This interdependence is visually depicted with a network relation map (NRM) [29]. Nowadays, DEMATEL has been successfully applied in various situations, including energy, marketing strategies, e-learning evaluation, control systems, and safety problems.

Furthermore, DEMATEL-based ANP (DANP) is utilized to identify the weights of the criteria [25]. The DEMATEL technique is employed to detect complex relationships and establish an NRM among the evaluation criteria for AFVs. The DANP approach is subsequently tapped to measure the importance degree of each criterion. Some studies also applied the fuzzy concept to ANP, which is also known as fuzzy ANP to overcome the uncertainty of human judgment that ANP was considered unable to deal with through its ratio scales [31–33]. However, Saaty and Tran [34,35] mentioned that the choice over the value of human judgment is already fuzzy and that using fuzzy concepts to deal with the uncertainty of human judgment is unnecessary. Therefore, this study applies DANP to determine the most critical criterion in developing AFVs by constructing an evaluation hierarchy for

AFVs from the sustainable development perspective. The result can also be used as a reference by automakers or researchers to expand the market diffusion of AFVs by improving AFV development.

The remainder of this paper is organized as follows. Section 2 describes the AFV concepts, sustainable development concepts, and the relationship between AFVs and sustainable development. Section 3 presents the evaluation hierarchy established on the basis of the sustainable development concept. Section 4 provides a brief introduction of the DEMATEL and DANP approaches is presented. Section 5 discusses and compares the analysis results with the traditional additive evaluation hierarchy. Section 6 concludes.

2. Literature Review

This section reviews related literature to present the development and definition of sustainable development. Subsequently, an alternative concept is presented to identify various types of AFVs and to present their definitions. Finally, the relationship between sustainable development and AFVs is introduced.

2.1. Sustainable Development

The term sustainable development was introduced in a report titled *Our Common Future* by the World Commission on Environment and Development in 1987. Since then, sustainable development has been invariably defined as "development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs." Sustainable development has been adopted as a policy principle by the United Nations, European Union, and various countries around the world; furthermore, sustainable development has likewise become an advocacy of companies, business councils, political parties, and NGOs [36].

Hacking and Guthrie [37] reported that "at an international workshop on 'SEA and Sustainability Appraisal' it was apparent that there is little consensus regarding the meaning of Sustainability Assessment." The definition of sustainable development establishes clear links with many issues of concern, such as poverty, equity, environmental quality, safety, and population control. In general, the field of sustainable development is subdivided into three areas: economic, environmental, and social [18].

Numerous schemes of indicators, such as the Kyoto Protocol and Cartagena Protocol on Biological Safety, have been developed by the United Nations, the Organization for Economic Co-operation and Development, the European Union, and various companies and NGOs. These schemes are also often subdivided into groups covering the economic, environmental, and social dimensions.

2.2. Alternative Concepts

The main parameter in defining AFV solutions is the fuel mode. According to collected data, AFVs are classified into four groups: conventional diesel engines, new modes of alternative fuel, electric vehicles (EVs), and hybrid electric EVs (HEVs) [38]. A dynamic worldwide effort exists to develop a means of transportation that utilizes new alternative fuels, including EVs/HEVs, fuel cell (hydrogen), natural gas [39], methanol, ethanol, biodiesel, and solar energy. Alternative fuels, as defined by the Energy Policy Act of 1992, include the following: methanol, ethanol, and other alcohols; blends of

85% or more alcohol with gasoline; natural gas and liquid fuels domestically produced from natural gas; liquefied petroleum gas (propane); coal-derived liquid fuels; hydrogen; electricity; biodiesel (B100); and P-series fuels [40]. Tzeng *et al.* [38] selected compressed natural gas, liquid propane gas, fuel cell for hydrogen, methanol, electricity with different types of charging, and several hybrid types of electricity to evaluate AFVs. Romm [39] referred to natural gas, hydrogen, and e-hybrid. For its part, this study in substance follows the Energy Policy Act of 1992 and the research conducted by Lin [3], thereby allowing ethanol to represent P-series fuels. Modern EVs are either HEVs or neighborhood EVs. Natural gas vehicles are saddled with problems, such as supply, distribution, and safety. These issues should be urgently improved.

Lin [3] divided AFVs into the following: electric/hybrid electric, fuel cell/hydrogen, natural gas, methanol, ethanol, and biodiesel. Furthermore, natural gas vehicles have failed to gain popularity even though they have become commercialized around the world. In this study, natural gas vehicles are not considered in the evaluation hierarchy.

2.3. Relationship between Sustainable Development and AFVs

Various studies have discussed AFVs in relation to sustainability or sustainable development [4–17]. However, merely a handful of studies have been geared toward AFV evaluation with consideration to all sustainable development elements: economic, environmental, and social. Various issues or criteria are identified in relation to sustainable development by reviewing the literature on AFV evaluation.

Research approaches were conducted in AFVs in relation to sustainability or sustainable development, such as multi-level analysis [4], cost prediction analysis [5], life-cycle modeling [6], qualitative research [7,10,11], the Energy PLAN model [9], NETPLAN [13,14], and the hybrid choice model [16]. However, those research approaches mostly used statistical data as their data resource. This study intends to construct an evaluation hierarchy from the sustainable development perspective to determine the most critical criterion in developing AFVs for expending the market diffusion of AFVs. Sustainable development involves professional judgement. The data source of determination of critical criterion and aspect is from expert choice rather than statistical data. Lin [3] applied a MCDM approach in AFVs evaluation by expert choice. Thus, this research adopts the sustainable development concept and employs the MCDM approach to evaluate AFVs. An evaluation hierarchy of sustainable development is constructed on the basis of the three major elements of sustainable development (*i.e.*, economic, environmental, and social).

3. Construct Evaluating Structure

Evaluating criteria were formulated after extensive research into the related literature and brainstorming. Subsequently, interviews with experts were conducted to confirm the evaluating structure, and the definition of each criterion is presented in Table 1.

Table 1. Evaluating criteria.

Goal	Dimension	Criteria	References	Definition of Criteria
Sustainable Development of AFVs	Economic	Price (Ec1)	[41,42]	Reasonable pricing
		Value-added (Ec2)	[41,43–46]	Additional service or benefits
		Modular (Ec3)	[42]	Towards modular product designing let vehicles more reliability and stability, will reduce maintenance time
		Maintenance and repair services (Ec4)	[41–43]	Maintenance or repair accessibility and cost
		Optimization transport network (Ec5)	[41,42,45]	Optimum transport to reduce cost, manpower cost, power usage, and emissions
		Vehicle life (Ec6)	[41–45]	Longer life cycle for reduced waste and materials used
	Environment	Energy usage (E1)	[45,47,48]	Use of less energy and material, or use of renewable/bio-materials and energy, during the vehicle lifecycle
		Disassembled (E2)	[42]	Can be easily disassembled for recycle at the end of lifecycle
		Dematerialization (E3)	[41,42,44,45,47,48]	Reduction of luxury item or unrecyclable material to minimize impact on the environment
		Reduce hazardous substances (E4)	[49]	Reduction in the use of hazardous substances such as Pb, Hg, Cd, Cr^{6+}, PBB, and PBDE during lifecycle
		Reduce emission (E5)	[41,44,45,47,48]	Reduction of emission to air, water, and land during lifecycle
	Social	User acceptance (S1)	[41–43]	User acceptance of alternative fuel vehicle with new usage patterns
		Fairness and justice (S2)	[47]	Based on fairness and justice for labor rights and trade in supply chain
		Healthy and safety (S3)	[47]	Improved stockholder health and safety in full life cycle
		Empowerment (S4)	[47]	Improved stockholders opportunities for participation, or provision of new channels for residents toward decision makers
		Sustainable consumption (S5)	[47]	Promotion of customer sustainable consciousness to encourage more responsible consumer behavior
		Improvement of quality of life (S6)	[45,47]	Promotion of user convenience and comfort for enhanced quality life, including reduced noise, odor, and so on
		Employment opportunities (S7)	[47,48]	Increased employment opportunities for better job safety to enhance regional/national economy

4. Evaluating AFV Based on Sustainable Development

In this section, the DEMATEL technique is combined with a novel MCDM to evaluate AFVs. DEMATEL is employed to confirm the influence relationship and level among dimensions and criteria from expert judgment by questionnaire and DANP to measure the importance degree for obtaining the weight of each criterion. First, we compute the data from expert questionnaires to gain the total relation matrix and influence map by DEMATEL. Second, we compute the weight of the criteria from the results of the DEMATEL using DANP. A flow chart of the proposed approach is shown in Figure 2, and the definitions of notations used in DEMATEL and DANP are presented in Table 2.

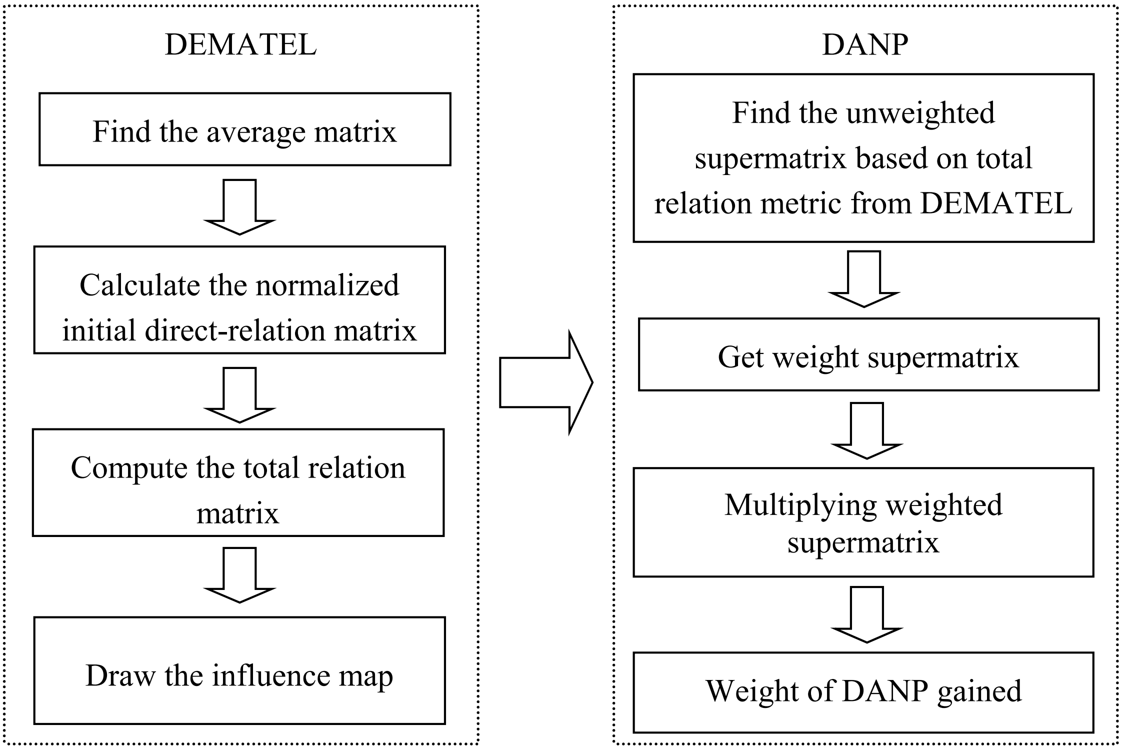

Figure 2. The flow chart of DEMATEL and DANP.

Table 2. Definitions of notations used in DEMATEL and DANP.

Formula	Definition
1	a_{ij} is the average number of average matrix $\boldsymbol{A}$ H is the number of experts x_{ij}^{k} is the influence score that *i*th criterion on *j*th criterion of *k*th expert
2	$\boldsymbol{s}$ is the largest number of the sum of each *i*th column or *j*th row in average matrix
3	$\boldsymbol{D}$ is the normalized initial direct-relation matrix which derived from $\boldsymbol{A}/\boldsymbol{s}$
4	$\boldsymbol{T}$ is the total relation matrix which derived from $\boldsymbol{D}(\boldsymbol{I}-\boldsymbol{D})^{-1}$ $\boldsymbol{I}$ is identity matrix
5	r_i denotes the row sum of the *i*th row of matrix $\boldsymbol{T}$
6	c_j denotes the column sum of the *j*th column of matrix $\boldsymbol{T}$
7	$\boldsymbol{T_c}$ is the matrix of total importance degree of influence relation of criteria $D_1, D_2 \ldots D_n$ is the *n*th dimension $C_{n1}, C_{n2} \ldots C_{nm_n}$ is *n*th criterion of *n*th dimension

Table 2. *Cont.*

Formula	Definition
8	$\boldsymbol{T_c^\alpha}$ is the normalized $\boldsymbol{T_c}$
9	d_i is the sum of *i*th row of $\boldsymbol{T_c^\alpha}$
10	$\boldsymbol{T_c^{\alpha 11}}$ is the normalized submatrix of dimension 1
11	$\boldsymbol{W}$ is the unweighted supermatrix
12	$\boldsymbol{W^{11}}$ is the transpose matrix of $\boldsymbol{T_c^{\propto 11}}$
13	$\boldsymbol{T_D}$ is the matrix of total importance degree of influence relation of dimension
14	d_i is the sum of *i*th row of $\boldsymbol{T_D}$
15	$\boldsymbol{T_D^\alpha}$ is derived by normalized $\boldsymbol{T_D}$
16	$\boldsymbol{W}$ is weighted supermatrix

4.1. DEMATEL Technique

The DEMATEL technique is a comprehensive approach for building and analyzing a structural model involving causal relationships among complex criteria [50]. The technique has been successfully applied in many situations, such as marketing strategies, e-learning evaluations, and air safety [25,28,30,51].

The DEMATEL technique can be summarized in the following steps [3]:

Step 1: Find the average matrix. Suppose we have H number of stakeholders in this study and *n* criteria to consider. Each stakeholder is asked to indicate the degree to which he or she believes a criterion *i* affects criterion *j*. These pairwise comparisons between any two criteria are denoted by a_{ij} and are given an integer score ranging between 0 and 4, representing "No influence (0)," "Low influence (1)," "Medium influence (2)," "High influence (3)," and "Very high influence (4)," respectively. The scores by each stakeholder will give us an $n \times n$ non-negative answer matrix $\boldsymbol{X^k} = [x_{ij}^k]$, with $1 \leq k \leq H$. Thus $\boldsymbol{X}^1, \boldsymbol{X}^2, \ldots, \boldsymbol{X}^H$ are the answer matrices for each of the H stakeholders, and each element of $\boldsymbol{X}^k$ is an integer denoted by x_{ij}^k The diagonal elements of each answer matrix $\boldsymbol{X}^k$ are all set to zero. We can then compute the $n \times n$ average matrix $\boldsymbol{A}$ for all stakeholder opinions by averaging the *H* stakeholders' scores as follows:

$$a_{ij} = \frac{1}{H}\sum_{k=1}^{H} x_{ij}^k \quad (1)$$

The average matrix $\boldsymbol{A} = [a_{ij}]$ is also called the initial direct relation matrix. Matrix $\boldsymbol{A}$ shows the initial direct influences that a criterion exerts on and receives from other criteria. Furthermore, we can map out the causal influence between each pair of criteria in a system by drawing an influence map. Figure 3 below is an example of such an influence map. Here, each letter represents a criterion in the system. An arrow from *c* to *d* shows the influence that *c* has on *d*, and the strength of its influence is 4. DEMATEL can convert the structural relations among the criteria of a system into an intelligible map of the system.

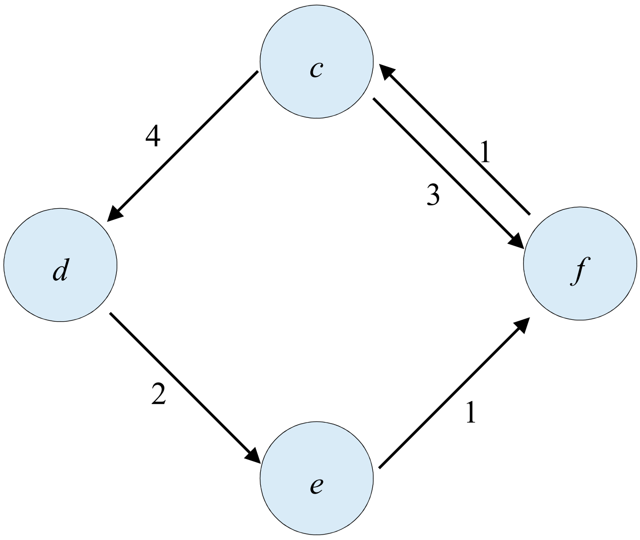

Figure 3. The direct influence map.

Step 2: Calculate the normalized initial direct-relation matrix. The normalized initial direct-relation matrix $\boldsymbol{D}$ is obtained by normalizing the average matrix A in the following way:

Let

$$s = \max\left(\max_{1 \le i \le n} \sum_{j=1}^{n} a_{ij}, \max_{1 \le j \le n} \sum_{i=1}^{n} a_{ij} \right) \tag{2}$$

then

$$\boldsymbol{D} = \frac{\boldsymbol{A}}{s} \tag{3}$$

Since the sum of each row j of matrix $\boldsymbol{A}$ represents the total direct influences that criterion i gives to the other criteria, $\max_{1 \le i \le n} \sum_{j=1}^{n} a_{ij}$ represents the total direct influences of the criterion with the most direct influences on others. Likewise, since the sum of each column i of matrix $\boldsymbol{A}$ represents the total direct influences received by criterion i, $\max_{1 \le j \le n} \sum_{i=1}^{n} a_{ij}$ represents the total direct influences received of the criterion that receives the most direct influences from others. The positive scalar s takes the lesser of the two as the upper boundary, and the matrix $\boldsymbol{D}$ is obtained by dividing each element of $\boldsymbol{A}$ by the scalar s. Note that each element d_{ij} of matrix $\boldsymbol{D}$ is between zero and 1.

Step 3: Compute the total relation matrix. $\boldsymbol{A}$ continuous decrease of the indirect influences of problems along the powers of matrix $\boldsymbol{D}$, e.g., $\boldsymbol{D}^1$, $\boldsymbol{D}^2$,…, $\boldsymbol{D}^\infty$, guarantees convergent solutions to the matrix inversion, similar to an absorbing Markov chain matrix, where $\boldsymbol{D} = [x_{ij}]_{n \times n}$, $0 \le x_{ij} < 1$, $0 < \sum_{j=1}^{n} x_{ij} \le 1$ and $0 < \sum_{i=1}^{n} x_{ij} \le 1$. If at least one row or column of summation is equal to 1, but not all, then $\lim_{k \to \infty} \boldsymbol{X}^k = [0]_{n \times n}$ and $\lim_{m \to \infty} (\boldsymbol{I} + \boldsymbol{D} + \boldsymbol{D}^2 + \boldsymbol{D}^3 + \cdots + \boldsymbol{D}^m) = (\boldsymbol{I} - \boldsymbol{D})^{-1}$.

The total relation matrix $\boldsymbol{T}$ is an $n \times n$ matrix and is defined as follows:

$$\boldsymbol{T} = \left[t_{ij} \right] \quad i, j = 1, 2, \ldots n,$$

where

$$\boldsymbol{T} = \boldsymbol{D} + \boldsymbol{D}^2 + \ldots + \boldsymbol{D}^m = \boldsymbol{D}(\boldsymbol{I} + \boldsymbol{D} + \boldsymbol{D}^2 + \ldots + \boldsymbol{D}^{m-1})$$
$$= \boldsymbol{D}[(\boldsymbol{I} + \boldsymbol{D} + \boldsymbol{D}^2 + \ldots + \boldsymbol{D}^{m-1})(\boldsymbol{I} - \boldsymbol{D})](\boldsymbol{I} - \boldsymbol{D})^{-1} = \boldsymbol{D}(\boldsymbol{I} - \boldsymbol{D})^{-1}, \text{ as } m \to \infty \quad (4)$$

We also define $\boldsymbol{r}$ and $\boldsymbol{c}$ as $n \times 1$ vectors representing the sum of rows and sum of columns of the total relation matrix $\boldsymbol{T}$ as follows:

$$\boldsymbol{r} = [r_i]_{n\times 1} = \left(\sum_{j=1}^{n} t_{ij}\right)_{n\times 1} \quad (5)$$

$$\boldsymbol{c} = [c_j]'_{1\times n} = \left(\sum_{i=1}^{n} t_{ij}\right)'_{1\times n} \quad (6)$$

where the superscript ′ denotes the transpose of a matrix.

Let r_i be the sum of the ith row in matrix $\boldsymbol{T}$. Then r_i shows the total influences, both direct and indirect, given by criterion i to the other criteria. Let c_j denotes the sum of the jth column in matrix $\boldsymbol{T}$. Then c_j shows the total influences, both direct and indirect, received by criterion j from the other criteria. Thus when $j = i$, the sum $(r_i + c_i)$ gives us an index representing the total influences both given and received by criterion i. In other words, $(r_i + c_j)$ shows the degree of importance (total sum of influences given and received) that criterion i plays in the system. In addition, the difference $(r_i - c_i)$ shows the net influence that criterion i contributes to the system. When $(r_i - c_i)$ is positive, criterion i is a net causer; and when $(r_i - c_i)$ is negative, criterion i is a net receiver [52].

4.2. DANP

The traditional ANP approach obtains the weighted supermatrix by normalizing the unweighted supermatrix. Each column of the unweighted supermatrix is divided by the number of clusters so that each column will sum to unity. This implies that each cluster has the same weight. However, this is not a good assumption because we already know that the effect that each cluster has on the other clusters may be different. Thus we need to find another way of normalizing the unweighted supermatrix that relaxes this assumption of equal weight among clusters. Here, we turn to the total-influence matrix T in DEMATEL and threshold value α for help.

The supermatrix assumes that each pair has the same weight in normalizing [25]. Although it is easy to normalize with such an approach, this neglects the fact that different groups should have different degrees of influence. So combining DEMATEL with ANP (DANP) solves this problem and will lead to a more practical result.

We use DEMATEL to find the levels of influence among groups, and use the total relation matrix $\boldsymbol{T}$ from DEMATEL as the basis for the influence network that forms the supermatrix in ANP. Although DEMATEL gives us the influence relationship, we still need to use ANP to confirm the influence relationship between each group and obtain the weight of each criterion.

The DANP approach can be described in the following steps [25]:

Step 1: Find the unweighted supermatrix. Normalize each level with the total importance degree of influence relation from the total relation matrix $\boldsymbol{T}$ for criteria by DEMATEL:

$$\boldsymbol{T}_c = \begin{array}{c} \\ \\ D_1 \begin{array}{c} c_{11} \\ c_{12} \\ \vdots \\ c_{1m_1} \end{array} \\ D_2 \begin{array}{c} c_{21} \\ c_{22} \\ \vdots \\ c_{2m_2} \end{array} \\ \vdots \quad \vdots \\ D_n \begin{array}{c} c_{n1} \\ c_{n2} \\ \vdots \\ c_{nm_n} \end{array} \end{array} \overset{\begin{array}{cccc} D_1 & D_2 & \cdots & D_n \\ c_{11}\ldots c_{1m_1} & c_{21}\ldots c_{2m_2} & \cdots & c_{n1}\ldots c_{nm_n} \end{array}}{\begin{bmatrix} \boldsymbol{T}_c^{11} & \boldsymbol{T}_c^{12} & \cdots & \boldsymbol{T}_c^{1n} \\ \boldsymbol{T}_c^{21} & \boldsymbol{T}_c^{22} & \cdots & \boldsymbol{T}_c^{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{T}_c^{n1} & \boldsymbol{T}_c^{n2} & \cdots & \boldsymbol{T}_c^{nn} \end{bmatrix}} \tag{7}$$

Normalize $\boldsymbol{T}_c$ with importance criteria with total degree of influence to get $\boldsymbol{T}_C^{\alpha}$.

$$\boldsymbol{T}_C^{\alpha} = \begin{array}{c} \\ \\ D_1 \begin{array}{c} c_{11} \\ c_{12} \\ \vdots \\ c_{1m_1} \end{array} \\ D_2 \begin{array}{c} c_{21} \\ c_{22} \\ \vdots \\ c_{2m_2} \end{array} \\ \vdots \quad \vdots \\ D_n \begin{array}{c} c_{n1} \\ c_{n2} \\ \vdots \\ c_{nm_n} \end{array} \end{array} \overset{\begin{array}{cccc} D_1 & D_2 & \cdots & D_n \\ c_{11}\ldots c_{1m_1} & c_{21}\ldots c_{2m_2} & \cdots & c_{n1}\ldots c_{nm_n} \end{array}}{\begin{bmatrix} \boldsymbol{T}_c^{\alpha 11} & \boldsymbol{T}_c^{\alpha 12} & \cdots & \boldsymbol{T}_c^{\alpha 1n} \\ \boldsymbol{T}_c^{\alpha 21} & \boldsymbol{T}_c^{\alpha 22} & \cdots & \boldsymbol{T}_c^{\alpha 2n} \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{T}_c^{\alpha n1} & \boldsymbol{T}_c^{\alpha n2} & \cdots & \boldsymbol{T}_c^{\alpha nn} \end{bmatrix}} \tag{8}$$

where normalized $\boldsymbol{T}_C^{\alpha 11}$ is as shown in Equations (9) and (10), and other $\boldsymbol{T}_C^{\alpha nn}$ values are obtained as above.

$$d_i = \sum_{j=1}^{n} t^{ij} \tag{9}$$

$$\boldsymbol{T}_C^{\alpha 11} = \begin{bmatrix} \boldsymbol{t}_{c11}^{11}/\boldsymbol{d}_1^{11} & \cdots & \boldsymbol{t}_{c1j}^{11}/\boldsymbol{d}_1^{11} & \cdots & \boldsymbol{t}_{c1n}^{11}/\boldsymbol{d}_1^{11} \\ \vdots & & \vdots & & \vdots \\ \boldsymbol{t}_{ci1}^{11}/\boldsymbol{d}_2^{11} & \cdots & \boldsymbol{t}_{cij}^{11}/\boldsymbol{d}_2^{11} & \cdots & \boldsymbol{t}_{cin}^{11}/\boldsymbol{d}_2^{11} \\ \vdots & & \vdots & & \vdots \\ \boldsymbol{t}_{cn1}^{11}/\boldsymbol{d}_3^{11} & \cdots & \boldsymbol{t}_{cnj}^{11}/\boldsymbol{d}_3^{11} & \cdots & \boldsymbol{t}_{cnn}^{11}/\boldsymbol{d}_3^{11} \end{bmatrix} = \begin{bmatrix} \boldsymbol{t}_{c11}^{\alpha 11} & \cdots & \boldsymbol{t}_{c1j}^{\alpha 11} & \cdots & \boldsymbol{t}_{c1n}^{\alpha 11} \\ \vdots & & \vdots & & \vdots \\ \boldsymbol{t}_{ci1}^{\alpha 11} & \cdots & \boldsymbol{t}_{cij}^{\alpha 11} & \cdots & \boldsymbol{t}_{cin}^{\alpha 11} \\ \vdots & & \vdots & & \vdots \\ \boldsymbol{t}_{cn1}^{\alpha 11} & \cdots & \boldsymbol{t}_{cnj}^{\alpha 11} & \cdots & \boldsymbol{t}_{cnn}^{\alpha 11} \end{bmatrix} \tag{10}$$

Turn the total relation matrix $\boldsymbol{T}$ into a supermatrix by grouping relationships, and we get an unweighted supermatrix:

$$\boldsymbol{W} = \begin{array}{c} \\ \\ D_1 \begin{array}{c} c_{11} \\ c_{12} \\ \vdots \\ c_{1m_1} \end{array} \\ D_2 \begin{array}{c} c_{21} \\ c_{22} \\ \vdots \\ c_{2m_2} \end{array} \\ \vdots \quad \vdots \\ D_n \begin{array}{c} c_{n1} \\ c_{n2} \\ \vdots \\ c_{nm_n} \end{array} \end{array} \overset{\begin{array}{cccc} D_1 & D_2 & \cdots & D_n \\ c_{11}\ldots c_{1m_1} & c_{21}\ldots c_{2m_2} & \cdots\cdots & c_{n1}\ldots c_{nm_n} \end{array}}{\begin{bmatrix} \boldsymbol{W}^{11} & \boldsymbol{W}^{12} & \cdots & \boldsymbol{W}^{1n} \\ \boldsymbol{W}^{21} & \boldsymbol{W}^{22} & \cdots & \boldsymbol{W}^{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{W}^{n1} & \boldsymbol{W}^{n2} & \cdots & \boldsymbol{W}^{nn} \end{bmatrix}} \tag{11}$$

where W^{11} is based on the $\boldsymbol{T}_{\boldsymbol{c}}^{\boldsymbol{\alpha 11}}$ transpose:

$$\boldsymbol{W}^{11} = \left[\boldsymbol{T}_{\boldsymbol{c}}^{\alpha 11}\right]' = \begin{bmatrix} \boldsymbol{t}_{11}^{\alpha 11} & \cdots & \boldsymbol{t}_{1j}^{\alpha 11} & \cdots & \boldsymbol{t}_{1m_1}^{\alpha 11} \\ \vdots & & \vdots & & \vdots \\ \boldsymbol{t}_{i1}^{\alpha 11} & \cdots & \boldsymbol{t}_{ij}^{\alpha 11} & \cdots & \boldsymbol{t}_{im_1}^{\alpha 11} \\ \vdots & & \vdots & & \vdots \\ \boldsymbol{t}_{n1}^{\alpha 11} & \cdots & \boldsymbol{t}_{nj}^{\alpha 11} & \cdots & \boldsymbol{t}_{nm_1}^{\alpha 11} \end{bmatrix}' \tag{12}$$

Step 2: Get weighted supermatrix. Set the dimensions to those of a total relation matrix; normalize with the degree of influence of each level and dimensions:

$$\boldsymbol{T}_D = \begin{bmatrix} t_D^{11} & \cdots & t_D^{1j} & \cdots & t_D^{1n} \\ \vdots & & \vdots & & \vdots \\ t_D^{i1} & \cdots & t_D^{ij} & \cdots & t_D^{in} \\ \vdots & & \vdots & & \vdots \\ t_D^{n1} & \cdots & t_D^{nj} & \cdots & t_D^{nn} \end{bmatrix} \tag{13}$$

Normalize the dimensions in total relation matrix $\boldsymbol{T}_D$, and get $\boldsymbol{T}_D^{\alpha}$:

$$d_i = \sum_{j=1}^{n} t_{ij}\ ,\ i, j = 1, 2, ..., n \tag{14}$$

$$\boldsymbol{T}_D^{\alpha} = \begin{bmatrix} t_D^{\alpha 11} & \cdots & t_D^{\alpha 1j} & \cdots & t_D^{\alpha 1n} \\ \vdots & & \vdots & & \vdots \\ t_D^{\alpha i1} & \cdots & t_D^{\alpha ij} & \cdots & t_D^{\alpha in} \\ \vdots & & \vdots & & \vdots \\ t_D^{\alpha n1} & \cdots & t_D^{\alpha nj} & \cdots & t_D^{\alpha nn} \end{bmatrix} \tag{15}$$

Turn $\boldsymbol{T}_D^{\alpha}$ into an unweighted supermatrix to make a weighted supermatrix:

$$\boldsymbol{W} = \begin{bmatrix} \boldsymbol{t}_D^{\alpha 11} \times \boldsymbol{W}^{11} & \boldsymbol{t}_D^{\alpha 21} \times \boldsymbol{W}^{12} & \cdots & \cdots & \boldsymbol{t}_D^{\alpha \boldsymbol{n}1} \times \boldsymbol{W}^{1\boldsymbol{n}} \\ \boldsymbol{t}_D^{\alpha 12} \times \boldsymbol{W}^{21} & \boldsymbol{t}_D^{\alpha 22} \times \boldsymbol{W}^{22} & \vdots & \cdots & \vdots \\ \vdots & \cdots & \boldsymbol{t}_D^{\alpha \boldsymbol{ji}} \times \boldsymbol{W}^{\boldsymbol{ij}} & \cdots & \boldsymbol{t}_D^{\alpha \boldsymbol{ni}} \times \boldsymbol{W}^{\boldsymbol{in}} \\ \vdots & \cdots & \vdots & \cdots & \vdots \\ \boldsymbol{t}_D^{\alpha 1\boldsymbol{n}} \times \boldsymbol{W}^{\boldsymbol{n}1} & \boldsymbol{t}_D^{\alpha 2\boldsymbol{n}} \times \boldsymbol{W}^{\boldsymbol{n}2} & \cdots & \cdots & \boldsymbol{t}_D^{\alpha \boldsymbol{nn}} \times \boldsymbol{W}^{\boldsymbol{nn}} \end{bmatrix} \tag{16}$$

The two steps are to get the limit of the supermatrix. Multiplying the weighted supermatrix by itself multiple times, we obtain the limit of the supermatrix; then the weight of each evaluating criterion will be obtained. $\lim\limits_{k \to \infty} = \boldsymbol{W}^k$, $\boldsymbol{W}$ represents the limit supermatrix, while *k* represents any number.

5. Analysis Results of DANP for Sustainable Development

The opinions of eight experts were combined to obtain the results. These experts have significant experience in vehicle development and sustainable development and hail from related fields in industry, government, and academia. The organizations they serve are shown in Table 3. These organizations confirm that the experts are professional, and so the results can be considered reliable. The results of DANP are presented in this section. The NRM by DEMATEL is also presented. The ranking of the criteria through DANP for AFV development based on sustainable development is also identified.

Table 3. The background of experts.

Expert	Organization
	Academia
1	Department of Vehicle Engineering, National Taipei University of Technology
2	Department of Vehicle Engineering, National Pingtung University of Science and Technology
	Industry
3	CPC Corporation, Taiwan
4	Toyota Taiwan co.
5	CIMC consulting co.
6	Daihatsu Taiwan co.
	Government
7	Automotive Research & Testing Center, Taiwan
8	Bureau of Energy, Ministry of Economic Affairs, R. O. C.

5.1. Constructing the Network Relation Map by DEMATEL

After establishing the aforementioned evaluation criteria, the influence map can be constructed via the three steps of DEMATEL, as discussed in Section 4. First, the average matrix must be calculated by Equation (1). Second, a normalized initial direct relation matrix is calculated using Equations (2) and (3). Third, the total relation matrix is computed by using Equations (4)–(6). The total relation matrix is presented in Table 4. The influence degrees of purchasing the concern dimension and criteria are shown in Table 5. The influence map of the total relationship is illustrated in Figure 4.

Figure 4 illustrates that the criterion of energy usage is the main net causer, thus indicating that energy usage can influence other criteria the most. Sustainable consumption has the highest value of total influence, thus indicating that either automakers or researchers should pay attention to this criterion. In other words, automakers or researchers should improve energy efficiency by using renewable energy in AFV development. Moreover, the sustainable consciousness of potential AFV buyer should be promoted as the first step to encourage responsible consumer behavior because AFVs simply cannot become popular without sustainable consciousness. After the influence of the relationship and level is obtained in Table 5 by DEMATEL, we can use this relationship on DANP to calculate the weights of the criteria for developing AFVs.

Table 4. The total relation Matrix T .

Criteria	Price	Value-added	Modular	Maintenance and Repair Services	Optimization Transport Network	Vehicle life	Energy Usage	Disassem-bled	Demateri-alization	Reduce Hazardous Substances	Reduce Emission	User Acceptance	Fairness and Justice	Healthy and Safety	Empowerment	sustainable Consumption	Improvement Life's Quality	Employment Opportunities
Price	0.150	0.176	0.176	0.115	0.069	0.166	0.142	0.115	0.159	0.149	0.147	0.229	0.133	0.140	0.097	0.185	0.190	0.099
Value-added	0.173	0.081	0.125	0.092	0.046	0.085	0.076	0.093	0.109	0.109	0.096	0.166	0.107	0.112	0.077	0.136	0.144	0.097
Modular	0.182	0.131	0.086	0.075	0.059	0.111	0.081	0.130	0.126	0.125	0.111	0.164	0.102	0.107	0.070	0.143	0.162	0.113
Maintenance and repair services	0.216	0.161	0.159	0.077	0.068	0.150	0.104	0.099	0.120	0.120	0.140	0.210	0.128	0.144	0.105	0.187	0.183	0.128
Optimization transport network	0.142	0.070	0.069	0.053	0.025	0.053	0.081	0.043	0.066	0.090	0.112	0.094	0.088	0.093	0.051	0.110	0.097	0.078
Vehicle life	0.196	0.124	0.133	0.121	0.049	0.080	0.081	0.087	0.127	0.115	0.114	0.188	0.103	0.096	0.083	0.156	0.142	0.114
Energy usage	0.193	0.125	0.167	0.097	0.078	0.149	0.081	0.088	0.131	0.154	0.164	0.209	0.126	0.145	0.081	0.188	0.182	0.103
Disassembled	0.175	0.124	0.157	0.098	0.040	0.115	0.126	0.067	0.118	0.118	0.083	0.168	0.125	0.119	0.072	0.158	0.166	0.106
Dematerialization	0.202	0.139	0.118	0.092	0.041	0.120	0.132	0.103	0.089	0.123	0.122	0.186	0.130	0.124	0.075	0.186	0.160	0.085
Reduce Hazardous Substances	0.158	0.127	0.114	0.080	0.051	0.119	0.099	0.092	0.145	0.089	0.122	0.196	0.130	0.169	0.087	0.188	0.181	0.075
Reduce emission	0.158	0.109	0.108	0.086	0.038	0.102	0.092	0.086	0.104	0.126	0.080	0.185	0.111	0.140	0.082	0.177	0.171	0.068
User acceptance	0.241	0.160	0.159	0.140	0.071	0.170	0.134	0.106	0.163	0.163	0.161	0.160	0.149	0.146	0.122	0.203	0.187	0.134
Fairness and justice	0.122	0.111	0.098	0.068	0.034	0.068	0.094	0.090	0.104	0.105	0.103	0.140	0.071	0.110	0.098	0.165	0.151	0.117
Healthy and safety	0.183	0.136	0.126	0.089	0.056	0.150	0.127	0.109	0.142	0.143	0.152	0.220	0.128	0.100	0.094	0.210	0.193	0.104
Empowerment	0.094	0.100	0.076	0.063	0.036	0.060	0.043	0.041	0.051	0.051	0.051	0.108	0.083	0.097	0.039	0.125	0.111	0.069
sustainable consumption	0.229	0.184	0.183	0.149	0.098	0.171	0.157	0.160	0.186	0.187	0.185	0.245	0.174	0.171	0.131	0.167	0.205	0.146
Improving life's quality	0.200	0.164	0.162	0.113	0.080	0.131	0.118	0.113	0.134	0.135	0.133	0.216	0.133	0.171	0.130	0.205	0.134	0.153
Employment opportunities	0.062	0.062	0.049	0.051	0.029	0.034	0.030	0.029	0.035	0.036	0.036	0.086	0.080	0.061	0.052	0.073	0.092	0.034

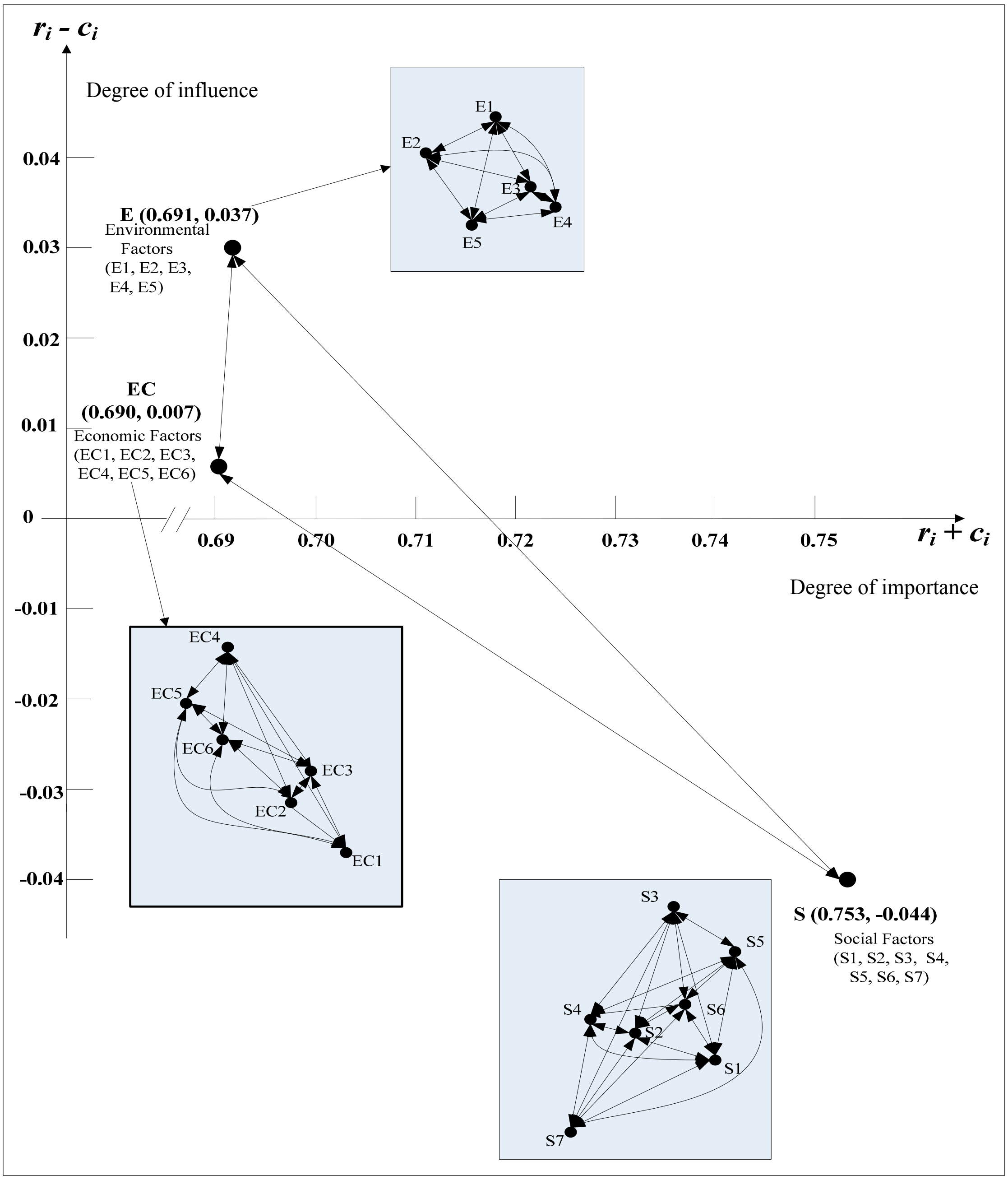

Figure 4. The influence map.

5.2. Weights of Criteria through DANP

This study obtained an unweighted supermatrix (Table 6) from the total relationship matrix of DEMATEL in Table 4. This technique was performed in accordance with the influence degree of each dimension to obtain a weighted supermatrix (Table 7) and the limited supermatrix to obtain the overall weight of each criterion (Table 8).

Upon obtaining the limited matrix, the calculating step is conducted to identify the weight and overall ranking of the criteria (Table 9).

The ranking of dimensions is determined by DANP, and the results imply that the social dimension (weight = 0.373) is the most important, followed by the economic dimension (weight = 0.320) and the environmental dimension (weight = 0.306). The three dimensions exhibit nearly equal importance, so they can be interpreted as three pillars that need to be balanced simultaneously to achieve sustainable development.

Table 5. The degrees of influence of purchasing concern criteria.

Dimension	Criterion	r_i	c_i	$r_i + c_i$	$r_i - c_i$
Economic		0.349	0.342	0.690	0.007
	Price	2.639	3.075	5.714	−0.436
	Value-added	1.923	2.284	4.207	−0.361
	Modular	2.077	2.268	4.345	−0.191
	Maintenance and repair services	2.499	1.658	4.157	0.841
	Optimization transport network	1.414	0.967	2.381	0.447
	Vehicle life	2.110	2.034	4.144	0.076
Environmental		0.364	0.327	0.691	0.037
	Energy usage	2.462	1.798	4.260	0.665
	Disassembled	2.135	1.652	3.787	0.484
	Dematerialization	2.226	2.111	4.337	0.115
	Reduce hazardous substances	2.222	2.138	4.360	0.084
	Reduce emission	2.023	2.111	4.134	−0.089
Social		0.355	0.399	0.753	−0.044
	User acceptance	2.770	3.171	5.941	−0.402
	Fairness and justice	1.851	2.101	3.952	−0.250
	Healthy and safety	2.461	2.244	4.705	0.216
	Empowerment	1.298	1.546	2.844	−0.247
	Sustainable consumption	3.129	2.961	6.090	0.168
	Improvement life's quality	2.626	2.851	5.478	−0.225
	Employment opportunities	0.929	1.824	2.753	−0.895

When probing the ranking of criteria, the importance ranking is evenly distributed in each dimension. The top three criteria are ranked as follows: "price," "user acceptance," and "reduce hazardous substance." Consequently, the most important consideration of users continues to be "price". For sustainable development, increasing AFV usage is an important subject. AFV-relevant infrastructure improvement is known to increase the purchase intention of AFVs, but price is still the main factor [53,54]. Sang and Bekhet [55] believe that government intervention, such as subsidizing the purchase price, increases EV purchase intentions in Malaysia. Moreover, AFV-relevant infrastructure suppliers, such as refueling station suppliers, hesitate to set up many facilities because only a few AFVs use the refueling infrastructure and because refueling stations cannot be economized [56]. Thus, if automakers or researchers can find a way to reduce the price of AFVs under sustainable development, AFVs will become popular, thereby attracting infrastructure suppliers involved in infrastructure development. At the same time, "user acceptance" is related to the new usage patterns of AFVs. Therefore, when automakers design a new type of AFV, they should be concerned about whether the user can accept new usage patterns; otherwise, AFVs will face a difficult situation in terms of sale.

Table 6. Unweighted supermatrix.

Criteria	Price	Value-Added	Modular	Maintenance and Repair Services	Optimization Transport Network	Vehicle Life	Energy Usage	Disasse-mbled	Demateriali-zation	Reduce Hazardous Substances	Reduce Emission	User Acceptance	Fairness and Justice	Healthy and Safety	Empowerment	Sustainable Consumption	Improving Life's Quality	Employment Opportunities
Price	0.176	0.288	0.282	0.261	0.344	0.279	0.239	0.246	0.283	0.244	0.263	0.256	0.244	0.247	0.220	0.226	0.235	0.216
Value-added	0.206	0.135	0.204	0.193	0.170	0.176	0.154	0.175	0.195	0.195	0.182	0.170	0.221	0.185	0.233	0.181	0.193	0.217
Modular	0.207	0.207	0.134	0.192	0.168	0.189	0.207	0.222	0.166	0.176	0.180	0.169	0.196	0.170	0.178	0.181	0.191	0.172
Maintenance and repair services	0.135	0.153	0.117	0.092	0.128	0.172	0.120	0.139	0.129	0.123	0.143	0.148	0.135	0.120	0.147	0.147	0.133	0.177
Optimization transport network	0.081	0.076	0.091	0.081	0.061	0.070	0.096	0.056	0.058	0.079	0.063	0.076	0.067	0.076	0.084	0.097	0.095	0.100
Vehicle life	0.195	0.141	0.172	0.180	0.130	0.114	0.184	0.163	0.169	0.183	0.170	0.181	0.137	0.203	0.139	0.168	0.154	0.118
Energy usage	0.199	0.157	0.142	0.178	0.207	0.154	0.131	0.246	0.231	0.181	0.188	0.185	0.190	0.189	0.180	0.180	0.187	0.183
Disassembled	0.161	0.193	0.227	0.170	0.109	0.166	0.142	0.130	0.181	0.169	0.177	0.146	0.181	0.162	0.175	0.182	0.178	0.172
Dematerialization	0.224	0.226	0.219	0.206	0.169	0.242	0.213	0.231	0.157	0.265	0.214	0.224	0.210	0.211	0.215	0.213	0.212	0.214
Reduce Hazardous Substances	0.209	0.225	0.218	0.206	0.229	0.220	0.249	0.230	0.217	0.163	0.258	0.224	0.211	0.212	0.215	0.214	0.213	0.215
Reduce emission	0.206	0.199	0.193	0.241	0.286	0.218	0.265	0.163	0.214	0.223	0.163	0.222	0.207	0.225	0.215	0.211	0.211	0.216
User acceptance	0.214	0.198	0.190	0.194	0.154	0.213	0.202	0.184	0.197	0.191	0.198	0.145	0.164	0.210	0.171	0.198	0.189	0.180
Fairness and justice	0.124	0.127	0.119	0.118	0.143	0.117	0.122	0.137	0.137	0.126	0.119	0.135	0.084	0.122	0.132	0.140	0.117	0.169
Healthy and safety	0.130	0.133	0.124	0.133	0.152	0.109	0.140	0.130	0.131	0.164	0.150	0.132	0.129	0.096	0.154	0.138	0.150	0.127
Empowerment	0.090	0.092	0.081	0.097	0.084	0.094	0.079	0.079	0.080	0.085	0.088	0.111	0.115	0.089	0.061	0.106	0.113	0.108
sustainable consumption	0.173	0.162	0.167	0.172	0.180	0.177	0.181	0.173	0.197	0.184	0.189	0.184	0.194	0.200	0.197	0.134	0.179	0.152
Improving life's quality	0.177	0.171	0.188	0.169	0.159	0.161	0.176	0.181	0.169	0.176	0.183	0.170	0.177	0.184	0.175	0.166	0.117	0.193
Employment opportunities	0.092	0.116	0.131	0.118	0.127	0.129	0.100	0.116	0.090	0.073	0.073	0.122	0.137	0.099	0.109	0.118	0.134	0.071

Table 7. Weighted supermatrix.

Criteria	Price	Value-added	Modular	Maintenance and Repair Services	Optimization Transport Network	Vehicle Life	Energy Usage	Disassembled	Demateri-alization	Reduce Hazardous Substances	Reduce Emission	User Acceptance	Fairness and Justice	Healthy and Safety	Empowerment	Sustainable Consumption	Improving Life's Quality	Employment Opportunities
Price	0.057	0.093	0.091	0.084	0.111	0.090	0.076	0.078	0.090	0.078	0.084	0.082	0.078	0.079	0.070	0.072	0.075	0.069
Value-added	0.066	0.044	0.066	0.062	0.055	0.057	0.049	0.056	0.062	0.062	0.058	0.054	0.071	0.059	0.075	0.058	0.062	0.069
Modular	0.067	0.067	0.043	0.062	0.054	0.061	0.066	0.071	0.053	0.056	0.057	0.054	0.063	0.054	0.057	0.058	0.061	0.055
Maintenance and repair services	0.043	0.049	0.038	0.030	0.041	0.056	0.038	0.044	0.041	0.039	0.045	0.047	0.043	0.038	0.047	0.047	0.042	0.057
Optimization transport network	0.026	0.024	0.029	0.026	0.020	0.023	0.031	0.018	0.018	0.025	0.020	0.024	0.021	0.024	0.027	0.031	0.030	0.032
Vehicle life	0.063	0.045	0.055	0.058	0.042	0.037	0.059	0.052	0.054	0.058	0.054	0.058	0.044	0.065	0.045	0.054	0.049	0.038
Energy usage	0.062	0.049	0.044	0.056	0.065	0.048	0.039	0.074	0.069	0.054	0.056	0.057	0.058	0.058	0.055	0.055	0.057	0.056
Disassembled	0.050	0.060	0.071	0.053	0.034	0.052	0.043	0.039	0.054	0.051	0.053	0.045	0.056	0.050	0.054	0.056	0.055	0.053
Dematerialization	0.070	0.071	0.068	0.064	0.053	0.076	0.064	0.069	0.047	0.079	0.064	0.069	0.064	0.065	0.066	0.065	0.065	0.066
Reduce Hazardous Substances	0.065	0.070	0.068	0.064	0.072	0.069	0.075	0.069	0.065	0.049	0.078	0.069	0.065	0.065	0.066	0.066	0.065	0.066
Reduce emission	0.064	0.062	0.060	0.075	0.089	0.068	0.080	0.049	0.064	0.067	0.049	0.068	0.064	0.069	0.066	0.065	0.065	0.066
User acceptance	0.078	0.072	0.070	0.071	0.056	0.078	0.077	0.070	0.075	0.073	0.075	0.054	0.061	0.078	0.064	0.074	0.071	0.067
Fairness and justice	0.045	0.047	0.043	0.043	0.052	0.043	0.047	0.052	0.052	0.048	0.045	0.051	0.031	0.046	0.049	0.052	0.044	0.063
Healthy and safety	0.048	0.049	0.045	0.049	0.055	0.040	0.053	0.050	0.050	0.063	0.057	0.049	0.048	0.036	0.057	0.052	0.056	0.047
Empowerment	0.033	0.034	0.030	0.035	0.031	0.034	0.030	0.030	0.030	0.032	0.034	0.041	0.043	0.033	0.023	0.040	0.042	0.040
sustainable consumption	0.063	0.059	0.061	0.063	0.066	0.065	0.069	0.066	0.075	0.070	0.072	0.069	0.072	0.075	0.074	0.050	0.067	0.057
Improving life's quality	0.065	0.063	0.069	0.062	0.058	0.059	0.067	0.069	0.064	0.067	0.070	0.063	0.066	0.069	0.066	0.062	0.044	0.072
Employment opportunities	0.034	0.042	0.048	0.043	0.047	0.047	0.038	0.044	0.034	0.028	0.028	0.046	0.051	0.037	0.041	0.044	0.050	0.026

Table 8. Limited matrix.

Criteria	Price	Value-Added	Modular	Maintenance and Repair Services	Optimization Transport Network	Vehicle Life	Energy Usage	Disassembled	Demater-ialization	Reduce Hazardous Substances	Reduce Emission	User Acceptance	Fairness and Justice	Healthy and Safety	Empowerment	Sustainable Consumption	Improving Life's Quality	Employment Opportunities
Price	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080
Value-added	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060
Modular	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059
Maintenance and repair services	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044
Optimization transport network	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Vehicle life	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053
Energy usage	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056
Disassembled	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052
Dematerialization	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066
Reduce Hazardous Substances	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067
Reduce emission	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065
User acceptance	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071
Fairness and justice	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047
Healthy and safety	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Empowerment	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035
sustainable consumption	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066
Improving life's quality	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064
Employment opportunities	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040

Table 9. Ranking of each dimension and criterion.

Dimensions	Criteria	Overall	
		Weight	Ranking
Economic		0.3201	2
	Price (Ec1)	0.0798	1
	Value-added (Ec2)	0.0599	8
	Modular (Ec3)	0.0589	9
	Maintenance and repair services (Ec4)	0.0437	15
	Optimization transport network (Ec5)	0.0251	18
	Vehicle life (Ec6)	0.0527	11
Environmental		0.3066	3
	Energy usage (E1)	0.0562	10
	Disassembled (E2)	0.0521	12
	Dematerialization (E3)	0.0663	4
	Reduce Hazardous Substances (E4)	0.0668	3
	Reduce emission (E5)	0.0652	6
Social		0.3732	1
	User acceptance (S1)	0.0710	2
	Fairness and justice (S2)	0.0472	14
	Healthy and safety (S3)	0.0503	13
	Empowerment (S4)	0.0345	17
	Sustainable consumption (S5)	0.0661	5
	Improving life's quality (S6)	0.0640	7
	Employment opportunities (S7)	0.0401	16

"Reduce hazardous substances" pertains to users' concerns about environmental sustainability. Meanwhile, the criteria "dematerialization" and "reduced emissions," which are both included in the environmental dimension, are ranked fourth and sixth, respectively. As mentioned earlier, focus should go beyond the dimension ranking.

The environmental dimension is at the top of the influence map (Figure 4). Thus, this dimension possesses the highest degree of influence on others and social dimension is the most important dimension in the evaluation hierarchy. This result shows a certain inconsistency with the ranking because it indicates that when evaluating AFVs, the environmental criterion has the highest degree of influence on the economic and social dimensions. In consideration of the evaluation hierarchy relationship, the social dimension has the highest importance. However, in the real evaluation of AFVs, the economic dimension continues to be most important for users.

On the basis of these findings, although the economic criterion is deemed most important by users, the result obtained by DEMATEL provides information that the economic criterion is not the most important or highest influencing factor in the evaluation hierarchy. Thus, these findings represent the major three elements of sustainable development (*i.e.*, economic, environmental, and social) that are most considered at the same time. The concept of sustainable development has reached a consensus.

6. Conclusions

Efforts to reduce climate change have resulted in the development of AFVs. However, AFVs are not only geared toward reducing climate change but also serve as the answer to the oil crisis. AFVs are not merely a transitional trend for road transportation but are the future of road transportation. The sustainable development concept is based on environmental, economic, and social sustainability; thus, AFV development should also be based on this concept. Various studies have focused on AFVs and sustainable development; however, they merely focus on AFV development through the MCDM approach. On the basis of the three major elements of sustainable development, this study constructs an evaluation hierarchy as a reference for today's automakers and researchers in reducing the effects of the fuel crisis and slowing down global warming. Furthermore, a novel MCDM evaluating approach called DANP is applied to determine the weight of the evaluation dimensions and criteria for the future design and planning of AFVs.

The results indicate that price is the most important criterion in the AFV industry, and we believe that reducing price is an effective way to improve the popularity of AFVs and motivate AFV-relevant infrastructure suppliers to become involved in the market. At the same time, user acceptance is related to the new usage patterns of AFVs. Therefore, when designing new types of AFVs, automakers should be concerned with whether users can accept new usage patterns; otherwise, AFVs will face a difficult situation in terms of generating sales. The criterion "reduce hazardous substances" is ranked third, thus indicating the concern of users for environmental sustainability.

Future Research

This research only focuses on constructing an evaluation hierarchy of AFVs under the perspective of sustainable development and not on a particular type of AFV. Thus, this evaluation hierarchy can be extended in the future to plan strategies and detailed applications for different types of AFVs, such as compressed natural gas vehicles, plug-in EVs, and pure EVs. Although price is the most critical criterion in AFV development, infrastructure optimization can be considered on the basis of different types of AFVs in the future research because one of the obstacles for AFV market diffusion is the lack of refueling infrastructure, which prevents potential users from buying AFVs [56].

The AFVs' life-cycle involves maintenance, and fuel and electricity prices [6]. We consider maintenance in our evaluation hierarchy, but not fuel and electricity prices because regional fuel and electricity prices can be affected by public policy or government intervention, as in the nuclear power phase-out policy in Germany that caused it to have the highest retail electricity price in Europe [57]. Thus, this evaluation hierarchy can be extended in the future to fuel or electricity prices under different public policies or government intervention.

Author Contributions

Dong-Shang Chang, Allen H. Hu, and Gwo-Hshiung Tzeng designed the research; Sheng-Hung Chen and Chia-Wei Hsu performed the research; Dong-Shang Chang, Sheng-Hung Chen, Chia-Wei Hsu, and Gwo-Hshiung Tzeng collected and analyzed the data; Dong-Shang Chang, Sheng-Hung Chen, Chia-Wei Hsu, and Allen H. Hu wrote the paper; finally, Chia-Wei Hsu revised the paper. All authors have read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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