Multi Criteria Decision Making (MCDM)

➢ Additive Ratio Assessments (ARAS) Method

The **ARAS method** is a ranking method used to evaluate alternatives by calculating an overall performance score for each option. ARAS ranks alternatives based on how well they satisfy each criterion relative to an ideal solution.

Step 1 Creating the initial decision matrix: The decision alternatives of the problem and the evaluation criteria to be considered while evaluating these alternatives are determined. Then, the initial decision matrix showing the scores of the decision alternatives according to the criteria is created as in Eq. (6). Here, *i* is the number of alternatives and *j* is the number of evaluation criteria ($i = 0, 1, \ldots, m; j = 1, 2, \ldots, n$).

$$X = \begin{bmatrix} x_{01} & x_{02} & \cdots & x_{0n} \\ x_{11} & x_{12} & \cdots & x_{1n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \tag{6}$$

Additive Ratio Assessments(ARAS) METHOD

Factors	Decarbonizatio	Regulatory Co	Opportunity co	Impact on the e	Safety	Global Availa	Supply Capac	Durability	Adaptability	Fuel availabili	Vessel Safety	Reliability	Energy storage	Infrastructur	Air pollution	Acquisition cos	GHG Emissio	Technical ma	Capital Cost	Public acceptance
Decarbonization	6	3.75	3.25	4.75	3.75	3.5	3.5	2.75	3.25	3.75	3.25	3.25	3.25	3.5	4.25	3	4.25	3.25	2.5	3.5
Regulatory Compliance	3.75	6	3.25	2.75	3.75	3	3	3.25	3.5	3.5	3.75	3.75	3.25	3.25	4	3.25	3.75	3.5	3.25	3.25
Opportunity cost	3.5	3	6	3	3	3.25	3.5	2.5	3.25	3	3.25	2.75	2.5	2.75	3	3.25	3	3.5	3.5	3
Impact on the ecosystem	4.75	3	3.25	6	4	3.75	3	3.75	3	3.5	3.75	3	3	3.5	4.5	2.5	4.25	3.25	2.75	3.25
Safety	3.5	3.75	3	4.25	6	2.75	2.5	3.75	3.75	3.5	4.75	4	3.75	3.5	3.5	2.75	3.75	3.5	3	3.75
Global Availability	3.75	3.25	3.5	3.75	2.75	6	4	3	3	4.25	3.5	3.25	3	3.5	2.5	2.75	2.5	3	3.25	3.25
Supply Capacity	3.5	3.25	3.25	3	2.5	3.75	6	3	3.5	4	3.75	3.75	3.25	3.75	2.75	3.25	2.5	3.5	3.25	3
Durability	2.75	3.25	3	3.5	4	3	2.75	6	3.5	2.75	4	4	3.5	3.75	3.5	3.25	3	3.5	3.5	3.75
Adaptability	3.75	3.5	3.75	3.5	3.5	3.25	3.5	3.5	6	3	4	4	3.5	3.75	3	3	3.25	4.25	3	3.75
Fuel availability	3.75	3.5	3.25	4	4	4.25	3.5	3	3.5	6	3.75	3.5	3.5	3.75	3.75	2.75	3.75	3.25	3.25	3
Vessel Safety	3.5	4.25	3	4	4.5	3.5	3.5	3.75	4	4.25	6	3.75	3.75	3.5	3.75	3.25	3.5	3.5	3.5	4.25
Reliability	3.75	4	3	3.5	4.25	2.75	3.5	3.75	3.5	4.25	4	6	3.75	3.75	4.25	2.75	3.75	4	3	3.5
Energy storage efficiency	3.5	3.25	3	3.25	3.75	3	3.75	3.75	3.75	4	3.75	3.75	6	4	3	3	2.75	3.75	3.75	3.75
Infrastructure	3.5	3.25	3	3.25	3.75	3.25	4	4	4	3.5	3.25	3.5	3.75	6	3.25	3.25	3.5	3.5	3.25	3.75
Air pollution	4.75	4	3.25	4.75	3.75	3	2.75	3.25	3.75	4	3.75	3.5	3.25	3	6	3	4.25	3.5	3.25	3.75
Acquisition cost	3.25	3	3.25	2.75	2.75	2.75	3.25	2.75	3.25	3	3	2.75	3	3.25	3.25	6	3.5	2.75	3.75	3.25
GHG Emission reduction	4.25	4	3.25	4.25	3.75	2.5	2.75	3.5	3.5	3.75	3.25	3.5	2.75	3.25	4.25	3	6	3.75	3	3.5
Technical maturity	3.25	4	3.25	3.25	3.5	3.25	3.5	3.5	3.75	3.5	3.5	3.75	3.75	3.75	3.5	3	3.5	6	3.25	3.5
Capital Cost	2.75	3.25	4.25	2.75	3.25	3.25	4	3.25	3.25	3.25	3.5	2.5	3.5	3.5	3.5	3.75	3.25	3.25	6	3.75
Public acceptance	3.5	3.5	3	3.5	3.75	3.5	3	3.25	3.25	3	3.75	3.5	3.75	3.5	3.5	3.25	3.25	3.5	3.25	6

Step 2 Creating the normalized decision matrix: Before the normalized decision matrix is created, the optimal value series is calculated and the different metric values are combined. The optimal value series is determined according to whether the decision criterion is cost or benefit-based. If the criterion is benefit-based, that is, if it needs to be maximized, the optimal value of the criterion is calculated with the help of Eq. (7), if the criterion is cost-based, that is, it needs to be minimized, the optimal value of the criterion is calculated with the help of Eq. (8).

$$\overline{x_{ij}} = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}} \tag{7}$$

$$\overline{x_{ij}} = \frac{{}^{1}/_{x_{ij}}}{\sum_{i=0}^{m} 1/x_{ij}} \tag{8}$$

Weights	0.049496092	0.04323955	0.048550399	0.064403686	0.0533314	0.06022343	0.05827554	0.054366	0.03726968	0.04856965	0.03718589	0.0507299	0.049429231	0.03738031	0.05820438	0.058090969	0.0610732	0.04028556	0.0506137	0.039281
Factors	Decarbonizatio	Regulatory Co	Opportunity co	Impact on the e	Safety	Global Availa	Supply Capac	Durability	Adaptability	Fuel availabili	Vessel Safety	Reliability	Energy storage	Infrastructur	Air pollution	Acquisition cos	GHG Emissio	Technical ma	Capital Cost	Public acceptance
Decarbonization	0.08	0.05154639	0.04797048	0.06440678	0.0505051	0.05204461	0.05054152	0.039711	0.0449827	0.05084746	0.04304636	0.0452962	0.046594982	0.04827586	0.058219178	0.046875	0.0596491	0.04513889	0.0371747	0.048276
Regulatory Compliance	0.05	0.08247423	0.04797048	0.037288136	0.0505051	0.04460967	0.0433213	0.046931	0.04844291	0.04745763	0.04966887	0.0522648	0.046594982	0.04482759	0.054794521	0.05078125	0.0526316	0.04861111	0.0483271	0.044828
Opportunity cost	0.046666667	0.04123711	0.088560886	0.040677966	0.040404	0.04832714	0.05054152	0.036101	0.0449827	0.04067797	0.04304636	0.0383275	0.035842294	0.03793103	0.04109589	0.05078125	0.0421053	0.04861111	0.0520446	0.041379
Impact on the ecosystem	0.063333333	0.04123711	0.04797048	0.081355932	0.0538721	0.05576208	0.0433213	0.054152	0.04152249	0.04745763	0.04966887	0.0418118	0.043010753	0.04827586	0.061643836	0.0390625	0.0596491	0.04513889	0.0408922	0.044828
Safety	0.046666667	0.05154639	0.044280443	0.057627119	0.0808081	0.04089219	0.03610108	0.054152	0.05190311	0.04745763	0.06291391	0.0557491	0.053763441	0.04827586	0.047945205	0.04296875	0.0526316	0.04861111	0.0446097	0.051724
Global Availability	0.05	0.04467354	0.051660517	0.050847458	0.037037	0.08921933	0.05776173	0.043321	0.04152249	0.05762712	0.04635762	0.0452962	0.043010753	0.04827586	0.034246575	0.04296875	0.0350877	0.04166667	0.0483271	0.044828
Supply Capacity	0.046666667	0.04467354	0.04797048	0.040677966	0.03367	0.05576208	0.0866426	0.043321	0.04844291	0.05423729	0.04966887	0.0522648	0.046594982	0.05172414	0.037671233	0.05078125	0.0350877	0.04861111	0.0483271	0.041379
Durability	0.036666667	0.04467354	0.044280443	0.047457627	0.0538721	0.04460967	0.03971119	0.086643	0.04844291	0.03728814	0.05298013	0.0557491	0.050179211	0.05172414	0.047945205	0.05078125	0.0421053	0.04861111	0.0520446	0.051724
Adaptability	0.05	0.04810997	0.055350554	0.047457627	0.047138	0.04832714	0.05054152	0.050542	0.08304498	0.04067797	0.05298013	0.0557491	0.050179211	0.05172414	0.04109589	0.046875	0.045614	0.05902778	0.0446097	0.051724
Fuel availability	0.05	0.04810997	0.04797048	0.054237288	0.0538721	0.06319703	0.05054152	0.043321	0.04844291	0.08135593	0.04966887	0.0487805	0.050179211	0.05172414	0.051369863	0.04296875	0.0526316	0.04513889	0.0483271	0.041379
Vessel Safety	0.046666667	0.05841924	0.044280443	0.054237288	0.0606061	0.05204461	0.05054152	0.054152	0.05536332	0.05762712	0.0794702	0.0522648	0.053763441	0.04827586	0.051369863	0.05078125	0.0491228	0.04861111	0.0520446	0.058621
Reliability	0.05	0.05498282	0.044280443	0.047457627	0.0572391	0.04089219	0.05054152	0.054152	0.04844291	0.05762712	0.05298013	0.0836237	0.053763441	0.05172414	0.058219178	0.04296875	0.0526316	0.05555556	0.0446097	0.048276
Energy storage efficiency	0.046666667	0.04467354	0.044280443	0.044067797	0.0505051	0.04460967	0.05415162	0.054152	0.05190311	0.05423729	0.04966887	0.0522648	0.086021505	0.05517241	0.04109589	0.046875	0.0385965	0.05208333	0.0557621	0.051724
Infrastructure	0.046666667	0.04467354	0.044280443	0.044067797	0.0505051	0.04832714	0.05776173	0.057762	0.05536332	0.04745763	0.04304636	0.0487805	0.053763441	0.08275862	0.044520548	0.05078125	0.0491228	0.04861111	0.0483271	0.051724
Air pollution	0.063333333	0.05498282	0.04797048	0.06440678	0.0505051	0.04460967	0.03971119	0.046931	0.05190311	0.05423729	0.04966887	0.0487805	0.046594982	0.04137931	0.082191781	0.046875	0.0596491	0.04861111	0.0483271	0.051724
Acquisition cost	0.043333333	0.04123711	0.04797048	0.037288136	0.037037	0.04089219	0.04693141	0.039711	0.0449827	0.04067797	0.0397351	0.0383275	0.043010753	0.04482759	0.044520548	0.09375	0.0491228	0.03819444	0.0557621	0.044828
GHG Emission reduction	0.056666667	0.05498282	0.04797048	0.057627119	0.0505051	0.03717472	0.03971119	0.050542	0.04844291	0.05084746	0.04304636	0.0487805	0.039426523	0.04482759	0.058219178	0.046875	0.0842105	0.05208333	0.0446097	0.048276
Technical maturity	0.043333333	0.05498282	0.04797048	0.044067797	0.047138	0.04832714	0.05054152	0.050542	0.05190311	0.04745763	0.04635762	0.0522648	0.053763441	0.05172414	0.047945205	0.046875	0.0491228	0.08333333	0.0483271	0.048276
Capital Cost	0.036666667	0.04467354	0.062730627	0.037288136	0.043771	0.04832714	0.05776173	0.046931	0.0449827	0.0440678	0.04635762	0.0348432	0.050179211	0.04827586	0.047945205	0.05859375	0.045614	0.04513889	0.0892193	0.051724
Public acceptance	0.046666667	0.04810997	0.044280443	0.047457627	0.0505051	0.05204461	0.0433213	0.046931	0.0449827	0.04067797	0.04966887	0.0487805	0.053763441	0.04827586	0.047945205	0.05078125	0.045614	0.04861111	0.0483271	0.082759

Step 3 Creating the weighted normalized decision matrix: The normalized decision matrix is weighted by taking into account the criteria importance weights (w_j) determined in line with the opinions of the experts or the subjective opinions determined by the decision maker. The weighted decision matrix is obtained with the help of Eq. (10).

$$\widehat{x}_{ij} = \overline{x}_{ij} \bullet w_{ij} \tag{10}$$

Factors	Decarbonizatio	Regulatory Co	Opportunity co	Impact on the e	Safety	Global Availal	Supply Capac	Durability	Adaptability	Fuel availabili	Vessel Safety	Reliability	Energy storage	Infrastructure	Air pollution	Acquisition cos	GHG Emissio	Technical ma	Capital Cost	Public acceptance
Decarbonization	0.003959687	0.00222884	0.002074222	0.004148034	0.0026935	0.0031343	0.00294533	0.002159	0.00167649	0.00246964	0.00160072	0.0022979	0.002303154	0.00180457	0.003388611	0.002723014	0.003643	0.00181845	0.0018815	0.001896
Regulatory Compliance	0.002474805	0.00356615	0.002328986	0.002401493	0.0026935	0.00268655	0.00252457	0.002551	0.00180545	0.002305	0.00184698	0.0026514	0.002303154	0.00167567	0.003189281	0.002949932	0.0032144	0.00195833	0.002446	0.001761
Opportunity cost	0.002309818	0.00178307	0.004299666	0.002619811	0.0021548	0.00291043	0.00294533	0.001963	0.00167649	0.00197571	0.00160072	0.0019443	0.001771657	0.00141787	0.002391961	0.002949932	0.0025715	0.00195833	0.0026342	0.001625
Impact on the ecosystem	0.003134753	0.00178307	0.002328986	0.005239622	0.0028731	0.00335818	0.00252457	0.002944	0.00154753	0.002305	0.00184698	0.0021211	0.002125988	0.00180457	0.003587941	0.002269178	0.003643	0.00181845	0.0020697	0.001761
Safety	0.002309818	0.00222884	0.002149833	0.003711399	0.0043096	0.00246267	0.00210381	0.002944	0.00193441	0.002305	0.00233951	0.0028281	0.002657486	0.00180457	0.002790621	0.002496096	0.0032144	0.00195833	0.0022579	0.002032
Global Availability	0.002474805	0.00193166	0.002508139	0.003274764	0.0019752	0.00537309	0.0033661	0.002355	0.00154753	0.00279893	0.00172385	0.0022979	0.002125988	0.00180457	0.001993301	0.002496096	0.0021429	0.00167857	0.002446	0.001761
Supply Capacity	0.002309818	0.00193166	0.002328986	0.002619811	0.0017957	0.00335818	0.00504914	0.002355	0.00180545	0.00263429	0.00184698	0.0026514	0.002303154	0.00193346	0.002192631	0.002949932	0.0021429	0.00195833	0.002446	0.001625
Durability	0.001814857	0.00193166	0.002149833	0.003056446	0.0028731	0.00268655	0.00231419	0.00471	0.00180545	0.00181107	0.00197011	0.0028281	0.00248032	0.00193346	0.002790621	0.002949932	0.0025715	0.00195833	0.0026342	0.002032
Adaptability	0.002474805	0.00208025	0.002687291	0.003056446	0.0025139	0.00291043	0.00294533	0.002748	0.00309506	0.00197571	0.00197011	0.0028281	0.00248032	0.00193346	0.002391961	0.002723014	0.0027858	0.00237797	0.0022579	0.002032
Fuel availability	0.002474805	0.00208025	0.002328986	0.003493081	0.0028731	0.00380594	0.00294533	0.002355	0.00180545	0.00395143	0.00184698	0.0024746	0.00248032	0.00193346	0.002989951	0.002496096	0.0032144	0.00181845	0.002446	0.001625
Vessel Safety	0.002309818	0.00252602	0.002149833	0.003493081	0.0032322	0.0031343	0.00294533	0.002944	0.00206337	0.00279893	0.00295517	0.0026514	0.002657486	0.00180457	0.002989951	0.002949932	0.0030001	0.00195833	0.0026342	0.002303
Reliability	0.002474805	0.00237743	0.002149833	0.003056446	0.0030526	0.00246267	0.00294533	0.002944	0.00180545	0.00279893	0.00197011	0.0042422	0.002657486	0.00193346	0.003388611	0.002496096	0.0032144	0.00223809	0.0022579	0.001896
Energy storage efficiency	0.002309818	0.00193166	0.002149833	0.002838129	0.0026935	0.00268655	0.00315572	0.002944	0.00193441	0.00263429	0.00184698	0.0026514	0.004251977	0.00206236	0.002391961	0.002723014	0.0023572	0.00209821	0.0028223	0.002032
Infrastructure	0.002309818	0.00193166	0.002149833	0.002838129	0.0026935	0.00291043	0.0033661	0.00314	0.00206337	0.002305	0.00160072	0.0024746	0.002657486	0.00309354	0.002591291	0.002949932	0.0030001	0.00195833	0.002446	0.002032
Air pollution	0.003134753	0.00237743	0.002328986	0.004148034	0.0026935	0.00268655	0.00231419	0.002551	0.00193441	0.00263429	0.00184698	0.0024746	0.002303154	0.00154677	0.004783922	0.002723014	0.003643	0.00195833	0.002446	0.002032
Acquisition cost	0.002144831	0.00178307	0.002328986	0.002401493	0.0019752	0.00246267	0.00273495	0.002159	0.00167649	0.00197571	0.00147758	0.0019443	0.002125988	0.00167567	0.002591291	0.005446028	0.0030001	0.00153868	0.0028223	0.001761
GHG Emission reduction	0.002804779	0.00237743	0.002328986	0.003711399	0.0026935	0.00223879	0.00231419	0.002748	0.00180545	0.00246964	0.00160072	0.0024746	0.001948823	0.00167567	0.003388611	0.002723014	0.005143	0.00209821	0.0022579	0.001896
Technical maturity	0.002144831	0.00237743	0.002328986	0.002838129	0.0025139	0.00291043	0.00294533	0.002748	0.00193441	0.002305	0.00172385	0.0026514	0.002657486	0.00193346	0.002790621	0.002723014	0.0030001	0.00335713	0.002446	0.001896
Capital Cost	0.001814857	0.00193166	0.003045597	0.002401493	0.0023344	0.00291043	0.0033661	0.002551	0.00167649	0.00214036	0.00172385	0.0017676	0.00248032	0.00180457	0.002790621	0.003403768	0.0027858	0.00181845	0.0045157	0.002032
Public acceptance	0.002309818	0.00208025	0.002149833	0.003056446	0.0026935	0.0031343	0.00252457	0.002551	0.00167649	0.00197571	0.00184698	0.0024746	0.002657486	0.00180457	0.002790621	0.002949932	0.0027858	0.00195833	0.002446	0.003251

Step 4 Calculating of the optimality function: The optimality function values for each decision alternative are calculated with the help of Eq. (12). Here, S_i is the optimality function of the decision alternative i. An alternative with the higher S_i value is the better alternative.

$$S_i = \sum_{j=1}^{n} \widehat{x}_{ij} \tag{12}$$

Factors		Si
Decarbonization		0.05084624
Regulatory Compliance		0.049334
Opportunity cost		0.04550374
Impact on the ecosystem		0.05108657
Safety		0.05083819
Global Availability		0.04807553
Supply Capacity		0.04823847
Durability		0.04930195
Adaptability		0.05026745
Fuel availability		0.05143928
Vessel Safety		0.05350069
Reliability		0.05236221
Energy storage efficiency		0.05051514
Infrastructure		0.05051194
Air pollution		0.05256119
Acquisition cost		0.04602529
GHG Emission reduction		0.0506988
Technical maturity		0.05022563
Capital Cost		0.0492953
Public acceptance		0.04911764

So	0.05350069

Step 5 Calculating of utility degree and the final ranking of alternatives: The utility degree of alternatives (K_i) is calculated with the help of Eq. (13). The degree of utility is obtained by dividing the optimality function value of a decision alternative by the optimality function value of the best alternative. The relative efficiency of the utility function values of the alternatives is calculated by using the K_i ratios that take values in the $[0,1]$ range. Calculated values are ordered from largest to smallest, and the best alternative with the highest value is found.

$$K_i = \frac{S_i}{S_o} \tag{13}$$

Ki	Rnking
0.95038472	6
0.92211893	13
0.85052621	20
0.95487691	5
0.95023427	7
0.89859636	18
0.90164201	17
0.92151983	14
0.93956637	11
0.96146945	4
1	1
0.97872024	3
0.94419607	9
0.94413631	10
0.98243953	2
0.86027465	19
0.94762884	8
0.93878469	12
0.92139559	15
0.91807483	16

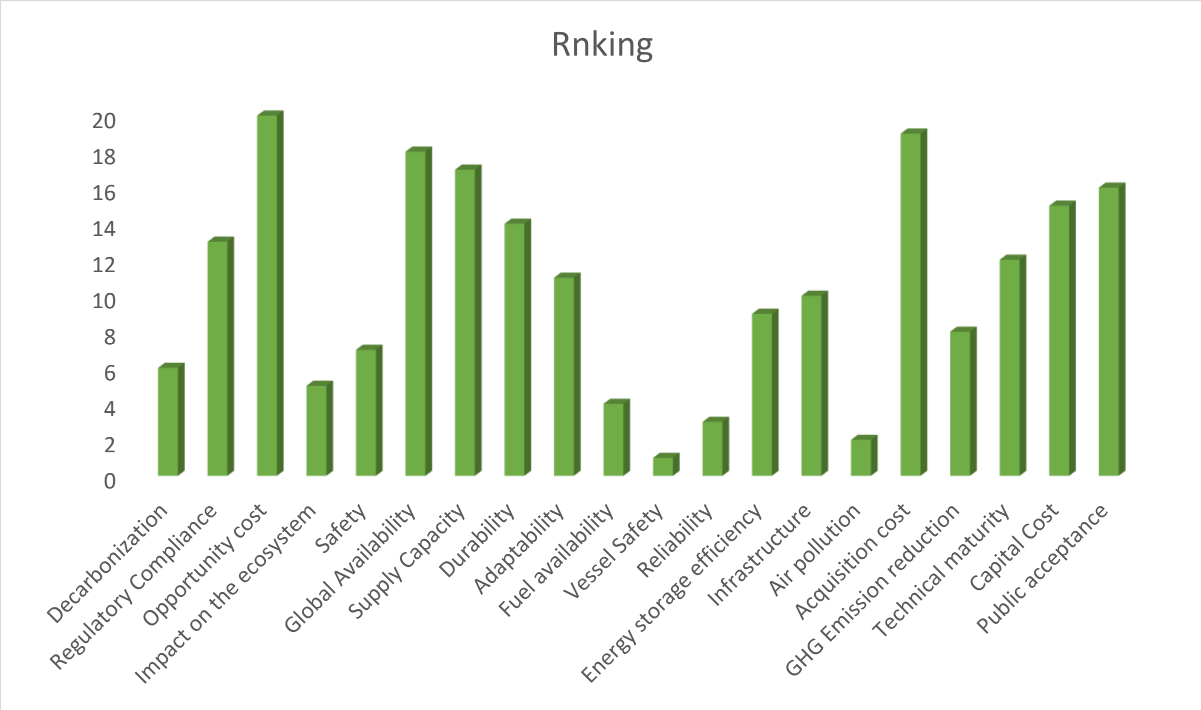

Figure 2. The utility degree and the final alternative ranking

The given above figure (Figure 2), we can find out what are the factors to be kept in mind when adopting alternative fuel and what benefits it will have for the maritime industry.

- In ARAS, each alternative's performance is assessed by adding up its relative contributions, allowing decision-makers to easily compare alternatives and choose the most suitable one.

- Together, **Entropy** (for determining weights) and **ARAS** (for ranking) provide a powerful combination in MCDM for making well-informed, data-driven decisions across multiple criteria.