A Renewable Energy Strategy for the Republic of Cyprus and the Potential Contribution from the Solid Waste Management Sector

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1. INTRODUCTION

The republic of Cyprus is at a critical stage in the evolution of its energy sector and more specifically in meeting the renewable energy and climate change targets set by the EU. The **flexibility** and **diverseness of renewable energy sources**, as well as the **rising cost-competitiveness** of the electricity market has driven renewable energy to the pinnacle of the global agenda for the provision of electricity security. **Solid waste** represents a **potential indigenous fuel** for Cyprus that may be harnessed for energy recovery, but this resource has not yet been exploited locally for this purpose.

2. MULTI-CRITERIA ANALYSIS (MCA)

MCA assists in **complex-decision making** situations and allows the incorporation of **conflicting criteria** in **incommensurable units** (Kylili et al., 2014). Two MCA assessments were carried out using the **PROMETHEE method:**

1. *MCA 1: Identifying the optimum renewable energy technology for electricity generation for deployment, noting the performance from Energy from Waste (EfW) systems*
2. *MCA 2: Identifying the contribution from the solid waste management sector*

3. PROMETHEE METHOD

Figure 1: PROMETHEE Ranking method (Adapted from Behzadian, 2010)

Step 1: Determination of the deviations according to pair-wise comparisons

$$d_j(a,b) = g_j(a) - g_j(b) \quad (1)$$

Where $d_j(a,b)$ represents the difference between the evaluations of a and b on each criterion

Step 2: Application of the preference function

$$P_j(a,b) = F_j\left[d_j(a,b)\right] \qquad j = 1,\ldots,n \quad (2)$$

Where $P_j(a,b)$ represents the preference between alternative a in respect to b on each criterion, as a function of $d_j(a,b)$

Step 3: Calculation of a global preference index Π for each pair of alternatives. This expresses the degree to which one action is preferred to another.

$$\Pi(a,b) = \sum_{j=1}^{n} P_j(a,b) w_j \qquad j = 1,\ldots,n \quad (3)$$

Where the preference $\Pi(a,b)$ of a over b [0, 1] is defined as the weighted sum $P(a,b)$ for each criterion, w_j represents the weight associated with the j_{th} criterion

Step 4: Calculation of outranking flows. PROMETHEE I Partial Ranking system

$$\phi^{+}(a) = \frac{1}{n-1}\sum_{x\in A}\pi(a,x) \quad (4) \qquad \phi^{-}(a) = \frac{1}{n-1}\sum_{x\in A}\pi(x,a) \quad (5)$$

Where $\phi^{+}(a)$ denotes the positive preference outranking flow and $\phi^{-}(a)$ the negative outranking flow

Step 5: Calculation of the net outranking flow. PROMETHEE II Complete Ranking system

$$\phi(a) = \phi^{+}(a) - \phi^{-}(a) \quad (6)$$

Where $\phi(a)$ denotes the net outranking flow for each alternative

4. OPTIONS

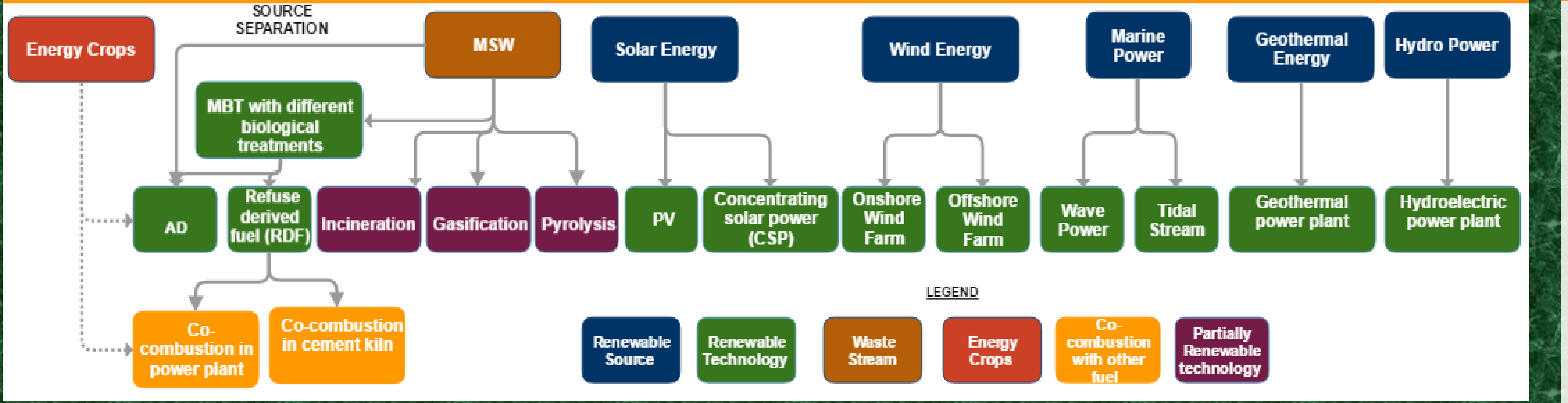

Figure 2: Flow chart of different options assessed

5. CRITERIA BREAKDOWN

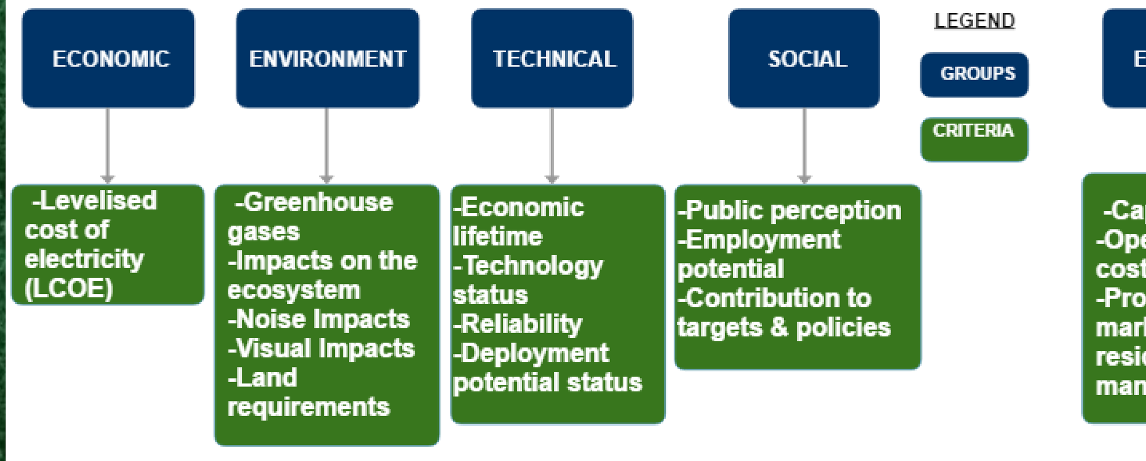

Figure 3: Criteria breakdown – Renewable Energy Options

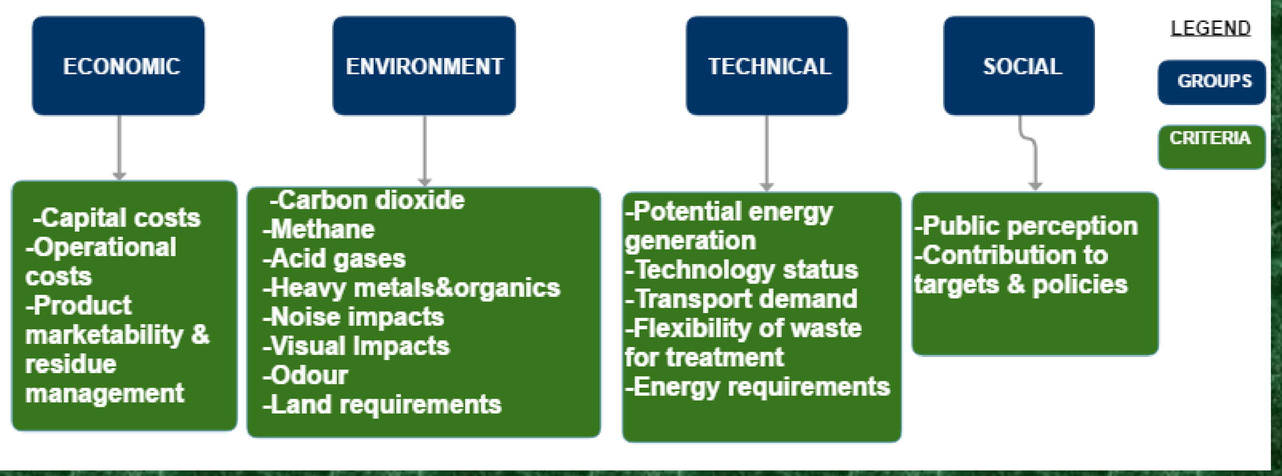

Figure 4: Criteria breakdown – Solid waste management methods

6. RESULTS

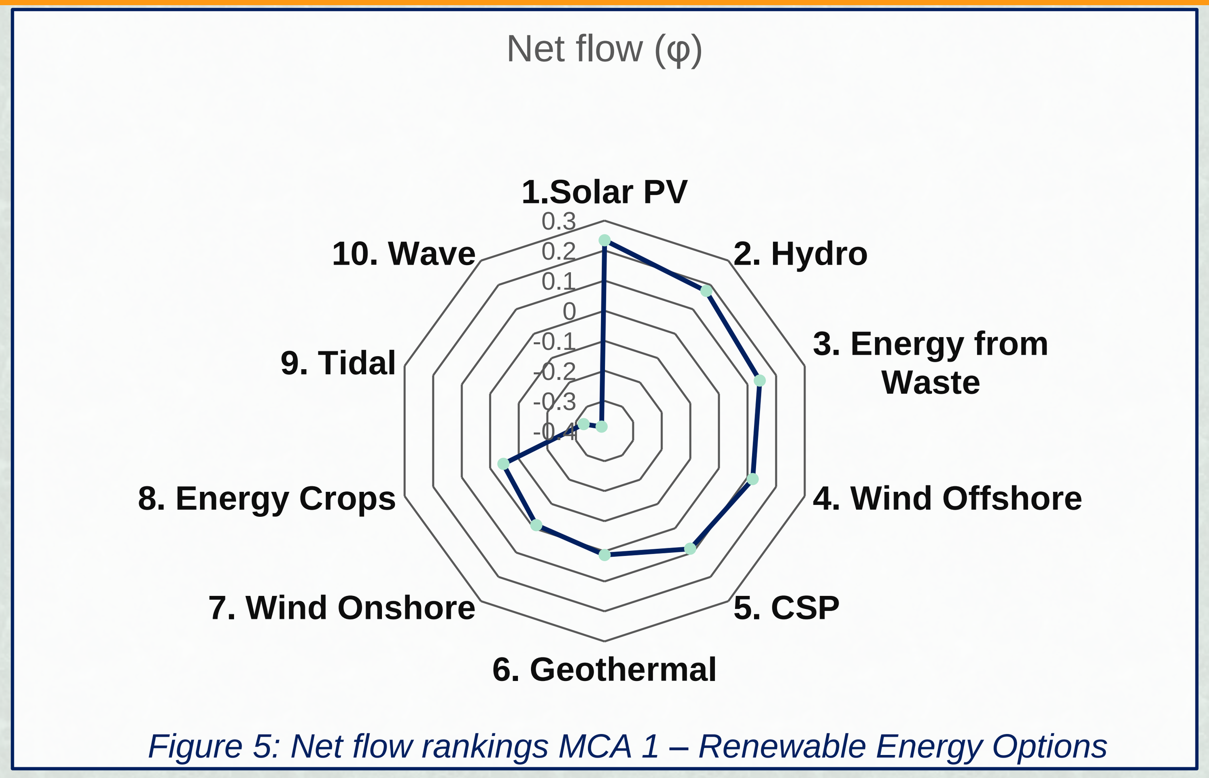

Figure 5: Net flow rankings MCA 1 – Renewable Energy Options

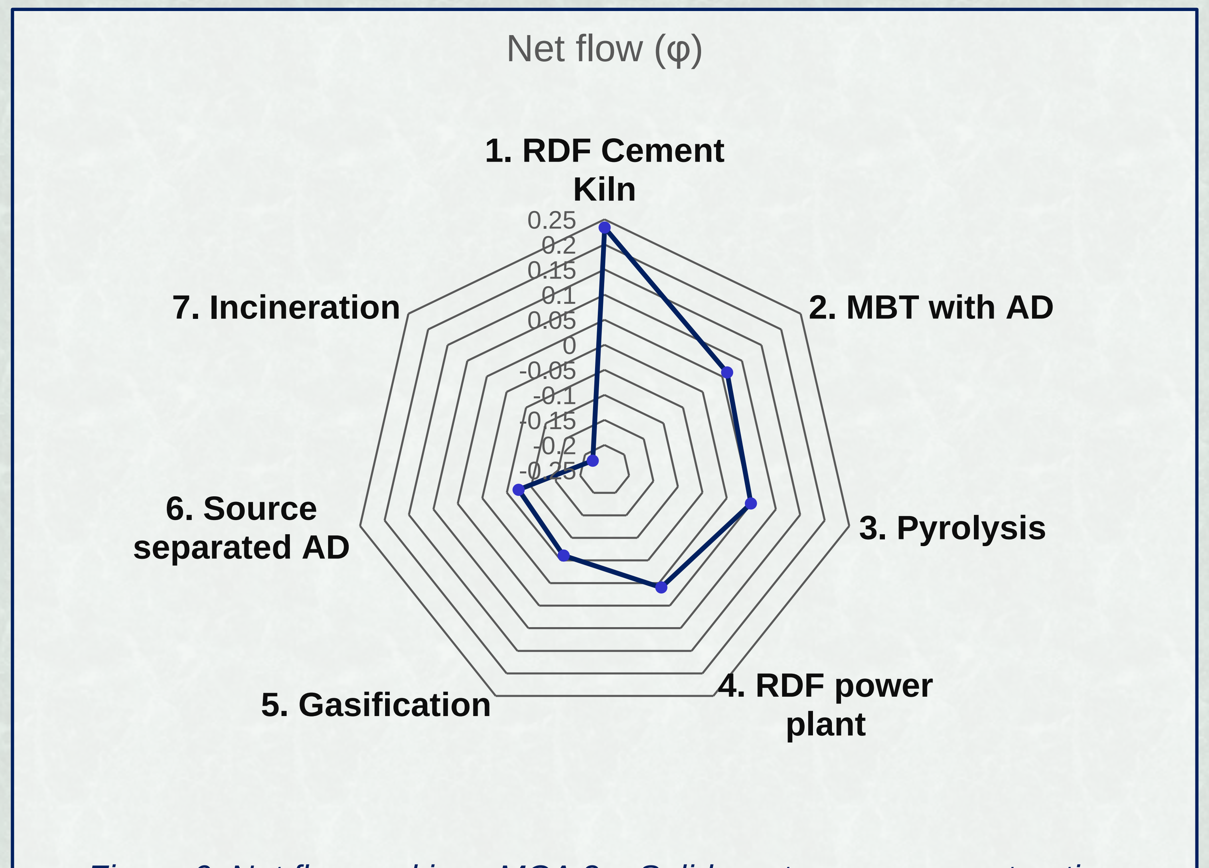

Figure 6: Net flow rankings MCA 2 – Solid waste management options

The results from MCA 1 yield **Solar PV in 1st** with **φ=*0.234*** place and **EfW in 3rd** with **φ=0.143**

Solar PV

- **PROS**: High irradiation potential, high social acceptance & gross positive net flow contribution from environmental criteria
- **CONS**: Variable source, thus low reliability

Energy from Waste

- **PROS:** Promotes the diversion of biodegradable waste from landfills and high reliability of supply
- **CONS**: Greenhouse gas emissions & high visual impacts

The results from MCA 2 yield the option of **co-combustion of RDF in cement kilns 1st**.

RDF co-combustion in cement kiln

- **PROS**: Low capital costs and land requirements due to the presence of the Vassiliko Cement kiln. High local marketability and export potential of cement.
- **CONS:** High specificity of processed waste for co-combustion, relatively high transport demand which will be required to take the RDF to the facility, and inexistent potential for energy generation.

7. REMOVAL OF UNCERTAINTY

The methods used to remove uncertainty from the MCA assessment were:

- Facilitating **stake-holder participation** and collaborative decision-making by conducting personal interviews in Cyprus
- Using **generalised criterion functions** in PROMETHEE to describe pairwise evaluation differences
- Using a **sensitivity analysis** to assess the uncertainty in the weighting of criteria

8. SENSITIVITY ANALYSIS

A sensitivity analysis was carried out to test the robustness of the results. The sensitivity analysis was performed by modifying the weight distribution of criteria and providing **weight stability intervals**. The analysis showed:

- **Solar PV was consistently identified as the optimum** renewable technology**,** except when raising the reliability criterion weight coefficient
- **RDF co-combustion in cement kilns was consistently identified as the optimum** solid waste management method when fine-tuning the weight coefficients

9. CONCLUSIONS & RECOMMENDATIONS

- Solar energy is the favoured renewable energy source and CSP systems could become attractive for deployment with future reductions in costs
- RDF co-combustion in cement kilns is the favoured solid waste management option, but there are **technical challenges imposed on the production of a co-fuel** product to a specification
- The study could be repeated using a stochastic method by defining the uncertainty in the input data with probability distributions

REFERENCES

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- Behzadian, M., Kazemzadeh, R. B., Albadvi, A. & Aghdasi, M. (2010) PROMETHEE: A comprehensive literature review on methodologies and applications. *European Journal of Operational Research.* 200 (1), 198-215.

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