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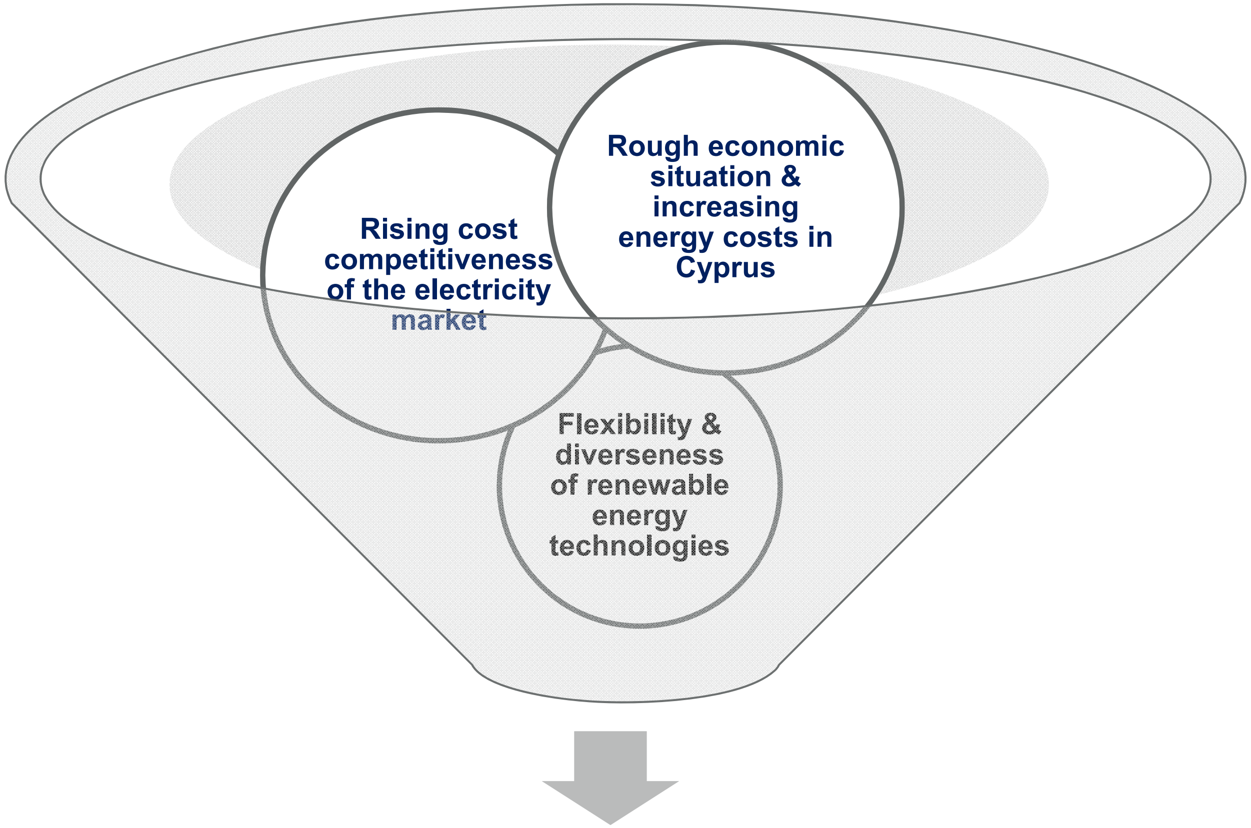
A Renewable Energy Strategy for the Republic of Cyprus and the Potential Contribution from the Solid Waste Management Sector

Motivation



Importance of harnessing renewable energy

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Motivation

Cyprus energy system

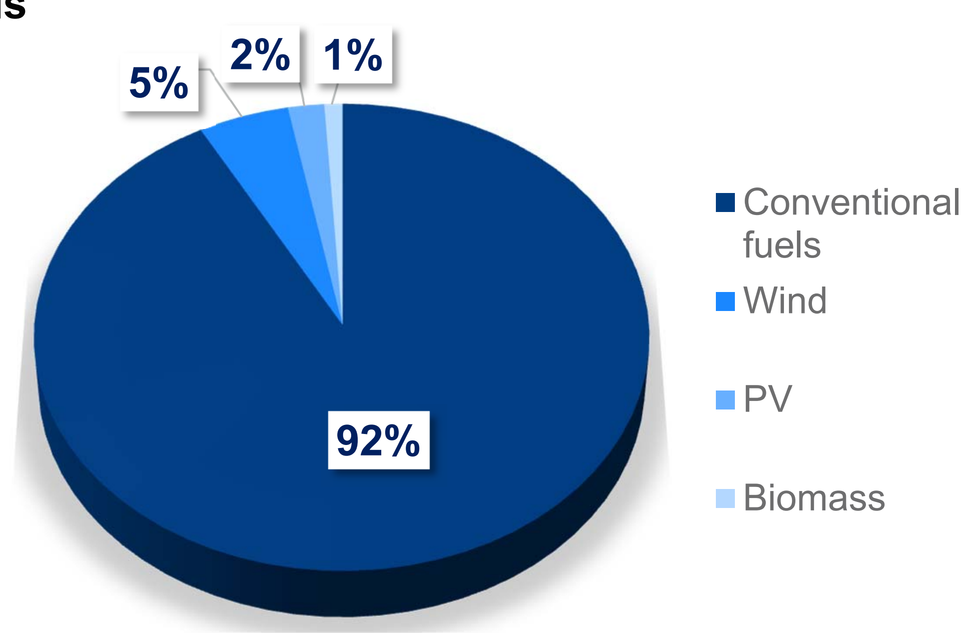
- Isolated mini-grid
- **Reliance on imported fossil-fuels**
- Diesel
- Heavy fuel oil

⇒ **High energy costs**

⇒ High specific greenhouse gas emissions

Solid Waste Sector

- Potential indigenous fuel
- One of the **highest waste generation** per capita countries in Europe



Legislation & Drivers

- Cyprus joined in 2004 as a member state of the EU
- Required to comply with targets and policies

2020 Climate & Energy Package

- 20% cut in greenhouse gas emissions
- 20% of energy produced from renewables
- 20% improvement in energy efficiency
- *All based on 1990 levels*

Renewable Energy Directive 2009/28/EC

- 20% renewable energy target translated to individual Member state targets
- Cyprus: 13% of energy supply from renewable sources
- Cyprus: 16% of electricity supply from renewables
- **Currently at 8% of electricity supply from renewables**

Landfill Directive 1999/31/EC

- Treatment required before waste sent to landfill
- Reduction targets of biodegradable waste sent to landfill from 1995 levels

Methodology

Use of Multi-Criteria Analysis (MCA) to serve the following objectives:

1. Identifying the optimum renewable energy technologies for electricity supply in the form of a ranking list, including EfW systems and assessing their importance

2. Identifying the optimum solid waste management option for energy recovery

MCA

- Used in complex decision-making processes
- Allows incorporation of conflicting criteria in incommensurable units

Methodology

1. Classification and calibration of performance criteria

2. Identification of options

3. Performance assessment (derivation of performance matrix)

4. Multi-criteria analysis (MCA)
   - Weight coefficients according to degree of significance

5. Sensitivity Analysis

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Methodology

MCA incorporates a **degree of uncertainty** and is **subjective**, as it is based on the decision-maker's preferences

Elimination of subjectivity:

1. Facilitating stakeholder participation and **collaborative decision making**

2. PROMETHEE method chosen for assessment – use of **generalised transfer functions** for pairwise evaluations of options depending on the type of criterion

3. Use of a **sensitivity analysis** to assess the subjectivity of criteria weighting

PROMETHEE-GAIA

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

$$d_j(a,b) = g_j(a) - g_j(b)$$

Step 2: Application of a preference function

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

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.

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

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

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

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

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

$$\phi(a) = \phi^+(a) - \phi^-(a)$$

Options – Renewable Energy Technologies

Solar PV

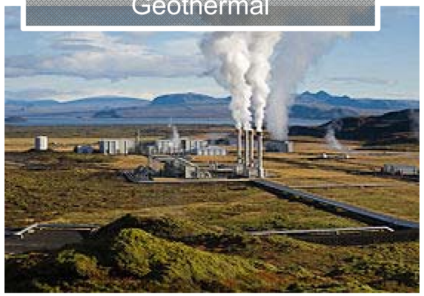
Concentrated Solar Power (CSP)

- Parabolic trough systems
- Solar tower
- Dish sterling

Wind energy

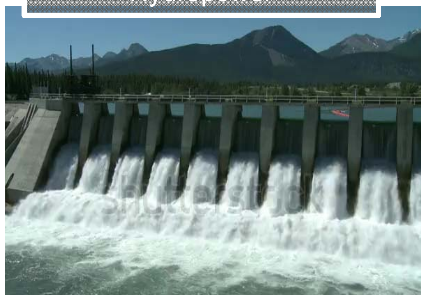
- Onshore Wind
- Offshore Wind

Geothermal

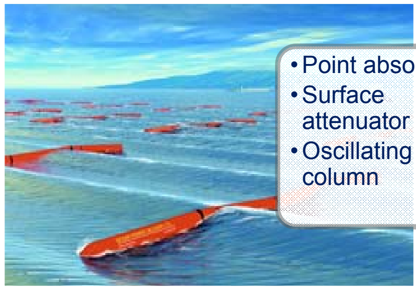


Tidal Energy

Hydropower



Wave Power



- Point absorber
- Surface attenuator
- Oscillating water column

Energy Crops

- Woody or herbaceous plants

Energy from Waste (EfW)

- Thermal technologies
- Non-thermal technologies

Options – Solid waste management methods

- Incineration
- Gasification
- Pyrolysis
- Co-combustion of Refused Derived Fuel (RDF)
  - ❑ Cement kiln
  - ❑ Power Plant

Anaerobic Digestion (AD)

- ❑ Source separated
- ❑ Mechanical Biological Treatment with AD

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Criteria Breakdown – Renewable Energy technologies

- **Economic**
  - **Levelised cost of electricity (LCOE)**
- **Environment**
  - **Greenhouse Gas (GHG) Emissions**
  - Impacts on the Ecosystem
  - Noise Impacts
  - Visual Impacts
  - **Land Requirements**
- **Technical**
  - Lifetime
  - Technology Status
  - **Reliability**
  - **Deployment Potential status**
- **Social**
  - Public perception
  - Employment potential
  - Contribution to targets & policies

Criteria Breakdown – Solid Waste Management

Economic
- **Capital costs**
- Operational costs
- **Product Marketability & Residue management**

Environment
- Carbon dioxide
- Methane
- Acid gases
- Heavy metals & organics
- Noise impacts
- Visual impacts
- Odour
- Land requirements

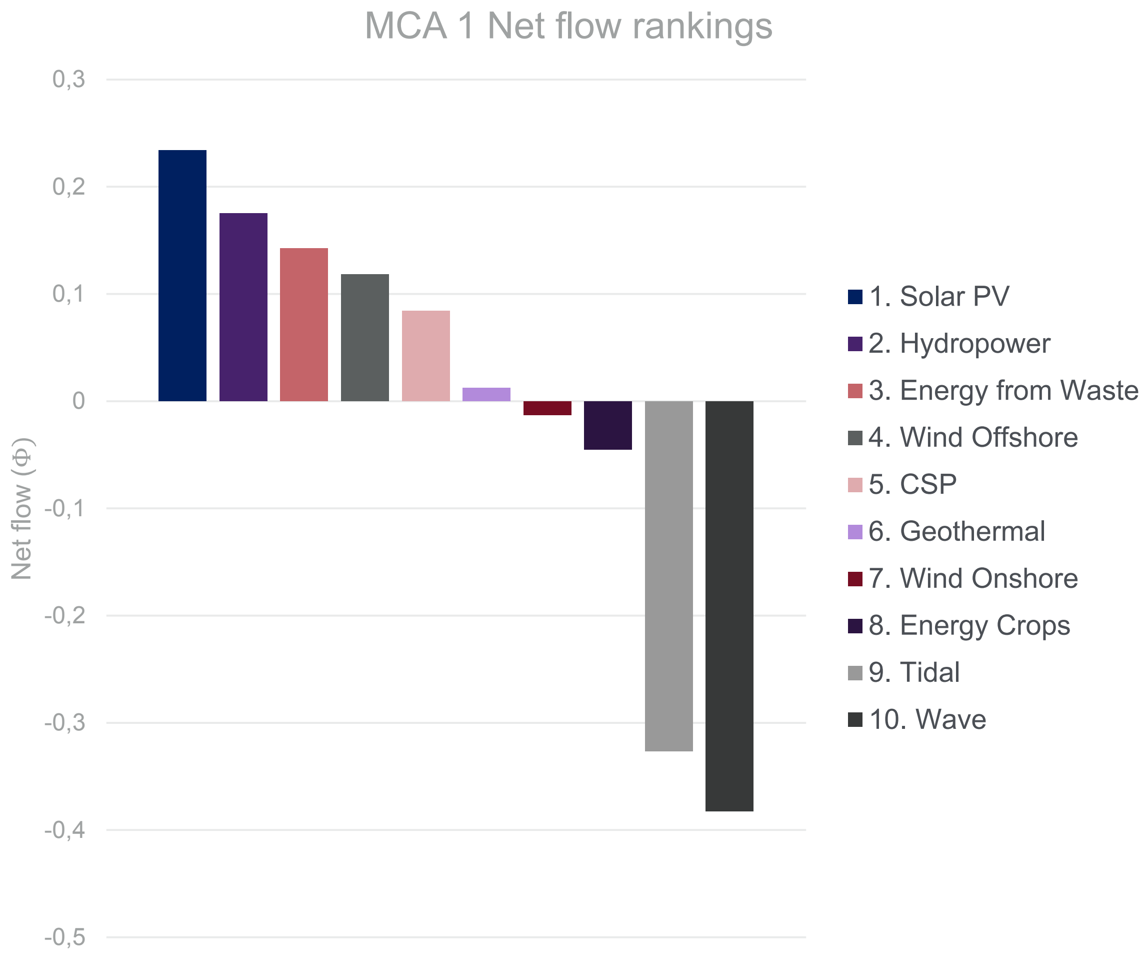
Technical
- Potential energy generation
- Technology Status
- Transport Demand
- **Flexibility of waste suitable for treatment**
- Energy requirements

Social
- Public perception
- Contribution to targets & policies

Results MCA 1 – Renewable Energy Technologies

Notes

- Solar PV ranks 1st with φ=0.234
- Hydropower ranks 2nd with φ=0.1753
- Energy from Waste ranks 3rd with φ=0.1427
- Tidal and wave power rank 9th and 10th with highly negative net flows



Discussion MCA 1 – Renewable Energy Technologies

Solar PV (1st)

PROS:

•**2nd highest irradiation potential** in Europe 1920 kWh/m2

•High social acceptance

•Good overall performance in environmental criteria

•Relatively good LCOE

CONS:

•Variable energy source ⇒ *low reliability*

EfW (3rd)

PROS:

•High contribution to targets & policies

•**High reliability of supply**

•High deployment potential status

CONS:

•Greenhouse gas emissions, land requirements

Tidal (9th) & Wave technologies (10th)

PROS:

•Lower visual and noise impacts

CONS:

•Low wave power potential & low tidal streams surrounding the island ⇒ *low deployment potential status*

•Very high capital costs

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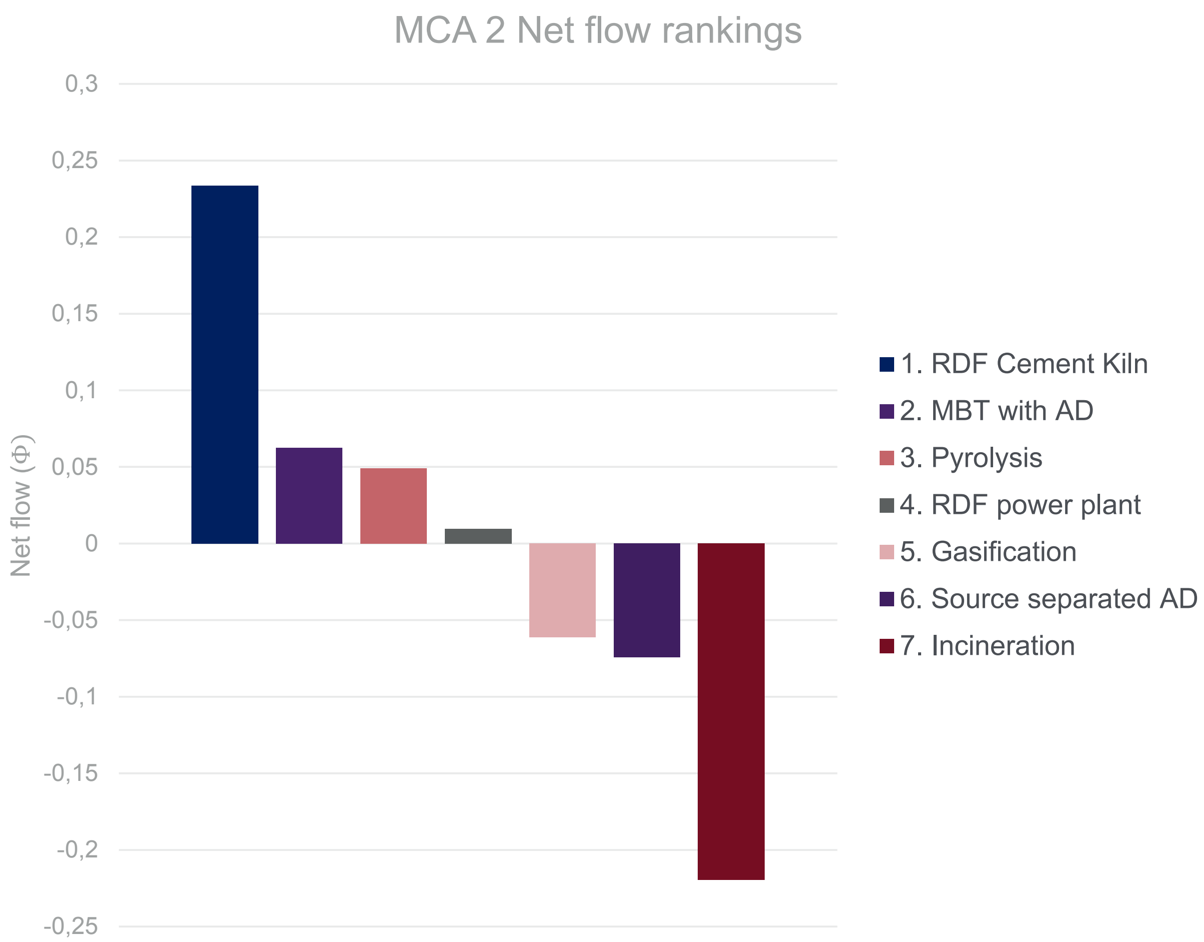
Results MCA 2 – Solid Waste Management Sector

Notes

- Co-combustion of RDF in cement kilns **ranks 1st** with φ=0.234
- MBT with AD ranks 2nd with φ=0.0624
- Incineration ranks 7th with φ= -0.2196



Discussion MCA 2 – Solid Waste Management Sector

Co-combustion of RDF in cement kilns

PROS:

•Vassiliko Cement kiln ⇒ Low capital costs & low land requirements

•High local product marketability & high export potential of cement product

•Strict environmental regulations ⇒ low pollutant emissions

CONS:

•Poor performance in technical criteria

•Technically challenging to produce co-fuel to a specification for co-combustion

•High transport demand

•Inexistent potential for electricity generation

Sensitivity Analysis

Modification of weight distribution of criteria ⇒ Weight Stability Intervals (WSI)

MCA 1 Renewable energy technologies

•Solar PV consistently the optimum during fine-tuning except when increasing the reliability criterion weight coefficient

- ↑ reliability weight coefficient ⇒ solar PV ↓, hydro ranks 1st
- ↓ LCOE weight coefficient ⇒ CSP ↑
- ↑ deployment potential ⇒ hydro ↓ and CSP ↑

MCA 2 Solid Waste Management Sector

•RDF co-combustion in cement kilns consistently identified as optimum method when fine-tuning

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Conclusion – Renewable Energy Options

Solar PV
•Solar energy is the favoured renewable energy source
•PV systems should be installed across the island

CONS: Variable Source ⇒ low reliability of supply

Concentrating Solar Power (CSP)
•CSP systems could become attractive for deployment with future reductions in levelised costs
•**Higher efficiency** than PV
•**Lower land requirements**
•Ability to store thermal fluid ⇒ ↑ **reliability**

Energy from Waste (EfW)
- Promotes the **diversion of biodegradable waste** from landfills
- High reliability of supply

Should be incorporated in the renewable energy mix

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Conclusion – Solid Waste Management Sector

Co-combustion of RDF in cement kilns
Preferable solid waste management option compared to energy recovery processes.
•Vassiliko Cement kiln ⇒ **Low capital costs** and **low land requirements.**

• Dependent on reliable technical processing to produce product to a specification ⇒ **TECHNICALLY CHALENGING** process

• **Use of an efficient biodrying reactor to produce product to a specification is required**

Recommendations

The study could be repeated using a **stochastic method**

• Defining the uncertainty in the input data with probability distributions

• Reliability-based approach ⇒ Monte Carlo simulations

• Distribution of total flows for each option will be produced according to the range of input parameters

• **The report provides a strong basis for future studies**

Thank you..

APPENDIX

3. PROMETHEE METHO

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

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

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

$$P_j(a,b) = F_j[\,d_j(a,b)] \qquad j = 1,\dots,n \qquad (2)$$

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.

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

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

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

$$\phi(a) = \phi^+(a) - \phi^-(a) \qquad (6)$$

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

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

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

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