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SOLAR ENERGY IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT

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I. Introduction

It is well known that of all the alternative energy resources in the ESCWA member states, solar energy is the most promising because of its diffuse nature and nations-wide availability. Moreover, the utilization of solar energy provides a suitable, clean, reliable, and cost-competitive energy source for many applications in these countries. Despite the fact that interest and investment in solar energy have remarkably increased in the last decade, a large proportion of the population has still not been exposed to the advantages of basic solar energy applications, and so the percentage of people using solar energy is still negligible compared to those using traditional sources of energy such as electricity, oil and gas.

The promotion of solar technologies is recognized as a national issue requiring the participation of many stakeholders and decision-makers. Additionally, the penetration of solar energy into existing energy markets is constrained by many factors such as technical and financial limitations, decision criteria, and policy instruments. In order to regard solar energy as an important element for the sustainable development of a given country, it is essential to foresee the economic and environmental advantages that will result from the applications of solar technologies. Such advantages could include electricity bill reduction to consumers, fuel bill reduction to electric utilities, introduction to more jobs on the national scale, and a cleaner environment in the whole region.

This paper will set a general framework to explore the feasibility of solar energy in the context of sustainable development. It proposes a methodology based on seven issues to be looked at while evaluating the solar energy potential in a given country. Once the investigation of these issues is done, then a general policy that encompasses local factors and constraints needs to be designed and adopted by decision makers for the purpose of ensuring a large-scale diffusion of solar energy in local energy markets. Such a policy will be developed using the Analytic Hierarchy Process technique. Throughout the paper, examples supporting the arguments presented will be extracted from the Lebanese experience.

II. First Issue: Resource Availability

When evaluating the contribution that solar energy can make to local energy needs, **the first issue** to be investigated is whether or not the solar resource is sufficient for the targeted applications. Such an issue can be resolved by carrying out long-term measurements of solar insolation in different locations as to form a solar atlas for the country under investigation.

As an example, the solar data in Lebanon have been collected for both the coastal and interior zones [1,2]. The coastal solar insolations are found from measurements made at Beirut Airport for the years 1965-1975, and at AUB for the years 1993-1999. In the interior zone, the solar insolations are obtained from measurements made at Ksara station for the years 1956-1965. Table 1 illustrates the averaged values of the total solar insolation on a horizontal surface, as well as other important data [1,2].

Table 1. Solar data for Lebanon

Month	Coastal Insolation, $KWh/m_2/day$	Interior Insolation, $KWh/m_2/day$	Coastal sunshine hours (Hrs/day)	Interior sunshine hours (Hrs/day)	Day length (Hrs)
Jan	2.4	2.4	4.6	4.5	10
Feb	3.2	3.4	5.6	5.5	10.8
Mar	4.1	4.4	6.4	6.4	11.8
Apr	5.5	5.9	7.7	8.5	12.9
May	6.6	7.2	10.1	10.5	13.8
June	7.3	8.5	11.5	13.1	14.2
July	7.0	8.4	11.4	13.2	14
Aug	6.3	7.7	10.6	12.4	13.2
Sep	5.3	6.5	10.4	11.2	12.1
Oct	4	4.7	8.1	9	11
Nov	2.9	3.3	6.4	6.7	10.2
Dec	2.3	2.4	5	4.8	9.8

III. Second Issue: Contribution of Solar Energy To Energy Needs.

The second issue to be tackled is whether or not solar energy can contribute to the energy needs of one or several sectors of the economy. This requires a micro-economic analysis on the level of residential, commercial, public, agricultural and industrial sectors. The core of such an analysis is to find out whether some applications that are currently satisfied by non-solar resources such as electricity, oil or gas can be partially or fully satisfied by solar energy. In the case of a positive answer, it is important to find out the net benefits that will result from such a move on both the customer and national levels.

For example, the residential and commercial sectors in Lebanon consumed 30% of the final energy consumption. The most consuming equipment are electric heaters, and electric domestic hot water systems. To find out the contribution of solar energy in water heating, an analysis was made based on the energy consumption of a typical Lebanese household of five people situated in Mount Lebanon at approximately 700 meters above the sea level. The measurements of both total electricity demand and electric boiler consumption showed that the average consumption is around 40 liters of hot water per person per day, and that the percentage of electric water heater (EWH) consumption to total household

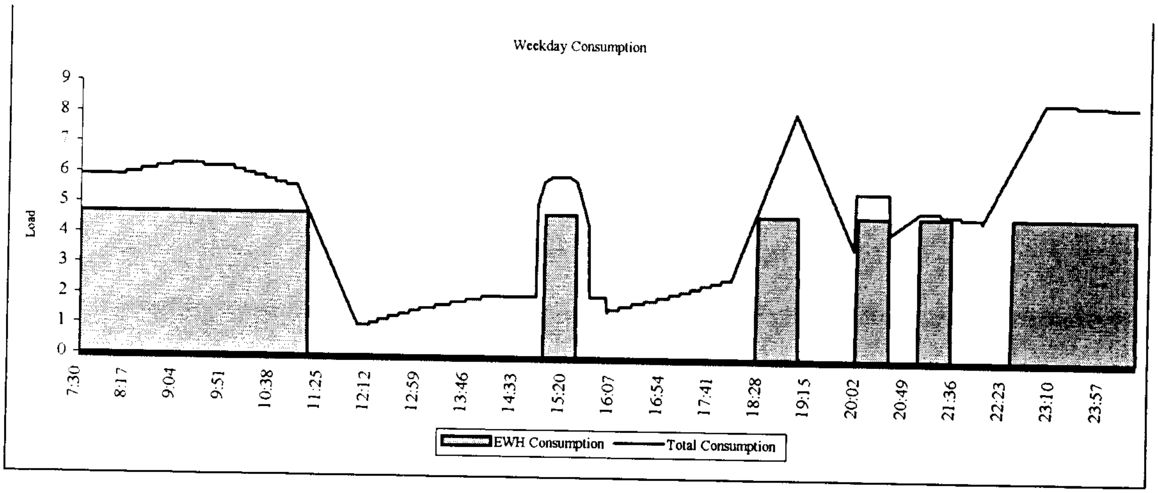

Fig. 1 Week day household electric energy consumption

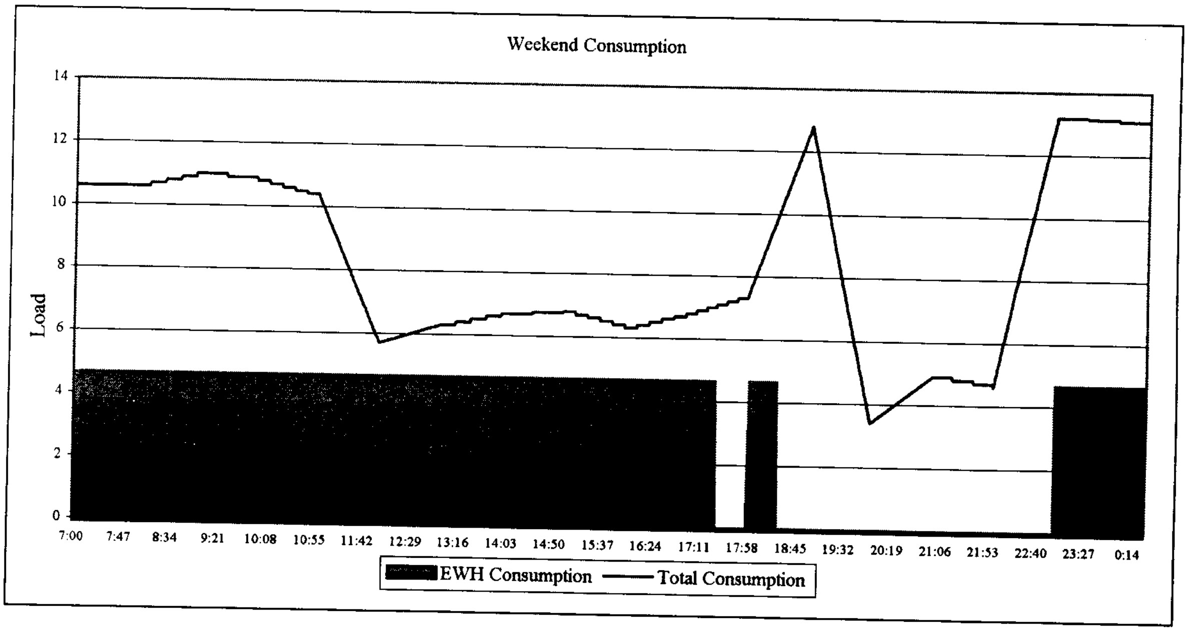

Fig. 2 Week end household electric energy consumption

electricity consumption is around 35% over a year. Additionally, two different consumption trends have been recorded. These are the weekdays consumption and weekends consumption. The following graphs summarize the consumption of both weekdays and weekends in the Spring season of 1999.

The curves in Fig. 3 show the available solar energy received by a standard solar collector suitable for a family of five people, the energy required to maintain the water tank at a minimum temperature of 60 C year round, and the back-up energy required. As the figure shows, solar water heaters (SWH) can cover the demand totally over seven months of the year and partially over the rest of the year. This

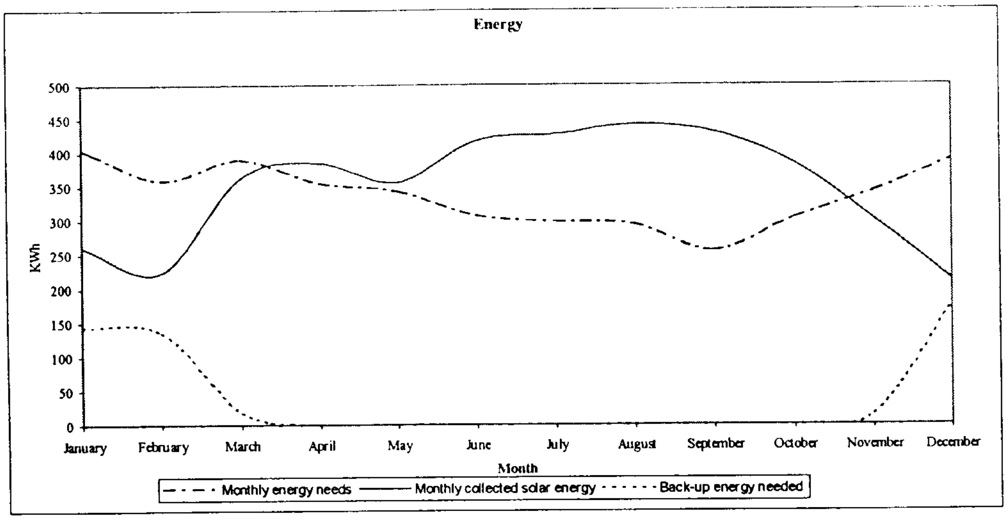

Fig. 3 Requirements and availability of energy for water heating of a single household

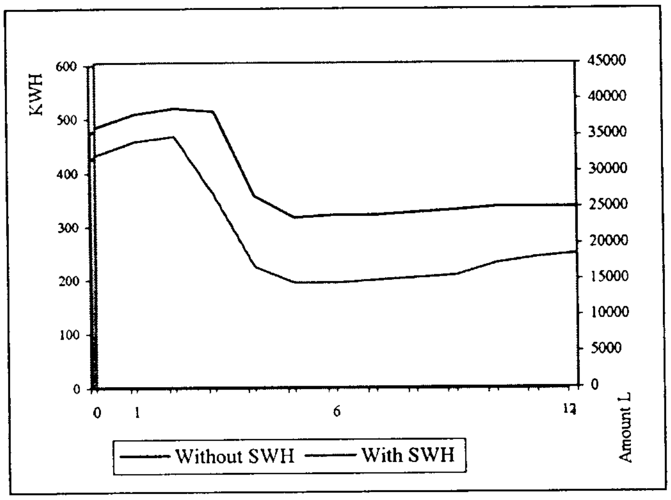

Fig. 4 Energy and bill for a household with and without SWH

demonstrates that SWH with a back-up electric resistance, for example, can successfully replace the EWH in Lebanon.

On the financial level, Fig. 4 gives a comparison of both electric energy consumption and electricity bill for two similar households of married couples with no children. The first couple uses SWH and the second uses an electric boiler, and both families acquire the same electric equipment and have a similar living standard. As can be seen, a reduction in electricity bill of around 23% can be achieved. Certainly, more savings will be attained as the number of family members increases.

IV. Third Issue: Evaluation of Long-Term Benefits and Associated Costs

The third issue to be considered is the effect of long term consideration of solar energy in energy planning in general, and in the plans for electricity generation in particular. In such analyses, all the long-term benefits should be highlighted together with their associated costs.

For instance, it will not be sufficient to state that the consideration of solar energy in the electricity generation plans will result in so much reduction in greenhouse gases, but it will be also of interest to calculate the cost of one ton of, say, CO_2 saved. It is, therefore, both the environmental benefits and the economic benefits of a given mitigation option which will drive decision makers selection of a given technology or measure. For example, in a GEF sponsored project in Lebanon on Climate Change [3,4], both the electricity supply sector and the electric energy demand in the residential and commercial sectors were studied for the period 1994-2040. The following scenarios were considered:

1. Baseline with no solar energy
2. Mitigation scenarios adopting solar thermal and wind energy generating units for partial contribution to the electricity supply sector, and
3. SWH systems for the residential and commercial sectors to replace electric boilers

The baseline scenario provided all the necessary information on activities that took place since 1994 (base line year) as well as the most likely developments that are planned for the future. Two plans have been distinguished:

- A short term plan extending from 1994 till 2005.
- A long term plan extending from 2005 till 2040.

All projections for future energy generation, demand increase and possible government actions have been made after consultation with officials from the Lebanese electric utility (EDL) [3] and in conformity with EDL published business plan for the years 1996-2002. Two scenarios are suggested to accommodate possible demand increase for the years 2005-2040. These are 3% (low growth), and 5% (high growth). As for the years 1994-2004 the demand increase was made to follow the historical trend of decaying from 10% in 1994 to 3% in 2004.

Since renewable energy is unlikely to significantly penetrate the market in the near future, it was assumed that only 5% of the generated capacity can be satisfied by renewable energy until the year 2010 and that 10% penetration can be maintained between 2010 and 2040. Additionally, the mitigation scenarios were developed under three categories:

- All solar
- 50% solar, 50% wind
- 70% solar, 30% wind

The total CO_2 emissions associated with every scenario have been calculated and are summarized in Table 2. As can be seen, from emissions point of view, the best policy is to exploit solar energy fully, where for a demand growth of 4%, the emission reduction is about 4% as compared with the baseline scenario. However, the cost of such a mitigation policy would be about US$33 per Ton of CO_2 saved. Therefore, due to their environmental benefits, the promotion of renewable energy technologies is recommended and should be given priority only when these technologies become economically competitive.

Table. 2. Total CO_2 emissions as compared with baseline scenario

Years	1994-2004	
Scenario	Demand growth➔	4%
Baseline	39644	741450
Ren. (All Solar)	39644	711498
Ren.(50%S-50%W)	39644	719886
Ren.(70%S-30%W)	39644	716538

As for the replacement of electric boilers by SWH in the residential and commercial sectors, different reasonable penetration rates of equipment have been assumed as we approach the year 2040 to reflect maturity of technology, expected reduction of prices, expected improvement of efficiency, and public acceptance.

By comparing the results of adopting SWH with those obtained from the business-as-usual scenario, it was concluded that a reduction in CO_2 emission of 6.98 million tons by the year 2040 can be expected from such a mitigation scenario [3]. The cost of mitigating one Ton of CO_2 based on the use of SWH was found to be US$-38.8, where the negative sign indicates that the adoption of SWH constitutes a win-win scenario for Lebanon [3].

V. Issues Related to Current Practices and Future Steps

Several questions concerning the status of renewable energy should be asked while evaluating solar energy potential in a given country. Model questions include the following: Do renewable energy systems in general and solar energy in particular constitute a priority for the energy authority?. Are there enough institutions and coordination among the institutions as to bring the issue of solar energy to focus? Are there any efforts made by the government, the national electric utility, the private sector, the NGOs and the educational and research centers in order to promote the use of solar energy technologies?. Is there any role for the international and donor agencies that can be activated?. Have the barriers hindering the wide diffusion of solar energy been identified?, and if yes, who is working on their removal?.

Therefore, **Issues 4 to 6** relate to investigations that aim at scrutinizing the current practices of promoting and/or developing renewable energy and recommending the appropriate steps for future improvement. Namely, **the fourth issue** is to analyze the institutional framework (if any) under which activities in renewable energy are carried out, and suggest appropriate improvements. An appropriate situation is when there is an energy ministry with an office taking care of renewable energy development.

The fifth issue is to study the ongoing/planned efforts for developing renewable energy. For instance are the following being pursued:

1. **Resource Assessment.** Meaurements and continuous database updating.

2. **Research and Development .** Who is carrying out research in renewable energy?. Who is financing this research and who is defining the research areas?.

3. **Field Experience.** Has there been any significant penetration of solar energy applications to yield enough skilled personnel to operate and maintain solar energy systems?.

4. **Education and Training.** Are courses on renewable energy being taught at local technical schools and universities?. Is there any national program to train engineers and technicians on solar systems?.

The sixth issue is to examine the ongoing coordination and cooperation programs with regional and international organizations as to try to benefit from the grants that organizations such as GEF, UNDP, UNFCCC normally offer to encourage the use of solar energy.

VI. Seventh Issue: Policy Development for a Significant Penetration of Solar Energy in Local Energy Markets

The seventh issue to be addressed is that once decision makers are convinced that solar energy can make significant contributions to the local energy needs, what is the best policy to be adopted in order to achieve a significant penetration of solar technology in the local energy market. For this, it is important to identify all the factors influencing this goal, whether technical, political, economical or may be social. A hierarchical structure of the system is, then, built descending from the main goal, down to the constraints, and then down to the policies affecting the constraints, and finally to the outcomes which represent the objectives. The various divergencies of opinions and influencing factors are identified, weighted and, accordingly, the objectives are assigned a priority order. The hierarchical structure suggested for this work is shown in Fig.5 [5]. As seen, level 2 includes the beneficiaries or major players. These are the government, the electric utility, the private sector and the consumers at large. Level 3 indicates the decision criteria which drive the decision to why should solar energy be promoted.

In the Lebanese case, decision criteria include financial viability, enhancement of national economy, social equity and environmental quality. The financial viability is judged upon based on availability of sources of financing, prices and competitiveness. The social equity is measured based on distribution of income, social prices, geographical distribution of energy supply and rural electrification. Environmental considerations include clean environment, harmless technologies, emissions standards, and renewable resources.

Level 4 includes the constraints that may prohibit the achievement of the main goal. Lack of resources, funding and immaturity of technology form the basic obstacles in the development of solar energy, whereas public acceptance and marketability are people dependant. Finally, Level 5 includes the policy instruments that highly influence the constraints. The provision of appropriate regulations and/or incentives (INC) from the government may encourage, say, the use of SWH as part of a plan that aims at a cleaner environment. Economic instruments (EI) such as "Build Operate Transfer" (BOT) or "Build Own Operate" (BOO) could also influence the different constraints, while the privatization (PRIV) of the electricity sector is an important factor for a fast market penetration of new designs and technologies especially that the main aim behind privatization is alleviation of electric utility debt. In order to decide on the various strategies that are built in this hierarchical structure and their mutual dependence, the Analytic Hierarchy Process (AHP) is used. A brief theoretical discussion on this technique is given in the Appendix [5,6].

A summary of the results obtained from the analysis of Fig. 5 is given in Table 3. The eigenvector of the constraints clearly indicates that consumer interests (CI) are the first in order of priority followed by the interests of public sector developers (PSD), government interest (GOV), and energy utilities (EU). The eigenvalues of level 3 (decision criteria) clearly indicate the priority of ensuring financial viability (FV) followed by social equity (SE), environmental quality (EQ) and economic efficiency (EE). The eigenvalues of level 4 (constraints) show that marketability (MC) ranks first followed by inadequacy of funding (IF), public acceptance, immaturity of technology and finally lack of resources. As for the final result of the analysis which ranks the policy instruments to be adopted by the decision makers, the eigenvector indicates that the provision of incentives and appropriate regulations (Inc) for customers is ranked first, the privatization of the electricity market (PRIV) will give an impetus of second importance after incentives, and the setting of appropriate economic instruments (EI) favoring solar energy development is of third importance. The hierarchical elements that were ranked first in all levels of the hierarchy are identified in Fig. 5 by a hashed background.

As can be seen, based on an analysis of this kind, the decision makers can be guided to their goals in a methodological manner that takes into consideration the various opinions of major stakeholders in the field of renewable energy.

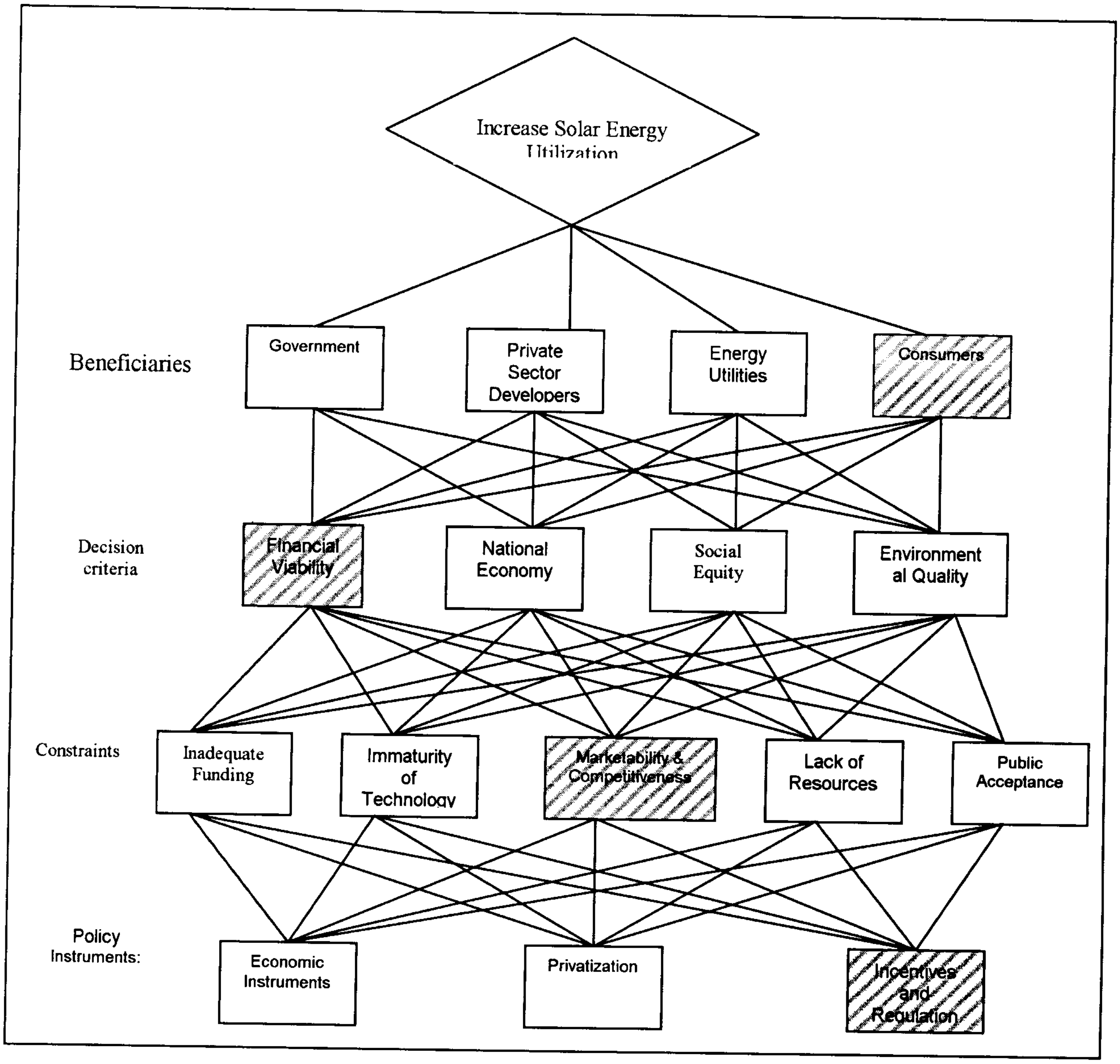

Fig. 5. Hierarchical structure for the SWH policy setting problem for Lebanon

Table 3. Composite priorities for levels 2, 3 ,4 and 5.

Level 2		Level 3		Level 4		Level 5	
GOV	0.1057	FV	0.38	IF	0.2616	EI	0.183
PSD	0.305	NE	0.13	IT	0.15	PRIV	0.387
EU	0.061	SE	0.327	MC	0.29	INC	0.429
CONS	0.5283	EQ	0.1623	LR	0.1317		
				PA	0.167		

VII. Conclusion

This paper has presented a general framework to evaluate solar energy as an element in a sustainable development policy for a given country. It has been indicated that it is essential to foresee the economic and environmental advantages that may result from the application of solar technologies in a given society because such benefits drive decision makers selection of a given technology, or a given policy measure.

The paper pointed out that the promotion of solar energy is a national issue requiring the participation of many stakeholders and decision makers, and that the penetration of solar energy into existing energy markets is constrained by many factors including technical and financial limitations, decision criteria, and policy instruments. The Analytic Hierarchy Process technique has been suggested as a tool to help decision makers develop a policy to ensure a significant contribution of solar energy to local energy needs. Throughout the paper, examples extracted from the Lebanese case have been used to support the proposed seven issues that need to be looked at while investigating the potential of solar energy in a given country.

VIII. Acknowledgement

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Appendix

Decision Analysis Using the Analytic Hierarchy Process [5,6]

The Analytic Hierarchy Process is a top-down structuring of a decision problem in a hierarchical fashion with the overall goal at the top followed by intermediate levels and the lowest level usually containing the set of options needed to attain the main goal [6]. There is no standard procedure for generating the objectives, criteria and activities to be included in the hierarchy. These are essentially determined by the way we choose to decompose the complexity of the system of interest. Such a process is interactive, involving brainstorming, evaluation, debate, as well as legal, political and social considerations. The aim of the analysis is to study the interaction among all the influencing parameters described in the Hierarchy of Fig. 5, and make recommendation on the best policy that should be encouraged or adopted by decision makers in order to ensure active penetration of solar energy into a given country.

Each element in a hierarchy level serves as a criterion to the elements in the level above. Pair-wise comparisons among elements in each level are made with respect to each element in the level above resulting in a set of judgmental matrices. Thus, the relative importance of the i^{th} factor over the j^{th} factor in a level is denoted by aij while the importance of the j^{th} factor over the i^{th} factor is denoted by 1/aij as shown in the matrix below [5, 6].

$$A = \begin{vmatrix} 1 & a_{12} & \ldots & a_{1n} \\ 1/a_{12} & 1 & \ldots & a_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ 1/a_{1n} & \ldots & \ldots & 1 \end{vmatrix}$$

The judgmental matrices corresponding to each level of Fig.1 are generated after consultation with electric utility personnel, design offices and private consultants, university professors and ordinary citizens using the scale of relative importance for ranking one factor over the other recommended in [6].

A local priority vector can now be generated by normalizing the principal eigenvector W of the matrix A:

$$[A]\ W = \lambda max\ W$$

where $\Sigma wi=1$ and λmax is the principal or largest eigenvalue value composed of positive real values. The priority vector ranks the variables in order of importance depending on the pair-wise comparisons. Such a priority vector with respect to the top level can be computed for any decision hierarchy by combining the priority vectors for each level. The priority vectors in each level are combined with the net priority vector of levels below in order to arrive at a global priority vector. This final priority vector represents the decision maker's scaling of the alternatives with all things considered. Details about both the priority vector calculation and the consistency of judgment can be found in [5, 6].