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TECHNICAL REPORT

RENEWABLE ENERGY FOR SUSTAINABLE RURAL LIVELIHOODS

2004-2006

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EXECUTIVE SUMMARY

The project works towards the implementation of clean and sustainable energy technology for poverty reduction and environmental protection in remote rural areas. The Renewable Energy for Sustainable Rural Livelihoods (RESURL) project's aims were to enhance understanding of the relationship between access to energy and the pursuit of sustainable livelihoods, to assess existing energy technology provision, to discover actual benefits to users of current energy technology systems in remote rural areas of developing countries, and to develop methodologies to assist in the promotion of appropriate and effective clean energy solutions for poverty reduction. The project took place in two phases, from August 2001 to July 2004; and from August 2004 to March 2006. The work undertaken between 2001 and 2004 designated RESURL I, constitutes a complete body of research and outputs. These outputs can be found under heading Technical Report on:
http://www.env.ic.ac.uk/research/epmg/RESURLWEBPAGE.htm

The current Technical Report focuses on the second phase of RESURL, RESURL II. RESURL II has built-up on the knowledge and methods developed during the first phase to tackle issues of technical and non-technical barriers to promote future sustainable livelihoods in remote rural areas. RESURL II aimed to scale up and complete an analytical system of energy development for such livelihoods. The project also sought to design training materials for local users of modern energy technology, and to acquire knowledge of the wider political and economic factors that may be hindering access to sustainable electricity by the poor.

One reason behind the development of this study was evidence that electricity by the poor had fallen short of expectations. To address this problem required access to and uptake of detailed research into the state of the installations in rural regions once they were functional, otherwise, any future renewable energy technology developments in these areas would also be likely to fail. RESURL II has established that a large part of the present failure is due to the unrealistic assessment of local conditions, prior to installation. RESURL II also concluded that it is important that any decision-making tools for future energy development for the poor should target livelihoods as a comprehensive concept, and should integrate the energy priorities of prospective users.

The project's remit of poverty eradication is in line with the Millennium Development Goals (MDG) and corresponds with the key commitments of the 2002 Earth Summit at Johannesburg to promote renewable energy and improve access to affordable and environmentally sound energy services to achieve the MDG. RESURL II in directly addressing this vital aspect of local infrastructure development has revealed that there is considerable potential for poverty reduction through the promotion of sustainable energy in remote areas. To do so, the project defined useful criteria and combined indicators by undertaking an in-depth assessment and implementing significant improvements to the devices created during RESURL I, producing an innovative decision-making method *SURE*: Sustainable Rural Energy. Decision-Support System. This is a completed computer program that uses multi-criteria methodology to model technical and non-technical components of rural energy development. The project has started the process of modelling its outputs for prospective users.

The project has achieved both methodological and theoretical results as well as succeeding in engaging the interest of experts and stakeholders in developing countries to pilot applications of the model in remote rural areas. RESURL II has produced a multi-criteria tool for energy development capable of assisting the poorest groups among the 2 billion without electricity and those inappropriately supplied worldwide. As a further contribution to realise the potential for renewable energy technology to improve livelihoods, the current project designed training and maintenance guide for users and decision-makers in rural areas. This was in the form of an illustrated leaflet containing information on economic applications, technical skills and environmental data, all in relation to renewable energy technologies used in rural areas. RESURL II has also compiled data on the effects of the electricity market reform of the 1990s in developing countries. There were considerable grounds to believe that electricity liberalisation might well be relevant to the extent of access and quality of energy supply to the poor, including renewable and sustainable energy services. See Annex I for the general outputs of the project.

During RESURL II, ideas, concepts and tools that emerged from the project were relayed to students and researchers. New fields of study have been developed in universities. MSc theses on the subject were produced at Imperial College, but importantly, two postgraduate dissertations have now been completed at the National University of Colombia, and a further one is in process at the University Las Villas, Cuba

RESURL II built on a partnership with the GEPROP (Priority Scientific Programmes Management) of the Cuban Ministry of Science, Technology and Environment; the Central University of Las Villas, Cuba; the National University of Colombia, at Medellín; the international NGO Solutions for Poverty (formerly Intermediate Technology Development Group (ITDG), at Lima and Cajamarca, Peru; and a specialist consultant from the regional programme Sahel (PREDAS-CILSS), under the leadership of the Centre for Energy Policy and Technology at Imperial College London.

The way forward

To promote energy technology that will prove sustainable in the long term and contribute to the improvement of the lives of the rural poor, appropriate assessment and evaluation tools are essential. Experience has taught us that existing decision-making tools that are dominated by technical factors have neither the flexibility nor the capability to provide prospective energy consumers with solutions that may meet their energy priorities.

The SURE decision-support system model for future energy development is a step forward in this direction. RESURL has shown that the application of the Sustainable Livelihoods approach to rural energy development enables energy interventions to be addressed in a more comprehensive manner. However, hitherto the SL has been insufficiently involved in energy provision analysis.

The RESURL project, and particularly its Decision-Support System, has been selected to join those scientific research programmes which the Ministry of Science, Technology and Environment of Cuba would like to prioritise for development. This is thanks to the acknowledged relevance of the project's multi-criteria approach and the practical tool designed by its participants which puts in place a useful framework to assist rural energy development. The adoption of the methodological tool SURE among the research and development priorities of a nation is definitely a most rewarding outcome for the work undertaken in this research project. Moreover, it presents real challenges on how best both to scale up the system programme, particularly its economic dimension, to improve its usefulness and applicability; and on how to build guidelines for policy-making and government to increase the system's take up by regional experts and stakeholders.

Overall, the experience of the project in this second phase have been gratifying and rewarding both academically and practically for all participants. Certainly the lessons learned will be applied in future research.

Furthermore, the project has naturally expanded in Colombia into related and novel areas. RESURL has generated a whole set of new interests surrounding the original questions raised by the project. The outcome has been the emergence of new research projects in subjects related to technology management, human and social capital, rural policy and the evaluation of the social return to energy development. The Colombian Institute for the Development of Science and Technology (COLCIENCIAS) has shown particular interest and has partially contributed to the realisation of a new project on these themes. This line of research needs to be continued. The project has started to develop sought-after capacities that will enable the incorporation of people involved in the project into policy-making and the labour market.

Chapter 1
INTRODUCTION

This Technical Report provides a summary of the results of the RESURL II research project. The main thrust of the study, undertaken between August 2004 and March 2006, examine, improve and consolidate the assessment methods designed by RESURL I with the purpose of evaluating barriers and opportunities to identify the status of installed energy machinery and undertaking construction of an analytical system that could model future rural energy decision-making for poverty reduction and sustainability. A large proportion of the team's research efforts in RESURL II was geared to making a more accurate and reliable analytical tool of the original decision-making system MUCSY-RE the so called ***SURE,*** **Sustainable Rural Energy. A Decision-Support System** (see Cherni, Chapter …., 2004). The latter became a fully developed multi-criteria computer program capable of modelling both technical and non-technical aspects of energy development. Another important target during the second phase has been to advance capacity-building in two directions: first, by offering more practical information to modern energy technology users in rural areas; and second, by expanding the RESURL presence among academics in the field. Finally, dissemination of the ideas behind RESURL, as well as exploration of the wider political and economic processes of electricity reforms in developing countries are two new aspects addressed by RESURL.

The report is structured as follows. Chapter 1 starts by giving an overview of the findings of RESURL I; these represent the antecedents to the RESURL II project. The main activities undertaken during this period are then described and venues highlighted that were used for disseminating the main outputs and transferring conceptual frameworks.

Chapter 2 focuses on the theoretical and practical aspects of the rural energy decision-support model SURE and explains how the model evolved into its current form. Chapter 3 looks into information delivery to technology users to encourage the long-term sustainability of clean and modular energy systems. The as yet unfulfilled potential of modern energy technology to deliver useful services is also covered.

Chapter 4 moves away from the practical dimensions of community and regional aspects of the problem of energy supply for sustainable rural livelihoods and steps into the theoretical field of the electricity liberalisation process and its effects on the poor. The chapter aim is to present information that contributes to an understanding of the current state of the extension of the electricity supply to rural areas and the promotion of renewable energy technologies. Finally, Chapter 5 reflects on issues raised by the research. In particular it highlights the importance of moving the project forward in the light both of the decision by Cuban policy-makers and scientific advisors to include one of our main outputs, the SURE decision-support model, within their national priority research programmes and to pilot it in a number of provinces; and of the support given by the Colombian National Counsel of Science to upgrading the system program.

1.2 Paving the way for RESURL II

From its inception in 2001, RESURL has produced original information and analyses on some of the poorest groups that constitute the 2 billion people without electricity and those inappropriately supplied world-wide. The project has made important inroads into an area of study that has the potential to contribute significantly to poverty reduction in Latin America and the Caribbean. The paragraphs below summarise RESURL I's findings, which are directly related to the rationale behind the work carried out by RESURL II.

I. A most important finding, and one that has been confirmed increasingly over time, is that knowledge from scientific sources as well as that gathered from participatory studies is no longer an optional requirement for sustainable and effective energy provision if poverty reduction and environmental protection are to be achieved in developing countries. In fact, the provision of systematically acquired information from different sources is vital to improve the chances of success of installed or to-be-installed energy technology in poor areas. The Decision-Support System designed and completed during RESURL II aimed to develop a multidisciplinary approach in order to address technical and non-technical dimensions of energy development as the most appropriate way to promote poverty reduction and sustainability through energy provision. This study aims to contribute to a policy area with the potential to reduce worldwide poverty. Swift agreement and uptake by governments and others to expand off-grid solutions to provide energy to rural areas have not been a guarantee of success. Progress in planning and development of rural energy assessment methods remains slower than decision-taking and actual expansion

II. Energy supply, particularly from renewable technology, is an important modern driving force for improving living conditions in rural areas. Sustainable development is a concept that regional policy-makers and key actors are starting to incorporate into their political lexicon. It brings a ray of hope to local poverty reduction, and prompts visions of how sustainable development might be. This may also bring a sense of connection for hitherto socially excluded and geographically isolated communities engaging them in global efforts to protect the environment. It was thought that 'sustainable livelihoods' (SL) is a more practical framework for the type of objectives set by the project. Energy provision is necessary to improve the collective well-being, e.g., for clinics and schools, to enable individual households to access basic services, water pumping, lighting and radio, and to promote economic production, e.g., coffee bean-drying. RESURL II aimed to establish novel links between SL as an analytical framework and energy services.

III. In order to improve livelihoods it is not sufficient to install modern energy equipment in poor areas. Malfunctioning, non-operational (in the case of photovoltaics) or technology unable to generate sufficient power to meet demand (e.g., due to micro-hydro intermittency in Manantiales, Cuba, see Cherni, 2004) reduces or even cancels out the benefits that people expect from the systems. Many users in the remote surveyed areas of Colombia, Cuba and Peru (during 2002-2003) only benefited for a short time because the energy schemes had been poorly planned. The reasons for current failure were lack of local technical capacity for maintenance, defective equipment when bought, and high equipment repayment costs. In addition, excess electricity generated was not being advantageously used. RESURL II aimed to supplement the content of the User's Guide, which emerged from phase 1 to provide practical guidance on maintenance and operation, and on environmental impact, in order to enlighten users as to the possible economic applications of the systems.

IV. Indications emerged of potential conflicts between local, regional and national government in relation to tariffs and repayments, responsibility for the equipment and micro-hydro plants, and the potential for revenue where excess electricity could be produced. The privatisation of the energy sector in the non-centralised economies emerged as a shadowy element that may or may not dictate the future characteristics of the administration of existing services. RESURL II aimed to present literature on the effect of electricity liberalisation and privatisation on the poor.

V. In general, farmers knew little about the relative advantages and disadvantages of different clean technologies for generating electricity even when they were given solar panels. Energy, however, is a high priority in most cases even when other necessities, such as roads and potable water, emerged as more urgent priorities. Barriers to and opportunities for effective energy access and sustainable livelihoods in poor rural areas are played out in various ways. For example, equipment must be of good quality in order to last. It is important to know how to operate it and also to have the finances to maintain it or to buy replacement parts. Importantly, policy should support every effort made by users of renewable systems in order to maximise their chances of success. Furthermore, access to electricity even for a short time meant that people wanted to keep the system. RESURL II brought the project's output, particularly the Decision-Support System, to the notice of policy decision-makers and stakeholders in Colombia and Cuba.

VI. The project has been of significant benefit to the collaborators and their institutions by improving their capacity, in some cases significantly, to assess the state of rural energy development by new methods as part of the national interest in promoting sustainable development in rural poor areas. Moreover, it has familiarised the teams with the practicalities of sustainable livelihoods and these have now been incorporated as concepts within their academic and developmental practice. RESURL II intended to transfer knowledge to collaborators in the operation of the new program system. It also aimed to increase its areas of influence by supervising students, delivering presentations and writing up results.

1.3. RESURL II

The approach

This process starts with scaling up previous outputs. The provision of expertise and the opportunities for learning were stimulated by RESURL. Sharing the insights and analyses on poverty reduction, energy technology and sustainability within the English-speaking world through journal submissions, conferences, PhD work, MSc theses and academic visits has now started in a number of countries

Additionally, the project has established an international network of links with government, academics and implementing organisations that work on behalf of the poor and the environment. Furthermore, the project has contributed to creating expertise in this area through capacity building within the team in the different partner countries and extending it to students on MSc and PhD programmes. The capacity building of information networks local authorities and communities through various initiatives, such as workshops and the distribution of capacity guide, among others.
Among the academic and research community, RESURL has established a reputation for innovative and high level research in an area that has hitherto not been fully addressed. The publication of papers in journals as well as contributions to international conferences have helped to build this reputation and forge links with researchers in related fields.

Methodology

RESURL II undertook desk-based research, ran computer trials and interviewed policy-makers.

The desk-based research was conducted in two main areas. On one research front the work was geared to formulate appropriate mathematical equations and to define indicators to build up the Multi-criteria Decision-Support model (DSS) and the design of the corresponding software. On the other, a literature review was undertaken to garner information on electricity market liberalisation policies and their effect on the poor. Such information was intended to dictate the projects approach and to be a preparatory to new research proposals on the issue.

A further method for advancing the quality and completion of the assessment and decision methodology designed by RESURL II was to run the software program. In order to test it, identify process, look for errors and improve the model, numerous trials were undertaken. Experts who had not been directly involved from the outset were now consulted (i.e., Berc Rustem, Head of the Mathematics Department at Imperial College and Dr Smail Khennas, Engineer Economist Consultant for RESURL) and contributed very valuable insights. Additionally, the computer model was simultaneously scrutinised by IT experts, particularly in Cuba and Colombia. These steps were part of a joint effort to generate an end product fully applicable in the collaborating countries to the promotion of sustainable rural electrification. This last step also required a reformulation of equations used in the MCD and selected indicators. The reformulation of the equations followed a mathematical logic based on MCD theory in which some team members are expert, The program was premised on both, hypothetical information about a community and real data obtained from RESURL I to test the programme.

Following on from the work of RESURL I were the interviews of policy makers. In November 2004 interviews were conducted at the Cuban Ministry of Science and Technology and these proved to be highly relevant to the Decision-Support Model and for establishing a framework for assessing energy policy in a country without electricity market liberalisation.

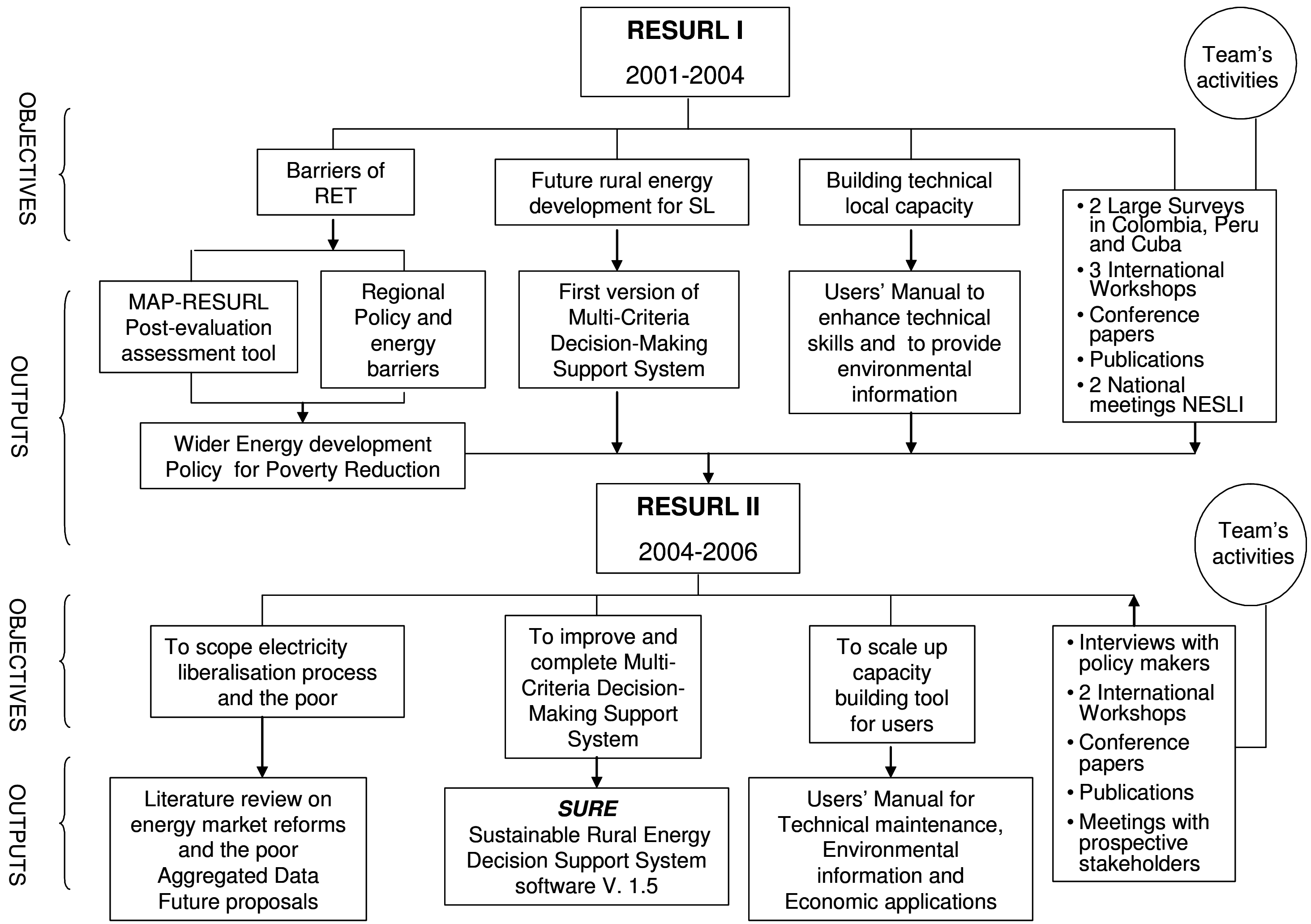
During every stage of RESURL II team members participated according to their particular experience and area of expertise. The multidisciplinary nature of the team was instrumental in fulfilling the project's objectives; this was particularly evident not only while carrying on the various tasks but primarily in the attendance at workshops where experiences and results were shared among the team.

Main Achievements

Over the past five years, RESURL has achieved a range of outputs:

- A fully operational Decision-Support System (*SURE)* consisting of original criteria for information and analysis has been designed to assist rural energy decision-making and has produced new software that employs a multi-criteria methodology.
- A connection between energy provision to the poor and the Sustainable Livelihoods approach in remote rural area has been established.
- A methodological package (MAP-RESURL) produced and tested in Colombia, Cuba and Peru to evaluate the performance and effectiveness of stand-alone modern energy technology has been installed in remote rural areas.
- A Users' Guide has been prepared that provides information on how to maintain equipment and the impact on the environment.

The Renewable Energy for Sustainable Rural Livelihoods project- 2001-2006.



1.4 Scientific interest and novelty

The main scientific contribution of this project was the development of a systematic methodology for tackling the complex relationships between the aspiration to enhance 'sustainable rural livelihoods' and the actual provision of appropriate energy technology to develop local infrastructure. The methodological tool can model the trade-offs that take place between the impact of energy technology and a community's current resources. These were not framed as isolated concepts but together allowed for multiple changes to be effected in order to alleviate poverty and strengthen sustainable livelihoods in rural areas. The scientific analysis is based on mathematical functions that indicate various relationships among the characteristics of the technology and the community's assets; our software processes the information with the Compromise Programming Multi-Criteria Method of Yu (1973) and Zeleny (1973).

Bringing social and technical scientific expertise together to solve a common problem created a very productive groundwork from which a new approach to sustainability and poverty reduction can evolve. The research project revealed that social science approaches to technical solutions provide an important window on how communities and other stakeholders recognise barriers and opportunities, define priorities, and interpret technological and political trends, so as to illuminate the mistakes of the past and to make better use of existing technology. However, the main message of RESURL is that effective and lasting energy provision in poor rural areas is impossible without the input of engineers and other technical professions. If these requirements are not captured by a research team with the appropriate expertise, the conflicts and problems may not find a durable solution.

The team undertook many initiatives during the three years of the project. These included two large field-work programmes in three developing countries, teaching and research at local universities, presentations at international conferences, meetings with regional and national policy-makers in collaborating countries, and wide-ranging publicity to the private and public sectors. These activities make the RESURL project a significant contributor to worldwide efforts to combat poverty and environmental degradation through its focus on infrastructure development and renewable energy provision.

Chapter 2

Energy development for sustainable livelihoods: A multi-criteria Decision-Support System

2.1 Introduction

RESURL II focused on revising and improving the decision-support programme designed by RESURL I, and on firmly establishing a final multi-criteria model for decision-making on local infrastructure development in poor rural areas.

One of the main objectives of RESURL has been to promote clean energy technologies in rural areas, and the new Decision Support System called ***SURE*** was created with precisely this aim in mind to assist future energy development and sustainability of rural livelihoods. Responsive to the full energy menu, i.e., every possible modern form of energy technology available to rural areas is part of the decision support system, ***SURE*** is designed to aid decision-makers to define and select appropriate energy supply options for isolated rural communities. Application of the programme is expected to assist in achieving long-term sustainable energy in rural areas. The model combines quantitative technological and qualitative criteria. A part of the model builds on a 'five capitals' perspective as defined in the Sustainable Livelihoods approach (SL) for assessing existing conditions in a rural community and for planning their future improvement through the operation of energy systems.

The model initially assesses the strengths and the weakness of a community by indicating its overall status. It then proceeds to draw up energy plans which would affect assets differently. The model aims to find energy solutions that would impact assets singled out by future users of the technology as in need of improvement. Our approach adds a novel method of decision-making. Particularly useful aspects are that ***SURE*** allows graphical representations of changes and trade-offs as they might occur during implementation of different energy alternatives; it includes technical as well non-technical aspects of energy and livelihoods; and finally, it has incorporated a time dimension of 'before' and 'after' an energy intervention.

The remaining sections of Chapter 2 explain the analytical components of the computer programme.

2.2 Advances on RESURL I: a multi-criteria approach to energy development

In order to assess the impact of any energy technology solution on a community, it is essential to evaluate the living conditions of such a community before and after an energy intervention has taken place. Although there are useful programmes such as Homer and Leap that estimate the impact of technology, SURE additionally offers the benefit of modelling aims that produce solutions taking into consideration further aspects - beyond the economic and environmental - of livelihoods. It also refers to the time dimensions of before and after an energy solution has been implemented. Unlike other existing software that assists rural energy decision-making, the SURE approach enables prospective users' priorities to be considered in the analysis.

To reflect the complexity of sustainability in poor rural areas, RESURL II moved the model forwards by refining criteria and indicators for assessing community resources and defining the characteristics of an energy technology.

Whereas during the first phase of the project the impact of the technology on a community was in large part intermingled with the calculation of the assets themselves – the physical resource and technology in particular were not clearly distinguished, and therefore it was more difficult to differentiate between the impacts of the technology before and after an application - the new design of the model completely overcomes these drawbacks. The SURE programme draws on the previous assumptions

developed by RESURL on the basis of its post-evaluation studies (See Chapter 3) and our use of the SL approach. It assumes that there is an 'ideal' state of development for a community; that we should obtain a clear description of the real current condition of a community - which in fact, will be the 'before' component in the time dimension; that the specific needs of a community must be identified by the population itself; that we need to anticipate the impact of various energy interventions on the actual state of a population; and finally, that decision-makers can opt for the most suitable energy solution to fulfil the priorities identified. These phases had been important from the outset of the conceptual development of the programme. However, due to the difficulties rooted in programming the above dimensions, only during the advanced stage of SURE during RESURL II was it possible to fully integrate these fundamental features into the programme.
The model anayses information at four levels, with the programme generating results that are interesting and useful in themselves at each stage. The four analytical modules:

I. assess the current conditions of a community, including both the provision of any modern energy technology, and prospective users' priorities for development, producing a unique baseline for each case that requires energy solutions;
II. establish what is an ideal state of development for a community (i.e, a fully developed pentagon);
III. estimate possible impacts of new interventions on the identified baseline.
IV. suggest the most appropriate and efficient technological option.

2.3 A multi-criteria approach to energy and sustainable livelihoods

The *SURE* software processes information using the Compromise Programming Multi-Criteria Method with metric two for decision-making and weights. The method, created by Yu (1973) and Zeleny (1973), assumes that decision-makers' preferences can be expressed as a measure of the distance between two alternatives in the space of objectives. The method has been widely applied to energy, environmental and water resources problems (Huang et al, 1995). An ideal score for an impact is the maximum value attainable for each of the community's assets, i.e., =1. An interior pentagon represents the actual impact on the resources (see Figure 1).

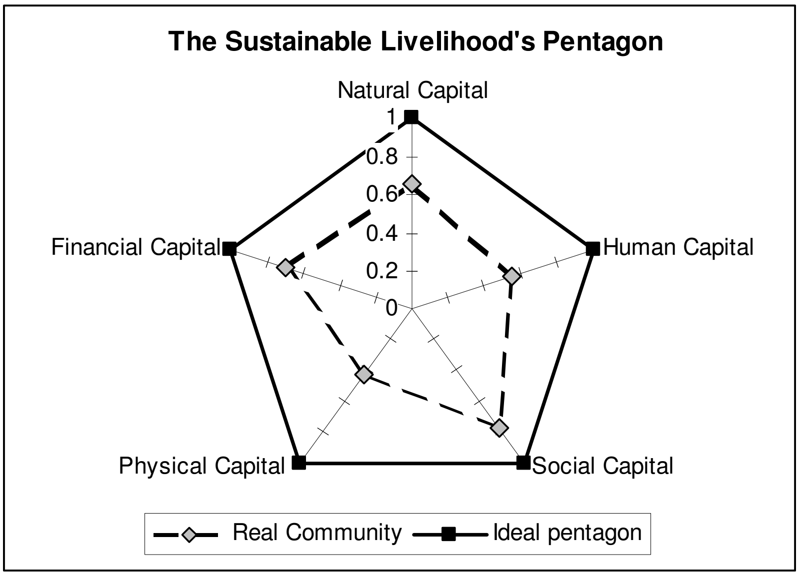


Figure 1. The ideal and actual development of a community

A multi-criteria approach was chosen because provision of energy to rural areas is a complex problem. If only a one- or two-dimensions approach had been used, it would have left out important aspects of livelihoods and the technology that contribute to the long-term sustainability of any improvement achieved through the application of the energy solution.

The study of electrification in isolated rural areas does not seem to give sufficient consideration to environmental, human, social and economic issues. This multi-factor perspective has been missing (Santos and Linares, 2003; Huang, *et al.,* 1995). Problems of providing rural energy are multi-faceted, affecting the development of different aspects of a community. It is likely that an energy solution could only facilitate partial development of certain resources while it might degrade others. Nonetheless, one should try to identify energy options that could best improve most resources, while not strongly disrupting the others.

Part of the SURE programme employs a "*Sustainable Livelihoods" (SL)* concept framework. The *SL* framework provides conceptual guidelines that improve our understanding of livelihoods, particularly of the poor, and the role of sustainability in improving resilience to risks (Chambers and Conway, 1991). The objective of applying this framework by RESURL is to suggest ways to reduce poverty and to contribute to enhancing the condition of rural, particularly isolated, communities - through supplying energy to rural areas. The SLA framework identifies that five main assets or types of capital defined as community possessions: *Natural, Human, Social, Physical* and *Financial* (DfID, 2000; Carney, 2002).

We argue that, together, the five assets defined by the SL approach –SURE employs the generic term 'resources' to cover these 'capitals' or 'assets' - can broadly reflect the state of development that a given population has achieved. The assets of a community are represented by a pentagon where the height of its spokes represent the amount of each asset owned by a population. No assets are represented by a spoke of length zero, whereas *1* indicates a fully developed resource. The shape of a pentagon changes at its edges, thereby implying the strengths and weaknesses of a community in terms of their access to and the availability of resources (see Figure 1).

The ***SURE*** software designed by RESURL introduces innovative elements into the analysis of energy for rural areas with access problems. There are emerging signs of increasing acceptability of the model among prospective users. The aim of a multi-criteria model is to choose the energy solutions that could best improve an existing condition in a community, or, in graphical terms, to most efficiently improve the shape of a community pentagon, as per the SL approach.

2.4 Defining a community baseline with energy provision in mind

Obtaining a representation of existing assets through the 'SL pentagon' shape can be very helpful. It definitively assists the identification of weakness and the strengths of a given population. The program task consisted however on finding the best way to evaluate benefits and drawbacks of energy technologies in a way that would truly reflect the way that each would affect a real community's assets.

The decision support model posed therefore two main challenges, the identification of the most relevant indicators that would add to a resource, or capital, and the design of the mathematical function that would measure the performance of a set of energy alternatives in relation to each asset. Each resource, or capital, gets to be calculated at the beginning, and the SURE program builds upon one function from which all other functions derive.

Defining the baseline

The baseline in the program is organised according to the five main resources found in a population, i.e., the *Natural, Human, Social, Physical* and *Financial* as per the SL approach. Information to fill this section of the computer program would originate in a structured household survey that uses a Questionnaire on Decision-Support System (see Annex of the RESURL report, Cherni, 2004), specialists, and observation by the decision-maker or assistant. The Questionnaire should provide enough data to identify a community's priorities for development, and other qualitative appreciations such as satisfaction with existing services, willingness to pay, and obstacles or barriers **(PP**).

The paragraphs below indicate RESURL II outputs in relation to definitions of the current conditions of a community. It shows how each SL indicator was constructed and what variables they contain in order to reflect their relevance to energy decision-making. Each variable represents a set of factors. The programme will calculate the final Resource.

1. Physical Resources Indicator

The community's *physical capital* refers to its basic infrastructure (Ashley and Carney, 1999; DfID, 2000). More precisely, physical capital refers to producer goods, such as buildings, roads, machinery and electricity, that may generate a future flow of output; as all are important for energy development. The formula for the physical resource indicator is:

$$\mathbf{P_R = In + Co + TT}$$

Where $\mathbf{P_R}$ stands for Physical Resources, In is the available infrastructure in the community, Co are the available means of communication and TT are the tools, technology and services of the energy system.

2. Financial Resources Indicator

In rural areas, in addition to households' need for a minimum amount of energy, there is an increasing demand for energy in the provision of rural services such as water supply, health care and education, and for productive activities such as agriculture and small industries. Ideally, all these needs should be met in an efficient, cost-effective and environmentally sustainable manner. The community will require the financial means to purchase the equipment and insure its maintenance. The financial indicator therefore shows what facilities a population has to obtain funds and what sources of income are available:

$$FE_R = FI + WS$$

Where FI are financial Institutions and WS are wages and stock.

3. Natural Resources Indicator

Refers to the natural resource that are accessible to households or individuals within their rural context from which resource flows useful for livelihoods can be derived (Carney *et al*., 1999; DfID, 2000). Natural resources are considered as both source for energy and for environmental impact of energy technologies:

$$NR_1 = S + Wa + Wi + Ws + Biod + LV + L_e$$

Where S is the solar insolation, Wa is water availability, Wi is Wind availability, Ws is Biomass waste, Biod is the Biodiversity, LV is the landscape value, Le is the available land for energy production.

4. Social Resources Indicator

Social assets or *social capital* refers to community and wider social claims on which individuals and households can draw in the pursuit of livelihoods by virtue of their belonging to different social groups (Ellis, 2000; DfID, 2000). This category of livelihood asset is meant to capture the reciprocal relations within communities and between households based on trust deriving from social ties (Moser, 1998) particularly because these may be affected by the presence or the lack of energy. Political association is a further variable incorporated by RESURL and it exists by virtue of people's affiliation, favouritism or political interests. The social resource indicator is calculated in the following manner:

$$\mathbf{SR = N + M_S + LO + MP}$$

Where N is networks, Ms is the mutual support, G is groups, CR is Collective representation and MR is mechanisms for participation

5. Human Resources Indicators

Human resources refer to qualities that can be improved, or otherwise, by the provision of energy.

$$H_R = H + N + AW + Ed + Ks + D + FT + PP$$

Where H is health, N is nutrition, AW is access to clean water, Ed is Education level, Ks Knowledge and skills, D demographic factors, FT free time and PP population participation.

2.5 Estimating Impacts of New Interventions

To advance into Module III (see 2.2), the program calculates the impact of different energy technologies on each resource of a chosen population. Equation 1 presents a structured function for the impact of the energy alternative on the five community's resources

(C_j, *j=1,…,5*).

(Eq.1) $$C_j(A_i) = \frac{1}{1+e^{-\alpha_j X_j(A_i)}}, \qquad (j = 1,..., 5;\ \ i = 1,..., n)$$

Where $C_j(A_i)$ represents the evaluation of the *i-th* energy alternative (A_i, *i=1,…,n*) against the resource *j, j=1, 2,…5,* (*1 indicates Natural, 2 Physical, 3 Social, 4 Human and 5 Financial*); $X_j(A_i)$ represents the effects of the *i-th* energy alternative on the corresponding community's resource *j;* and α_j is a scale parameter, associated to the number of factors that compose each resource *j.*

$$\alpha_j = (20*(X_j - a)/(b - a)) - 10$$

Where ***a*** is the lower limit of the $\boldsymbol{X_j}$ range of values; and ***b*** is the upper limit of the $\boldsymbol{X_j}$ range of values.

The program makes comparative calculations on the basis of characteristics of the characteristics of the technology (i.e. efficiency, lifespan of the equipment, modularity, dependency on fossil fuels, cost, generation capacity and environmental impacts). The model will produce a single "technology index" (*t*) per energy system. Annex II shows the Energy Matrix. The impact will be estimated between 0 and 1, where 0 means the lowest effect (which may have a positive or negative connotation depending on the issue) and 1 means the highest. A score for each technology is helpful for the decision-makers who may start considering the most appropriate option.

The *SURE* program includes a Technology Matrix which provides information about basic technical and non-technical features of a number of energy technologies, i.e. micro-hydro, photovoltaics, biogas, firewood, wind, geothermal. In the Technology matrix, qualitative information was classified in two main characteristics: "advantages" and "disadvantages" of the technology, including aspects such as requirements for installation, modularity availability to scale up and environmental considerations. The quantitative data refers to the lifespan of the equipment in years, costs per unit of electricity, costs of generation and costs of maintenance.

Whereas the estimate of possible impacts of new interventions is a central part of the program, the decision-maker will be most helped by the last module of the program, i.e., the suggestion the program produces of the most appropriate and efficient technological option.

A selected option means that a particular technology contributes best to increase resources of capitals. Using the sustainable livelihoods approach it means that the best technology option can generate a pentagon that is closer to the ideal as it is generated in Module II. The program produces a graph thereby it shows the decision-maker three results: the ideal condition of a community, its present and real condition and the future condition after the energy system has been implemented. Thus, *SURE* calculates the smallest difference between new pentagons, that have modelled various energy options through the Compromise Programming technique, and the ideal pentagons and this is how it reaches a most appropriate solution.

Additionally, RESURL II learnt that is now needed to improve the current survey questionnaire that will produce data relevant for running the model.

2.6 SURE Sustainable Rural Energy. A Decision-Support System. Version 5

The *SURE* program was significantly improved during RESURL II. It is now a "friendly" system. required changes that were related both, to the content and functioning of the program and the visual aspect or "look" of it, in order to make it more "friendly" for the user. The graphic way to deliver information is a main advantage of the system. The literature demonstrates that the use of a fast, reliable and useful visual aid has proved to be of aid for policy making and decision-makers (Diaz-Chavez, 2003).

The following images show the main windows of the software (Fig .2).

Fig. 2. Windows of the SURE model new version V1.5

2.7 Reaching out with the Decision-Support System

Few team members focused on new definitions of indicators and reformulation of equations while a general technical workshop provided more extensive feed-back from the team's experts.

A first Technical Workshop was convened for RESURL members from March 29th to April 2nd 2005. The aim of the meeting was to create debate on various aspects of the computer programme, to start training partners on the use of the programme, and to extract useful guides to improve the model.

On the 29th September 29th, a seminar was held in La Habana, Cuba. The aim of the gathering was to let stakeholders and academics of the results achievee by RESURL in Cuba, and in other countries. A main aim of the seminar was to expose the computer programme and its philosophy to experts on the subject. The event was convened by RESURL partners, GEPROP, of the Ministry of Science, Technology and Environment (CITMA), along with the Central University of Las Villas, of Cuba. The meeting was particularly successful not only because a large number of participants (25) from 6 different provinces in Cuba arrived, representing a very critical crowd constituted by local authorities, regional decision-makers, energy NGOs representatives, professionals in the energy sector, and academics.

The model was found potentially very useful by the seminar's participants. The outcome was that a number of organisations voluntarised to pilot the soft-ware in rural areas of their respective constituencies. This was a particularly important test for RESURL as a research project, and for und in the programme designed by RESURL. The previous version of the software, 1.4, and the User's guide were distributed among the participants and some of them showed interest in becoming part of the pilot study to be organised in 2006.

CHAPTER 3

Improving the potential of energy technology for sustainable livelihoods

3.1 Introduction

The RESURL project has produced information and analyses on some of the poorest groups in three developing countries in Latin America and the Caribbean among the 2 billion people without electricity and inappropriately supplied world-wide. However, technologies are now available to improve access to energy by the rural poor in remote areas. We claimed that unless appropriate information is made available to users and to decision-makers, new developments will end up with the same flaws as previous schemes and will not succeed in reducing poverty in the longer-term (Cherni, 2004). Post-evaluation studies under RESURL I had been, therefore, fundamental to recognising the operational status of existing modern energy installations and to identifying barriers that prevent their successful adoption. Important lessons were drawn from this information, in conjunction with further knowledge from the literature and experts,

The explicit link between access to energy services and poverty reduction has now been recognised. The Johannesburg Plan of Implementation (JPOI) called for an improvement in the access to reliable and affordable energy services for sustainable development sufficient to facilitate the achievement of the Millenium Development Goals (UN, 2005). The MDGs and energy provision are linked because, for example, access to energy services promotes economic development through micro-enterprises, livelihoods and local business and can therefore contribute to the objective of halving extreme poverty; improving access to safe drinking water often involves use of energy for pumping water; reducing child and mother mortatlity can involve reducing disease through the use of energy for refrigerating vaccines; education and gender equality can be promoted through greater access to energy services reducing the time spent on gathering firewood, and time saved may be used in promoting education of girls and women; finally, more sustainable natural resource use can be promoted through development of clean energy services (DFID, 2002).

The insights and analyses that RESURL has produced on energy technology and rural sustainability are related to the Millenium Development Goals (MDG) in that they promote well-informed sustainable energy development in poor rural communities of developing countries. This was achieved by variety of means. For example, methodologies and tools were developed to help with the decision-making processes of choosing the most appropriate energy systems to fit the characteristics of the locality, notably through the development of the Multi-Criteria decision-making tool (***SURE***).

RESURL II applied the MAP-RESURL approach. The Multi-criteria Approach for Post-Evaluation of Renewable Energy for Sustainable Rural Livelihoods (MAP-RESURL) was applied to a particular case in Argentina as part of an MSc dissertation at Imperial College. MAP-RESURL is both a participatory and an expert tool that guides the assessment of current energy technology in places where energy schemes have been implemented. It helps gain knowledge about the types of energy systems that are in use, the cost, efficiency and problems encountered by the community in using them. This knowledge helps local authorities and the community consider if a new energy alternative should be introduced in the near future. Along with MAP-RESURL, the use of survey questionnaires and interviews with local authorities are valuable to find out about the strategies and policies that are being implemented with respect to energy and poverty alleviation. For example, RESURL II carried out interviews with Ministry representatives and scientists in Cuba which helped understand the present situation of energy access in rural areas in a country without a liberalised energy market.

The findings from the post-evaluation MAP-RESURL in Colombia, Cuba and Peru during RESURL I indicated that lack of technical capacity among the direct beneficiaries was a considerable barrier that stood in the way of more effective and sustainable energy solutions. Villagers were very keen on owning and operating renewable energy installations but often reported great disappointment at the unexpected technical problems that they needed to face and for which no solutions were readily available. In order to solve this problem, RESURL designed a User's Guide which provided with some basic technical information to help the communities maintain and repair the equipment. This Guide was expanded in RESURL II to include the use and application of energy systems for income generation.

Chapter 3 explains the advances achieved by RESURL II in relation to the potential for modern renewable energy technology to improve the livelihoods of local populations and those who use or may use it. Results of the interviews with policy-makers are then analysed.

3.2 Barriers to successful energy provision

Reliance of the poor on their natural surroundings indicate that any step towards poverty alleviation should incorporate environmental and economic sustainability as a priority for enhancing sustainable livelihoods. Drawing on conclusions from the literature review and learning from the experience of the team members, we sought a multidimensional approach that would enable the technical and non-technical aspects of energy development to be embraced in our analysis for future development of energy design for poor rural areas. We knew that the degree of success and failure of energy system development depended upon factors that did not circumscribe technology and economic risks, albeit these are of great importance. In order to promote energy solutions in remote poor areas, these must be sustainable in the long term.

Knowledge was needed concerning the main barriers standing in the way of more sustainable energy development applications in rural areas. However, a comprehensive method that would focus on technical as well as non-technical factors was not readily available. Therefore, one of the main outputs of RESURL I was the design of a methodology to help evaluate the current performance of energy schemes installed in remote rural areas in the developing world. The project designed MAP-RESURL, a Multi-criteria Approach for Post-Evaluation of Renewable Energy for Sustainable Rural Livelihoods. MAP-RESURL was instrumental in defining important aspects to address when evaluating the success of renewable energy technology programmes for remote communities. MAP-RESURL is a participatory expert tool that guides the assessment of current energy technology in places where energy schemes have been implemented. It helps gain knowledge about the types of energy systems in use, the cost, efficiency and the problems encountered by the community using them. It was applied to three countries (MAP-RESURL; see Cherni, 2004, Chapter 2).

In RESURL II, the post evaluation approach (MAP-RESURL) was applied to a case study in Jujuy, in the north of Argentina.

Key technical aspects of project design such as the type and size of technology used, govern how the technology is used to meet energy service requirements and influence livelihoods. The importance of consultation with local communities and all stakeholders at every stage of the project was demonstrated. Education and training is essential to support the use of the technology. With high-technology such as solar PV there is a role for technical specialists. However, training and education in technology use and basic maintenance at the user level can reduce the need for external assistance. This is especially important in remote rural areas.

The case study resulted in interesting findings. It showed that solar PV technology enables remote rural communities in Jujuy to receive an electricity service that, in many cases, would otherwise not be possible by any other means. The systems in use in Jujuy demonstrate the ability of solar PV to make significant contributions to improving rural livelihoods. The financial assistance has been provided by PERMER; a national programme to supply electricity services to remote rural communities using solar PV technology. The programme involves the privatised energy sector through a private energy company with a rural concession contract and external funding from The World Bank and the Global Environment Facility (GEF). The fieldwork was done in collaboration with SIGLA, an Argentine energy consultancy, as part of the first ever comprehensive provincial assessment of PERMER in Argentina. The work with SIGLA also formed part of a World Bank assessment of this approach to rural energy services.

There remain significant barriers preventing the systems from being used in a way that maximises the potential benefits. There are also barriers preventing the technology from functioning optimally and hence enabling the benefits to be felt (Jamieson, 2005). The barriers that prevented the technology from functioning optimally and being effectively used were related to technical faults, system use and the quality of the service. Fear and lack of understanding of the capabilities of the PV system by the users was also a principal barrier to expanding the installation. Additionally, the lack of information and lack of training received by the users who are responsible for the internal fittings after initial installation has been reported as another problem. This study also identified that social barriers, such as parentless families, alcoholism, and changes in household structure increase the difficulty of supplying information and training to those that need it.

It is recommended that five directions are taken in order to help overcome the barriers to the effective use of the solar PV systems in Jujuy. i. Training local representatives through a specialist course would help to reduce the need for external specialist assistance and speed up response times to problems. ii. Empowering users by shifting more responsibility for essential basic maintenance onto the users. iii. Access to information and capacity to help the community be self-sufficient in solving technical energy problems. iv. Focusing on education particularly using the local schools as centres for training. Finally, v. the incorporation of other rural development projects utilising the energy from the PV system will bring considerable benefits to the community and help with the maintenance of the systems.

3.3 Guide for Users of Renewable Energy Technologies in Rural Areas - Maintenance, Environment and Applications.

Findings from the post-evaluation survey in Colombia, Cuba and Peru indicated that lack of technical capacity among the direct beneficiaries was a considerable barrier that stood in the way of more effective and sustainable energy solutions (Cherni, 2004). Villagers were very keen on owning and operating renewable energy installations but often reported great disappointment at the unexpected technical problems that they needed to face and for which not solutions were ready available.

In order to address this problem, RESURL designed a User's Guide. The objective of the Guide was to optimise existing energy systems by providing technical information on how to maintain the systems and to promote local decision-making. The guide concentrates on micro-hydro, solar, biogas and wind systems. The Guide for Users of modern energy technology in rural areas was originally written in Spanish and was later translated into English to provide a broader applicability.

RESURL II scaled up this tool by adding value to existing information. It did so through the incorporation of possible practical uses that could generate income on renewable energy technology in rural areas (see Annex III). The first version of the Guide was distributed among those attending the Technical Workshop in La Habana, Cuba in 2005 and to remote communities in Cuba in 2004. The User's Guide should be made available to users and stakeholders as soon as possible. Chapter 5 on future activities of the project explains the new directions on this issue.

To better understand the uses and applications of renewable energy technologies that help to increase the size of the local economy through the creation of business and employment, a literature review was done to explore examples in other countries. Applications range from technical uses, e.g. cooking stoves, to policies and programmes (like the *Rural Energy Development Programme* REDP in Nepal) focused on rural areas and poor urban and semi-urban settlements developed by local governments or international organisations.

Important examples of programmes that also encourage productive applications are given below.

i. Programmes related to the improvement of the traditional sector of biomass cooking stoves. These programmes have been running since the 1980s in developing countries, especially in Africa, India and China, and have had mixed results. In China people used the improved stoves for life, while in India only one third of the stoves were still in use after 20 years. This was attributed to poor programme design and implementation (Goldenberg, 2000).
ii. The UNDP energy portfolio aims to help national policy frameworks to support energy for poverty reduction and sustainable development by, for example, training government officers in Burundi. It also has expanded access to energy services in remote rural areas in Nepal with the *Rural Energy Development Programme* (REDP) through micro-hydro, solar power and cooking stoves; it promotes clean energy technologies such as wind farms in Tunisia; and finally, it encourages innovative financing for sustainable development in Philippines where the UNDP has supported the *FINESSE* project whose objective is to address barriers to the diffusion of renewable energy technology (UNDP, 2004).
iii. Local efforts to link energy to sustainable livelihood by NGOs. For example, ITDG evaluated conditions and undertook full installation of a hydro plant in El Punre, Peru, principally to chill milk from a dairy farm and additionally to provide energy to 10 more families in the area (Herrera and Ramirez, 2005).

RESURL's User's Guide is important to encourage communities to use renewables. This is not only to have access to energy which will improve the quality of life of the inhabitants but also to consider the economic opportunities that it may bring to boost the local economy (see for example the case of Camajarca, Peru promoted by ITDG).

3.4 Policy makers on energy and sustainable development

The geographical focus of RESURL has been on three developing countries in Latin America and the Caribbean. Interviews with policy makers in Cuba in particular were helpful to establish the government approach to sustainable development and within this, its position on renewable energy technology in Cuba.

The interview with the President of the NGO CubaSolar revealed the achievements of programmes on the introduction of energy systems in rural areas. The first Programme of CubaSolar aimed at the installation of electricity in surgeries with support from the National Commission of Energy. Cubasolar and another NGO have participated in the programme since 1994 and today there are 200,000 electrified surgeries in rural areas in Cuba. A second main aim is electrification of rural schools in order to enable lighting and the use of a T.V. and a video player/recorder equipment which will allow the local community to have information about the rest of the country and the world. Two thousand schools were provided with solar panels.

The use of renewable energy appears in the energy agenda of the Cuban government. The National Environmental Agency is one of the institutions that promotes it. Before the 1990s, the country was highly dependent on oil supplied from the ex-Soviet Union; but that energy was 'wasted' (Alonso, 2004). Between 1990 and 1991, known as the "special period" when the supply from the Soviet Union came to an end and the American embargo worsened, Cuba confronted an extreme lack of resources, particularly, oil. The need to search for alternative sources of energy began with the conversion of sugar cane biomass into electricity. It is still used as a source of electricity. Some renewable energy technologies were introduced and are still undergoing research. For example, wind energy is an unrealistic alternative for Cuba because of the geographic characteristics of the country although it is used on a very small scale in some rural areas. A total of 94 % of the population has access to electricity through the national grid and also through the use of solar energy.

It is apparent that the problem of technology transfer may have an influence on the use of renewable energy. In Cuba research has been carried out on the crystals that are used for solar panels. Still, this is a highly specialised and costly technology which is difficult to develop domestically. Nevertheless, the government is still convinced of the need to use alternative renewable energy and is committed to its development. To achieve this, several programmes have been undertaken to provide electricity to surgeries and schools in remote rural communities such as those by CubaSolar above. Environmental protection is a political priority and the use of renewables contributes to this objective. The energy sector has not been privatised in Cuba (Alonso, 2004).

Importantly, a further lesson drawn in this report was that the use of renewable energy and technology can assist the independence, sovereignty and national security of a country, particularly a developing nation. In Cuba's case, government interest in renewable energy and technology is high. A national Centre for Renewable Energy was created to work on the regulation of systems and to link it to practical applications of the concept of sustainable development in the country (Santos, 2004). Implementation of sustainable development has sometimes been jeopardized by financial problems but not because of lack of understanding or lack of will to implement it.

The three interviews helped to elucidate the importance of having a policy that supports the introduction of renewable energy for the benefit of the population and the environment. The Cuban case is particular in the region due to its centralised government. Precisely because of this, it has been excellent to compare with the rest of the partner countries in Latin America where energy liberalised markets exist and where electrification of rural areas is still on the way. It is difficult in Cuba because it is not part of its current government social policy. In this social policy "man" is at the centre, productive systems are in the hands of the working class and the main objective is the wellbeing of the people. To privatise any activity would be to detract from the main social goal (Santos, 2004). The pragmatic view is that renewable energy technology would help the country to become independent were there no longer access to oil. Though it limits its applicability in other countries, the considerations of the Cuban domestic policy provide a good lesson for other cases.

Chapter 4

A scope study of electricity sector reform and energy provision to the poor

4.1 Introduction

Electrification in developing countries more than doubled from 25% of households in 1970 to 64% in 2000 (IEA, 2002). Despite growth in electrification in each of the main regions of the world (North Africa, Sub-Saharan Africa, South Asia, Latin America, East Asia/China, and the Middle East) in many African and south Asian countries the rate of network expansion in rural areas was lower than the rate of population growth (Barnes, 2005). In rural sub-Saharan Africa as a whole there was little change in the electrification rate during the 1990s.

The issue of electricity reform in developing countries was explored in relation to the task of extending energy services to the poor and the potential for sustainable energy development. Key questions asked were:

- Is market liberalisation facilitating the access of the poor to modern energy services or is it by-passing the poor? Does it pose a further barrier to access electricity by the poor?
- Is market liberalisation facilitating or hindering the introduction and use of new and environmentally sound energy technologies?

Whereas the main focus of the review is on the first issue, the first and second questions were the subject of a research proposal submitted to the ESRC-DFID joint call on Poverty Reduction last November. Chapter 4 refers thus to facts and principles that led to changes in policy as well as leading, in many cases, to the process of privatisation, of the electricity sector.

RESURL II carried out a scope study of the literature on the impact of energy market reforms in developing countries on the poor and established informative and analytical foundations to continue investigating the real impacts. This chapter briefly reports on global trends in electricity reform over the past three decades; the rationale for neo-liberal reforms, and the extent of access to electricity. It presents an account of the known effects that liberalisation has produced on the poor, drawing novel conclusions and also reflecting on the usefulness of existing statistical information to fully comprehend the issue.

4.2 Antecedents of electricity reform policy

Market reforms in the energy sector of developing countries have multiplied rapidly in the past couple of decades, particularly during the 1990s. Of the over US$237 billion public and private sector investment in energy sector projects with private sector participation in developing countries during 1990-2003, Latin America accounted for just over half, while East Asia/Pacific accounted for almost a third of the total (see Table 1).

Table 1: Energy infrastructure investment with private sector participation 1990-2003

	1990-95 ($ millions)	1996-2003 ($ millions)	Total ($ millions)
Sub-Saharan Africa	215.9	7114.1	7330.0
N. Africa / Middle East	5341.4	8663.2	14004.6
South Asia	6545.1	13713.4	20258.5
East Asia/Pacific	25500.0	46905.6	72405.6
Latin America / Caribbean	19504.2	104204.7	123708.9
Total:	57106.6	180601.0	237707.6

Source: based on data in World Bank (2005, Table 5.1)
Note: includes both public and private investment

'Energy reform' encompasses a range of changes in the way the sector operates (Bacon, 1999), and with respect to electricity, can apply to activities from power generation, to transmission and distribution, wholesaling and retailing (Zhang et al, 2002). Reforms aimed at ensuring competitive service provision, termed 'liberalisation' (Jerome and Ariyo, 2004), include 'de-mopolization', 'unbundling' and restructuring vertically integrated government utilities (Gabriele, 2004), deregulating prices creating wholesale or retail markets, establishing energy trading mechanisms, and allowing the operation of private enterprises. 'Private sector participation' entailing private sector involvement in the ownership, management, or financing of utilities, and 'privatisation' involving transfer of state-owned assets into private ownership and sometimes viewed as the ultimate goal of the reform process, are often considered key reforms associated with liberalisation, but the latter can be considered a distinct policy goal that necessitates neither. Increasing competition is often aimed at forcing enterprises to achieve 'productive efficiency' by operating at the lowest cost, 'allocative efficiency' by forcing prices down to marginal cost eliminating super-normal profits (Stevens, 1998), and greater customer responsiveness and innovation. Where undertaken without altering monopolistic industrial structures, neither privatisation nor private sector participation involve liberalisation.

The literature review drew several major conclusions on the present situation of electricity market reforms.

The major trend towards electricity market reforms occurred worldwide in the 1990's and the rationale for reform varied. In Latin America and the Caribbean reforms were motivated particularly by problems of under-investment and inability to meet maintenance costs and desire to deliver acceptable levels of service in terms of cost, reliability and coverage. In Asia governments tended to stress the 'necessity' of reforms for investment to meet rising demand, while pressure from international financial institutions is reported to have been a dominant factor in Africa.

Marked differences in average per capita energy consumption both between developed and developing countries, and within developing countries, is associated both with the growth in the horizontal component of demand, i.e., access to energy by new users, as well as in the vertical component, that is, growth stemming from increased ownership of household equipment that characterises modern life styles. They reflect two problems: lack of access to energy by a large segment of the population, especially in rural areas, and the low consumption level of poor households who, in many cases, cannot afford the electricity service in either urban or rural areas, or the purchase of further electrical equipment (Kozulj *et al.*, 2004). Declines in average household electricity consumption after reforms in countries such as Kenya and Uganda (Karekezi and Sihag, 2004) reflect, at least in part, growth in the horizontal component of demand.

Electricity market reforms of the 1990s did little to address the problems of access, consumption and affordability. In the case of Latin America and the Caribbean, energy sector reform led the way in the privatisation process under conditions created in order to guarantee an accelerated accumulation and ownership transfer. The lack of access to energy by a large segment of the population, especially in rural areas, low consumption by poor households, and inability to afford the cost of electricity service in urban as well as rural areas, has changed little despite the reforms (Kozulj *et al.*, 2004). Where reforms brought domestic energy prices close to international levels by means of sudden monetary appreciation, this has disrupted and de-structured the productive system to such an extent that it has been a principal cause of worsening structural poverty. One of the main impacts of macro-economic reforms, especially in Argentina, was unemployment - creating a new group of poor which had difficulty in meeting electricity bills. If macro-economic conditions make existing users increasingly unable to pay, this process may ultimately prove counterproductive (Karekezi and Sihag, 2004).

There is little evidence that market reforms aimed at goals such as making existing service provision more cost-effective and competitive, reducing public subsidies and enhancing economic growth, significantly benefit the poor. Private companies have tended to neglect extending services to rural areas, in favour of more lucrative business providing electricity to industrial and urban customers (World Bank, 1996a). In Asia privatization is reported to have worsened access by the poor in many cases (Prayas et al, 2004). In Columbia coverage of poor households fell slightly after privatization (Clarke and Wallsten, 2002). In Argentina disconnection of illegal connections following reforms initially reduced access to electricity by the urban poor, with efforts to provide services to the 10% of the rural population without access to electricity largely unsuccessful (Dubash, 2002). Case studies for Argentina, Peru and El Salvador show marked declines in rates of network expansion, apparently demonstrating how the absence of explicit interventions aimed at the poor can result in reforms adversely affecting the interests of the poor, and a decade after the introduction of the reforms, questions concerning the role of the state, subsidies and the most desirable solutions remain (Kozulj *et al.*, 2004). Privatisation, in particular, is reported to be very unpopular and increasingly so in Latin America, with a widespread public perception that it increases poverty and inequality (Estache et al, 2001, Nellis et al, 2004).

Where services have been successfully extended to poorer households, government investment and so-called “good subsidies”, or well-designed contracts specifying electrification or price targets for private utilities, have often played a key role, especially in rural areas (Barnes and Foley, 2005). For reforms to benefit the poor, tariffs have to be designed bearing their needs in mind, and with subsidies provided if extensions of the grid for some rural populations are to occur (Powell and Starks, 2000). Lifeline tariffs, whereby those consuming least electricity pay the lowest tariff, have been used successfully in countries including Costa Rica (Barnes and Foley, 2005), Mexico (Gutierrez, 2005), and Thailand (Voravate and Barnes, 2005), and have performed well where closely related to the poverty profile of consumers and set so as not to compromise the financial viability of the power companies (Barnes and Foley, 2005).

Empirical evidence on the impact of reforms on the poor is limited and its interpretation is open to dispute, with insufficient data to infer the impacts in terms of access by the poor to electricity services in many cases. However, there is a widespread perception that electricity market reforms have often harmed the poor and deepened poverty. This appears consistent with theoretical predictions of ‘tariff rebalancing’ to base prices upon marginal cost and eliminate cross-subsidies after liberalisation, which could lead to higher prices for poor, and with heightened economic incentives for focusing service provision on the most profitable market segments, neglecting services to the poor. It is also consistent with the empirical evidence of increased tariffs for low-demand households and job losses in countries such as Argentina (see: Delfino and Casarin, 2001, Kozulj et al, 2004, Nellis et al, 2004) and of falls in electrification rates countries such as El Salvador, Peru, Argentina, Kenya and Uganda (Kozulj et al, 2004, Karekezi and Sihag, 2004).

4.3. Data-sets: usefulness in assessing poverty and provision to the poor

RESURL II undertook a review of the data sets of energy information available today. This was necessary to establish the gaps in research and empirical data needed to understand the present situation of the energy market reforms.

The findings of this review showed there is a relative paucity of data currently available to evaluate the impacts of energy market reforms on the poor in developing countries. Of the data of relevance, such as electricity access, price and consumption data, most of the primary data is held at national level, with few international and regional sources. Much of the existing international time series data, including the International Energy Agency (IEA) and World Bank data, is accessible online from the ESRC-funded Economic and Social Data Service (ESDS) led by MIMAS at the University of Manchester.

Illustrative of the relative paucity and aggregate nature of the data available, the main international sources include the *International Energy Authority*, which has published the most comprehensive electricity access data to date, but which applies only to a single year. IEA (2002) constitutes the only global country-by-country analysis of household access to electricity, providing estimates of the total population with and without formal electricity connections in each developing country in 2000. The study is an important secondary source of data providing an overview and analysis of data from national databases, the World Bank and other sources, supplemented by the IEA Secretariat's own estimates where other data was unavailable. It includes rural and urban electrification rates for main developing country regions in 2000, and the proportion of the total world population with access in the years 1970, 1990 and 2000. While not disaggregated by household type, the IEA keeps a database for the period from the 1970s onwards with annual average electricity and gas consumer price data for selected developing countries and years, with much of the Latin American data drawn from OLADE.

Both the *World Bank* and the *World Resources Institute* have also published electricity access data, including data on the percentage of the population with access to electricity in 2000 for many countries, citing the IEA as the source of the data. World Bank (1996) provides data on the percentage of rural and of urban households in main developing country regions with access to electricity, and the total numbers served in 1970 and 1990, with some further data published in Townsend (2000) and Clarke and Wallsten (2002). The study also includes some data for several developing countries from surveys of indoor air pollution associated with biomass combustion. The World Bank's Private Participation in Infrastructure (PPI) database holds information on 3,200 projects, including annual data on numbers of energy sector PPI projects, types of project, total and cumulative electricity project investment 1990-2004, the five countries receiving the greatest share, and amounts invested in the five largest projects. The World Bank's Privatization database contains data on 9000 privatisation transactions in developing countries over the period 1988-2003 and proceeds from each energy sector privatisation, with some further information published in Bacon (1999), Brook and Besant-Jones (2000), and Izaguirre (2000). The World Development Indicators include information on residential electricity prices and household expenditure on electricity for selected countries, with some further information published in Clarke and Wallsten (2002) and case studies in Barnes (2005), but contains no data on energy tariffs or consumption by the poor (World Bank, 2005). The World Bank Living Standards Measurement Study and the US Aid initiated Demographic and Health Surveys project both maintain databases with household survey data for selected countries and years which include electricity access information.

The *World Energy Council* energy efficiency indicator database includes annual data on per capita electricity consumption, average electricity consumption of households with electricity, and average household electricity prices for selected countries and years during the period 1980-2002. It has also published some developing country studies with electrification rate and energy access data, and its website reproduces electricity access data for 1970, 1980 and 1990 from Davis (1995, Table 3, p.8). The *US Energy Information Administration* global database keeps annual time series data for 1980-2003 on levels of different types of energy generation, electricity distribution losses, and net electricity consumption in individual countries, as well as annual household electricity price data for around 30 developing countries for some years during the period 1994-2002. It also publishes country briefs describing sectoral reforms, in some cases including electricity access information, as well as providing a list of worldwide energy data sources.

The *United Nations Environment Programme Risoe Centre on Energy, Climate and Sustainable Development* publishes country studies on climate change mitigation and on renewable energy, including descriptions of national energy supply policies. The *United Nations Department of Economic and Statistical Affairs* publishes annual total and per capita electricity consumption data for developing countries in its Energy Statistics Yearbooks (as well as annual electricity production data), but not disaggregated by household type.

The *World Health Organisation* has published statistics for 2000 on the proportion of the population of main developing country regions using biofuels and the associated mortality attributable to indoor air pollution. The *Organisation for Economic Cooperation and Development* (OECD) has published a study on power sector privatisation in sub-Saharan Africa, including some information on the employment impacts of privatisation in Cote d'Ivoire and of restructuring in South Africa (Barthélemy *et al.*, 2003). The Public Services International Research Unit (PSIRU) at the University of Greenwich maintains a database on multinational companies involved in the privatisation and restructuring of energy services around the world.

Some developing country data are published by regional organisations. These include the *African Energy Policy Research Network* (AFREPREN), which has published data on rural electrification for African countries for 1998, the numbers of rural households with electricity in 1996, and annual data on per capita "modern energy" consumption for some countries, although not disaggregated by household type. The *Asian Development Bank* keeps an environmental statistics database with data on total power generation and use, per capita CO2 emissions and methane emissions, and the percentage of the rural and urban population below the national poverty line and below $1 a day in member countries in Asia for selected years. The *Association of Southeast Asian Nations (*ASEAN) Center for Energy publishes some residential electricity price data. The *Asia Pacific Energy Research Centre* (APERC) in Tokyo has published regional summaries for 2003 and 2004 with information on power sector policies and reforms in each member country of the region, and a 2003 study on natural gas reforms, but apparently no data on the impacts on the poor. The *Latin American Energy Organisation* (OLADE) has published data for 2003 on per capita electricity consumption, generating capacity of different types of power stations, and CO2 emissions from electricity generation, as well as other energy sector data for Latin American countries. The *Bariloche Foundation* has published some data on access, annual electrification rates, and average household electricity consumption for selected countries, undertaking analyses of data from other sources. The EU-funded *Latin America Thematic Network on Bioenergy* is in the process of constructing a database including bioenergy production, per capita electricity consumption and residential electricity price data for selected Latin American and African countries, and China.

4.4. Electricity reform and renewable energy technology: The case of China

Electricity reform and renewable energy technology: The case of China
Almost 700 million new connections were made in China during the final two decades of the twentieth century, leaving 20-30 million households, under 2% of the total, without electricity by 2000. The remarkably successful electrification programme is primarily attributable to the poverty-alleviation policy introduced in the mid-1980s backed by subsidies and low interest rate loans (IEA, 2002), creation of largely independent local and regional public power companies, and decentralised generation, especially small-scale hydropower (Yao and Barnes, 2005).

Market reforms began in China in 1979. Reforms spread to the electricity sector relatively late and occurred in three phases (Zhang and Heller, 2004):

Phase 1 (1986 onwards) – Independent power producers (IPPs) enter
Phase 2 (1997-2002) – 'Corporatisation' of entities within the electricity industry
Phase 3 (end 2002 onwards) – Unbundling of the market structure

Encouraged from the mid 1980s, private sector participation has become an increasing feature of power generation in China, with bank loans contributing an increasing share of investment funding as projects have become more financially attractive, and a total of over $22bn in public and private funds invested in energy sector projects with private sector participation during the period 1990-2003 (World Bank, 2005). Although services reportedly remain of poor quality and unreliable, with much wiring undependable or unsafe (IEA, 2002), the rapid electrification in China illustrates how extending electricity services to the poor need not entail privatisation. Economy-wide market reforms led to rapid income growth, stimulating increasing demand for electricity. With government control of energy companies remaining the dominant feature, liberalisation in the sector played a relatively minor role in network expansion. Extension of services to 98% of households had already occurred by around the time of the creation of the state power corporation in 1997 (Karekezi and Sihag, 2004) and well before its split into two government owned grid companies and five state generation companies in December 2002 (Zhang and Heller, 2004).

China has the second largest electricity industry in the world, with installed capacity of 353GW in 2002 (Zhang and Heller, 2004). Rapid economic growth has contributed to a chronic shortage of supply (Webb 2004). Generation capacity does not meet current demand and will need to rise substantially if it is to meet the increasing demand in coming years.

Coal, the primary fuel, accounting for almost three-quarters of the overall fuel mix in 2003 (Woo, 2005), is contributing to significant local, regional and global environmental damage, and a key problem facing China is how to achieve its development ambitions without further exacerbating environmental problems. Urban pollution is a major issue - seven out of ten of the world's most polluted cities are in China, with pollution levels greatly exceeding World Health Organisation standards (Hertsgaard 1997 cited by Zhang et al. 2001). Acid rain damage to crops and forests has affected more than one third of the land in China, and economic losses approach 2% of the country's gross domestic product (Zhang et al. 2001). Indoor air pollution in rural areas is also a major problem, with respiratory disease one of the leading causes of death, claiming 1.46 million lives in 1995 (Zhang et al. 2001). The second largest emitter of greenhouse gases in the world, just behind the USA (Liu et al., 2002; Zhang et al., 2001), China has been coming under increasing international pressure to control its emissions.

In 2004 the government announced that China will generate 10% (approximately 60GW) of its electricity from renewable resources by 2010 (Landler, 2004). Renewable energy resources in China, particularly wind and hydropower are abundant but significantly under-utilised at present, and offer an opportunity for the reconciliation of economic growth with environmental protection. Table 2 below summarises existing capacity, resources, and manufacturing capability for each of the main renewable energy types.

Renewable Resource	**Installed capacity (end 2003); (MW)**	**No. units**	**Economically exploitable potential (GW)**	**Manufacturing Capability**
Wind – large-scale grid-connected	750	40 wind farms	250GW – offshore 750GW – onshore	Batch production of 750kW
Wind – small standalone systems	35	180,000	(included within onshore figure above)	Good capability; 25 manufacturers; exporter
Solar	50		1700 billion tce/annum	10 manufacturers; annual manufacturing capacity 20MW
Hydro[12]	90 (installed) 50 (under constructio n)	Not available	265GW – large hydro 125GW – small hydro	Mature industry; good capability
Biomass	1900	Not available	Not available	Not available

Table 2: Status of renewable energy in China (Shi, 2004)

Liberalisation has created a range of barriers to the development of renewable energy. Corporatisation introduced the 'profit motive' into decision-making, and as the cost of electricity from renewable energy generation is higher than from coal, to date, this has limited the ability of renewable energy to develop within the sector. The social mandate of the electricity sector has moved from the internal decisions of the former state-owned enterprise, the SPC, to the autonomous decision making of market participants, so that decisions relating to investment in renewable energy technologies are no longer under the direct control of Government. The electricity sector is currently in a state of partial reform whereby the power purchase price is determined by negotiation on a plant by plant basis, but the sales price is fixed by Government without full incorporation of the costs of production, and this limits the willingness of grid companies to purchase renewable energy, creating a significant barrier to the development of the industry. Lack of independence and power of the new regulator, the SERC, necessary to maintain a fair and transparent system, and uncertainty during a period of reform also act to deter private investment in renewable energy.

A new Renewable Energy Law passed in 2005 and effective from January 2006 will provide a single coherent policy framework for the development of renewable energy. While many details of the law remain unspecified, it addresses some of the current barriers to development of renewable energy, providing funding for some

[1] Includes both large and small hydro

renewable energy projects, imposing a requirement on grid utilities to purchase all the renewable energy that licensed power generators produce within the area of the grid, and allowing additional costs to be passed on in the selling price.

4.5 Conclusion

There is some very useful data published that is relevant to assessing the impact of market liberalisation on access of the poor to modern energy services, but it is relatively sparse and much is highly aggregated. Information on the timing and type of energy markets reforms is available from the World Bank, but the data required to evaluate their impacts on the poor is limited. Information on access to electricity by households in each country has been compiled for 2000 by the IEA, but there is no data on access specifically by poor households, and little available for other years, with rural and for urban household access data available from the IEA only for main developing country regions in 2000, and not for individual countries. Some developing country data on residential energy prices is available from the IEA and the US Energy Information Administration, but not on those applicable specifically to poorer households. Information on average household consumption of electricity are available from the World Energy Council for around 30 developing countries for selected countries and years since 1980, but not consumption data specifically of poor households. The research proposal submitted to the ESRC-DFID joint call addresses some of these gaps for Latin American countries.

Although empirical evidence on the impact of reforms on the poor is limited and its interpretation is open to dispute, the widespread perception that electricity market reforms have often harmed the poor and deepened poverty appears consistent both with evidence of increased tariffs for low-demand households and lower electrification rates in some countries. Where services have been successfully extended to poorer households, government investment and so-called “good subsidies”, or well-designed contracts specifying electrification or price targets for private utilities, have often played a key role. In the case of China, the country’s remarkably rapid electrification was a consequence of government intervention rather than electricity market liberalisation, while electricity market liberalisation creating significant barriers to the development of renewable energy, some of which are addressed by the new Renewable Energy Law.

Chapter 5

CONCLUSION

5.1 INTRODUCTION

The RESURL project had since its origins the firm conviction and objective that collaboration and partnership with other stakeholders in the region would contribute to the promotion of renewable energies and the provision of an option in the decision-making process through its own developed methodology and tools.

The RESURL project completed an important piece of research.
It has designed and tested a new Multi-criteria decision-support system soft-ware to promotes rural energy for sustainable livelihoods; it has produced a 'Guide for Users of Renewable Energy Technology in Rural Areas. Maintenance, Environment, and Applications'; it has designed a Post-evaluation Methodology to assess technical and non-technical barriers that interfere with the expected performance of renewable energy technology; and has had influence at policy-making levels and national research programmes; has increased capacity building in universities, and enhanced knowledge of the relation between poverty reduction and the use of energy in poor rural areas.

It has worked with international organisations (Practical Actions, UK and Peru), National Universities (Colombia, and Central University Las Villas, Cuba), government (GEPROP, from the Ministry of Science, Technology and Environment, Cuba) and international consultants. The purpose of the project was achieved and further venues for investigation and application of the outputs had been opened.

When comparing to other advanced available software, i.e., HOMER, Hybrid 2, RET Finance, VIPOR, Energy 10, E- analysis, and LEAP that also approach rural and renewable energy for the poor, we learnt that LEAP is probably the closest model to ***SURE*** as it is also based on scenariorelated to the process Models included:. Annex IV shows the main characteristics of these computer programs. Nevertheless, none of the models reviewed had an innovative scheme such as ***SURE*** which actually incorporates the resources that "belong" to the community, especially the human and social, into the calculations, makeing ***SURE*** a stronger and particularly competitive model in terms of reflecting sustainable development for rural and poor areas through energy provision.

5.2 The future of ***RESURL***

It is necessary to put the objectives and work of RESURL forward into a proper context. RESURL project's concern with poverty alleviation is in line with the Millenium Development Goals (MDG) and corresponds with the key commitments of the 2002 Earth Summit at Johannesburg to promote renewable energy and improve access to affordable and environmentally sound energy services. Much of future directions of the research should orient into the improvement of life quality and alleviation of poverty in the region through the promotion of accessibility to services including energy.

The project has expanded in Colombia into related and novel areas. RESURL has generated a whole set of new interests surrounding the original questions raised by the project. The outcome has been the emergence of new research projects in subjects related to technology management, human and social capital, rural policy and the evaluation of the social return to energy development. The Colombian Institute for the Development of Science and Technology (COLCIENCIAS) has shown particular interest and has partially contributed to the realisation of a new project on these themes. This line of research needs to be continued. The project has started to develop sought-after capacities that will enable the incorporation of people involved in the project into policy-making and the labour market.

The project's achievements has meant that it has been moved forward in the light of the decision by Cuban policy-making and scientific authorities to include one of our main outputs, the SURE decision-support model, within the national priority research programmes and to pilot it in a number of provinces. This step would open possibilities to implement the project's outputs, validate its methods and analysis, look for ways to execute energy options development, and to monitor outcomes in the future.

Overall, the experience of the project in this second phase have been gratifying and rewarding both academically and practically for all participants. The lessons learned will be applied in future research

During this second phase of the project an extension of the aims go beyond the remote rural areas. It is highly important that the promotion of renewable technology will benefit population also in urban slums and peri-urban areas where conditions of poverty may exacerbate due to the lack of policies in respect to the developing energy markets.

Most of the work accomplished on poverty alleviation is still focused on geographical and temporal basis. Short term solutions are still being performed and Africa and some parts of Asia are on the immediate geographical agenda. RESURL is a clear indication that the Latin America and Caribbean regions are in need of poverty alleviation as well.

As part of the future activities, the RESURL project would focus efforts on the enhanced understanding of the impact of the liberalisation model on the poor as it applies to the relationship between electricity market reform, the rural and urban poor, and the promotion of alternative energy technologies under the influence of such liberalisation on the socio-economic and infrastructure conditions of actual livelihoods and sustainability in Latin America and the Caribbean, one of the first major regions of the developing world to adopt market reforms and which is currently bedevilled by some of highest levels of poverty.

For the nearest future, there is imperious need to focus on further writing up the project's outputs for refereed publication journals. It is also highly recommended that soon pilot applications of SURE in rural areas will be undertaken. It is thought that the new 'Guide for Users of Renewable Energy Technology in Rural Areas. Maintenance, Environment, and Applications' should be made available for dissemination. It is recommended that efforts are made to establish useful links between access to sustainable energy of people in poor rural settings and the reform process of electricity sector in developing countries.

5.3 The way forward

Technologies are now available to improve access to energy by the rural poor in remote areas. However, unless appropriate information is made available to users and to decision-makers, new developments will, no doubt, end up with the same flaws as previous schemes and will not succeed in reducing poverty in the longer-term.

There is a general sense among the project's members that valuable work has been done during the years of intense, participatory and professional undertakings. It is also felt that RESURL team has completed an important stage in its mission of poverty reduction in the developing world.

New funds and new research directions are now required to accomplish the full potential of the outputs produced by RESURL I and RESURL II. By having provided recognition to RESURL outputs among their national priorities due to the framework it provides in the pursuit of rural development, the Ministry of Science, Technology and Environment in Cuba gives us all indication of the potential application of the system programme. Pilot applications of the model are now necessary in order to improve its contents and to test its applicability to rural, remote or not, areas with poor populations.

Regular upgrading of the computer model and the methodological packages would allow its application more widely. It is thought that the computer system would benefit from a more comprehensive financial section as well developing into new directions to provide for impact assessment of various types of ownership of energy systems. The latter is particularly relevant given the advances of privatisation in the energy sector of developing countries. A further and most important research direction that emerges is research and application of new policy guidelines for promoting sustainable energy for the poor.

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