Abstract— Several computer Models are available for analyzing Energy systems world-wide, however these have been developed in ‘Industrialised’ nations depending upon their own peculiar requirements. Energy crisis have led to integration of Hydrogen into the world energy research programs. Developing nations need to employ computer models for evolving their “Hydrogen Economy”. This paper provides a brief review of modeling tools that can potentially fulfill this objective.

Keywords- Computer model, Renewable energy, Hydrogen, Energy system, Developing countries.

I. INTRODUCTION

The future of a Hydrogen Economy is still largely unknown; however major funding programs for R&D in transition to Hydrogen Infrastructure are underway worldwide. This clearly indicates an increased focus on Hydrogen as the next best energy option. It is imperative that these activities clearly translate into effective steps towards a Hydrogen Economy. Options need to be analyzed effectively for the development of Hydrogen energy infrastructure from its embryonic stage to well established roles in the wider regional, national and global energy economies. Different pathways under evolution need to be optimised for potential benefits in terms of environmental up gradation as well as freedom from fossil fuel use.

The shape of any future hydrogen infrastructure would have foundations based on the current energy economy and its elements. Geographically hydrogen production methods, techniques and sources would vary from region to region. Similarly siting of Hydrogen energy Infrastructure whether stand-alone or cluster would be dictated by ground conditions. Thus the building of anticipated Hydrogen supply chains requires extensive analysis of current energy resources and availability under the principles of Integrated Resource planning (IRP). Conversion from a fossil fuel based Energy to a renewable Hydrogen system require coherent technical analysis of how such an implementation world occur and its effects on other parts of the energy system. Computer Tools have been developed to perform such analysis that model the defined energy system.

Development of a computer tool for each region and each analysis is not only very time consuming but also require trained manpower and above all financial expenditures. Thus for a developing country like Pakistan, it is recommended that the available tools if feasible and accessible be used for any future Hydrogen Integrated strategies in Energy planning.

A number of studies have been carried out that provide information pertaining to a single tool without any reference to the renewable Hydrogen Energy systems. Comparative studies have been made by Lund et al [1] on Energy plan & H₂ RES. Similarly NEMS and MARKAL - MACOR have been compared by [2]. Urban et al has discussed the six energy tools mainly EMINENT, CO2DB MARKAL, IKARUS, E3 DATABASE and Synopsis. For developing countries, the only study carried out analyses the suitability of 12 energy tools however none of them targets Renewable Hydrogen studies. Thus to pin point a specific tool that has been well – researched and implemented across the world and with documented results, a detailed analysis has been carried out in this paper.

II. MODEL CRITERIA

Keeping in view the economic concerns as well as security of supply, in addition to the geographical dictates embedded in a model, a criterion as per Table.1 has been developed for selection of the modeling tool. Hydrogen production, storage and transportation technologies have been the key criteria for selection, for promotion of Hydrogen Economy. Similarly environmental concerns have also been included for addressing the climate change concerns.

III. METHODOLOGY

Different Energy systems were studied in detail that targeted Renewable Hydrogen Scenarios. The implementation phase and documented research results were then analyzed from studies carried out world-wide.

Another important point in consideration reflected by F Urban [3] is that the large majority of currently used energy models are developed in industrialized countries, based on their experiences and assumptions. Nevertheless, the assumptions and the data for energy systems of industrialized countries vary significantly

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<tr>
<th>TABLE.1</th>
<th>CRITERIA FOR SELECTION OF ENERGY MODEL</th>
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<td>Criterion</td>
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<tr>
<td>1.</td>
<td>Geographical Scale: Global, Regional, National, Local, Project.</td>
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<td>2.</td>
<td>Hydrogen targeting</td>
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<td>3.</td>
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from those of developing countries. Therefore, these modeling approaches are not always able to present plausible results for developing regions. The major differences that are relevant include the electrification rates and fuel use, policy frames and economic structural change. Hence energy Models in use in developing countries is summarized in Table 2 for a concluding Energy model for Integrated Hydrogen Energy system.

A. BALMOREL

Balmorel has been developed in GAMS language and is a partial equilibrium tool. The tool can be modified to suit specific requirements for a given application. Balmorel is able to carry out electricity and heat sector simulation, however transport sector technologies are not represented. Electricity storage is represented by hydrogen storage or pumped hydroelectric. Electricity transmission is represented through nodes that are connected by transmission lines that are also able to identify bottlenecks in the transmission system. The tool is employed as part of modeling approach in the German Energy system [4].

B. EMINENT

EMINENT has been developed by the Organization for Applied Scientific Research, in Netherlands. Still in the development stage, it is meant for introduction of new energy technologies and new energy solutions into market at a faster pace. EMINENT evaluates the National energy systems with the help of database and the assessment tool. It analyses the impact of new technologies in the on-going Energy supply chains and consists of two databases:-

a. One pertaining to energy infrastructure containing information about the installed capacity, type and quality of demand as well as the number of consumers in various sectors.

b. Second database contains information on existing as well as new thermal generation and renewable energy technologies [5].

C. ENERGY PLAN

ENERGYPLAN has been continuously under development and ten different versions have been launched since 1999, by Aalborg University. The entire energy system can be simulated that can assist in the design of national & regional, energy planning strategies. ENERGYPLAN is able to model all thermal and renewable energy, storage/conversion costs. ENERGYPLAN optimizes the operation of a given system instead of optimizing investments.

The model has been used to analyse the potential of CHP and Renewable Energy in Europe & UK, and also to simulate 100% renewable energy system for Ireland, Denmark & Croatia [6].

D. ENPEP BALANCE

ENPEP developed by Argonne National Lab USA in 1999 is a non linear equilibrium tool. The changes in energy prices and demand are used to simulate responses in the entire energy system. All thermal & renewable energy generation can be simulated, but hydrogen production is the only storage/conversion technology that is accounted for. All financial aspects are also considered and equilibrium is reached when tool is able to satisfy all relevant equations as well as inequalities [7].

ENPEP BALANCE has been used to estimate GHG mitigation in Turkey [8] & Bulgaria [9] and to analyse Mexico’s energy needs and associated environmental costs.

E. H2 RES

The tool developed in 2000 is a joint effort of University of Zagreb, Croatia and Technical Institute of Lisbon, Portugal. It simulates the integration of Renewable Energy into energy system especially island energy system which operates as standalone systems. It can cater for small as well as large energy systems.

H2 RES can handle all thermal generations, other than nuclear and all RETs except tidal. All storage and conversion technologies are integrated except compressed air, while in transport sector only hydrogen vehicles are simulated. Costs are presently not included in H2 RES.

The tool has been used to simulate 100% renewable energy system for island of Mijet in Croatia and Island of Porto Santo in Portugal [10].

F. HOMER

NREL has designed this micro power tool that simulates and optimizes stand alone and grid connected power systems with any combination of Renewable Energy Technologies, including all costs. The optimization is aimed at evaluating the technical and economic feasibility of a large number of technology options, while integrating the changes in technology costs and availability of energy resources. HOMER has been used to simulate a system where 100% of the electricity and heat is met by Renewable Energy [11].

G. HYDROGEMS

HYDROGEMS, developed by Institute for energy technology is a set of Hydrogen Energy tools for simulation of integrated Hydrogen energy systems, particularly Renewable Energy Technologies based standalone power system. Hydrogen system processes such as Hydrogen mass flows; electricity consumption and Production can be conveniently simulated, and can also be used to simulate the performance of integrated hydrogen system.
HYDROGEMS has been used to analyse the operation of standalone PV-hydrogen and Wind-hydrogen systems. More recently renewable hydrogen generation based on electrolytic production has also been simulated [12].

H. IKARUS

IKARUS developed by Institute of Energy research, Germany, adopts a bottom up, optimisation approach to build strategies for GHG mitigation.

IKARUS uses a five years time step for the simulation up to a max of 40 years; however it cannot take into account future changes in each time-step to paint a realistic picture for analysis and forecasts. Optimisation is aimed at reduction of total system cost; however emission reduction objectives can also be achieved. All sectors of energy system are simulated in all production, conversion, storage and transport technologies. Wave, Tidal and electric battery vehicles are excluded.

IKARUS has mainly been used for CCS investigations and effects of energy prices on long term energy scenarios in Germany [13].

I. INFORSE

It is an energy balancing tool for National energy systems which gives an overview for the possible energy development in a state or region. A maximum time frame of 10 years can be simulated, providing energy balance for every decade. The tool has been developed by (International Network for Sustainable energy) and made available to NGOs.

Its database includes a chain of spread sheets containing information to be used as input for the energy system being modeled. These include energy demands, production and policies. All thermal renewable and hydrogen based generation is represented along with conventional and hydrogen vehicles as well [14].

A number of European states including Belarus, Bulgaria, Denmark, Latvia, Rumania, Russia, Slovakia, Ukraine and UK have simulated the renewable utilization potential up till 2050. Denmark has simulated 100% renewable energy system up till 2030 with this tool.

J. LEAP

Stockholm Environment Institute developed Long Range Energy Planning (LEAP) tool for integrated modeling of energy economy in national energy system. Different methodologies have been incorporated in LEAP for modeling, except optimization. LEAP can simulate all technologies with resulting scenarios describing energy system evolution over the defined time period. Results are displayed the form of Tables, Charts and Maps that are importable in Excel and Power Point. LEAP has extensively been used for research purposes and several analyses all over the world [15].

K. MARKAL/TIMES

MARKAL/TIMES developed by International Energy Agency is a family of energy/economic/environmental tools. The code is written in GAMS and is one of the most used tools in energy modeling.

MARKAL can simulate a specific energy environment system at the global, multi-regional, national or community level for a period of 20-100 years. All thermal and renewable generation, conversion & transportation technologies can be simulated in this model. For each simulated time-period many different energy networks or reference energy systems are represented. Hence, for each time period, MARKAL finds the “best” reference energy system.

MARKAL/TIMES tools have led to several studies including prospects of hydrogen fuel cell vehicles and to frame policies for Renewable Energy integration in EU [16].

L. MiniCAM

MiniCAM has been developed by Pacific Northwest National Laboratory USA and is designed to analyse long time and large-scale changes in Global, regional energy & agriculture systems. It has a time-step of 15 years ranging within 1990- 2095, for simulating economy, energy consumption and GHGs. Energy supply Technology forms focal point in MiniCAM including all conventional and renewable technologies except district-heating, pumped hydro-electric, battery and hydrogen storage[17].

MiniCAM has been used to investigate the technology options for GHG stabilization levels, & its feasibility by 2100. MiniCAM has also simulated Energy Efficiency & Renewable Energy technologies [18].

M. RETScreen

National Resources Canada has developed this decision support tool in collaboration with government, industry and universities. The software has a world wide applicability to analyse the energy production, costs, emission reductions and its feasibility analysis.

The software draws a comparison between a “Base case” and a suggested technology or “Proposed” clean energy technology, and includes all costs as well as “IRR”(Internal rate of return) and “NPV”, (Net present value). The final analysis is based on the costs of the proposed case which is liable to be on the higher side as compared to the conventional “base Case”. The proposed case naturally has higher initial costs however the annual costs are comparatively lower. The Major advantage of RETScreen is its applicability from micro to macro level.

RET Screen has been used globally to assess the feasibility of Renewable Energy development particularly in developing countries [19].

N. SimREN

SimREN (Simulation of renewable Energy Networks) follows a bottom up approach to develop energy supply/demand models. Institute for sustainable solutions and Innovation developed SimREN in 1999. SimREN is primarily designed for study of energy systems based on renewable resources. All thermal and renewable generation except wave &tidal power can be simulated; however transport technologies have not been incorporated. The tool has been used to simulate generation of 100% renewable
electricity for Catalonia, Spain as well as an energy system for Japan [20].

O. TRNSYS

TRNSYS is a joint effort of USA, France and Germany and was first developed in 1975. It has an open source code for simulation of electricity and heat sectors. TRNSYS can simulate all thermal and renewable generation other than nuclear, wave/tidal and hydro power. Energy storage options available in the tool are Battery energy storage, while Hydrogen systems are using HYDROGEMS. User can define a time step ranging from 0.01 secs to 1 hour; however analysis can be carried out for multiple years.

TRNSYS has primarily been used for simulation of solar energy application, solar thermal system as well as hybrid PV-thermal systems. TRNSYS has also been used to simulate 100% renewable energy system [21].

P. UniSyD 3.0

UniSyD3.0 has been jointly developed by Unitec Institute of Technology, New Zealand and Stanford University, USA. It has a 15 day time step with an analysis time-frame of 50 yrs. It addresses all sectors of the energy including the financial aspects. Also all thermal generation except nuclear and all renewable technologies other than wave/tidal are considered. Transport technologies included are conventional vehicles, Battery vehicles, hydrogen fuel cell and hydrogen IC vehicles.

New Zealand has used the tool for assessing the potential of Hydrogen Economy as well as the impacts of alternative vehicle fleets and its economic effects due to GHG emissions [22].

Q. E3DATABASE

E3 stands for Energy, Emission, and Economy and has been developed jointly by Ludwig-Bölkow System Technik, Germany (LBST), CEA and IFP. It uses a bottom up approach and is based on E2 Database, an energy and emissions balance tool that calculates all possible energy chains from the energy source to end-user. E3 version performs an economic evaluation of Hydrogen Energy chains in key energy sectors. It is mainly concerned with modeling of Hydrogen Energy chains however other supply chains can also be built.

E3 Database has been used for “Well to Wheel Analysis of future automotive fuels” in Europe. European Space Agency has also used the tool for comparison of space-based versus terrestrial solar energy systems [23].

IV. CONCLUSION

This review provides the information necessary to identify a suitable computer model for the analysis of Integrating Hydrogen in a Renewable Energy system with varying objectives. This article clearly indicates that there is no model that can be termed “perfect”, which is able to respond to all issues pertaining to Renewable Hydrogen Energy. However selection of any energy model is highly dependent on any definite aims that are required to be achieved.

Finally, this writing is a guideline for making decision as regards a suitable energy model for any study that is to be concluded.

REFERENCES


[23] Ludwig-Bölkow System Technik, Germany (LBST)http://www.e3database.com/> [accessed 21.05.10].
### Table 2: Model Usage Comparison—Developed Vs Developing World

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