Rural Energy Planning Incorporating Energy and Agricultural Interactions

R. Ramanathan
Indira Gandhi Institute of Development Research
Film City Road, Goregaon(East)
Bombay - 400 065
INDIA

ABSTRACT

Energy issues in rural areas have been tackled using two different classes of models: rural energy planning models for the optimal allocation of energy resources for different end-uses, and rural energy systems models for estimating the share of the energy sector in getting rural resources which *are needed* by *end-uses in the energy and agricultural sectors. In this paper, an integration of both these classes of models is proposed for more efficient energy planning. An application of the integrated model is illustrated using data for a typical village.*

1. INTRODUCTION

Rural areas in many developing countries essentially depend upon traditional fuels for virtually all their energy requirements (UN, 1989). Many of the rural resources have multiple uses. For example, the crop residues can be used as fuel, or as feed for livestock, or as fertilizer. Similarly, dung can either be used as fuel or as fertilizer. Thus, there is competition between the rural energy sector and the agricultural sector in using such rural resources. Efficient rural energy planning should explicitly account for such interactions between the energy and agricultural sectors.

These interactions have been studied by many researchers. Parikh (1985) was perhaps the first to incorporate them into a comprehensive Rural Energy System (RES) model. Parikh and Kromer (1985) employed this model for the rural areas of Bangladesh (Parikh, 1988). A revised form of the model, called INGRAM (the Indira Gandhi Institute of Development Research Rural Energy and Agriculture Model), has been applied to many states in India: Panesar et al. (1989) employed INGRAM for the state of Punjab; a case study of Gujarat have been carried out by Painuly et al. (1992); the rural energy and agriculture interactions in Uttar Pradesh have been analyzed by Singh et al. (1992); and, recently, a study on the Kamataka state was reported by Painuly et al. (1995).

Similarly, there is a voluminous body of literature on Rural Energy Planning (REP) models to provide optimal allocation of resources to various energy end-uses. Joshi et al. (1991) applied such a model for the rural areas of Nepal. Sinha and Kandpal (1991a,b,c;1992) applied a similar model for estimating the optimal number of end-use technologies for rural regions. Other similar studies include Ramakumar et al. (1986), Ashenayi and Ramakumar (1990), Subash and Satsangi (1990), Joshi et al. (1992) and Ramakumar et al. (1992). Though these models are highly useful for rural energy planning, they ignore the existence of the interactions between the energy and agricultural sectors. Clearly, the methodology of these models would improve if a rational mechanism is built into REP models to account for the energy-agricultural interactions. In this paper, the integration of the REP models with the RES models is proposed for the purpose.

The next two sections describe briefly the concepts behind the RES and REP models. The integrated model will be described in Section 4. Its utility will be illustrated with a case study, and will be compared with the results of the application of the REP model alone. The last section provides a summary of the paper.

2. THE RURAL ENERGY SYSTEM MODEL FOR CONSIDERING THE ENERGY AND AGRICULTURAL INTERACTIONS

The Rural Energy System model developed by Parikh (1986) provides a systematic framework to analyze the linkages between the agricultural and energy sectors in rural areas. The model has been used for exploring a number of policy implications related to rural energy systems.

Figure 1 provides a sketch of the interactions considered in a simplified RES model (Singh et al., 1992). The objective function and other constraints of the model are briefly described below.

Objective Function:

The objective function is maximization of the net revenue generated in the system. The net revenue is the sum of the revenue from crops and milk minus the cost of purchased items, viz., feed, fertilizers and energy. Several other objective functions, such as minimisation of total costs, could have been employed instead of the maximization of net revenue. However, this objective function (net revenue) has received a wider application in the literature (see section 1). In fact, all the models which employ this objective function have been validated using past data, which shows that the rural energy and agricultural systems indeed aim at maximizing net revenue.

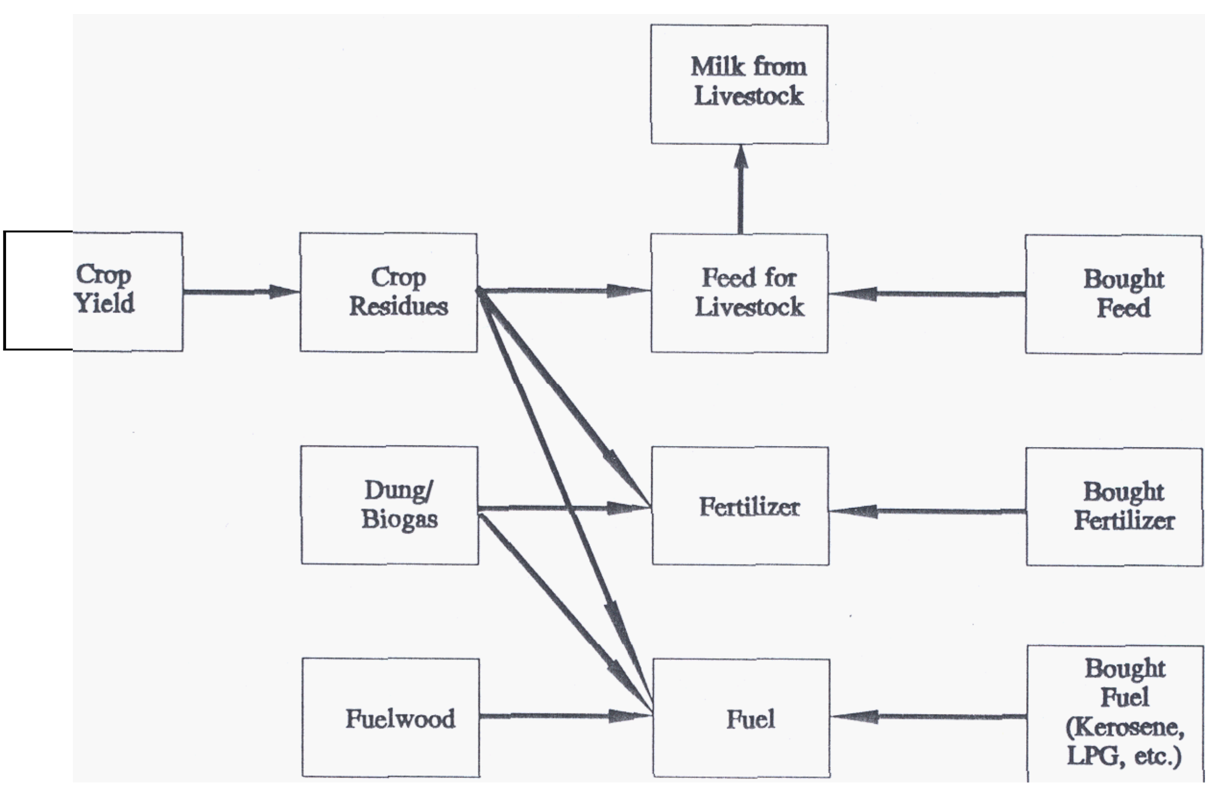


Fig. 1. Interactions in a simplified rural energy system model.

It is assumed that the locally available non-commercial fuels (such as fuelwood. dung, crop residues and biogas) will not be sold outside the rural system. Hence, their costs are not incorporated into the objective function, as any cost associated with these fuels involves transfer of revenue within the system only, and does not change the net revenue of the system.

Constraints:

The constraints pertain to the availability of different rural resources and the demands of the energy end-uses.

Crop Residue Balance:

The availability of crop residues is estimated on the basis of yield of crops, land availability, and crop-residue coefficients. They are allocated for altemative uses, namely, feed for livestock. fuel for households, fertilizer for farms, and others such as construction, handicrafts, etc. depending on requirements and other opportunities.

Animal Feed Balance:

Cattle and buffaloes are considered. They are divided into four categories: working, milk, not-working, and young. Their feed is obtained from pastures, crop residues, and/or using bought feeds. The feed requirements of animals in terms of their Total Digestible Nutrients (TDN) and Digestible Crude Protein (DCP) intake is estimated, and is balanced with the TDN and DCP contents of crop residues, bought feed and the feed from pastures.

Animal Dung Balance:

The availability of dung from the livestock is estimated using suitable dung coefficients, after accounting for the loss of dung in the form of collection coefficients. It is allocated to the alternative uses of dung, viz., manure for farm, biogas production, and energy.

Fertilizer-nutrients Balance:

The amount of fertilizer required based upon the level of fertilizer application in terms of kg/hectare. It is exogeneously given. Four ways of obtaining fertilizers are considered: using crop residues, using dung, using biogas sludge, and purchasing chemical fertilizers.

Household Cooking Energy Balance:

The minimum amount of energy required for cooking is exogeneously given. The total energy of all the resources (allocated for cooking) such as crop residues, dung, biogas, fuelwood, and bought fuels such as kerosene and LPG should at least be equal to the cooking energy requirements.

Wood Balance:

There are three ways of obtaining fuelwood: from homesteads, forests and plantations. This supply should be greater than or equal to the allocation of fuelwood for cooking.

Biogas Conversion Balance:

The total quantity of biogas produced (which is specified exogeneously) should be greater than or equal to the allocation of biogas for cooking.

Kerosene Balance:

The total quantity of bought kerosene should be at least equal to its allocation for cooking. Similar equations can be written for other bought fuels, such as LPG or electricity. The requirements of LPG and electricity are exogeneously specified while the demand for kerosene is determined endogeneously by the model.

This model has been extensively applied to various locations with a view to understanding their characteristics and to predicting the impact of different policy alternatives that may be considered for their development.

Thus. RES models estimate the share of the energy sector in receiving different allocations of various rural resources. However, the RES models have not considered the distribution of these resources to various energy end-uses. Such distributions are usually carried out using the REP models, which are described next,

3. THE RURAL ENERGY PLANNING MODEL FOR OPTIMUM ENERGY RESOURCES ALLOCATION

The REP models examine the locally available energy resources along with the traditional fuels for providing optimum energy resource allocation (Codonietal., 1985). REP models are usually linear programming (LP) models of energy supply with cost minimization as the objective. They take into account the resource constraints with respect to supply, efficiency and cost,

The format of a representative REP model is shown in Fig. 2 (Joshi et al., 1991). The following are the salient features of this model.

The Objective Function:

The objective function usually involves the minimization of the total economic cost of meeting the demands of the energy end-uses in different end-use devices of the energy resources for a given year.

Constraints:

There. are two types of constraints.

Demand Constraints:

These constraints require that the amount of energy released in different end-use devices should meet the energy demand of the individual end-uses.

Supply Constraints:

The total usage of energy resources is constrained by their individual availability.

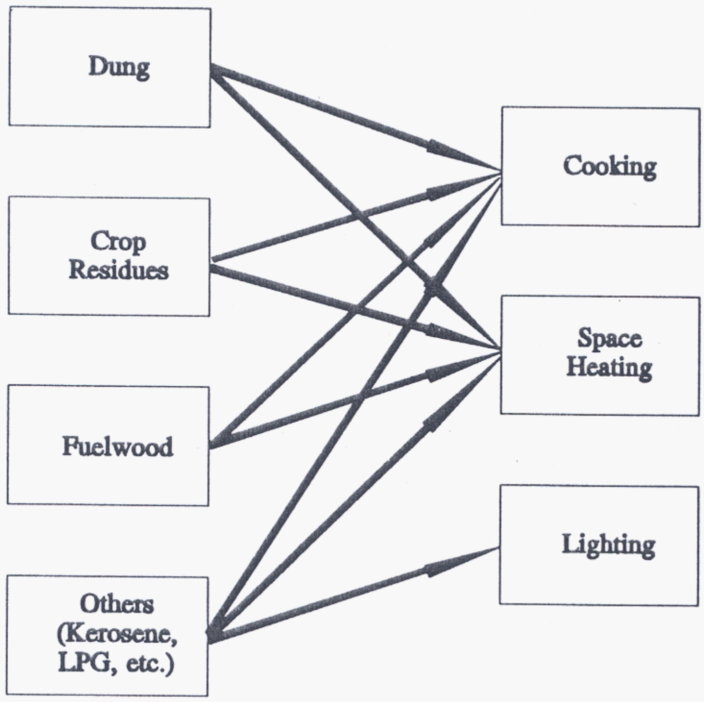


Fig. 2. A rural energy planning model.

On the basis of the objective function and other constraints, the REP model distributes the energy resources to different end-uses.

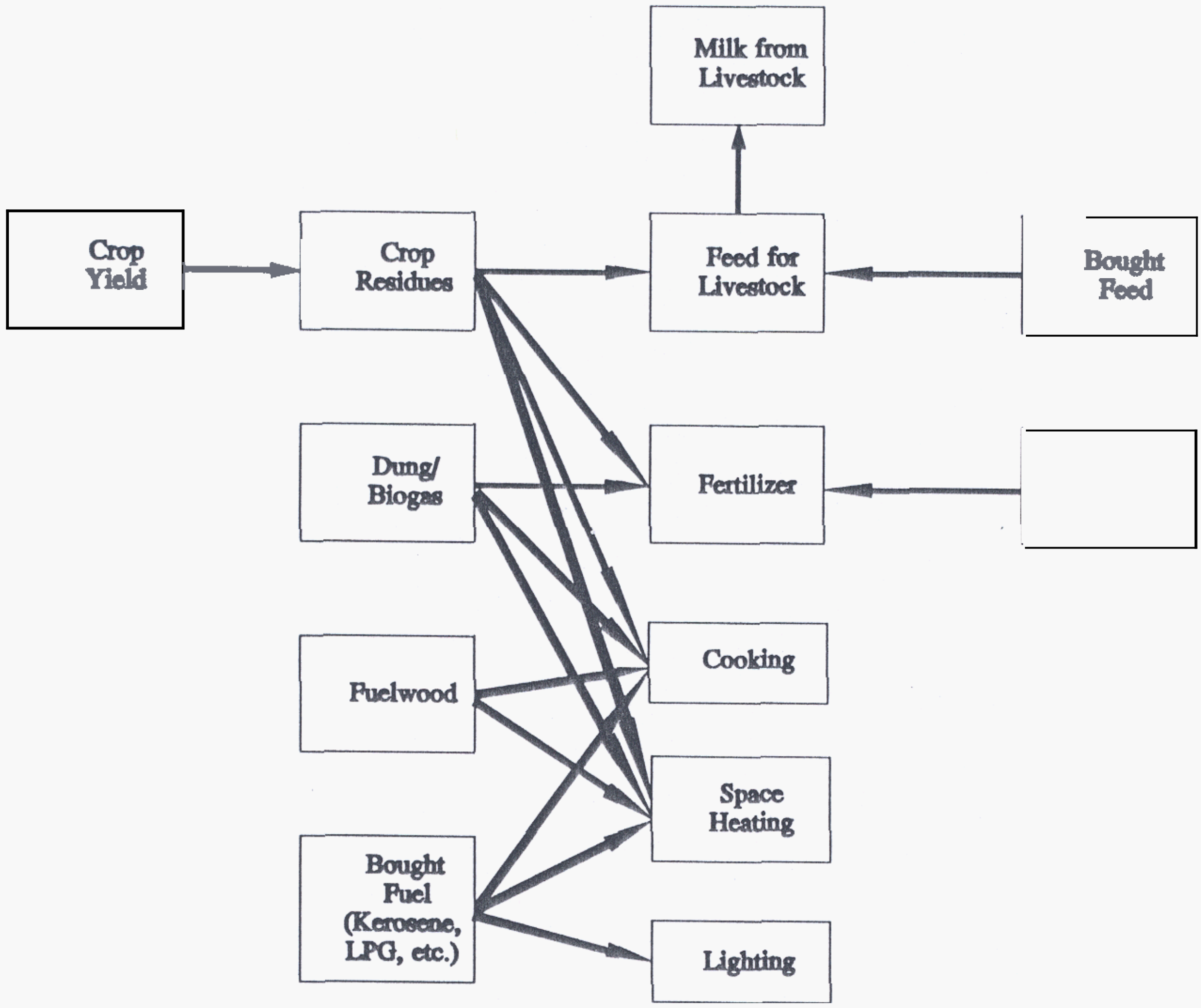
These models ignore the existence of the interactions between the energy and agricultural sectors. They usually assume a specific percentage of the individual resources as the share of the energy *sector,* and then *carry* out the optimal energy resource allocation. For example, Joshi et al. (1991) have assumed that 55% of the available crop residues would be used for meeting energy needs. Clearly, such assumptions may not be correct, and incorporation of a rational mechanism for estimating the shares of various rural resouces for the competing sectors will improve the quality of the models for rural energy planning. As the RES models do exactly the same, this paper proposes the integration of the RES and REP models for providing efficient energy planning for rural areas. The integrated model is described in the next section.

4. THE INTERGRATED RES-REP MODEL

The integrated RES-REP model uses the RES model for estimating the proportion of individual rural resources available for the energy sector, and then employs the REP model for providing the optimal energy resource allocation. Figure 3 explains the integrated model. The salient features of the model are discussed below.

The Objective Function:

The objective function of the integrated model is obtained by combining the objective functions of the individual models. Thus the new objective function involves maximization of the net revenue (the objective function of the RES model) minus the total economic cost of allocating the energy resources to the end-uses (the objective function of the REP model).



Constraints:

The integrated model employs the constraints of both the RES and REP models. Thus it has equations representing the necessary resource balances (such as the crop-residue balance) and the demand constraints of the energy end-uses. The supply constraints of the resources will be taken into account in the form of the respective balances.

Though the integrated model is applicable to any region, it is especially suited for rural areas where the interactions between the energy and agricultural sectors is more pronounced. The following section illustrates the application of the integrated model to a typical village in Nepal.

4.1 Application of the Integrated Model – An Illustration

The integrated model has been run using data obtained from Joshi et al. (1991) (denoted as "Joshi" for the remainder of this section) on the Baijnathpur village in the Terai region of Nepal. These choices have been made just for facilitating the comparison of the results of the integrated model with the REP model.

Relevant data representing the village for the integrated model have been directly taken from Joshi. These include the crop area, household expenditure, primary energy requirements. and the availability of various resources. However, the integrated model required several more parameters which could not be directly obtained from Joshi. Hence the parameters of the model were adjusted so that it provides output comparable to the relevant data for the Baijnathpur Village. Several repeated runs of the model were required. For example, after the trial runs, the model provided outputs such as livestock unit, agricultural production, agricultural land, forest area, etc. which were approximately equal to the values shown in Joshi. This exercise is needed to ensure the correctness of the allocations of the rural resources to meet the fuel, fodder and fertilizer needs as provided by the model, and is a usual procedure in validating RES models. In addition, some more data, such as the prices of crops.' milk, and energy resources, have been assumed based upon the average figures for a normal Indian village. After all the adjustments are made, the model was run and the results are shown in Table 1. The results obtained by applying the REP model (as given in Joshi) are also shown in the same table for comparison.

It is clear that the integrated model has allocated only about 37% of the crop residues for energy purposes, in contrast to the 55% as assumed in Joshi. Similarly, only 16% of the crop residues have been used as fodder, against the 45% as assumed in Joshi. The corresponding percentages for fertilizer are 44% and 0% respectively. Similarly, while Joshi assumed that all the dung will be available for energy purposes, the integrated model has allocated most of it for use as fertilizers as this happens to be a more beneficial use of dung. Because of the reduced allocation of crop residues and dung for energy purposes, the share of kerosene in the total energy demand has increased (to 68% in the integrated model, against only 5% in Joshi). Due to the same reason, fuelwood has also been similarly allocated in the integrated model.

As several data have been assumed, the results presented here may not be accurate. However. these results have successfully illustrated the utility of the integrated model for energy planning.

Table 1. Results of the integrated model.

	Integrated Model %	REP Model %
Crop Residue Balance		
Fuel	31	55
Feed	16	45
Fertilizer	44	–
Others	3	–
Dung/biogas Balance		
Fuel	0.37	100
Fertilizer	99.63	–
Fuel Balance		
Crop Residue	25.00	66.00
Dung/biogas	0.15	25.00
Fuelwood	3.85	–
Kerosene	68.00	5.00
Electricity	3.00	3.00

5. SUMMARY

In this paper, an integrated model has been developed for providing efficient rural energy planning after considering the interactions between the energy and agricultural sectors. It has been pointed out that the previous rural energy planning models did not possess a rational mechanism for the allocation of rural resources for the various end-uses in the energy and agricultural sectors. The integrated model has overcome this problem by using the rural energy system models developed for accounting the rural energy and agricultural interactions. The integrated model has been applied using data for a typical village as an illustration. It is hoped that the integrated model enables more efficient planning for rural areas.

REFERENCES

1. Ashenayi, K. and R. Ramakumar **(1990).** IRES - A Program to Design Integrated Renewable Rural Energy Systems, ***Energy – The International Journal,* 15(12), 1143-1152.**
2. Codoni, Rene, Park, Hi-chun and K.V. Ramani **(1985).** ***Integrated Energy Planning: A Manual, Vol.I, Energy*** Data, ***Energy Demand,*** Asian and Pacific Development Centre, Kuala Lumpur.
3. Joshi, Bharati, T.S. Bhatti, N.K. Bansal, K. Rijal and P.D. Grover **(1991).** Decentralised Energy Planning Model for Optimum Resource Allocation with a Case Study of Domestic Sector of Rurals in Nepal, ***International Journal* of *Energy Research,* 15(1), 71-78.**
4. Joshi, Bharati, T.S. Bhatti and N.K. **Bansal (1992).** Decentralised Energy Planning Model for a Typical Village in India, ***Energy – The International Journal,* 17(9), 869-876.**
5. Painuly, J.P., Jyoti K. Parikh and D.R. Shah **(1992).** Rural Energy System and Agriculture: Alternative scenarios for Gujarat, ***Economic and Political Weekly,* 27(34), 1801-1809.**
6. Painuly, J.P., Hemlata Rao and Jyoti K. Parikh **(1995).** A Rural Energy-Agriculture Interaction Model Applied to Karnataka State, ***Energy – The International Journal,* 20(3), 219-233.**
7. **Panesar,** B.S., A.P. Bhatnagar, Jyoti K. Parikh and J.P. Painuly **(1989),** ***Modelling of Energy and Agricultural Interactions: A Case Study of Punjab State,*** **Indira** Gandhi Institute of Development Research, Bombay.
8. Parikh, J. **(1985).** Modelling Energy and Agriculture Interactions-I: A rural Energy Systems Model, ***Energy – The International Journal,* 10 (7), 793-804.**
9. Parikh, J. and G. Kromer **(1985),** Modelling Energy and Agriculture Interactions-II: Fuel-fodder-food-fertiliser Relationship for Biomass in Bangladesh, ***Energy – The International Journal,* 10(7), 805-817.**
10. Parikh, Jyoti K. **(1988).** Bangladesh: Agriculture, Biomass, and Environment, In: J.K. Parikh, ***Sustainable Development in Agriculture,*** Martinus Nijhoff Publishers, Dordrecht, **pp:331-364.**
11. Ramakumar, R., P. Sudhakara Shetty and K. Ashenayi (1986), A Linear Programming Approach to the Design of Integrated Renewable Energy Systems for Developing **Countries,** ***IEEE*** Transactions ***on Energy Conversion,* EC-1(4), 18-24.**
12. Ramakumar, R., I. Aboozahr and K. Ashenayi **(1992),** A Knowledge-based Approach to the **Design of Integrated Renewable Energy** Systems, ***IEEE Transactions on Energy Conversion***, 7(4), **643-659.**
13. Singh, R.P., J.P. Painuly, Jyoti Parikh and Chandra Sen **(1992).** Rural Energy and Agricultural Interactions in **2000** A.D.: A Study of Uttar Pradesh, ***Indian Journal of Agricultural Economics,*** **47(4), 601-617.**

14. Sinha, Chandra Shekhar and Tara Chandra Kandpal, (1991a), Optimal Mix of Energy Technologies for Rural India: The Cooking Sector, *International Journal of Energy Research,* 15(2), 85-100.
15. Sinha, Chandra Shekhar and Tara Chandra Kandpal (1991b), Optimal Mix of Energy Technologies for Rural India: The Irrigation Sector, *International Journal of Energy Research,* 15(4), 331-346.
16. Sinha, Chandra Shekhar and Tara Chandra Kandpal (1991c), Optimal Mix of Energy Technologies for Rural India: The Lighting Sector, *International Journal of Energy Research,* 15(8), 653-665.
17. Sinha, Chandra Shekhar and Tara Chandra Kandpal (1992), Optimal Mix of Energy Technologies for Rural India: Combined Model for Cooking, Irrigation and Lighting Sectors, *International Journal of Energy Research,* 16(2), 119-127.
18. Subash, C. and P.S. Satsangi (1990). An Integrated Planning and Implementation Strategy for Rural Energy Systems, *Energy – The International Journal,* 15(10), 913-920.
19. UN (1989), *Energy Issues and Options for Developing Counties,* Taylor & Francis, New York, 234-244.