The Vulnerability of the Electrical Sector to Natural Hazards in Costa Rica

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Introduction for Presenters

This case study of the vulnerability of the energy sector in Costa Rica to natural hazards covers the essential points of a first analysis of alternative strategies for mitigating the impact of natural hazards on the sector. It describes the possible negative impacts of events such as earthquakes, landslides, floods, drought, and volcanic eruptions, and presents for discussion possible mitigation measures for the sector to protect itself and deliver reliable service to its customers.

Although further study at the feasibility level and implementation of mitigation measures for the sector are still on-going in the country, this case nevertheless presents a number of aspects that make it of substantial interest for examination and for teaching purposes.

First of all, with the beginning of the International Decade of Natural Disaster Reduction (IDNDR) as proclaimed by United Nations General Assembly Resolution 44/236, efforts at disaster prevention should receive more prominence, for such activities presently form the minor part of natural hazard management in developing countries. The theory and practice of incorporating natural hazard mitigation into integrated development planning, such as proposed by the Organization of American States, have received less attention than necessary, and disaster prevention as supported by UNDRO has had to focus on post-disaster emergency situations given recurring destructive events worldwide. This case presents an opportunity for the teaching staff and participants to discuss disaster prevention in a non-crisis context. Senior policy makers might be asked to consider what courses of action they would recommend to mitigate the impact of natural hazards under existing conditions. This type of discussion is relevant in numerous countries.

Secondly, the case of Costa Rica is sufficiently complex to illustrate that there are several courses of action given the makeup of the sector and scope of consumers, and also that it is the interplay between the composition of a service sector and the demands placed on it that complicate the choice of action. As such it allows the participants to discover and discuss several viable courses of action depending on the governing policy orientation.

Thirdly, the case of Costa Rica is rich in available data due to continuing attention to management of the sector. The case has many interesting characteristics, such as the fact that Costa Rica has one of the most extensive electrical energy networks of any developing country and a full 50% of electrical energy consumption resides with the residential and commercial groups, thereby tying the sector's natural hazard vulnerability directly to overall social well being. As other countries strive to achieve high levels of residential and commercial consumption of electrical energy, their increased dependence on the sector and the sector's vulnerability to natural hazards are a subject that should shape policy decisions affecting the development of the sector.

Lastly, mitigating the impacts of natural hazards on the sector is a need to be met with finite resources in a way that demonstrates investment efficiency within the sector. The proposed mitigation actions identified in the case are at the profile level and the discussion should center on which mitigation action should be taken to the feasibility level, a task which implies dedication of additional scarce resources, and perhaps the eventual collaboration of an international development funding source.

This case does not explore the evaluation of mitigation measures for the energy sector as a competitive exercise with other sectors for there exists little theory and less practice in simultaneously evaluating natural hazard impact reduction measures in all sectors at the same time to choose the most efficient among them. But intrasector consideration of possible disasters caused by natural events must become more common as both international and national development assistance agencies focus on the self-sufficiency and security of investment in sectors dominated by public and quasi-public control.

The question therefore arises in the Costa Rican case as to what natural hazard mitigation strategy to select since different strategies achieve different, sometimes competing purposes. To what extent should the chosen strategy be as broad as possible to address simultaneously the major concerns of the sector itself (investment, income) as well as those related to energy consumers (employment, export earnings)? Do effective strategies need to be so specific as to leave out vulnerability reduction of one geographical area or one consumer group? And what criteria other than economic efficiency may have to be introduced to evaluate proposed strategies if political and technical issues are to be resolved?

The strategies to reduce the vulnerability to natural hazards used thus far in most developing countries are most evident in the structural design and construction of new investment projects in the energy sector. Yet much of the existing vulnerability has been inherited from projects undertaken when less attention was given to such aspects during the project preparation cycle. Participants must consider the dynamic aspect of natural disaster vulnerability as the physical environment of the sector is modified. They must also consider the trade-offs between addressing high probability minor losses and low probability catastrophic damage

This case will be enriched by additional data as the country finds support for implementing chosen mitigation strategies, and by the preparation of comparative cases after similar analyses are done for other sectors and documented in other countries.

Possible Conclusions

One of the first conclusions to be noted from the case study of energy sector vulnerability to natural hazards in Cost Rica is the necessity of examining the objectives of a mitigation strategy. The results of implementing a strategy may be very highly focused in terms of location, energy source affected, and consumer group benefited. Selecting the appropriate strategy among alternatives depends on the desired outcome.

Of equal importance, competing claims for protecting the investment of the sector or its income, or protecting employment or export earnings may be made when considering which strategy to implement. While the effect of different strategies may be obvious, it may be difficult to calculate their costs and benefits in detail. This is due to the often rudimentary nature of the probability information available concerning the occurrence of natural hazards and the complexity of calculating indirect losses.

Developing countries such as Costa Rica wish to expand their energy infrastructure to include a greater portion of their population in petroleum derivative and electrical energy consumer groups. As they achieve this goal, the impact of natural disasters on economic and social well-being through damage to the energy sector will become more apparent and more complex to determine. Thus, detailed information as to the source and use of energy as related to location, investment cost, income generation, employment support, and export earnings becomes increasingly important.

Countries may choose to focus attention on more appropriate design of new investment projects; on reducing the vulnerability of the existing energy system by duplicating infrastructure elements (redundancy); by retrofitting existing elements, and by providing alternative infrastructure; or on modifying the natural event so that it presents less danger. In general, these three mitigation approaches are in order of ascending cost and decreasing efficiency. Quite often much needed vulnerability reduction can be achieved through routine maintenance and repair programs, or through providing redundancy in the

Whatever the approach, disaster reduction measures stand the best chance for approval is they are integrated into sector development programs. This challenge faces of unmet capital investment needs, demands for more extensive and efficient cost recovery, and shifting sources of financial support.

Finally, the Costa Rica case demonstrates that when the energy sector is to serve a dominant urban area with a large population concentration, and a significant portion of energy consumption is in the residential and commercial groups, vulnerability reduction strategies must be viewed increasingly in terms of the natural hazard source and the mitigation actions taken by other possible energy generation and distribution sources, particularly those in the private sector

Topics for Discussion

It is suggested that the presenter facilitate discussions about the content of the specific case study on Costa Rica by covering the following questions:

Relative to the objectives of the mitigation analysis, has the problem been adequately analyzed?
- Where are the weaknesses in the analysis?
- What should be done to correct them?

Are the events appropriately selected?
- What other events, if any, should be analyzed?

Are the proposed mitigation actions properly selected and analyzed?
- What other mitigations, if any, might be considered?

What national mitigation strategy might be suggested for Costa Rica?

What institutional mechanisms might be suggested to implement this strategy?

Should this analysis be repeated on a regular basis in Costa Rica? By whom?

What differences would you expect in the analyses and conclusions in countries other than Costa Rica?

Section 1
Overview of Hazard Vulnerability Identification and Reduction Strategy Method

1.1 Background

The catastrophic damages caused by the 1987 earthquake in Ecuador has helped the energy sector focus more attention on the impact of natural hazards on energy supply. Two factors that influenced the destructiveness of the event are the economic dependence of the country on petroleum export (60% of export earnings), and unprecedented destruction of the energy distribution network. It has been estimated that the direct costs of the earthquake for the energy sector was more than US$120 million, and that the total costs surpassed US$890 million due principally to the loss of export earnings. The physical damage appears to have surpassed that of any other natural disaster in the history of energy sector development.

There exist other relationships between the energy sector and natural disasters that are less obvious than those in the Ecuador case. At the local level, energy supply to every citizen can be interrupted by an earthquake, volcanic eruption, tsunamis, landslide, storm, flood, drought, fire or hurricane (typhoon or cyclone) in the affected area.

The energy sector forms part of a nation's, or city's lifeline network (critical facilities). These are the facilities in the energy, transportation, communications, health, and public safety sectors that should function properly before, during, and immediately after an emergency. These facilities also form part of the basic and service infrastructure for development. The best way to reduce the vulnerability of the critical facilities to natural disasters is to include mitigation measures in the design and implementation of infrastructure projects.

This case study examines the relationship between the energy sector and natural hazards. It focuses on the aspects of energy consumption by type and location, and of the sector's infrastructure including extraction, generation, transport, storage and distribution. It presents a method of analysis to define the essential components of the sector, their vulnerability to hazardous events, and examine different mitigation strategies. The selected mitigation strategy or strategies can be incorporated into the sector's development plan, and into natural disaster emergency preparedness and response plans

1.2 Objectives

The objective of this case study is to analyze the vulnerability of the energy sector at a national level, in this case Costa Rica, and to select among alternative disaster mitigation strategies those most suitable for implementation.

Formulating the basic elements of such a strategy will necessitate an understanding of the relationship of the sector to natural hazards in not only its locational, functional and structural characteristics, but more importantly, in terms of what goals the mitigation strategy is to achieve. Choices must be made among alternative strategies which address comparable, parallel or even competing goals. These goals reflect possible priorities within the sector as well as those placed on it from the outside. They also reflect differences between technical, economic, social and financial concerns which help shape the priorities.

1.3 Analysis of Energy Sector Vulnerability

The type of analysis presented here is usually the first analysis of the vulnerability of the sector. It uses available information, without elaborating further data as to the location, severity, frequency and probability of the natural events that present hazards. These are the basic characteristics of natural hazards that are of interest to the analysis. Often only locational data and information concerning historic events (with some estimate of severity) are available. For geologic hazards (earthquakes, tsunami, volcanic eruptions, landslides, subsidence and liquefaction), locational information is becoming increasingly accessible for certain regions of the world. Data for analysis of atmospheric and hydrologic hazards (hurricanes, wind storms, floods, drought) and related events such as desertification and insect infestations are also becoming more common, depending on the geographical area of interest. But still, there is less information for use by non-hazard specialists than one would hope.

The analysis is comprised of the following:

1. The definition of the principal components (or sources) of the energy sector infrastructure and the elements (or pieces) which make up each component.
2. The vulnerability of the those components to natural events.
3. The identification of mitigation strategies to reduce the impact of the disaster on a component (or one of its elements).
4. The review of mitigation strategies in accordance with predetermined criteria as to strategy goals.
5. The analysis of the costs and benefits of the mitigation strategies compared with the costs if the strategies are not implemented.

The components or sources of energy to be considered in such an analysis are petroleum and it derivatives, electrical energy with its hydro and thermal generation, firewood and charcoal, and biomass derivatives. Depending on the particular country or portion thereof, secondary energy components such as solar, wind, and geothermal may also be considered, although their contribution to sector supply and infrastructure investment are most often minimal.For the analysis, the elements or pieces of each component are considered. These include extraction and generation, transformation, transmission and transport, storage, and distribution. Obviously some of these elements represent a dependency on other sectors, as in the case of energy transport and the transportation modes of road, rail, river barge and ocean tanker.

The analysis of the vulnerability of the components and their elements begins with a comparison of their respective geographic location in different natural hazard zones according to the type of natural hazard present. This phase of the analysis is based on the utilization of available information concerning natural hazards. The sources of this information are from diverse origins such as the energy sector itself, other operational sectors, scientific research and natural phenomena monitoring centers, and integrated development planning studies. The last source mentioned is becoming increasingly important as development studies consider in more detail and earlier in the planning process the use of natural hazard management information

When information concerning all types of natural hazards that affect the area in question (multiple hazards map) is available, it should be compared with the entire energy sector network with all its components and elements. In this way the possibility of missing some vulnerable element is overcome, including those elements or components that may not make up part of the lifeline network or group of critical facilities.

It is also possible to begin the analysis by first describing the sector and its components, and identifying those elements most crucial to its operation. Then a review is made to see to what degree those elements are vulnerable to natural hazards.

Whichever approach is used, the analysis should concern itself with the location, severity, and frequency of the natural hazards, and a quantitative and qualitative description of the expected impact, and the probability of occurrence of the event. This phase can also contribute to the setting of an agenda for priority future studies of natural hazards, whatever the type of hazard, geographical location of the study, or level of hazard assessment required.Once the components and elements susceptible to natural hazards are identified, a vulnerability reduction strategy can be defined. For the existing components, it may be that structural measures such as reinforcing of physical installations are the most appropriate. If the study includes elements to be constructed, non-structural measures such as locating these elements in less vulnerable areas, can play a major role in the mitigation strategy. The repetition (redundancy) of critical elements of the network can also play a role in the mitigation strategy.

The selection of a mitigation strategy should respond to certain criteria which reflect the goals of the sector. It is probable that the sector will not have sufficient financial resources to attend to all of the vulnerability reduction actions needed at one time. If this is the case, the selected mitigation strategy should be oriented towards specific goals, and their selection should reflect the priorities accepted from among those presented by interested groups.

For the energy sector, the definition of those criteria should include two aspects related directly to the protection of the sector itself. They are maximum protection of the capital investment of the sector, and the maximum protection of the those components and elements of the energy network which generate the greatest amount of income for the sector, regardless of the users serviced. Two other aspects that frequently require consideration to determine which mitigation strategy should be followed are protection of those portions of the energy network which will limit to the greatest extent possible the loss of jobs in other sectors, and the protection of the energy network to assure to the greatest extent possible the generation of foreign currency earnings, whether through the sale of goods and services overseas (exports), or in the country (tourism, for example).

Decisions about vulnerability reduction to natural hazards may reflect similar decisions to be made about the rationing of energy during other types of emergencies.

The protection of the energy network to maintain the maximum national employment and foreign currency earnings may imply similar actions. In other situations, actions that assure the availability of energy to one or another energy user group may be inconsistent with the need to protect foreign currency earnings

This is reflected in more complex economies. In smaller economies or those less complex, the sector which generates the greatest foreign currency earnings often also offers the greatest number of jobs.

Once the mitigation strategy is selected based on the vulnerability reduction goals of the sector, the costs of anticipated losses without implementing the strategy can be compared with the costs and benefits of implementing it. The methods of analysis of benefits and costs vary as to their requirements for information and to their sensitivity to the particular hazard in question, particularly to the speed of on-set, and to the probability of occurrence of the event. The strategy can appear as part of a broader plan of new investment in the sector, as part of a cyclical repair and maintenance plan, or as part of a specific natural hazard vulnerability reduction program.

Section 2
Methodology

Figure 1 is a flow diagram which depicts the principal components of the methodology used in this analysis.

The analysis begins with a review of the Costa Rican energy infrastructure and its use as seen through the evaluation of energy flows. The year 1988 has been used as the model year for all energy and economic information from which the impact analysis is based.

The energy infrastructure has its own critical components, that is, components which are essential to the supply of energy to certain areas in the country. These are identified.

Natural hazards are then introduced. Each component of the entire energy infrastructure is evaluated with respect to its own vulnerability to natural hazards.

With this combined information, it is easy to identify the components of national energy systems that are both at risk to specific natural hazards and that, if lost, would cause serious impacts on the country. In the diagram, this step is identified in the box called Critical Natural Events.

In this study, three of these events were selected for more detailed analyses. Events 1 through 3 consist of the occurrence of one or more specific natural events and the consequent damage to one or more energy infrastructure components.

Steps to reduce vulnerability are designed to mitigate the impacts of certain events to achieve certain goals These goals include the protection of investment, income, employment and foreign exchange earnings. As a result the following measurements of impacts were made for each of these events:

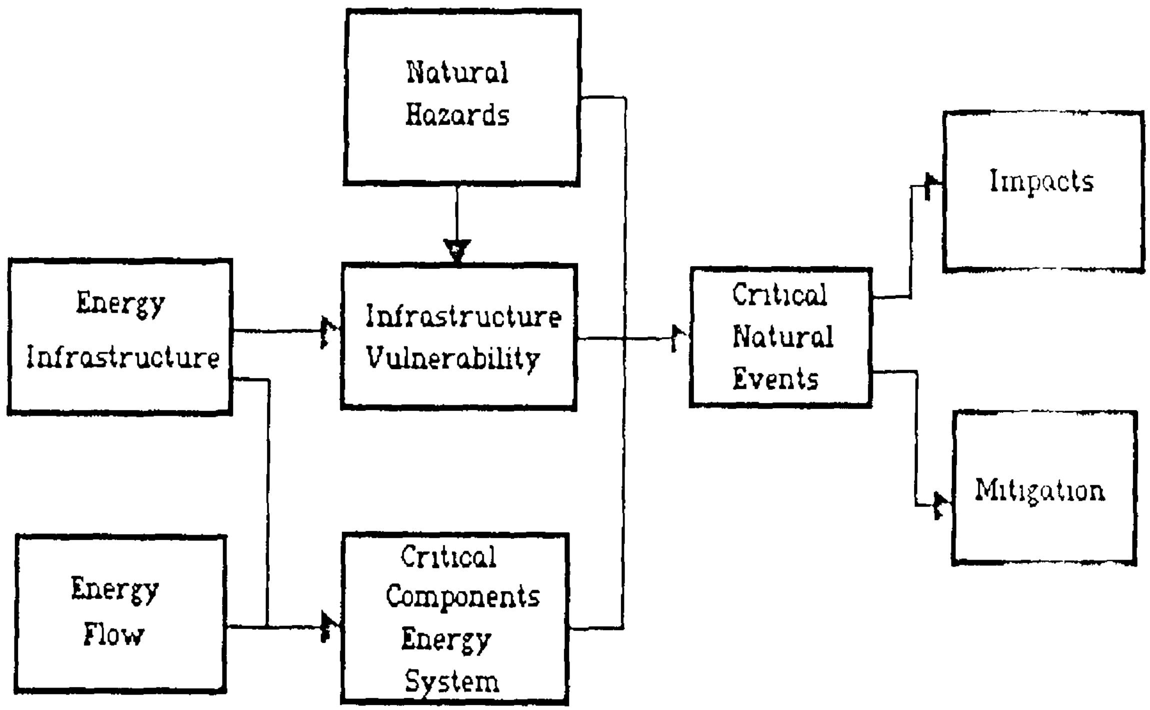
- Costs of repair of the destroyed infrastructure
- Costs for the provision of replacement energy
- Costs of lost production
- Costs of lost exports
- Hours of lost labor

The first two of these measures are costs to the energy companies which in the case of Costa Rica are national government entities, and as such, represent government financial losses.

The last three of these measures require additional analyses. The national economic and labor accounts of 1988 were disaggregated to the canton level for production, exports and labor for the agriculture and industrial sectors[1] For

[1] These two sectors were selected because of data availability and the fact that they represent a large portion of national production. Also, these two sectors cover the majority of exports. In future analyses, it will important to extend the analysis to include other components of national accounts, especially the commercial and transportation sectors.

Figure 1. Impact of natural hazards on the energy system of Costa Rica



Source: OAS - DSE

production, these sectors represent about 40 percent of the total gross domestic product.

This level of aggregation provided a mechanism for evaluation of a portion of the impacts of shortfalls of energy caused by geographically-specific damage to the energy infrastructure. Fuel dependence coefficients (electricity and petroleum) were assigned for each of the 89 classifications of agricultural and industrial activities. Total losses (production, exports, or labor) were calculated by multiplying canton output in that activity by the appropriate coefficient, summing across the cantons affected, and then summing across all the 89 activities.

To complete the methodology, for the three events selected, an effort was made to identify investment projects that would be effective in mitigating or eliminating the negative impacts of the specific selected events. The costs of these projects are then compared against the costs of the impacts of the events without these projects

Section 3
The Energy Sector Infrastructure and Its Operation

This section provides a brief overview of the Costa Rica energy infrastructure and its use in 1988. The reader is encouraged to review this information from the perspective of energy system weakness, that is, to seek:

1. Energy system components with high energy flows that do not have adequate alternatives in case of their failure; and,

2. Components that are "bunched" geographically that might imply a compounded incident involving several fuel sources arising from just one natural event.

The energy infrastructure is subdivided into electricity network, petroleum network, railroad and road components Normally roads and railroads are not considered a part of energy infrastructure. In Costa Rica, both are used for the transport of liquid fuels and are therefore included in this analysis at a level consistent with their importance to the question at hand. It should also be noted that other fuels such as LPG, fuelwood, and charcoal, are not included in this analysis because of their minimal use in Costa Rica.

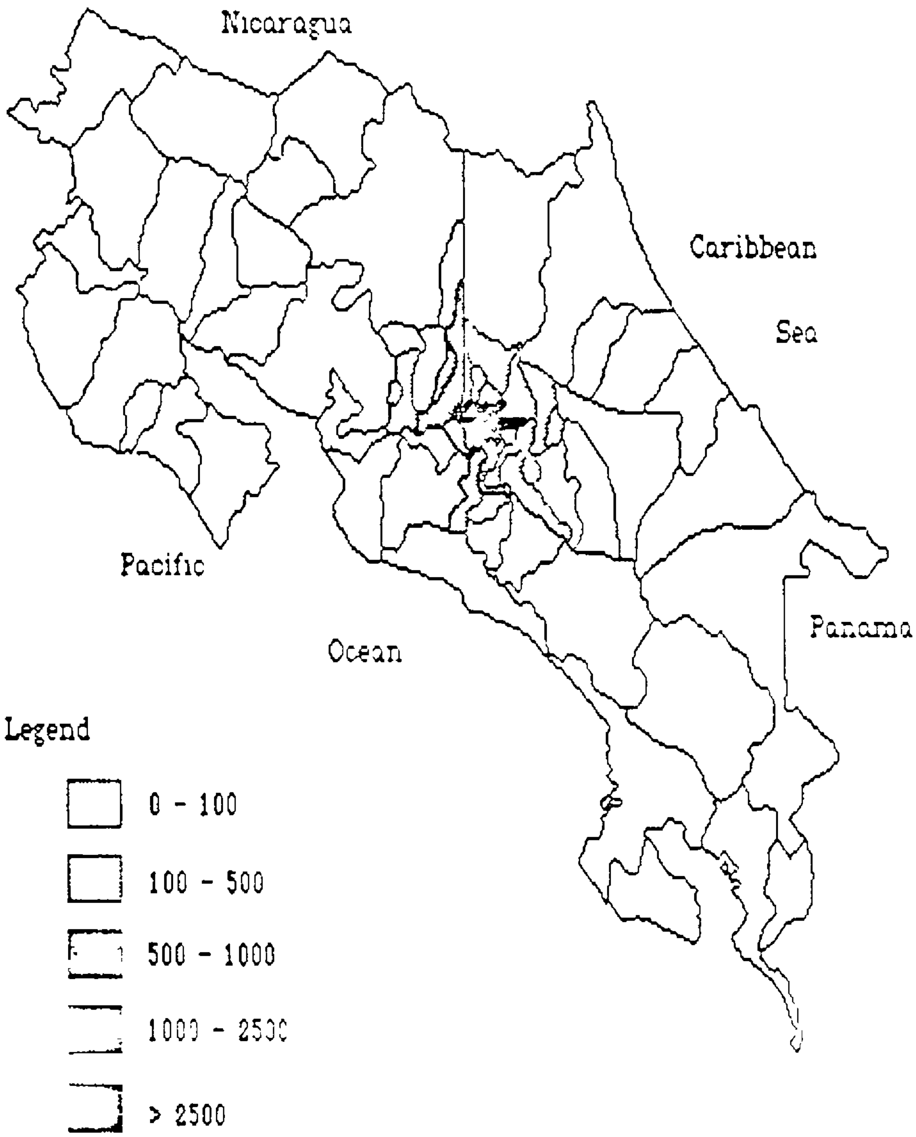
Energy infrastructure is organized to satisfy the energy needs of the population and its activities. One of the first requirements in the analysis is to select a level of aggregation of the population, its activities as well as the geographical coverage of the country to permit a meaningful yet efficient analysis. What is needed is a balance between the likely geographical specificity of a natural event and the level of statistical information that the energy and economic institutions maintain in a country. In Costa Rica, the level of aggregation selected is the canton. Costa Rica has 81 cantons distributed among seven provinces.

Map 1 describes the distribution of population density across these 81 cantons. The presentation vividly depicts the centralization of the population of Costa Rica in and around its capital, San José in the Central Valley.

3.1 Costa Rica 1988 Energy Demand

Table 1 summarizes the distribution of energy sales by fuel type across the seven provinces and 81 cantons for the year 1988. The cantons that comprise the highly populated area in the Central Valley account for approximately 62 percent of all the country's purchases of electricity, 70 percent of the gasoline, 54 percent of the diesel, and 84 percent of the fuel oil. This breakdown is consistent with the location of industrial, commercial, and residential uses of the Central Valley compared with the agricultural focus of more rural areas, which depend heavily on diesel fuel.

Map 1. Population density (*inhabitants per km²*)



Source: OAS - DSE

Table 1. Electricity and petroleum derivatives sales by canton, 1988

Province		Canton	MWH	Gasoline BBL	Diesel BBL	Kerosene BBL	Fueloil BBL
San Jose	S1	CANTON CENTRAL	596826	463109	630713	21782	677649
	S2	ESCAZU	60137	28990	12614	0	2668
	S3	DESAMPARADOS	105526	22208	31554	12	8445
	S4	PURISCAL	12201	6786	16620	0	0
	S5	TARRAZU	4257	0	0	0	0
	S6	ASERRI	19396	9462	11429	0	1400
	S7	MORA	8257	6298	10167	262	0
	S8	GOICOECHEA	126958	83491	131060	16629	18859
	S9	SANTA ANA	23863	11486	12929	429	568
	S10	ALAJUELITA	25109	0	0	0	0
	S11	VAZQUES DE CORONADO	29603	10548	13502	0	913
	S12	ACOSTA	3618	821	2512	0	0
	S13	TIBAS	91604	53091	91272	0	36770
	S14	MORAVIA	41992	21168	12786	0	746
	S15	MONTES DE OCA	84173	54855	18732	0	19568
	S16	TURRUBARES	973	0	0	0	0
	S17	DOTA	2076	8143	18562	107	0
	S18	CURRIDABAT	73933	27293	28435	3155	3044
	S19	PEREZ ZELEDON	37230	26789	70963	3857	578
	S20	LEON CORTES	2809	3512	3583	0	0
		SUBTOTAL	1350541	838050	1117433	46233	771208
Alajuela	A1	CANTON CENTRAL	180170	98504	139413	2087	116782
	A2	SAN RAMON	30742	17193	31521	262	273
	A3	GRECIA	35050	18812	42621	0	1283
	A4	SAN MATEO	1777	4164	5614	0	0
	A5	ATENAS	11857	6286	10191	167	0
	A6	NARANJO	20531	10996	25795	310	328
	A7	PALMARES	14478	9612	18342	381	0
	A8	POAS	8747	4191	12453	0	0
	A9	OROTINA	7244	2941	4893	214	0
	A10	SAN CARLOS	62289	31218	86504	993	163
	A11	ALFARO RUIZ	2825	3453	9822	71	489
	A12	VALVERDE VEGA	7942	3250	6608	0	723
	A13	UPALA	4060	2841	6884	938	0
	A14	LOS CHILES	2231	0	0	0	0
	A15	GUATUSO	1338	2357	7715	1238	0
		SUBTOTAL	391281	215818	408376	6661	120041
Cartago	C1	CANTON CENTRAL	159546	56472	116158	14031	236963
	C2	PARAISO	29831	8185	21096	0	5759
	C3	LA UNION	54311	12929	19610	393	3410
	C4	JIMENEZ	5253	0	2679	0	70
	C5	TURRIALBA	40368	15109	41844	660	0
	C6	ALVARADO	4418	1619	3857	0	93
	C7	OREAMUNO	18912	4357	11034	24	0
	C8	EL GUARCO	19484	2381	7441	0	3873
		SUBTOTAL	332123	101052	223919	15108	250168

Table 1. (cont.)

Province	Canton		MWH	Gasoline BBL	Diesel BBL	Kerosene BBL	Fueloil BBL
Heredia	H1	CANTON CENTRAL	93034	68881	63907	1219	2667
	H2	BARBA	16831	0	0	0	488
	H3	SANTO DOMINGO	33808	7046	9369	0	1750
	H4	SANTA BARBARA	13829	0	14143	1167	0
	H5	SAN RAFAEL	18214	0	0	0	0
	H6	SAN ISIDRO	6310	5470	17839	0	0
	H7	BELEN	138956	15284	26838	0	46540
	H8	FLORES	14283	0	0	0	23
	H9	SAN PABLO	12578	10882	6060	0	0
	H10	SARAPIQUI	9373	6448	15849	488	0
		SUBTOTAL	357216	114011	154005	2874	51468
Guancasta	G1	LIBERIA	32103	23326	66887	1088	396
	G2	NICOYA	16010	11221	21369	645	0
	G3	SANTA CRUZ	14911	8310	15102	470	0
	G4	BAGACES	5887	3088	7360	114	0
	G5	CARRILLO	15205	8927	28710	0	409
	G6	CANAS	14968	10968	41111	688	235
	G7	ABANGARES	42859	7850	16358	0	132705
	G8	TILARAN	13051	5312	11560	131	0
	G9	NANDAYURE	3553	3131	4179	167	0
	G10	LA CRUZ	4256	3747	9541	0	0
	G11	HOJANCHA	1903	0	0	0	0
		SUBTOTAL	164706	85880	222177	3303	133745
Puntarenas	P1	CANTON CENTRAL	112945	24555	125044	1393	40827
	P2	ESPARZA	21437	16375	44392	0	9984
	P3	BUENOS AIRES	7465	8915	30264	483	0
	P4	MONTES DE ORO	4425	0	0	12	0
	P5	OSA	6659	4688	15379	619	0
	P6	AGUIRRE	11726	6295	11567	0	0
	P7	GOLFITO	13465	7109	32259	702	0
	P8	COTO BRUS	12715	7326	21094	286	0
	P9	PARRITA	5598	3310	12617	655	0
	P10	CORREDORES	17760	9372	28149	536	0
	P11	GARABITO	5227	3238	3083	0	0
	SUBTOTAL		219422	91183	323848	4686	50811
Limon	L1	CENTRAL	84151	35299	83886	1729	8513
	L2	POCOCI	29132	19402	86565	1118	5416
	L3	SIQUIRRES	17623	7474	18404	417	0
	L4	TALAMANCA	5188	0	233	24	0
	L5	MATINA	8510	0	0	0	0
	L6	GUACIMO	8623	9214	33469	239	0
	SUBTOTAL		153227	71389	222557	3527	13929
	TOTAL		2968516	1517383	2672315	82392	1391370

Source: DSE

3.2 The Petroleum Industry

The principal petroleum activities and transactions in Costa Rica are controlled by the state-owned petroleum company, RECOPE. Costa Rica imports all of its petroleum supplies through the port at Moín located adjacent to the city of Limón on the Atlantic Coast. Crude oil passes to the RECOPE refinery in Moín producing a portion of the light products (gasoline, diesel, etc) as well as all of the fuel oil used by the country. The light products, either imported directly or proceeding from the refinery, are either distributed locally or transferred to the RECOPE pipeline for transport to petroleum terminals located across the country. Fuel oil is transferred to tank trucks or to railroad tanker cars for delivery to other parts of the country.

3.2.1 The RECOPE Product Pipeline

As shown in Figure 2, the RECOPE pipeline consists initially of two parallel lines starting at Moín and ending at the principal petroleum terminal at El Alto located near the continental divide to the east of San José. From here a single pipeline continues to the west, feeding the La Garita terminal near the international airport and Barranca, the final terminal located near the Pacific coastal town of Puntarenas. The pipeline system incorporates two pumping stations, one at Moín and the other in the town of Turrialba, approximately half-way up the eastern slope of the mountains.

All the pipelines are of 6" diameter except for 20 km of 4" line in the last stretch between El Alto and La Garita. Both pumping stations use one electric and four diesel motors, each with an equivalent capacity of 165 horsepower. Turrialba stores no less than 15 days of diesel supply for this purpose.

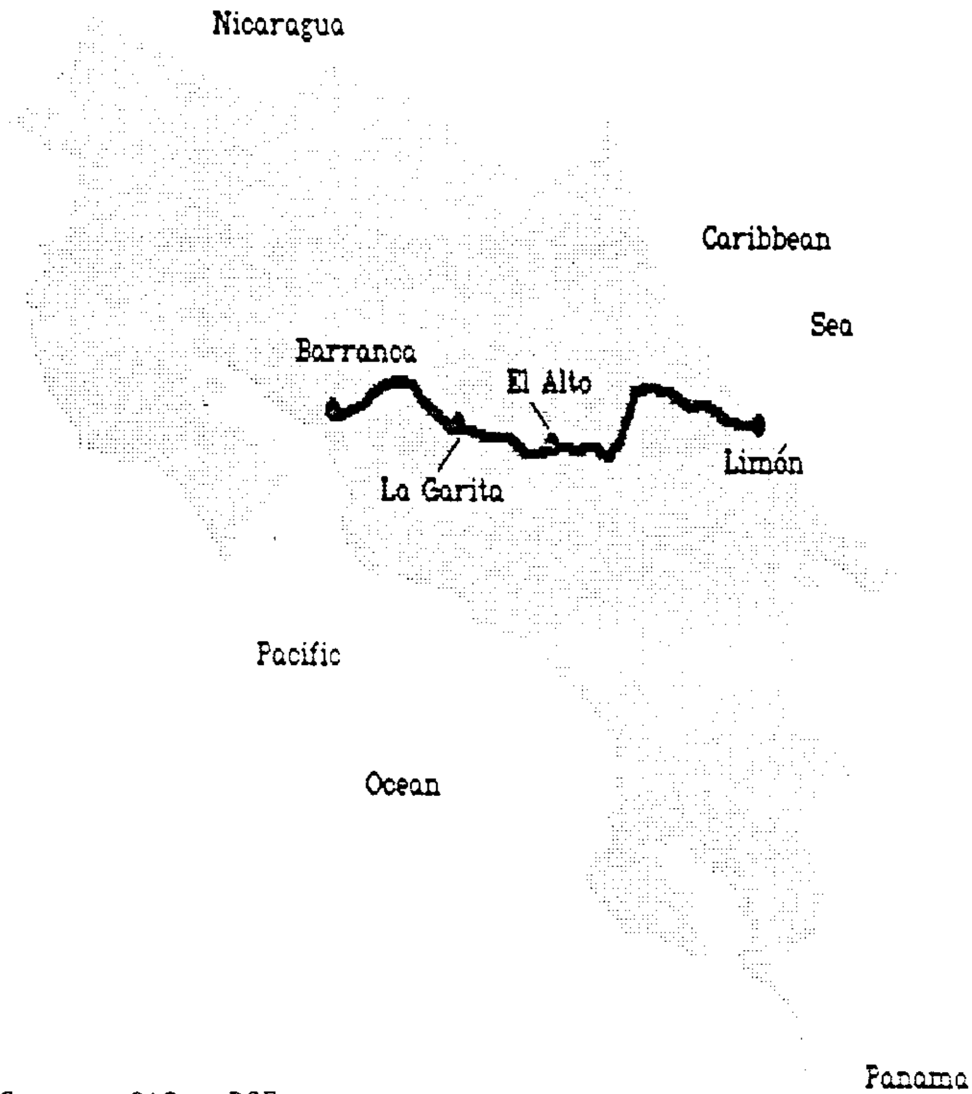
In full operation, the pipeline system between Moín and El Alto transfers approximately 550 barrels per hour depending on the product and the number of pumps and pipelines being used. RECOPE reports a system load factor of 78 percent. The only current limitations to pipeline operation are refinery production scheduling and the pipeline scheduled maintenance. The pipeline system has not experienced any forced outages since December 24, 1987.

Figure 3 displays the RECOPE statistics for the transfers of diesel, gasoline, jet fuel and kerosene through the pipeline system for the year 1988.

3.2.2 The Railroad and the Transport of Fuel Oil

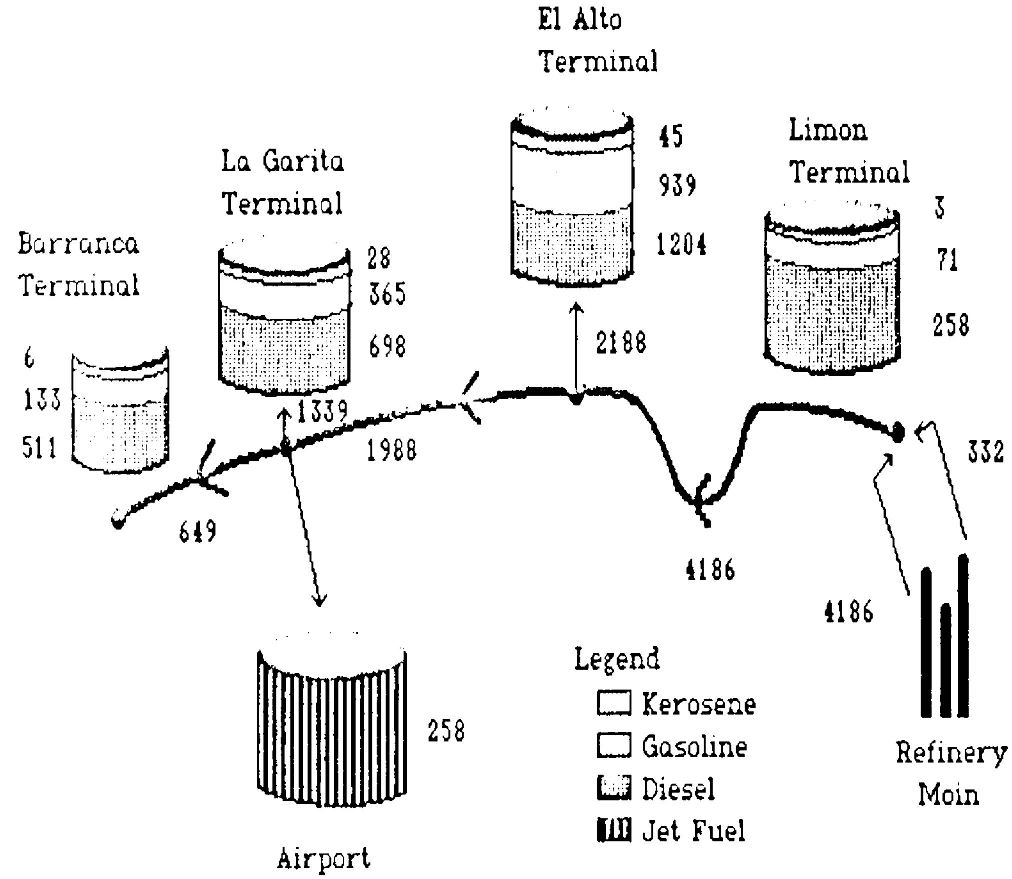
The only major energy transportation use for the railroad system is the transfer of fuel oil between Moín and El Alto. In 1988, of the total 970 620 barrels of fuel oil consumption in the country, 577 449 barrels (i. e., 59.5 percent) were transferred in this manner The remainder is carried by truck directly from Moín Also trucks are used to deliver fuel oil from the terminal at El Alto to other distribution and consumption points in the country.

Figure 2. Oil pipeline: RECOPE.



Source: OAS - DSE

Figure 3. Transference of combustibles by RECOPE oil pipeline, 1988 (10^3 *barrels*)



Source: OAS - DSE

Figure 4 provides a map of the Costa Rica railways and principal highways.

The eastern part of the railway system is used principally for the delivery of bananas to the eastern ports; the segment between the town of Gu cimo and Limón is electrified and also used for passenger traffic. The portion of the railroad roadbed in its steep ascent from the eastern plains to the continental divide is in poor condition and at risk of being decommissioned due to a severe landslide condition just to the west of Turrialba. This eastern segment, once renowned as a tourist attraction, no longer is used for passenger traffic because of the dangers associated with landslides and roadbed instabilities.

The western portions of the railroad are electrified and in excellent condition. These segments are not presently used for any significant energy product transfer.

The southern segments of the national railroad near the Panama border, once used for banana transportation, are now being decommissioned.

According to data provided by RECOPE, Costa Rica has 111 railroad tanker cars with a total capacity of 674 811 gallons.

3.2.3 National Highways

The major highways of Costa Rica have been included along with railroads in Figure 4. The reader is referred to Section 4.3 where the condition of roads applicable to energy transfer is discussed.

3.3 The Electrical Energy System

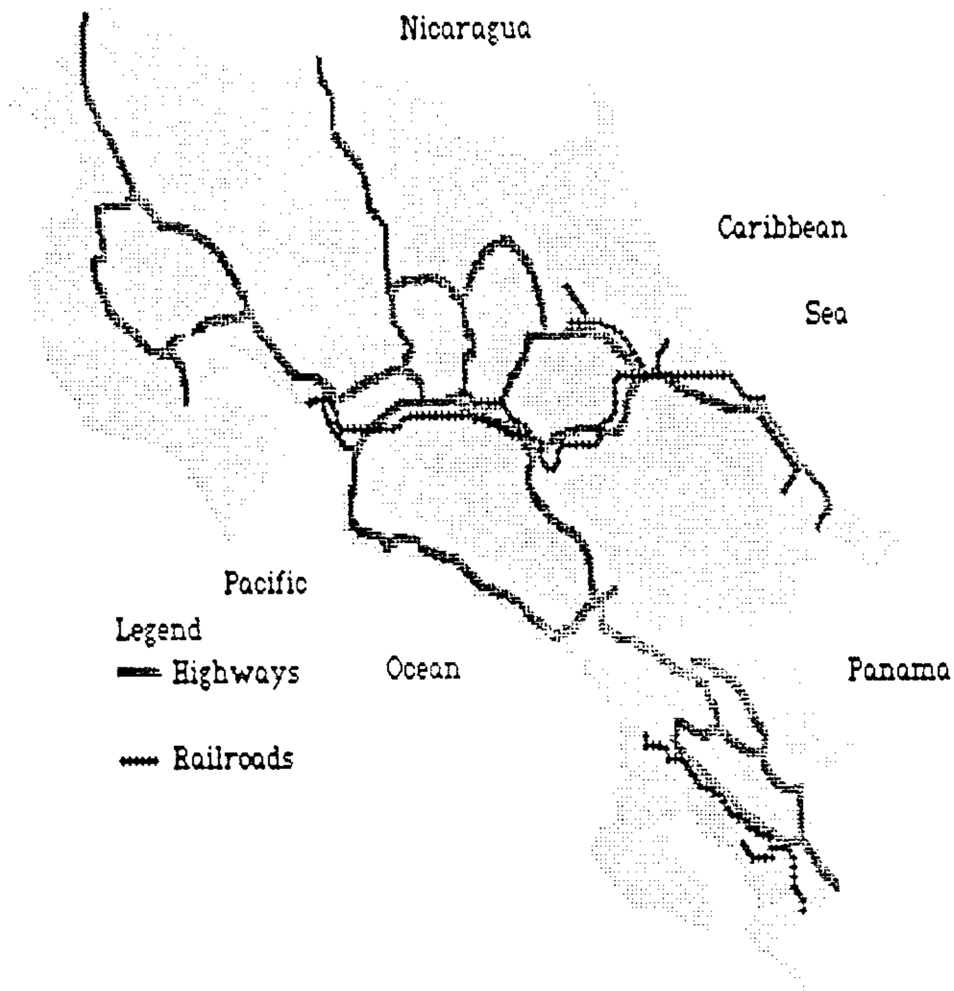
As shown in Figure 5, the Costa Rica electrical infrastructure consists principally of five hydroelectric plants, various diesel and steam-powered plants used for peaking power and emergency backup, and a network of transmission and distribution systems. The interconnected system covers nearly all of the country and also provides ties to the electrical systems of Nicaragua and Panamá. ICE, the national electric company, manages the large power plants and the interconnected transmission system. Other small companies and cooperatives, some with their own small hydroelectric generators, service regional areas. Most of these systems are also connected to the national electric grid.

Figures 6 and 7 describe the balance between electric energy supply and demand in the ICE system in 1988. Although supply is fairly evenly distributed between the five major hydroelectric plants, the principal demand is centered in the Central Valley, which is served by its ring of 138 KV transmission lines and local substations.

3.3.1 Electric Power Plants

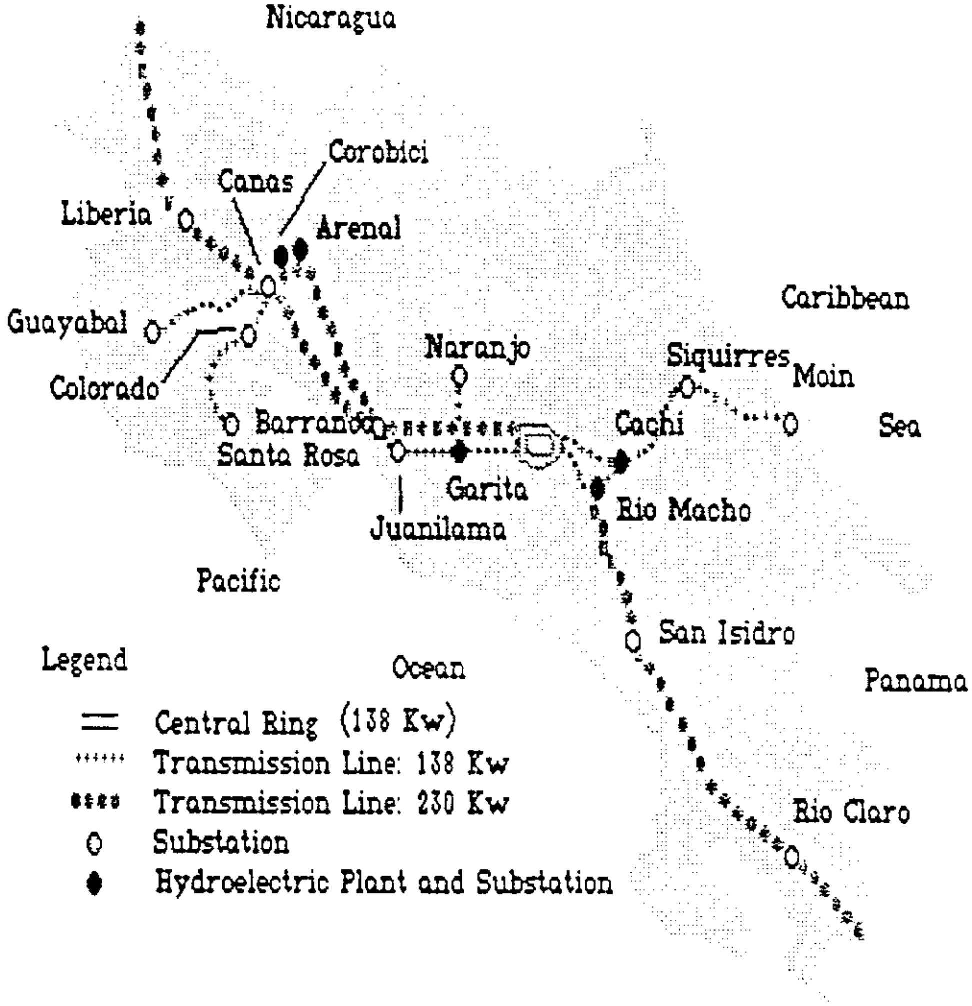
Table 2 presents a summary of the principal characteristics of the five major hydroelectric power plants in Costa Rica.

Figure 4. Principal highways and railroads of Costa Rica.



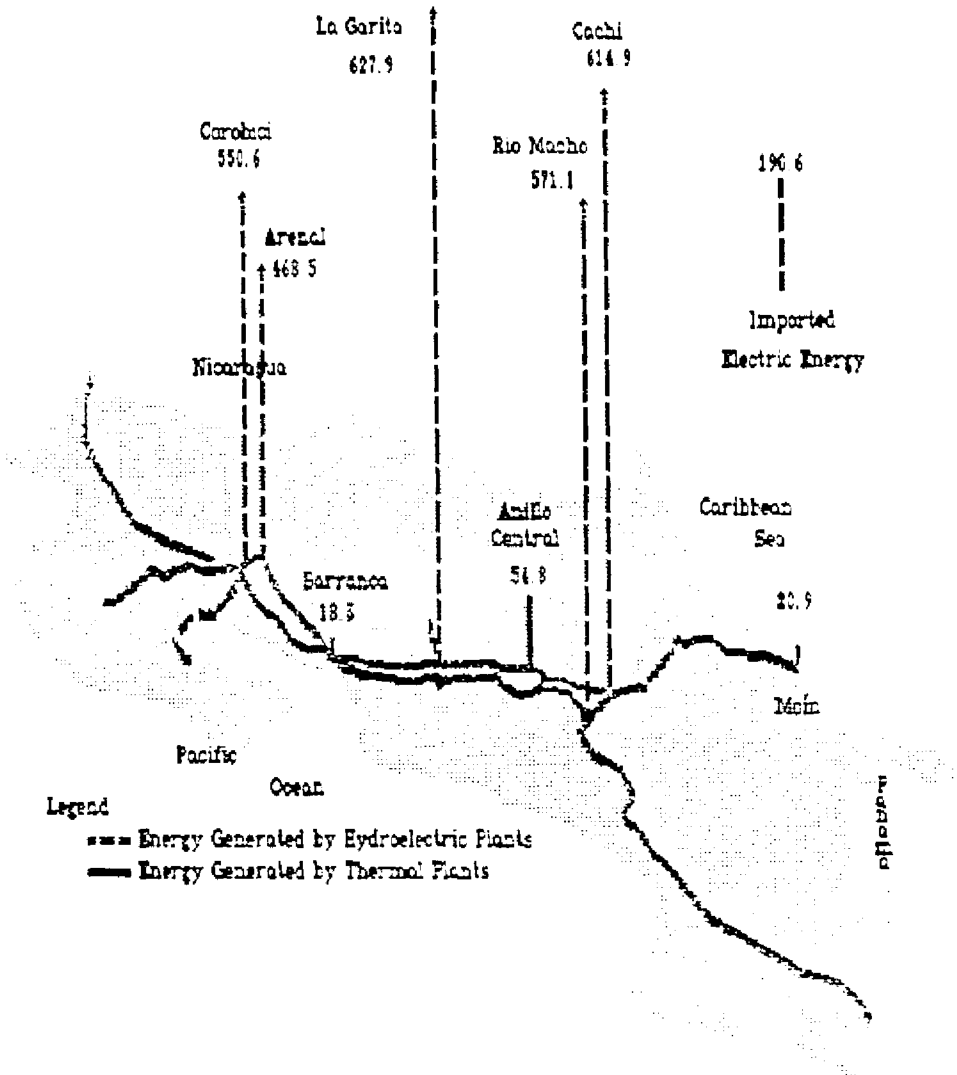
Source: OAS - DSE

Figure 5. Electrical interconnected system



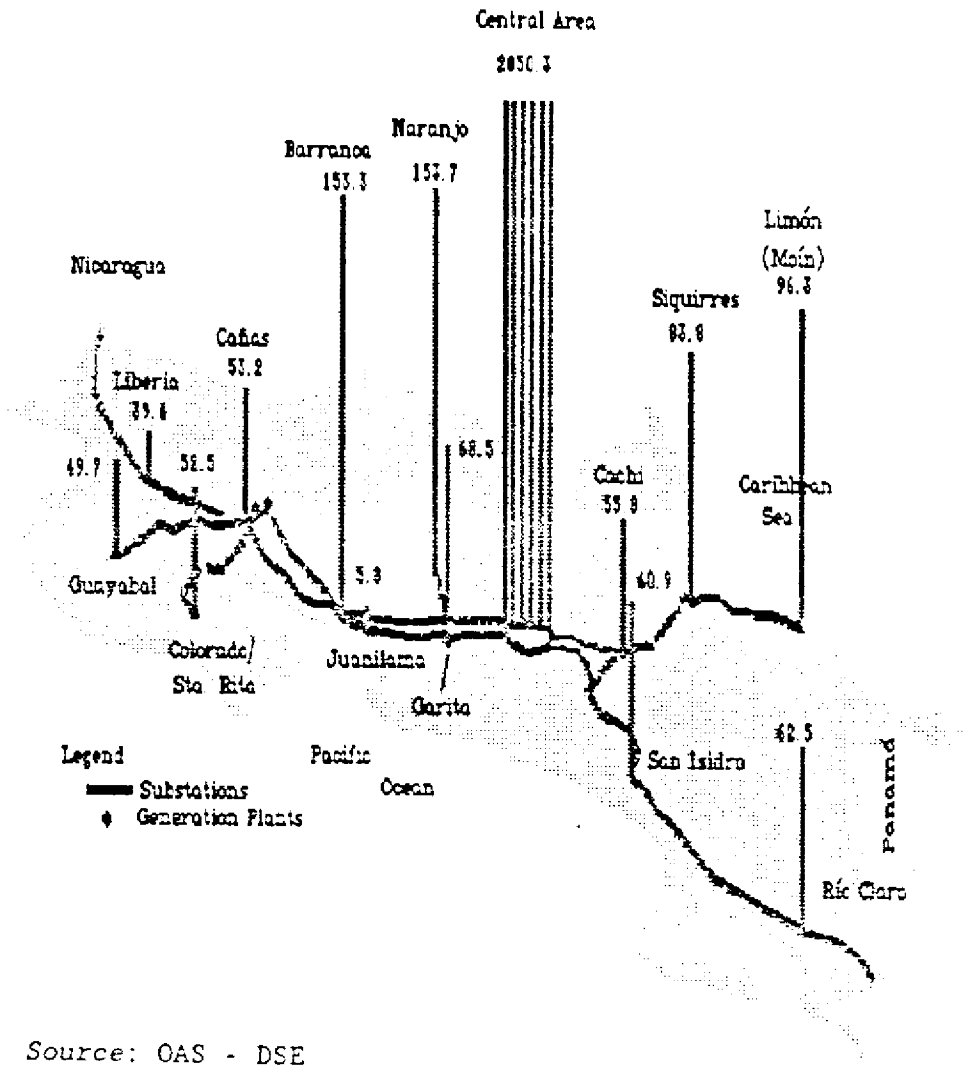
Source: OAS - DSE

Figure 6. National integrated system for the generation of electricity, 1988 (10^3 mwh)



Source: OAS - DSE

Figure 7. Electric energy provided to the central area and national substations, 1988 (10^3 *mwh*)



Source: OAS - DSE

Table 2. Principal hydroelectric plants in Costa Rica

Name	River	Canton	Generator Turbines Num - KW	Total Capacity KW
La Garita				127 380
	Grande	Central	2 - 15 000	
	Virilla	Central	2 - 48 690	
Río Macho				120 000
	Macho	Orosi	2 - 15 000	
	Macho	Orosi	3 - 36 800	
Cachí				100 800
	Reventazón	Jimenez	2 - 32 000	
	Reventazón	Jimenez	1 - 36 000	
Arenal				157 398
	Arenal Lake	Tilarán	3 - 52 466	
Corobicí				174 012
	Arenal Lake	Tilarán	3 - 58 004	
TOTAL				679 590

Source: ICE

The last two plants in the list, Arenal and Corobicí are supplied by waters from Lake Arenal. This lake, forming the upper part of the drainage of the Arenal River emptying towards the Atlantic, is dammed at the natural outlet at its southeastern corner The increased level of the lake permits water transfer through tunnels constructed at the lake's northwest shore and directed to a series of power plants on the Pacific slope, first Arenal, then Corobicí and finally, a smaller plant named Sandillal, now under construction. The initial two plants, now in operation, have a total capacity of 331 MW, representing 48.8 percent of the country's total installed hydroelectric capacity. Their operation depends jointly on the integrity of the dam, the intakes and tunnels above the Arenal plant as well as the adequacy of rainfall and runoff into the Arenal reservoir. Before Hurricane Joan in 1988 in which the Arenal Lake was completely filled, there had been a requirement for water rationing because of low lake levels.

La Garita and Río Macho, although they have small reservoirs, operate as run-of-river plants, tapping directly the daily river runoffs. The Río Macho plant has an extensive system of multiple intakes and tunnels which allow the capture of waters from various watersheds that feed into the main river. This river is noted for its clean waters due in large part to the protection of its upper watershed as a national reserve.

The Cachí plant, built on the Río Reventazón, has a large reservoir. Due to slope instability and development in the river basin, this reservoir is experiencing serious sedimentation problems. ICE drains the reservoir once a year in an effort to control the sediment accumulation, using careful timing to guarantee full storage before the beginning of the dry season.

For peak load operation and emergency backup, ICE operates four petroleum powered power plants with a total capacity of about 141 MW. Many of these units are old and have limited reliability. Table 3 provides a summary of these plants.

Table 3. Principal thermal plants of Costa Rica

Name	City	Type	Fuel	Capacity of Generators Num - KW	Total Capacity KW
Colima	San Jose	Recip	Diesel/Fueloil	4 - 2 970	19 540
		Recip	Diesel/Fueloil	2 - 3 830	
San Antonio	San Jose	Steam	Fueloil	2 - 5 000	48 100
		GasTurb	Diesel	2 - 19 050	
Barranca	Barranca	Gas Turb	Diesel	2 - 20 800	41 600
Moin	Limon	Recip	Diesel/Fueloil	4 - 8 000	32 000
TOTAL					141 240

Source: ICE

3.3.2 Electric Transmission and Principal Substations

Figure 8 provides another view of the national electric grid, focusing on its overall capacity. The installed capacity of the five hydroelectric power plants is presented in bar format with dotted lines. In solid bars are the maximum substation (and Central Area) peak loads as recorded in 1988. Next to each segment of transmission is the value of the SIL capacity of that line. SIL provides an indicator of the efficient transmission capacity of a line. Thermal capacity, which typically is two to two and a half times the SIL value, is the absolute upper limit that a line can transmit, albeit at very low efficiency This planning map is useful for identifying transmission and substation weaknesses. For example:

- The transmission line from Arenal to Barranca is critical for the transfer of electricity from the Arenal/Corobicí complex to San José. The backup line between Cañas and Barranca has insufficient capacity to carry all the generation capacity of the complex in case the primary line is unusable.

- A more stringent but similar condition exists for the main line between Barranca and San José (the substation called La Caja where this line meets the central ring). The southern line between Barranca and La Garita, and the segment from La Garita to La Caja would not be able to take any significant portion of the Arenal/Corobicí generation load with a loss of the main line.

- Two separate 138 KV lines connect Río Macho and Cachí, respectively, to the central ring. Their individual capacity is questionable for carrying the loads of both power plants to San José much less for adding any additional purchased power that may be needed from Panamá.

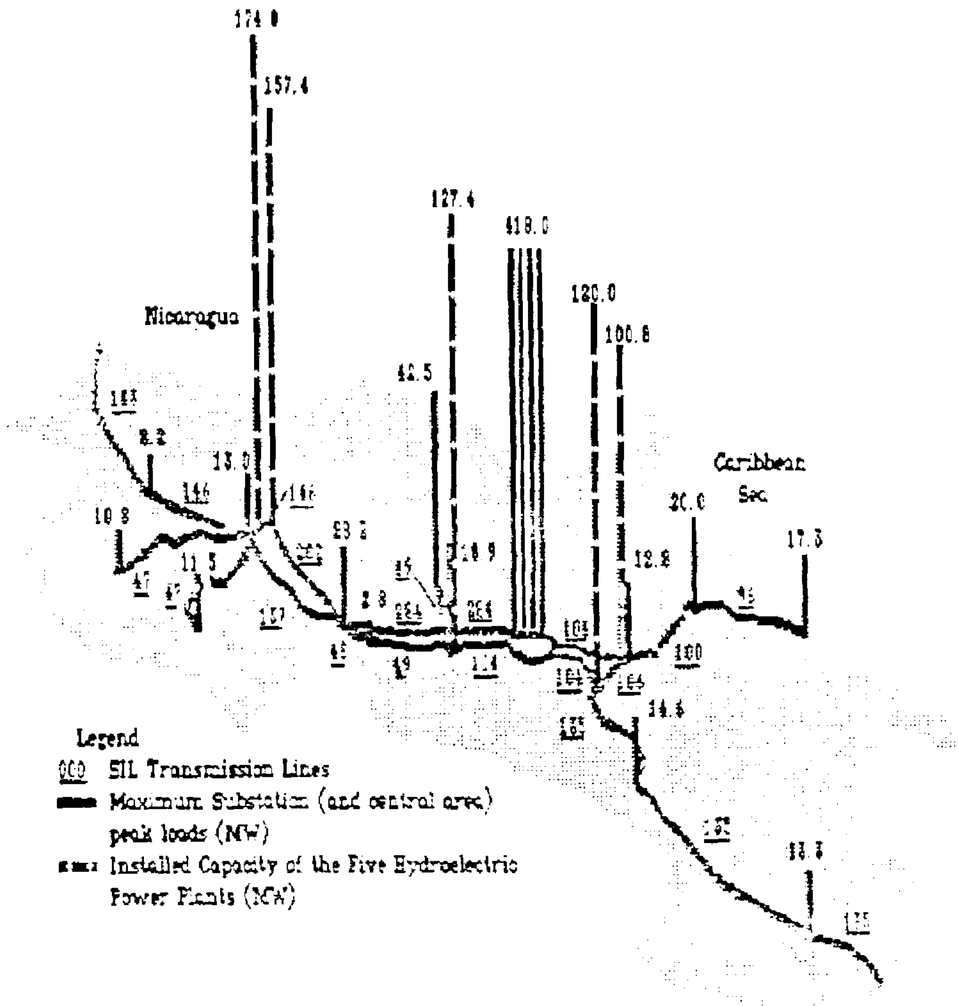
- Of all the substations, Barranca and, especially, La Caja are critical to the operation of the entire system. The Barranca substation is used for all power transfer from the northern plants as well as any transfers to or from Nicaragua. La Caja substation is also required for all of the above as well as all the input of the La Garita power plant to the central ring.

3.3.3 Distribution Systems

In the case of natural disasters such as hurricanes and earthquakes, it is often specific portions of the electric distribution systems that are affected and are time-consuming to repair. Damage is likely to be localized (i. e , one city or one or two areas within a city). For this reason, in the case of Costa Rica, distribution systems were not included in the national level analysis.[1]

[1] For other countries, such as the islands of the Caribbean under high hurricane risk, distribution systems must be included in national-level analyses.

Figure 8. Maximum demand and capacity of the principal electrical infrastructure of Costa Rica, 1988 (mw)



Source: OAS - DSE