nuclear park, a station consisting of several reactors on one site complete with the necesary fuel fabrication and reprocessing facilities. See: Sir J. Hill in Patterson, *op cit*, Ref 1, p 217.

[17]Understandably enough the answer to the question of what constitutes a supreme national interest was left to the country concerned.

[18]Initially the formulation and observance of international rules on plutonium production and handling was entrusted to the nuclear industry who were also responsible for promotional activities in the nuclear reactor field. Comparatively recently these two tasks were separated with the former being entrusted to the International Atomic Energy Agency and to Euratom, a similar Agency set up by the European Economic Community.

[19]This is far from saying that the rules have always been adhered to. In 1968 200 tonnes of uranium fuel disappeared from a ship sailing in the Mediterranean. The incident was initially kept secret and later played down with assurances that the material in question was natural (eg non-enriched) uranium ore. The important fact that some countries with known nuclear weapons ambitions were provided with CANDU reactors operating on natural uranium was omitted; some years later it was reported that senior Euratom officials were involved in the diversion. See B. Johnson in Patterson, *op cit*, Ref 1, p 235. In 1974 India exploded a 'crude' nuclear bomb made of plutonium diverted from an experimental nuclear reactor. And there is now little doubt that a number of countries have acquired nuclear weapons capability in the same way.

[20]There are reports that the subject of safeguards on plutonium production and handling has played a decisive role in the decision of the Argentinian government to turn to the West Germans for supply of a nuclear power station. Their negotiations with Canada broke down over the Canadians' insistence on much stricter safeguards. Argentina is one of the countries which have refused to sign the Non-Proliferation Treaty. See *Financial Times*, 1 April 1980.

[21]A few years ago the US Administration decided to resume supplies of enriched uranium to India, thereby reversing a Congress ban imposed after the explosion of the Indian nuclear bomb in 1974.

The Brazilian nuclear power programme: A case not proven

Energy demand in the less developed countries is sometimes estimated using a correlation between standard of living, population and energy consumption. Using this argument, it is possible to project a shortfall in conventional energy supply and thus derive a case for nuclear power in LDCs. Yet there seems no reason to suppose the LDCs will follow the pattern of energy use in the developed countries. The authors question the need for nuclear power in individual LDCs, with particular reference to Brazil.

Future global energy demand and, within this, the demand from the less developed countries (LDCs), is sometimes estimated by means of a putative correlation between standard of living, population and energy consumption. Using such an approach[1] it is possible to project a shortfall in conventional energy supply and hence derive a case for nuclear power in the LDCs.

Yet it is becoming increasingly difficult to speak of LDCs as all of a type, and there seems no reason in principle to expect their energy use patterns to faithfully reflect those of the developed countries, let alone to reflect the usage patterns extant in developed countries at the end of a period of cheap and readily available fuel. Therefore, when one examines more closely the circumstances of individual LDCs, the case for nuclear power may be even more strongly questioned.

This is what we seek to show here, with reference to Brazil. In so doing, we intend also to acquaint European readers with the arguments which have been deployed within that country by critics of the Brazilian nuclear programme. Before proceeding to that discussion, however, note that similar cases can be made in respect of two other LDCs with ambitious nuclear programmes, namely,India and Argentina, even though in both of these cases, internal criticism of the nuclear programme is markedly less common than in Brazil.[2] In all three cases, it is possible to show that the availability of other energy resources calls seriously into question the need for major immediate commitments to nuclear power on energy policy grounds.[3]

Brazil's nuclear programme

Brazil's nuclear programme dates from soon after the second world war, achieving some prominence in 1953 when Brazil tried secretly to acquire three gas centrifuges from Germany for uranium enrichment.[4] Although much work related to nuclear energy has been undertaken in Brazil since then, and a 600 MWe Pressurized water reactor (PWR) (Angra-1) was ordered from Westinghouse in 1968[5] (not yet operating at the time of writing), these earlier activities have been completely overshadowed by the 1975 collaborative agreement with West Germany.

The programme which is being undertaken through that agreement initially aimed at the installation, by 1990, of some 10 GWe of nuclear capacity.[6] (1977 projections for nuclear and total electrical capacity are shown in Table 1). This agreement refers also to the prospecting and mining of uranium and envisages the establishment of uranium enrichment, spent fuel reprocessing and fuel fabrication facilities, and a joint German-Austrian-Brazilian heavy engineering company. It will evidently be the main determinant of the development of the nuclear industry in Brazil for the next 20 years.

The initial plans entailed the construction of eight 1300 MWe PWRs by 1990, the construction of the first two of which, Angra-2 and -3, began in 1976 and 1978 respectively. Firm commitments had been made to only four power plants at the time of writing but there remained some official hope that all eight planned reactors would be built at least by 2000. Despite this, it seems increasingly clear that the programme will suffer some delay and may even be reduced.[7]

Brazil has chosen to adopt reactors which require enriched uranium. This choice has been criticized within the country on the grounds that, given

Table 1. Projection of electrical installed capacity in Brazil, nuclear and total (MWe).

Year	Nuclear	Total	Nuclear/total (%)
1976		22 280	
1980	630	33 830	1.9
1985	3 100	51 470	6.0
1990	10 600	81 000	13.1
1995	28 200	125 000	22.6
2000	75 000	185 000	40.5

Source: C.S.M. Pinto *et al*, 'Organization and development of the Brazilian nuclear programme', in IAEA, *Nuclear Power and its Fuel Cycle*, Vol 6, Vienna, 1977, Figure 1a.

Brazil's huge thorium reserves, it would have been wiser to adopt natural uranium reactors, as in India and Argentina, thus preparing the way for the introduction of thorium-consuming breeders.[8] The choice of PWRs, however, coupled with Brazilian determination to achieve security of fuel supplies, encouraged demand for an enrichment plant in the country.

Policy rationales

The official arguments for a Brazil's nuclear programme, in essence, maintain that the country's dependence on imported fuel is large enough to make the nuclear option not only sensible but urgent.[9] Note that, in 1977, oil imports cost US $3.6 billion, an amount nearly equal to Brazil's deficit in the balance of payment current accounts. Furthermore, this occurred at a time when the government had been forced to deflate the economy in order to solve the foreign currency problem – the external debt of the country being around US $40 billion in 1978. Moreover, the dependence on imported oil has increased from 66% of all oil consumed in 1966 to 82% in 1976.[10] Against this background, a former Minister for Mining and Energy spoke explicitly of the possibilities of substituting electricity for oil,[11] the role of nuclear power in that substitution being obvious.

Two observations are appropriate. First, 1977 official estimates of the significance of imported oil (based on the assumption that total oil consumption in 1986 could be held at 79.9 million tons) suggest that by 1986 imported oil might account for between 67 and 0% of total consumption, depending upon which alternative hypothesis on the discovery of new reserves proved the more correct.[12] Second, even ignoring the possibility of discoveries of substantial new Brazilian oil reserves, doubt may be cast on the extent to which nuclear electricity could substitute for oil and thus reduce imports.

Table 2. Consumption of oil derivatives for energy production, Brazil, 1976 (1000 m^3).

Product	Volume	%
Combustible oil	16 479	32.1
Petrol	14 829	28.9
Diesel	13 797	26.7
Liquid petroleum gas	3 540	6.9
Kerosene	2 380	4.6
Naphtha	342	0.7
Total	51 367	100.0

Source: Ministerio de Minas e Energia, 'Balanco Energetico Nacional', Brazilia, 1977, p 90.

Main defects in the rationales

The point here is that very little oil is used for electricity generation in Brazil, and in its other uses, substitution by electricity presents formidable difficulties. Thus, in 1976 hydroelectricity accounted for 84% of total installed capacity, with most of the remainder met by coal-fired stations.[13] In addition, as Table 2 shows, more than 50% of total oil consumption corresponds to diesel and petrol for transport which, in the short term, rules out the use of electricity (especially as in the last two decades the development of road transport has been heavily emphasized in Brazil). Therefore, a reduction in oil consumption *via* electrification of transport is unthinkable in the near future, a view which official electricity experts support.[14]

It might, however, be argued that, although this pattern of oil consumption has been stable for a decade,[15] the rising demand for electricity consequent upon industrialization could, unless the nuclear option were deployed, require an increase in imports of oil for electricity generation. To meet this objection we must consider Brazil's resources of hydroelectric potential and of coal.

The hydro potential

In 1976, as has been said, hydroelectricity accounted for 84% of the total installed capacity, rising from 73% in 1966. According to official forecasts, hydroelectricity is likely to continue to supply 84% of the total capacity up to 1986 despite the introduction of nuclear stations.[16]

The overall hydroelectric potential is a matter of dispute. Official estimates calculate that hydroelectricity might ultimately yield an installed capacity of approximately 160 GWe, distributed by regions as shown in Table 3. This potential does not include 6.3 GWe corresponding to the Paraguayan share in the Itaipu binational hydroelectric project, which will be almost totally bought by Brazil in the next 30 or 40 years.[17]

Official arguments state that this potential will be insufficient to cover the demand forecast. They state first that as most of the estimated potential (approximately 50%) is located in the north, which accounts for only a tiny fraction of the demand, it could not be effectively used to meet the demand in the most developed and energy-consuming areas – especially the south-east. Second, that it is expected that the demand for electricity in the north-east and south-east regions will exceed their respective potentials by about 1990.[18]

Table 3. Brazilian hydroelectric potential by regions (official estimates).

Regions	* Equivalent installed capacity (MWe)	%
North	72 000	45.8
North east	14 500	9.2
South/centre east	44 500	28.3
South	26 200	16.7
Total	157 200	100.0

Source: L.C.A. Magalhaes, *Energia Hideletrica, 1977*, paper presented at a conference in the Escola Superior de Guerra, Rio de Janeiro, 21 June 1977.

Finally, it is supposed that, even if the hydroelectric resources could eventually be fully exploited, their potential would be less than the demand projected for the late 1990s. According to official projections, by the end of the 1990s electricity demand will require an installed capacity of 180 to 200 GWe, higher than the hydroelectric potential, estimated at approximately 160 GWe.[19] Consequently, it is argued that nuclear energy will be increasingly needed to complement hydroelectricity until the end of the century.

A final official argument is that the great distances from those hydroelectric sites with large potential to the major consumer centres reinforces the case for nuclear power stations close to the high electricity consumption areas. In this connection, it has been argued that the exploitation of a large part of the hydroelectric potential in Amazonia might not be feasible in the next 20 years because of transmission costs.[20]

Energy economic considerations

Against these arguments it has, firstly, been objected that the rate of growth of the Brazilian economy assumed in the estimates of electricity demand growth was too high in relation both to the historical growth of the economy and to the foreseeable problems of the country in the short term. So, while the forecasts of electricity demand are based on a high rate of growth of the economy, it will probably be expanding at a lower rate.

While the GNP has an historical rate of growth in Brazil of 6% per annum the rates used in the official projections were 10% or 8% per annum. Even these small differences will produce a considerable disparity between actual and projected electricity demand, for that difference will be accumulated for around 20 years. Hence, Castro has concluded that as a result of the over-estimated rate of growth of GNP assumed in the official estimates, there will be a steady excess of installed capacity from 1983 onwards, especially when the first hydro-developments of the Amazonian basin come into service.[21]

Second, it has been argued that, even accepting the optimistic assumptions about the economy's performance, the hydroelectric potential of the country would cover the demand for electric power. Thus, it is argued that the south, south-east and centre-west potential was under-estimated in the official studies, since it was evaluated in the early 1960s by taking as the basis for comparison thermal stations over 20 MWe and costing less than US $600.00/kW; since the price of fuel has gone up dramatically since then, this potential is certainly unrealistic in today's terms, as is clearly indicated by the price of US $1540/kW for the nuclear stations already under construction, and could be raised by 20 GWe.[22]

Transmission

Third, regarding the complete exploitation of the estimated potential in Amazonia, Gomes remarks that compared with the high cost of fuel oil, it is economic to connect that potential to the grid of the main consumption centres, despite the large distances involved. The transmission of electricity from the huge Itaipu hydroelectric plant (12600 MWe) – under construction – to Sao Paulo already implies a transmission line of about 900 km, whereas the use of most of the Amazonian hydro-potential would require transmission distances between 1000 and 2500 km. Apart from the likelihood that the technological difficulties could be overcome, there being about 20 years before it becomes really necessary, the transmission cost over such long distances would not, according to estimates made by Gomes, make non-viable the incorporation of the Amazonian potential into the national grid when compared to the price of nuclear energy.[23]

Coal and hydro – better choices

Therefore, making the, admittedly major, assumption that it is feasible to utilize all the officially estimated hydroelectric potential of the country (163.5 GWe, including the Paraguayan share of Itaipu), and considering that 20 GWe can be added to the south, south-east,and centre-west evaluated potential (as argued above), Gomes suggests that there would be enough hydroelectric resources to satisfy even the over-estimated electrical energy demand projected by the government for the year 2000.[24]

In addition note that Brazilian coal reserves seem to allow the hydroelectric capacity to be complemented by thermally-generated electricity. According to one estimate, Brazilian coal reserves are sufficient to add another 30 GWe to the installed capacity of the country.[25] The availability, convenience and economic feasibility of using coal for electricity generation has also been emphasized by Telles.[26]

The same conclusion is reached in the Barber report, even though this study was based on a figure for Brazilian coal reserves which is much smaller than the current estimate.[27] Garcez and Oliveira have gone further and claimed that 'Even with geometrically progressing exploitation, Brazil's steam coal potential can supply the country's needs for another 200 years'.[28] Finally, *The Times* has observed that, even though Brazilian coal is in general not very good for steel-making, currently the main market for coal in Brazil, nevertheless there had been three major finds in the mid-seventies, and much surveying was still to be done.[29]

Conclusions

On the whole, the debate in the western industrialized nations about nuclear exports to LDCs has been couched in terms of the proliferation issue, the dubious value of large reactors in countries with small electricity supply systems,[30] and the need for developed countries not to export nuclear power but to use it themselves, thus saving fossil fuels for use by the LDCs. (Whether international mechanisms exist which could ensure that the fossil fuels *did* reach the LDCs is another matter).

Our analysis suggests an additional dimension to this debate. The figures presented here for the availability of non-nuclear energy sources suggest that, in terms of energy requirements, the scale of the Brazilian nuclear programme is open to question. A small programme, to enable experience to be gained of nuclear power and to keep the nuclear option open, would be incontestable on energy policy grounds. But a programme of the size and speed of Brazil's seems of questionable value in terms either of likely gaps between supply and demand for electricity, or of energy security.

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[1]For example, Fred Hoyle, *Energy or Extinction? The Case for Nuclear Energy*, Heinemann, London, 1977.
[2]On the Brazilian case, see 'The politics of power in Brazil', *Nature*, Vol 284, 24 April 1980, pp 655–7. On India, see Dhirendra Sharma, 'Time to move away from nuclear power', *The Times of India*, 21 and 22 August 1980.
[3]For further details, and for an analysis of these cases from the standpoint of development theory, see Mario Duayer de Souza, *The Establishment of Nuclear Industry in LDCs: The Cases of Argentina, Brazil and India* unpublished PhD thesis, Manchester University, 1979.
[4]N. Gall, 'Atoms for Brazil, dangers for all', *Foreign Policy*, Vol 23, Summer 1976, pp 155–201.
[5]Republica Federativa do Brasil, Documents distributed to the press by the Brazilian Government on 27 June 1975, Document No 1, p 4.
[6]*Ibid*, pp 3-4; H. Frewer and W. Altvater, *Technology Transfer by Industry for the Construction of Nuclear Power Plants*, KWU, paper presented at the conference on Transfer of Nuclear Technology, Shiraz, Iran, 10–14 April 1977, mimeo; and C.S.M. Pinto *et al*, 'Organisation and development of the Brazilian nuclear programme' in IAEA, *Nuclear Power and its Fuel Cycle*, Vol 6, IAEA, Vienna, 1977, pp 85–99.
[7]See, for instance *Der Spiegel*, No 38, 1978, p 134; *Journal do Brasil*, 11 March 1980 and *Nature*, Vol 284, 24 April 1980, pp 655–7.
[8]See H.J. Rosenbaum, 'Brazil's Nuclear Aspirations', in O. Marwah and A. Schulz, eds, *Nuclear Proliferation and the Near-Nuclear Countries*, Ballinger, Cambridge, MA, USA, 1975, p 260.
[9]The urgency of the programme has been stressed by the chairman of Nuclebras, the State-owned nuclear company. See P. Batista, 'A Politica Nuclear Brasileira', *Nuclebras*, paper presented at a conference at the Escola Superior de Guerra, Rio de Janeiro, 22 June 1977, p 6.
[10]Ministerio de Minas e Energia, *Balanco Energetico Nacional*, Brasilia, 1977, p 84.
[11]*Ibid*, p 4.
[12]*Ibid*, p 86.
[13]L.C.A. Magalhaes, *Energia Hidreletrica, 1977*, paper presented at a conference at the Escola Superior de Guerra, Rio de Janeiro, 21 June 1977, p 22.
[14]L.N. Garcez and J.M.G. Oliveira, 'Brazil's development prospects in relation to its energy situation', *Revue Francaise de L'Energie*, Vol 25, 1974, p 82.
[15]Ministerio de Minas e Energia, *op cit*, Ref 10, p 90.
[16]*Ibid*, p 89.
[17]F.M. Gomes, *A Energia Hidroeletrica no Brazil*, Symposio Nacional de Energia: Energia Eletrica, Sociedade Brasileira de Fisica, Vol 1, Sao Paulo, March 1978, p 54.
[18]L.C.A. Magalhaes, *op cit*, Ref 13, pp 17–20 and 23.
[19]See Batista, *op cit*, Ref 9, p 4; and Republica Federativa do Brazil, *O Programa Nuclear Brasileiro*, Brasilia, March 1977, pp 8–9.
[20]Republica Federativa do Brasil, 1975, *op cit*, Ref 5, Document No 1.
[21]A.B. Castro, 'O Crescimento da Economia Brasileira e a Demanda de Energia no Sector Eletrica', *Sociedade Brasileira de Fisica*, Vol 1, Sao Paulo, March 1978, pp 1–2.
[22]See F.B. Magalhaes, 'Perspectivas a Longo Prazo de Energia Eletrica no Brasil', *Sociedade Brasileira de Fisica*, Vol 4, Sao Paulo, July 1977, pp 17–23; Castro, *op cit*, Ref 21, p 2; and (for the cost of nuclear electricity), the *Financial Times*, 3 February 1978.
[23]Gomes, *op cit*, Ref 17, pp 54–66.
[24]*Ibid.*
[25]F.B. Magalhaes, *op cit*, Ref 22, p 31.
[26]A.S. Telles, 'Participacao de Carvao na Producao de Energia Eletrica: Estudo para Planejamento', *Sociedade Brasileira de Fisica*, Vol 1, Sao Paulo, March 1978, p 11.
[27]R.J. Barber Associates Inc, *LDC Nuclear Prospects, 1975–90: Commercial, Economic and Security Implications*, Report prepared for the Energy Research and Development Administration, Report No ERDA – 52, Washington, DC, 1975, II – 40.
[28]Garcez and Oliveira, *op cit*, Ref 14, p. 84.
[29]*The Times*, 8 August 1977.
[30]See, for instance, the discussion between Sir John Hill (chairman of the UK Atomic Energy Authority) and Brian Johnson at the 1977 Royal Institution Forum on nuclear power, in G. Foley and A. van Buren, eds, *Nuclear or Not?* Heinemann, London, 1977, pp 193–4.

There is more to Canada's constitutional problems than Albertan oil

At both national and international levels energy issues are increasingly ones of debate and conflict between governments. Canada is no exception, as illustrated by the recent paper by Walter Goldstein. Peter Crabb argues, however, that the provincial viewpoints in Canada have not been fully appreciated.

At both national and international levels, energy issues are increasingly ones of debate and conflict between governments. The situation in Canada is no exception, and Professor Goldstein's recent paper is a valuable contribution to the literature on the important role of governments in energy issues.[1] He is right to stress the importance of energy in Canada's current debate over its constitution and of any new constitution to future energy policies and developments. However, in presenting a viewpoint that is essentially pro-federal and giving almost unquestioned support to the actions of Mr Trudeau and his government, some difficulties emerge.

On the basis of available evidence, Prime Minister Trudeau certainly has strong support for increased Canadian ownership and control of Canada's energy industries, especially oil and gas. The latest indication is the formation of a citizens' movement called the Committee for the Canadianisation of the Petroleum Industry.[2] However, Mr Trudeau has nowhere near the same level of support for his unilateral constitutional proposals and his moves into traditionally provincial areas of responsibility, particularly natural resources.

The return to office of René Lévesque and his Parti Québecois government, relatively soon after the resounding Referendum defeat of his constitutional proposals, is one indication. Another is the united opposition to the Trudeau proposals by