Energy Economics and Policy
Prof. Shyamasree Dasgupta
Department of Humanities and Social Sciences
Indian Institute of Technology, Mandi

Week - 08
Special Topics on Energy
Lecture - 01
Energy Security

Welcome to the last week of the course on Energy Economics and Policy. This week we are going to discuss several special topics related to energy.

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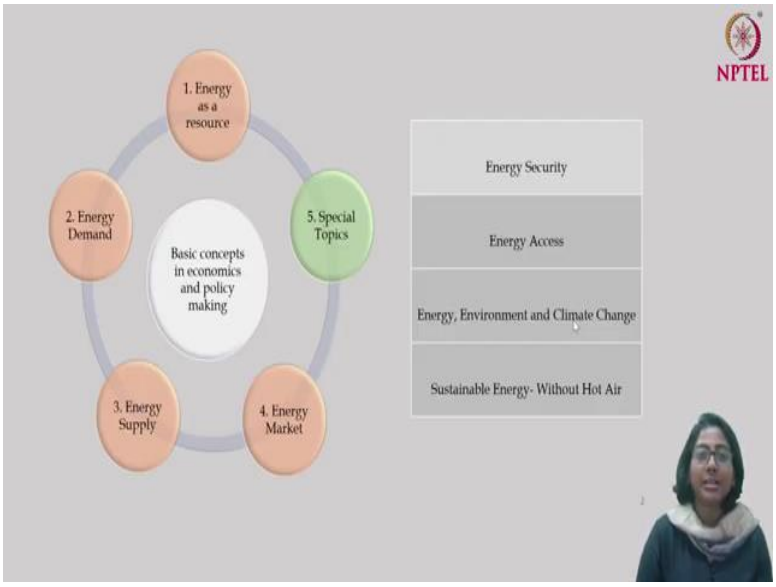

If we go back and take a final look at the structure that we tried to follow since the beginning, we have already covered issues such as energy as a resource, energy demand, energy supply, energy market. Finally, we are going to focus and discuss some of the issues related to energy which have very contemporary applications.

This week we are going to talk about issues like energy security, energy access, energy environment and climate change, the nexus between these three emerging areas. Finally, I will introduce you with a book, which is an open access, free available book,"Sustainable Energy - Without the Hot Air".

In this video we are going to focus on Energy Security. Before I begin the discussion on energy security, I would like to put a small disclaimer that energy security can be discussed from

various perspectives. There is no definition of energy security which is written on the stone, it has been derived and evolved as time passed. The second thing is, it also depends on the context of analysis. So, when we say energy security; of course, it gives you a certain sense of whether I am secure with respect to the supply of energy. Essentially it is related to supply.

However it can be discussed with respect to the supply of energy from the outside world to one particular country, where we discuss more about dependency on import etc.. However, it can also be discussed from the perspective of the domestic supply of energy like 'What is the fuel mix that a particular country is using in order to produce electricity?' In this video we are going to particularly focus on different indicators that can be used to understand the issue of energy security, specifically in the context of import dependence. We are not going to talk too much about domestic energy security, but we are going to talk more about how you address the geopolitical issues, the import dependence etc.?

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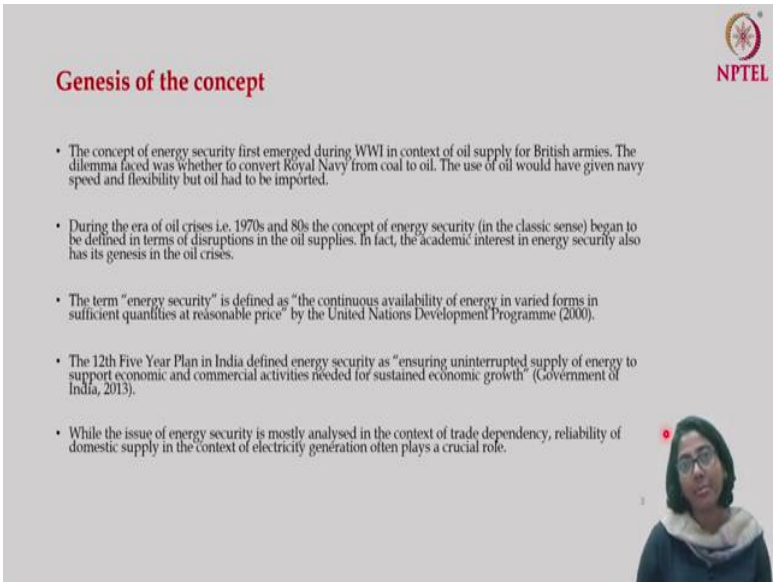

Let us begin with the genesis of the concept of energy security. Now here we are trying to wrap up things and will relook at various concepts that we have been discussing since the beginning of the course. If you recall the first lecture, we discussed that economics is essentially a discipline, which talks about efficient management or optimum utilization of scarce resources. Similarly, the concept of security emerges when you understand that something is not available in abundance in the context of energy. When was this first realized? Although we talked about the oil crisis in the 1970s and so on.

Also we talked about how demand was overshooting the supply in the late 1950s and 1960s in the developed world, but the concept of energy security, in a very vague manner, can be seen when the First World War was going on. How was it manifested? If you go back to the history of the First World War, there was a big dilemma in the British Government: whether the British army should be fueled by coal or should it be fueled by oil? Why was the dilemma? Because the British Government at that point of time understood that, if the fuel is oil; then the army can be run in a more efficient manner, the equipment can be run in a more efficient manner as compared to coal and that will give them an edge in the world.

However, the problem was that if they convert from coal to oil, then they have to depend on the other countries because Britain at that point of time didn't have that much oil as the amount of coal it had. It had to work out a tradeoff between the efficiency of the army vis-a-vis the security of supply of a particular fuel. Therefore in this context we see that the tradeoff was between energy efficiency and energy security. Although this was manifested in the context of a war; in today's world also we can see these kinds of tradeoffs. We always talk about these in contemporary literature. One of the biggest trade-offs that is being discussed nowadays is the trade-off between climate change mitigation and energy security. Suppose a country is rich in oil, should it use oil because it gives it energy security; however, it is using a particular fuel which is reducing efficiency with respect to climate and environment. These trade-offs are always discussed with respect to energy security and in literature you will find analysis of these.

The second boost that the concept of energy security received which truly influenced the academic literature in this area was the oil crisis in the 1970s. The shock that was percolated in the 1980s as well. If we have a quick recap of this, in 1973 because of the Arab-Israeli war and the fact that certain developed countries supported Israel in the war, Arab countries set an embargo against these particular countries and reduced their supply of oil in the world market. Not exactly in the world market, but to these particular countries; but the repercussion was felt all over the world. As a result the price of oil shot up in the world market from 3 $ per barrel to almost 12 $ per barrel over a period of one year. Then it was realized that the countries who are importing oil from the Arab countries are exposed to a kind of risk and they have to somehow hedge it.

This was the time period when it was realized that, if you are import dependent, then it's really important to understand how to mitigate the risk of this import dependence; otherwise you are exposed to this reduction in supply or increase in price. As I said that this is the point where

the academic interest in energy security also began. A lot of literature started coming out at this point of time which encompasses such issues. However, as the time passed, multiple definitions of energy security came up, there is no one definition of energy security.

If you follow the definitions that have emerged over time; you will see that in the current period of time, it has become more development oriented. Why am I saying it's more development oriented? If you look at the definition which was given by the United Nations Development Program (UNDP) in 2000; they are saying that: Energy Security is defined as continuous availability of energy in varied forms, in sufficient quantity at a reasonable price.

There are multiple dimensions to this definition. It doesn't only say that I should have a continuous supply at some particular price, It also says that the continuous availability of energy in varied forms. Now, this is very important. Why varied forms? Because if a particular country is dependent only on one fuel, no matter whether it is domestically produced or it is imported from another country, this involves the risk. However, the risk is less if that one fuel is domestically available, but you think of a situation where a country is mostly dependent on one particular fuel and that too is being imported from other countries. That increases the risk with respect to energy supply a lot. So, here they are emphasizing on the importance of having a fuel mix in the country. Second it says in sufficient quantity, it's not only that the continuous availability should be there but also the fact, it should be able to support the demand which is being generated, so in sufficient quantity at a reasonable price.

It may happen that a particular fuel is available in sufficient quantity all over the year but the price is so high that a person cannot have access to it. Now we have brought the word called 'access' and we are going to discuss energy access in the next video. Now why is this definition important? It is going from a single dimensional treatment of energy security to a multidimensional treatment of energy security;How? Because, they are not saying who is the stakeholder concerned? The continuous availability of energy in varied forms in sufficient quantities at a reasonable price, this is an important criteria for a particular country to be energy secured.

However if you come down to a more micro level, for example if you think about a particular household, for them also this is a very important criteria to have continuous availability of energy in varied form, in sufficient quantities, in reasonable price. Consider a rural household in a developing country, how important it is for them to have continuous availability of for

example, electricity or LPG or both. This is the essence of varied form in sufficient quantity. It should not be the case that electricity is available only for 8 hours a day. It should be available throughout the day, so that the household can do different works that they want to do with the electricity at a reasonable price and the government has to work out how they can be supplied electricity at a reasonable price whenever it is required.

Thus we see that energy security emerged from more of a supply oriented dimension to a more development challenge kind of a thing. If you look at the different documents in India one very interesting thing would be to follow the documents of Five Year Plans. In the annual reports of NITI Aayog the emphasis on energy was not there from the very beginning, it has emerged over time. If you look at the 12th Five Year Plan of India, there energy security is discussed and it is written that it is ensuring the uninterrupted supply of energy to support economic and commercial activities needed for sustained economic growth.

This will be fulfilled if two things take place together; first of all India has supply of fuel both domestically as well as through import, that is one challenge that needs to be made in order to fulfill this criterion. The second thing is that once India has all kinds of energy, the country has to make sure that it reaches to different stakeholders, to the transport sector, household, the commercial sector, to the industries etc.

So, it's a two layered challenge; first of all the country should have the energy and the second is that the country should have the mechanism to distribute the energy. This is the last point in the genesis of the concept. I have been mentioning this in the previous slide as well.

The literature of energy security has both international as well as domestic aspects. The international aspect such as the trade dependency, reliability of the countries from which you are importing the oil or other kinds of energy resources are important. The domestic issues are also very important. For example, the reliability of domestic supply in the context of electricity generation or having a fuel mix in the context of energy generation. We are going to focus only on a tiny bit of the concept or of the literature which encompasses the idea of energy security.

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As I said that from the international perspective, the concept of energy security emerged from a supply side, supply oriented concept to a more multidimensional concept. One of the main and highly discussed frameworks with this regard is called the framework of 4 A's. There is a large volume of literature which tries to describe the energy security position of a country based on four dimensions; not the indicators. There are different indicators to represent this dimension but they want to focus on four dimensions.

What are these four dimensions; availability, accessibility, affordability and acceptability. There is a lot of literature on this; people tried to play around these four themes in different ways. They have come up with different indicators to represent availability. They have come up with different indicators to represent for example, affordability but they have also tried to go beyond this framework of 4 A's. They added other dimensions to it as well; but this is a good point to start with, in developing our understanding on how we can analyze the energy security of a country? If we look at these four points, we will see where the challenges are; but in a nutshell if we look at the four dimensions what do they actually imply?

It's sometimes ambiguous to understand or differentiate between two dimensions; however, it's context specific. Let us have a quick look to understand what these dimensions mean. Beginning with availability; what is availability? It's more like a geological concept, so is coal available to your country. Now when I say is it available to your country;it can be thought

about in two ways, whether it is domestically available and the second thing is it available to a country from which you can access it?

It might be available to a country from where you cannot access it, probably it's too far or there is no proper transportation mechanism device, or maybe, it might be the case that with that country you do not share a proper diplomatic relationship. So, there are many things that can prohibit country A to import a particular fuel from country B. Although it is available, it's not accessible to the importing country. So, there comes the concept of accessibility and while availability is more like a geological dimension, accessibility is more of a geopolitical dimension. If you come back to the domestic understanding of energy security, then you can think about the difference between availability and accessibility in a more distinct manner. In the next video we are going to discuss the difference between availability and accessibility.

The next one is fairly simple, it is affordability. This is more of an economic dimension. As you now know the price charged, especially if it's not a perfectly competitive market, is determined by the producer because they have certain monopoly power.

Now whatever be the price the consumer is facing is it affordable to them? It's more of an economic dimension. It's also a social dimension, because the same price may seem to be affordable for one section of the society where it may not be affordable for the other economic group in the society. So, it's also a social dimension and the government has to work out; how these two different purchasing powers can be addressed within the country?

Finally, comes the concept of acceptability. This is very interesting. What is acceptability? Whether this is environmentally or socially acceptable? Why am I saying both environmentally and socially? For example, you think about coal. India has, let me say abundant supply of coal and most of it comes from domestic sources. So, if we try to fundamentally base all our economic activities on coal, then the energy security is relatively higher. However, the problem is, from burning coal there is a lot of CO_2 being emitted. If my power sector is fully dependent on coal, then there is a lot of CO_2 emission which is going on, which is environmentally not accepted.

So, this is the problem of environmental acceptability. Environmental acceptability or social acceptability is actually a much broader concept and it goes beyond the greenhouse gas emission. How? Think of wind power generation. In the context of European Countries you will find a lot of literature where it discusses the societal embedding of a technology. If I have

these wind generating turbines in front of a locality, whether the locality is actually going to accept it or not; that is very important and there is a lot of literature on that. You think about the hydropower projects, the dams which are being set up; whether it is environmentally acceptable? What is it doing to the flow of the river? How much displacement will take place if the dam is built up in one place? Is it socially acceptable? So, all these questions are actually addressed.

Hence, whenever you are thinking of energy security, there are these diverse dimensions which come into the place and this 4 A's framework is one of most clear approaches to address this. However, there are drawbacks. What is the genesis of this 4 A's? These were for the first time brought together in a report on energy security in Asian countries by Asia Pacific Energy Research Center (APERC) in 2007. Why was the mixing up of these concepts or bringing all these dimensions together interesting? It is that in energy security there are two types of literature; one is more classical literature where people talk about the indicators like availability and affordability. So, this has been discussed over a long period of time, they are more classical dimensions. What are more contemporary dimensions? These are accessibility and acceptability and in this report by APERC, for the first time they brought together these two concepts, two dimensions which are more classically discussed along with the dimensions which are more contemporary. So, there comes their sense. However, there are questions raised by people when you are talking about energy security, whose energy security are you talking about?

It might be the case that a particular country is energy secured; however, the electricity has not reached each and every household. While the country is energy secure probably, relatively energy secure from the perspective of geopolitics, import dependence, fuel diversification, however all the households in the country are not really energy secured.

So, again coming back, hammering to the same point, when you are talking about energy security, be very careful whose energy security you are talking about. The second thing as I said is, if you look at the literature of energy security, it emerged more from a supply based literature to a development concept. So, a corollary question that is asked, that is the access equitable? Again the same point that we are coming back to, the country has energy but is it equitably distributed within the country? Is it this equitably distributed within sectors? Is it equitably distributed within households? etc. So, this is why I am saying this over and over again, if you want to do some research in the future in this area, it has to bring about your

subjectivity into it and be very careful about answering these questions before you start with analyzing energy security.

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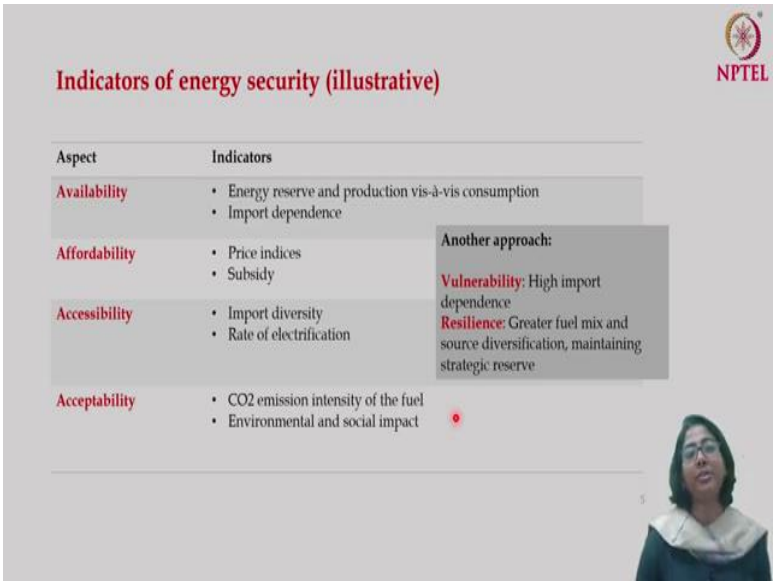

As I said that, different researchers tried to work with different indicators to understand these dimensions. This is a very small list of the indicators just to give you an idea, how they approached it. There are hundreds and thousands of indicators which are used to address these dimensions. These are also not watertight dimensions, you can add to these dimensions; you can say that one particular dimension is not sort of relevant in your work, etc. So, let us see what these indicators are.

For availability I have given examples of two indicators; energy reserve and production vis-a-vis consumption. So, referring to the slide this is availability. How much energy does a particular country have, and it's not only how many reserves do I have, how much production am I making. Different researchers have worked with different indicators in order to represent these dimensions. This slide gives a glimpse of these indicators.

This is a very small list of indicators, people have worked with various indicators. These dimensions are not written on the stone, you can change these dimensions. You can add more things to these dimensions, you can find out that one dimension is not particularly interesting in your case.

Let us begin with availability. I have given the example of two indicators; energy reserve and production vis-a-vis the consumption. Energy reserve means, how much reserve of a particular energy resource a country has; production, how much of it is being produced, so how much can be economically taken out from the reserve and finally the consumption, it also depends on the consumption. If your consumption is relatively lower as compared to production, then you are better off with respect to your energy security.

Second is import dependence. Now suppose your consumption is much higher as compared to your reserve in production; then obviously, you have to import the energy. You need a particular type of energy for certain production processes and the country doesn't have it, so, you need to import the energy. What is the pattern of your import dependence that also identifies your availability. What proportion of consumption is being imported or you can also take the indicator, what is the ratio of import to total primary energy supply or total domestic primary energy supply. Again if you go back to the energy balance table that we discussed in the first few weeks; that comes handy when you try to understand these kinds of indicators. However, when we are talking about import dependence, you can say that some of the indicators which capture import dependence are addressing the dimension of accessibility.

Next comes, affordability. These are basically the price indices; how the prices of these particular fuels are moving. If you think about the domestic energy security, it also talks about how affordable the fuel is to different economic groups within a particular country. In many cases subsidy plays a big role for the domestic energy supply in the context of domestic energy security.

The third one is accessibility. Two indicators are very frequently used. First one is the import-diversity. There is a little bit of difference when we talk about import dependence and import diversity. When I say import dependence, it tries to capture what proportion of consumption is coming from outside the country. When I am talking about import diversity, it is more related to access. I am trying to say that how many countries are you actually importing the fuel from, are these countries geopolitically stable? So, these are the things that we are going to discuss here. Accessibility, rate of electrification; if you think about more of a domestic pattern, the rate of electrification often is an indicator of accessibility. So, can you access electricity?

Again in the later slides or in the later video, we will discuss that the high rate of electrification does not necessarily mean that the households are using electricity. It also depends whether they can afford it or not and what other infrastructure is being created.

The final one is acceptability and this we have already discussed. CO_2 emission intensity of a fuel; if a fuel has high CO_2 emission intensity, then it's less environmentally acceptable. If you compare between coal and oil; coal is relatively less environmentally acceptable as compared to oil because it has higher emission intensity. But again technology plays a very big role, for example, for India you are trying to understand whether India should go for supercritical coal fired power plants or should India go for renewable energy; or should India go for nuclear energy for production of power?

Alot of acceptability issues come into the fact when you talk about coal, oil, natural gas, the nuclear, then renewable. Which one is more acceptable? It's not really about viability, but it's more about acceptability and environmental and social impact. This is very relevant as we discuss with respect to building dams or installation of a particular plant or the rate of displacement, what is going to happen to the local community etc..

This is, however, not the only approach that you can take in order to discuss energy security. Sometimes energy security is discussed beyond these 4 As. I mean in those literature nobody will talk about these dimensions. These are no direct indicator based and what this kind of literature tries to say is that; we need to identify the sources of vulnerability with respect to energy supply and then we have to see, what is the resilience? What are the adaptation measures that the country has taken? Where does the vulnerability arise from? The vulnerability arises from high import dependence.

For example, 80 % of the energy that country A uses, has to be imported from other countries. This is, this increases the vulnerability of the country. However, what creates resilience? The country can become resilient by saying that okay I have to import 80 % of energy but I will import this energy from a number of countries. I am going to import this energy for maybe 20 countries. So, my risk is reduced; if suddenly one country stops the supply, then now I have 19 other countries who will supply me the energy resource. This is how you become more resilient or the country can say, I am going to import energy from the countries who are geopolitically stable, with whom my country has a better diplomatic relationship. This is how resilience is built up, because you can't probably avoid this 80 % import because the country doesn't have

energy resources. Again the disclaimer is that these are not working in silos, it is not that either you go for 4 As or you go for vulnerable resilience kind of approach. It all depends on the context in which you are trying to understand energy security.

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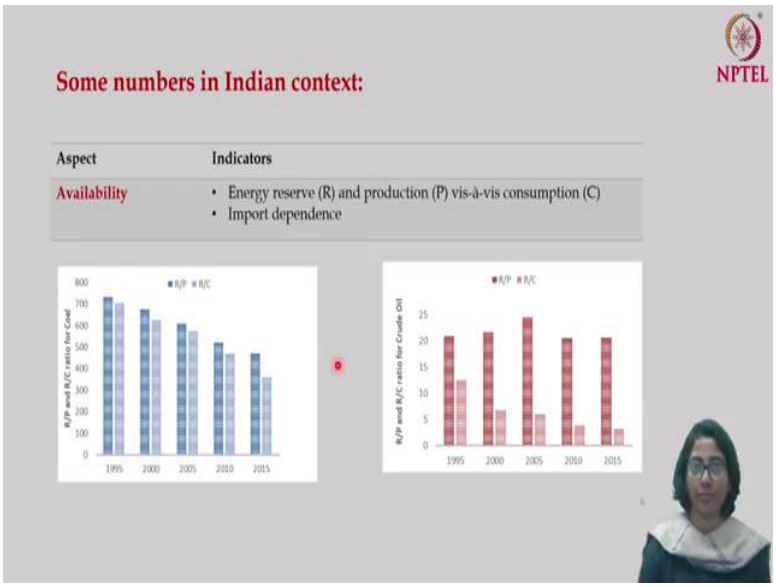

Having said so, let us have a quick look at what is the situation in India. Here we have taken the indicators based on reserve, production and consumption. Reserve is represented by R, production is represented by P and the consumption is represented by C. In these two diagrams (shown above) we have plotted the reserve to production ratio and reserve to consumption ratio over a period of time from 1995 to 2015 in the left panel for coal and in the right panel for crude oil.

Now, what do we see here? If you look at just give a glance to it, the darker lines to the left. These lines; this line, this line, this line and all, this is actually representing the reserve to production ratio. You have reserves, how much of it is being produced?, how much can be economically retrieved?, how much is being produced? We observe that the reserve to production ratio is declining. Over the time both reserve and production are increasing. However, a declining reserve to production ratio means production is increasing at a higher rate as compared to reserve. So, the denominator is increasing at a higher rate as compared to the numerator. As a result the R by P ratio is falling for coal.Thus, although India has a lot of coal reserves, the production is also high. Hence, the future availability of coal is declining

over time. So, in future the dependence on other countries for coal in India will increase, if the consumption is not decreased.

Now let us see what is happening to consumption. The lighter bar to the right is representing the reserve to consumption ratio. This is also declining, in fact at a faster rate; that means, both reserve and consumption are increasing. However, consumption is increasing at a much higher rate as compared to the increase in reserve. We see that, all these factors reserve, production and consumption are increasing over time, although not captured in this particular diagram but the consumption and production they are increasing at a faster rate as compared to reserve. So the energy reserve that you have that will not be sufficient in future to support the consumption part that India is taking; therefore, in future the import dependence is going to go up.

You look at the diagram here on the right side, this is for the crude oil. If you look at the □ratio, □

the reserve to production ratio, there is no secular decline here. It's more or less constant with some ups and downs. However, if you look at the reserve to consumption ratio, it has significantly come down. Why? Because of the fact that while some reserves are found out however, the consumption of oil in India has grown up in a very significant manner and therefore, India has to import a lot of oil from the other countries.

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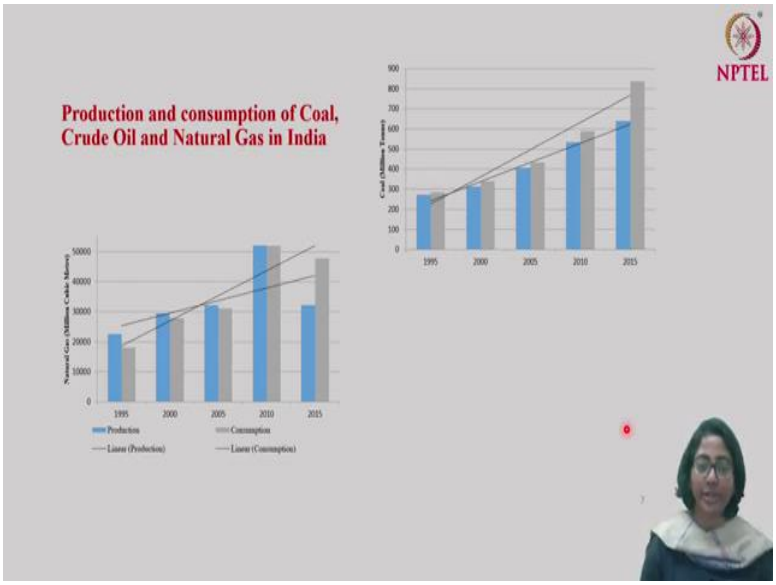

Let us now have a quick look at the figures for production and consumption with respect to coal and crude oil.

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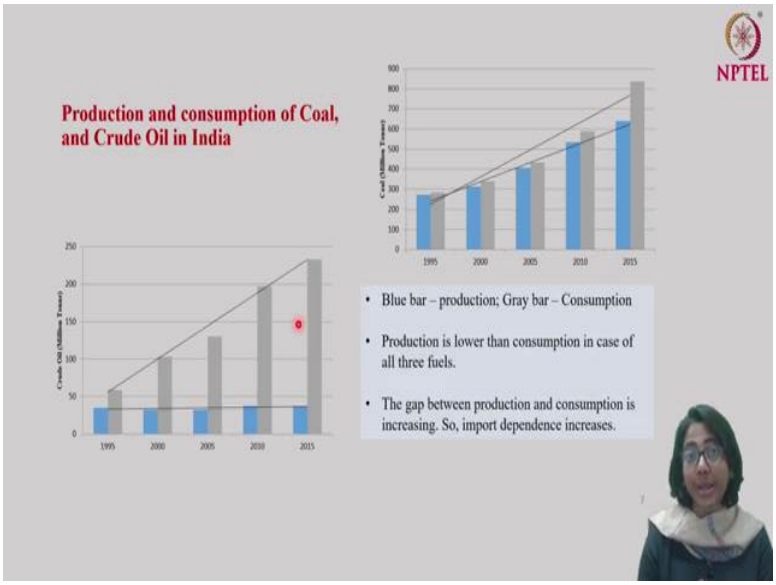

Here we are going to see how the production and consumption is actually moving. We have taken the same two fuels, coal and crude oil for India to show the gap between production and consumption and what the implications are with respect to energy security.

If you look at these two graphs, what you can see?; for example, In coal you see these grey lines, if I say this blue bar, they represent the production in million tones and the gray bars to the right, they represent the consumption in million tones. Now see over the years what is happening, the gap between production and consumption with respect to coal is increasing in India.

Now where is the gap, where this gap will be supported, how the gap is going to be filled in? Of course, by the import. So, higher the gap between the production and consumption, higher is going to be the import dependence for that particular fuel. These are the linear trends fitted for production and consumption.

Similarly if you see crude oil, the situation with respect to energy security is not very good, you know, if you look at the import dependence. This is the trajectory of increase in the consumption of oil over time in India from to 1995 to 2015. However, you see that the production has remained almost unchanged because other than Assam and Bombay High, there is hardly anything discovered in India with respect to oil reserves and hardly is being produced. This big gap between consumption and production is being filled in by the import and India is heavily dependent on a lot of OPEC countries for the import of oil. This is putting or

emphasizing on some concern with respect to energy security in India especially in the context of oil.

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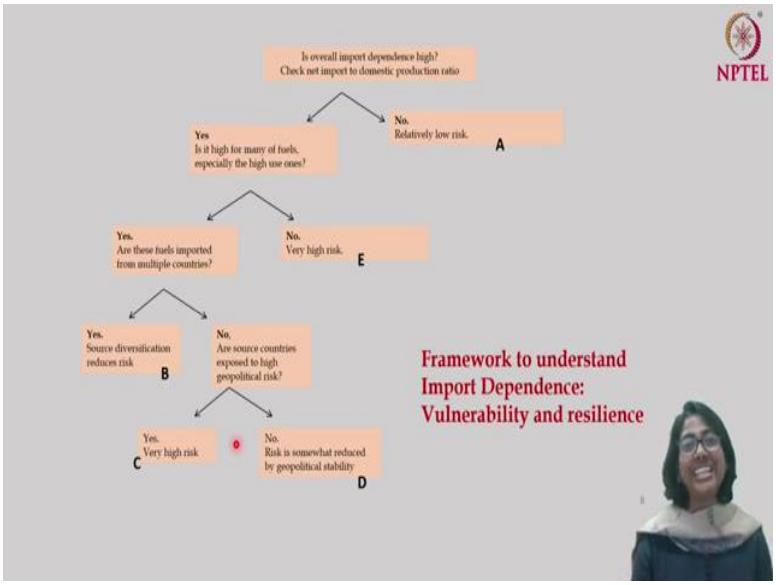

In the next slide we are going to briefly discuss how you conceptualize or what kind of framework can you develop in order to understand vulnerability and resilience with respect to energy import by a particular country. Let's go by this binary answer Yes/No questions. We start with this particular question; is the overall import dependence of a particular country high? What is the proportion of total primary energy supply which is being imported by this particular country vis-a-vis what is being produced domestically?

Again as you know this kind of indicator can be derived from the energy balance table. You remember, the first block was the supply block where we were discussing how much is being produced domestically, how much is being exported, how much is being imported, etc. So, the first question: is overall import dependency high? If the answer is yes, then there is a follow up question. If the answer is no, so the import dependency is relatively less which means that the import related energy security is not very low for this country.

However, if the answer is, Yes. So, fundamentally it means that the country has to depend on a number of other countries in order to procure these energy resources. Here comes the follow up questions, that okay there is a risk but what have you done to hedge the risk? Have you developed some kind of resilience mechanism or not? The follow up question to these countries for whom the answer is Yes is: Is it very high for many fuels, especially the fuels that your

particular country uses? Do you import a lot of your strategic fuel ,not, I should not say strategic fuel but I should say the most important fuel that you are using for production and consumption purposes. If the answer is, Yes, then you remember, this is a country with high import dependency for most of the fuels. Then of course, you are exposed to high risk. Now if the answer to this is, Yes; there comes a follow up question, are these fuels imported from multiple countries? So, you are importing fuels from other countries but are you importing them from 2 or 3 countries or are you importing from multiple countries? If the answer is yes; this means that, although there is high import dependence, you have to depend on other countries but you have diversified your risk as you have diversified your source of import.Thus, the source diversification will reduce your risk as you have developed some kind of resilience in your system.

However, if the answer is no; then inherently you have not probably developed too much resilience in order to counter the energy security risk that you have. But there is another question that follows up, the final follow up question that you have to ask; that, okay you are not importing the fuel from multiple countries, you are probably importing the fuel from 2 or 3 countries, but what is the geopolitical situation of these 2 or 3 countries? What is the diplomatic relationship between your country and these 2 or 3 countries?

If they are exposed to high geopolitical risk, then you are in a very difficult situation with respect to energy security. If I say this category C, these are the countries who are importing a high proportion of fuel from other countries, they have not diversified their sources and the countries from which they are importing are exposed to high geopolitical risk. This is the worst kind of situation that you can have with respect to your energy security.

Now, if you look at country D, these are the countries who are importing a large amount of energy from other countries, probably not from too many countries. However, the countries from which they are importing are relatively safer from a geopolitical perspective. But this is a very risky proposition to go for D, because you never know when the geopolitical situation changes.

However if you look at B, they have somehow developed a resilience by the form of diversification of sources of the import. Country E: they are not exposed to too much energy security risk. If you look at A, they are also not exposed to the energy security threat. If you want to rank these countries with respect to energy security, then A and E are the countries

which are exposed to less energy security risks. However, countries like B, C and D, especially C and D are exposed to high energy security risks. These are the questions that you can ask if you want to understand the situation of energy security of a country especially with respect to import dependence.

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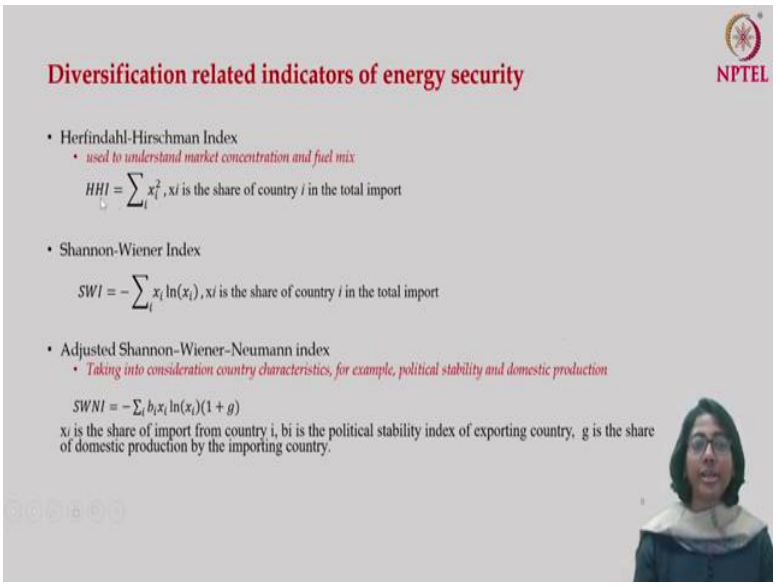

Finally this is the last bit of it and we are going to discuss a couple of diversification related indicators of energy security. These are the indicators whose genesis are more into ecological science to understand the ecological diversity. The same indicator in a different manner is also used to understand market concentration, to understand whether you have diversified your import sources or not. What are these indicators? Let us have a quick look at it. The first one is called the Hirschman-Herfindahl Index or the Herfindahl-Hirschman Index. What does it do? It's used to understand the extent of market concentration. We will come back to fuel mix later but let us first talk about the market concentration. This is represented as a Σx_i^2, where x_i is the share of country 'i' in total import. Suppose I am importing oil from three different countries, I am importing 10 % from country A, another 10 % from country B and 80 % from country B. Then the Hirschman-Herfindahl Index, HHI = $0.1^2+0.1^2+0.8^2$, so x_i is the share of import from a particular country. We will go to the numericals where it will be more clear to you.

The second one is the Shannon-Wiener Index. What does the Shannon-Wiener Index do? This is again the same as Hirschman-Herfindahl Index, it tries to capture the diversity in the import

sources. This is represented as $-\sum x_i \ln(x_i)$. So, what is the role of this minus? When you are talking about the import share, this is a fraction and if you take the log of a fraction that will give you a negative number. So, in order to make this index positive, you add this minus in the front. So, you are multiplying x_i with log of x_i and summing them up.

As I said if you take the previous example if a particular country is importing oil from three different countries, 10 % from country A, 10 % from country B and 80 % from country C, then the Shannon-Wiener Index, SWI = $-[(0.1\ln(0.1)) + (0.1\ln(0.1)) + (0.8\ln(0.8))]$; this is Shannon-Wiener Index. Now let us just quickly show you one worked out example which will make things more clear.

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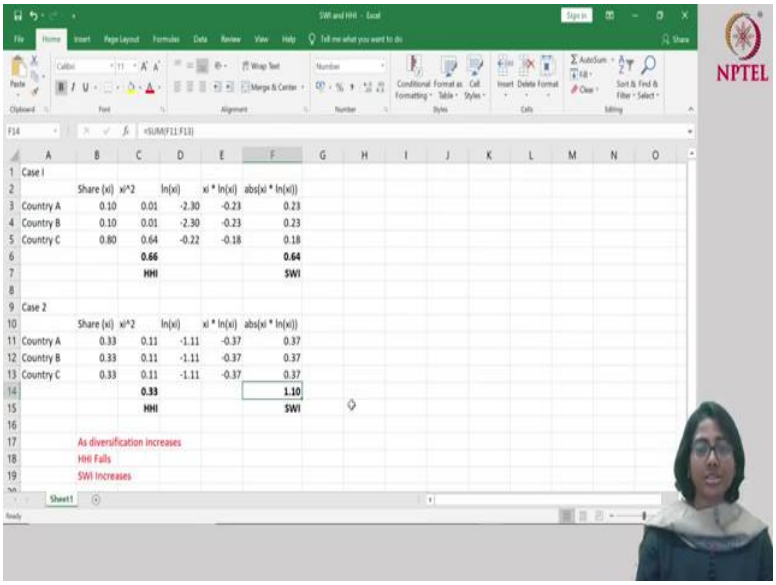

This is the example that we were talking about, taking it as case 1. So, in case 1, this particular country is importing oil from country A, B and C; from country A they are importing 10 %, country B they are importing 10 %, country C they are importing 80 %. So, in order to calculate the Hirschman Herfindahl Index; what we have done, we have taken the square of the market share, that is, the square of the import share.

So, this is 0.1^2. If you see this one, this is again 0.1^2, this is again 0.8^2. After squaring them up, if you remember the Hirschman-Herfindahl Index is Σx_i^2. So, this 0.66 is actually the sum of 0.01, 0.01 and 0.64. This gives you 0.66 as the Hirschman-Herfindahl Index. Let us see how we calculated the Shannon-Wiener Index. If you go here I have used the natural log (ln), you take the ln(0.1), here again you take the ln(0.1) and here you take the ln(0.8). You multiply

each of them by the import share. So, ln(0.1)is being multiplied by 0.1, similarly for the rest of the entries. So, for example, here you see that 0.8 is being multiplied by ln(0.8), all of them are negative. Now, what we are doing, we are taking the absolute value of x multiplied by $\ln(x)_i$.

So, these are the values now that we have to add up in order to obtain the Shannon-Wiener Index. So, this 0.64 which is the Shannon-Wiener Index, this is the sum of 0.23, 0.23 and 0.18. In this particular example the Hirschman-Herfindahl Index is 0.66 and Shannon-Wiener Index is 0.64. Now one disclaimer is that the Shannon-Wiener Index and Hirschman-Herfindahl Index are not readily comparable. We should not say that HHI is higher than SWI and there is another reason why we should not do that.

Now let us take another example. Before we do that, if we talk about this distribution, do you think this country is exposed to import related risk? The answer is: at the beginning the answer is yes because they are importing 80% from country C, while the rest 20% is distributed between country A and B. So, C has a very high market share, if tomorrow C denies supplying oil to this particular country, they will be in a very difficult situation. Now under case 2, we have developed a scenario which is a more diversified scenario. Here also they are importing oil from three different countries, probably the same three different countries but the market share or the import share of these three different countries are equal.

Now, if tomorrow C says I am not going to supply you the oil, then it's only 33 percent of your total supply which is in a problematic situation. With these figures, each country supplying the same amount of oil, we have again calculated the Hirschman-Herfindahl Index and the Shannon-Wiener Index. Interestingly we observe that, if you go for a more equitable import distribution, then the Hirschman-Herfindahl Index declines from 0.66 to 0.33.

Readily you can now understand that it's good to have a lower Hirschman-Herfindahl Index, if you are thinking about source diversification. However, as we have higher, more diversified sources, the Shannon-Wiener Index goes up. So, it's good to have a higher Shannon-Wiener Index. Hence, it's good to have the lower HHI whereas it's good to have the higher Shannon-Wiener Index. This is one thing that one needs to remember. I will upload this excel file, so that you have more understanding about how to do the calculations and all.

Now coming back to the presentation, so this is how we calculated HHI and SWI. Now one inherent problem in these indicators especially we discuss with respect to Shannon-Wiener indicator is that, this particular indicator does not take into account what proportion of your

supply is actually coming from import. If we go back to our previous framework, which is this one; you see in the case of Shannon-Wiener Index or in case of Hirschman-Herfindahl Index, we are actually answering only this question, are these fuels imported from multiple countries or not? However, we are not taking into consideration the questions raised before and questions raised after. This is the only thing that we are taking into consideration. We are not taking into consideration whether the overall import dependence is high, we are also not taking into consideration the geopolitical situation of the country from which the fuel is being imported.

How can these two things be incorporated in the framework of Shannon-Wiener Index? It is done in this way; so this is called the modified or adjusted Shannon-Wiener-Neumann Index, where the previous concept remains. You have the component $-\sum x_i \ln(x_i)$, however with that you are multiplying b_i and (1+g). So, what is b_i? b_i is the political stability index of a country.

Now there is a lot of controversy and debate about how you can exactly measure political stability; but there are certain reports which provide you some kind of an understanding about the political stability of the countries. Let us not go into a detailed discussion on that. So, if b_i is high, then your Shannon Wiener Index is high, which is good with respect to your energy security. What is 'g'? 'g' is the share of domestic production. Again if g is high, that is your share of domestic production is high; then Shannon-Wiener Index is higher, as a result you are better off with respect to your position in energy security.

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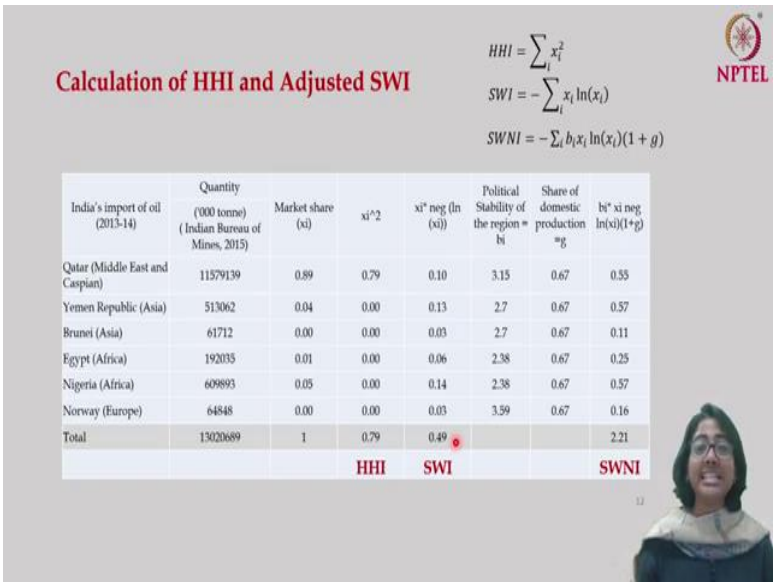

This is the final worked out example to illustrate how you calculate the HHI, SWI and the modified Shannon-Wiener-Neumann index but I haven't shown all the calculations here. This is the summary, you can use an excel file to use that. So, one point is that see, whenever I am using this log, I am actually using the natural log (ln). If you are using the log base 10, you might have a little different result but that's comparable. These are the figures on India's import of oil in the year 2013-14 and this has been obtained from the report of Indian Bureau of Mines that was published in 2015.

In this particular year India imported oil from Qatar, Yemen Republic, Brunei, Egypt, Nigeria, Norway and some other countries with a very small share. The major part came from Qatar, the Middle East and the Caspian region which is 0.89. So, almost 90 percent of oil that India imported actually came from Qatar and the rest of these, like Norway, that this is showing as 0.00 because I have reduced it to two decimal points, if you go for 5-6 decimal points you will get some positive value for it, which is reflected in others. These are the market shares, you take the square of the market shares and you add them up and you get the Hirschman-Herfindahl Index which is 0.79. Now there is a benchmark for Hirschman-Herfindahl Index. It is usually said that, if the Hirschman-Herfindahl Index calculated this manner is higher than 0.18 then the market concentration is high and of course, that is reflected here because 90% of oil India imported from Qatar.

What happens in case of Shannon-Wiener Index, they are calculating the x_i and negative of $\ln(x_i)$, so this takes care of the minus sign $\ln(x_i)$. These are the values you are getting and your Shannon-Wiener Index is derived as 0.49. Finally, comes the calculation of the modified or adjusted Shannon-Wiener Index, for that we need two things; one is the political stability of the region. Now the report that we used does not give the country wise political stability of all. So, what have we done? We have taken the political stability of the Middle East and Caspian area altogether, we have taken the average political stability of Asia and Africa and Europe.

This is a very crude measure but it is just to give you an understanding. These are the b_i's. We are going to multiply this b_i's with these columns first and if higher the b_i higher will be the components of the Shannon-Wiener Index. Then you have a share of domestic production, which is g. Now in this particular year you see 2013-14, it's the domestic production of the consumption, the proportion of domestic production was higher. So, the import was not very high in this period. That gives an edge to India to improve the Shannon-Wiener Index. Finally, the adjusted Shannon-Wiener Index is calculated by multiplying this particular column by b_i

and (1+g). This is giving the result of the adjusted Shannon-Wiener Index which is equal to 2.21. Now what do these numbers say in absolute terms?

For HHI, you can say that the market concentration is very high, but for the Shannon-Wiener Index and the adjusted Shannon-Wiener Index, what can one do? One can multi calculate these indices for a particular country over a period of time to understand whether the energy security position is being better off or is it worsening over time.

But just looking at the number, it's difficult to conclude much. It's more for a comparative purpose. Thus, these absolute values tell you some story but not the entire story. One very interesting exercise could be to identify or to calculate these indices for India for different fuels over a period of time.

So, we are going to end this lecture here. In the next lecture we are going to talk about energy access and there we are going to discuss as I have said in this lecture; what is the difference between availability and access, why is it so important that you talk about the stakeholder when you are talking about energy security.

Thank you.