Staff Paper

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Abstract. This is the first paper showing empirically the share of direct and indirect energy costs in the agrifood supply chains in Asia, or for that matter, in developing countries generally. We show a substantial share of total value chain costs come from energy costs. While the debate has focused on energy costs on the farm, we show that off-farm components of the value chain/food system have a higher share of total energy costs. The energy costs on the farm and off-farm in the food system are correlated with the degree of "transformation" of the value chain and its segments, such as capital intensification and geographic lengthening. While energy costs and food costs are generally correlated in the macro literature, the analysis here allows policymakers to unpack the black box of energy costs in the food sector and ascertain where energy vulnerability challenges are and energy economizing opportunities may best pay off for overall national food security.

1. Introduction

The focus of the food security debate in Asia has usually been on the farm level; that focus basically equates the cost of food with the costs of production on farm. That focus was justified

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when food was produced and then consumed locally – on the farm as home-consumption or mainly sent to local village markets, in a situation where urban consumption was a small share of total food consumption. This image would be empirically applicable let us say in the 1960s and 1970s when the urban share of population was 10-20%, and the marketed surplus rates of farms would have been around 20-30%, of course depending on the country. In this setting, the share of the costs on farm would have been a very large share of the total cost of food.

But now fast forward the film to the 2010's. Our rough estimates based on secondary data and our extensive primary surveys are that the urban food share in total food consumption is around 60-70%, that the farm share of costs in the overall food supply chains feeding cities is about 30-50% depending on the product, and that farms are now high commercialized, with for example marketed surplus rates of 70-90% in the main rice baskets over Asia. Agrifood value chains (VCs) have shifted from being mainly local to being much longer, stretching from rural areas to urban consumers and a little bit to export markets.

In this new situation, it is clear that post-farm gate segments of the food supply chains form a large share (around 50 to 70%) of costs of food to consumers, and two-thirds of the food is consumed by consumers in cities who are thus paying farm and post-farm gate costs.

Moreover, there has been a lot of transformation of agrifood VCs in Asia in the past decade or two – in terms of massive expansion of the non-rice VCs, in terms of consolidation per segment such as with the rise of supermarkets, large processors, wholesale markets and specialized modern wholesalers, logistics firms, fast food chains, and modern input manufacture and distribution companies (Reardon and Timmer 2014).

This has been accompanied by "capital led intensification" (capital/output and capital/labor ratios increases) in nearly all segments of the food VCs – not just in the intensification of farming with its large increase in the use of chemicals and irrigation and farm machinery across Asia, but also in the increased use of energy-using equipment in the other segments, coupled with the increased use of (energy using) transport services to link the segments of the geographically long supply chains. It is unknown empirically how the structural and organization changes noted in the earlier paragraphs and the technological changes in this paragraph are interacting in reality in terms of implications for costs (including energy costs) along the food supply chains – efficiency gains from scale increase and dis-intermediation might decrease for example energy costs, but capital-intensification might compensate those changes by net-increasing energy costs.

Much can be discussed about the nature of the costs along the transformed agrifood chains, but in this paper we focus in on a category of cost that has come under policy debate and scrutiny economy-wide in developing Asia - that of energy costs. The importance of energy costs was reemphasized in the oil price shock of 2008; electricity and diesel price policies are important in public debate in China (for example, Lin and Jiang 2010) and India (Singh 2006); energy market liberalization and restructuring is planned or already underway, with the expectation of sharp increases in energy costs. There was at the same time much discussion, with the "food crisis of 2008" about the correlation at the macro level of food and oil prices (for example, in ADB 2008).

Despite the surge of interest in energy costs and food costs, there has been little exploration of this empirically in terms of analysis of these costs in food supply chains in developing Asia. Yet there is little survey-based empirical research on the incidence of energy costs in food VCs in the study countries or other developing countries. Most of the analysis and discussion has been not specific to food, has been sector (for example for Thailand, Bhattacharyya and Ussanarassamee, 2005, for an inter-industry energy intensity macroeconomic decomposition analysis) or macro focused, or in a few cases, has analyzed energy costs at the farm level only. Parikh (1986), for India, used broad energy-input, product output assumptions for different scales of plants and types of transport and made macroeconomic "energy accounting" estimates of energy use for food distribution, processing, and preparation. This macroeconomic line of work does not differentiate over products, over types of supply chains, nor track differential costs facing different kinds of regions or supply chain actors.

Nevertheless, one expects those costs to be important (Mattoo et al. 2007): in transport, in cold chains and warehouses, in packing and processing, in loading and unloading between segments, in retail storage and shelves. Moreover, they may even be of increasing importance not only with energy price shocks globally but with the lengthening and capital-intensification of food VCs in Asia.

The lack of debate and analysis of energy costs along the segments of food VCs in developing Asia contrasts with the strong interest in this topic in Western Europe, and to a certain extent in the US. There have been three strands of this literature.

The first strand focuses on how energy costs affect farm technology choice and efficiency. The emerging literature shows that this impact can be substantial, such as with the energy price shock on greenhouses in the Netherlands, inducing technical change to save energy (Lansink and Ondersteijn, 2006); or the potential effect can be modest on technology and incomes as in row crops in the US (Sands and Westcott, 2011).

A second strand that is somewhat a subset of the first strand is the literature emerging mainly in the 1990s on energy costs and environmental impacts of "sustainable agricultural systems" at the farm level, compared with less sustainable ones (Liedtke et al. 2010).

A third strand, flourishing in particular in the past decade (Liedtke et al 2010) but with its roots in the 1970s/1980s during earlier energy crises, has focused on energy costs (and environmental effects such as greenhouse gas (GHG) emissions) not just from farming but in the post-farmgate segments of the food supply chain. Interest has been keen in tradeoffs between "reducing food miles" to reduce energy costs and environmental damage (as well as the "carbon footprint") of food supply chains, and food cost, seasonality, and availability from geographically broad supply chains. (For the fruit case in/to UK, see for example Sim et al. 2007, or into Germany, Blanke and Burdicke 2005). Recent research has emphasized that energy use and the "carbon footprint" of supply chains can differ sharply over different kinds of VCs: (a) depending on different modes of transport, such as Coley et al. (2011) show for produce imported to the UK; (b) depending on different degrees of product perishability and technologies used in producing, processing, and transporting food (such as Ramirez et al. 2006 for a comparison of energy efficiency of different horticultural chains in the Netherlands).

In this paper we seek to start to contribute to the gap in the literature in developing Asia concerning energy costs in transforming food VCs. We cannot hope in a short space and with limited data to address all the aspects of the strands of literature on this subject in developed countries over the past decade. Rather, our goal is narrow and specific – we analyze new VC survey data from two main foods in Asia, rice and potato, to ascertain the share and thus the importance of energy costs along the supply chains. This allows policymakers to see how vulnerable these long chains are to energy costs shocks, and to tell where the main energy using points are along the chain, like a "hot spot" analysis (Liedtke et al. 2010).

We present the evidence by product (rice and potato) by VC segment (gleaned from "stacked surveys of rice and potato VCs" in the past five years), and discuss its implications.

There is nothing like this paper in the literature: there are no empirical tests of the shares of energy costs in the segments of the main grain and the main vegetable of Asia. We compare a grain and a vegetable because we surmise there may be a difference between a non-perishable and perishable involving transport, processing, and storage/cooling costs.

For energy costs, we analyze first-round or "direct energy costs" which include oil and electricity expenditures to run farm machines and irrigation and vehicles and cold storages and mills and trading and retail posts. We also discuss in a limited way second-round or "indirect energy costs." For the latter we limit ourselves to chemical fertilizer, because it is important in the debate about indirect energy costs in developing country (and developed country) agriculture World Bank 2007 in the World Development Report 2008). Limiting to fertilizer is of course somewhat arbitrary, and certainly a lower bound, as a full analysis of second-round energy costs in the system would have to take into account all energy going in to all inputs in all segments of the value chain. That is complex and demanding of data we do not have. For chemical fertilizer cost's conversion into energy costs we use a simple coefficient of 0.8 times the fertilizer cost; this comes from the US Congressional Research Service (2004) finding that natural gas, a primary component in nitrogen fertilizer production, represents 75 to 90 percent of the production costs of nitrogen fertilizer.

2. A Unique set of Primary Data on Rice and Potato VCs

The data come from **5839 observations of economic actors from 9 sets of surveys** (covering all the segments of the VCs each), using comparable questionnaires both for a given product and across the two products, across all the sites; there is no such comparable data base in the developing country literature.[2] Table 1 shows a combined sample of **4169 rice VC actors** interviewed, using approximately the same questionnaire per segment across the zones.

[2] The six rice value chain studies include Das Gupta et al. (2010, 2013); Minten and Murshid (2010); Reardon et al. (2010); Wang et al. (2013); Dao et al. (2013). The potato studies include Reardon et al. (2010b); (Das Gupta et al. 2010b); Minten and Murshid (2010b).

Table 1. Rice Study zone Surveys

	More advanced zone	Less advanced zone	Total
China Bangladesh India Vietnam	Heilongjiang Noagaon West UP Mekong River Delta	Jiangxi -- East UP	
Paddy/rice Surveys fielded:			
Farmers	925	840	1765
Rural traders	110	147	257
Mills	162	110	272
Urban traders	150	133	283
Urban traditional retailer	275	870	1145
Supermarkets	170	182	352
Village heads	47	48	95
Total	1839	2330	**4169**

Table 2 shows a combined sample of **1670 potato VC actors** interviewed, using approximately the same questionnaire per segment across the zones.

Table 2. Potato Study zone Surveys

China Bangladesh India	Gansu Bogra West UP (Agra)
Potato Surveys fielded:	
Farmers	810
Rural traders	173
Cold Storages	51
Urban traders	90
Urban traditional retailer	350
Supermarkets	160
Village heads	36
Total	**1670**

The rice data on which we draw in this paper come from Asian Development Bank-funded surveys (done by ourselves) in six areas over four countries. The six include four dynamic, commercial zones that are the mainstays of rice supply to four major cities of Bangladesh, China, India, and Vietnam – to wit: (1) Noagoan district to Dhaka; (2) West-Central Uttar Pradesh (UP) to Delhi; (3) Heilongjiang province to Beijing; and (4) Mekong River Delta (MRD) (in An Giang and Hau Giang provinces near Can Tho city) to Ho Chi Minh City. The six also include two less-developed rice zones, relative hinterland areas, for comparison, to see whether rice VC transformation had diffused further than the commercial zones near the mega cities. These zones are: (5) the Shangrao district of Jiangxi in southern China to cities of Zhejiang province; (6) the Allahabad district of eastern UP to the city of Jabalpur in Madhya Pradesh. Together, these six zones are not, strictly speaking, nationally representative of the four countries; rather, they were selected by "reasoned choice sampling" to represent more advanced and less advanced rice zones, for comparison.

The potato data on which we draw were also from Asian Development Bank-funded surveys (again, done by ourselves) in three areas over three countries. The three include two dynamic commercial zones that are key to supply to major cities in Bangladesh and India, that is: (1) Bogra District to Dhaka; and (2) West Uttar Pradesh (UP) to Delhi; moreover we included one less developed potato zone, in a relative hinterland area (further from cities) for comparison; this included (3) Gansu in western China.

The data come from unique "stacked surveys." They are "stacked" in the sense that the survey is done over the segments of a supply chain, and not merely a survey of for example farm households and then just small sample key informant interviews with the other segments, as is usually done. The stacked survey approach uses representative sample surveys in every segment of the rice VC from farmers to wholesalers to mills to retailers. These differ from "key informant rapid reconnaissance" studies that are usually made of supply chains in that the "stacked survey" samples are large enough in each segment to allow for testing of statistical robustness of differences over strata, such as over farm size strata, and for study of study of size strata, such as large versus small farmers.

3. Evidence of Energy Costs in Rice and Potato VCs

To maintain this paper within the space limits, we present the substantial detail of the analysis of the "stacked survey data in the Annex and summarize the findings over the products and VCs in the following text table, which shows:

- the total shares of direct energy costs (on electricity and diesel) in total costs of the VC;
- the shares of "indirect energy" (roughly calculated as 80% of fertilizer cost to show the share of natural gas embodied in it) (we used this as a "lower bound" for indirect energy costs, given its prominence in the debate about energy in agriculture; but of course there is indirect energy embodied in all the non-labor inputs used in all the segments, and at one greater remove, embodied in labor itself via food consumed);
- the total of the above shares to provide a rough lower bound idea of how important energy is in the whole value chain;
- the share of direct energy from off-farm segments; this is the first time in the literature in Asia or indeed any developing country where this figure has been calculated for food value chains;
- the share in direct energy costs of the value chain of direct energy costs form the farm; we note this for its own interest but also to compare with the off-farm component as the debate about energy in agriculture tends to focus nearly exclusively on on-farm costs.

Product/VC (by end point)	Total share of **direct energy in VC costs**	Share of **indirect energy (only via fertilizer**) in VC costs	**Ratio of fertilizer energy cost to farm direct energy cost**	**Total energy share (direct+ indirect) Of farm costs**	Share of direct + indirect in VC costs	Share of direct energy **from off-farm**	Share of direct energy **from farm**
1. Rice VC (simple average over sites)	**22%**	**9%**	**1.1**	**28%**	**31%**	**58%**	**42%**
a. Delhi India	21%	6%	9:19 or 0.5	9+19=28%	27%	50%	50%
b. Jabalpur India	22%	10%	14:11 or 1.3	25	32%	64%	36%
c. Dhaka Bangladesh	15%	11%	13:10 or 1.3	23	26%	40%	60%
d. Near Hangzhou China	21%	7%	11:14 or 0.8	25	28%	57%	43%
e. Beijing China	28%	5%	11:15 or 0.7	26	33%	61%	40%
f. HCMC Vietnam	27%	15%	29:13 or 2.2	42	42%	75%	25%
2. Potato VC (simple average)	**18%**	**8%**	**3.3**	**18%**	**26%**	**74%**	**26%**
a. Delhi India	23%	3%	2:6 or 0.3	8	26%	50%	50%
b. Dhaka Bangladesh	16%	13%	22:3 or 7.3	25	29%	88%	12%
c. Beijing China	14%	8%	14:6 or 2.3	20	22%	85%	15%

Three general findings stand out.

First, the Table presents a point that has never been documented empirically in developing countries in general and Asia in particular – the **large importance of energy costs in agrifood value chains. For rice, direct energy use averages 22% of the costs of the value chain, and with the indirect energy use from fertilizer, averaging 9%, fully 31% of costs of**

the value chain and thus of rice to urban consumers. For potatoes the shares are 18, 8, and 26% for the overall. These are based on 9 detailed value chain stacked surveys, for only two products, one a non-perishable grain and one a long-storage semi-perishable. These figures might be considered lower bounds for the importance of energy in food value chains in general in Asia, as only about a third of food expenditures are on grains, and the rest of perishables like meat and fish and dairy and fruits and vegetables as well as processed foods.

It may be that this has not been explored in the literature to date because of the prevailing image of value chains as based upstream in farms that are little mechanized and selling into midstream and downstream segments that are still short in distance and peopled with many small actors using little mechanized technologies. The reality of the food value chains supplying two key foods – rice and potatoes – to Asian large cities has changed over the past decade: (1) they now start upstream from very commercialized farms, even in the case of very small farms, that have undergone widespread mechanization as wages have risen and machine costs have gone down, as fertilizer use has become ubiquitous and substantial, as irrigation has extended the seasons; (2) these same supply chains now include substantial use (with differences over the study sites with Agra in India presenting the most "advanced" case) of modern, energy-using cold storages, of medium and large energy consuming mills, of medium and long distance transport by medium and large trucks and boats, and retailers using electricity and motorized transport.

Second, while the debate about energy in agriculture in developing countries focuses on the farm segment, our taking a value chain or food system perspective shows that this focus neglects the important role of the off-farm components (in the midstream and downstream, post-farmgate) in energy cost formation in the value chain, and ultimately, of food prices for consumers. This is the first time this point has been made with survey data to support it in developing countries. In **the rice VCs, the share of off-farm components moderately exceeds (58 to 42) that of the farm for direct costs, and for potato VCs, exceeds (74% to 26).**

Of course, **this point is moderated but not contradicted when the indirect costs of fertilizer-embodied energy costs are added to the farm segment's share**; however, it is interesting that doing so merely brings to equality the role of off-farm and farm components in total energy costs in the value chains of rice, and still leaves the off-farm components dominant in energy-cost formation for potatoes.

Importantly, two conditioners of the relative share of the off-farm segments stand out. These are: (1) energy from transport (hence the cases **where the supply chains are geographically long** - where the farm area is relatively far from the consuming city (such as for Beijing rice and potatoes, Jabalpur rice, or the high energy costs of waterway transport in south Vietnam) show high off-farm energy shares; (2) **cold storage costs for potatoes** (especially in the south Asian cases) **and large mill energy costs** (in the China and Vietnam cases).

Third, farm segment energy costs are composed of (1) direct energy costs and (2) indirect (in our case confined to just the energy embodied in chemical fertilizer). We present a column which shows the ratio of (2) to (1) to test the hypothesis, coming from the developed country literature (e.g., USDA (2006), that the indirect energy use (via chemical fertilizer) is about 2:1 times the direct energy use on the farm, and the total of direct plus indirect (via fertilizer & other chemicals) is 16% of total farm costs in the U.S**. Interestingly, the average of the rice and potato cases in Asia comes out to the same ratio of indirect to direct as in the US. That potato has a higher ratio than rice in the Asian cases can be explained by the higher fertilizer intensity of rice and the greater machine intensity of rice; in the US there would also be such variation around the average. Moreover, it is interesting that the total energy share for the potato case in Asia (18%) is nearly the same as the US case overall (16%); if one excludes the outlier Vietnam case in the rice data, the average share (25%) is not much higher than the US or Asia potato cases.** Thus, although the average sizes of the farms are smaller than in the US, the energy share in farm costs is roughly similar; that is a testament to the capital-led intensification of the Asian farms in the past decade or two. There is obviously substantial variation over the zones but that is mainly explained by differences in mechanization and irrigation costs, with the highest mechanization rates that were discussed in the text in the specific cases section.

4. Implications

This is the first paper showing empirically (from primary survey data) the share of direct and indirect energy costs in the agrifood supply chains in Asia, or for that matter, in developing countries generally. We show a substantial share of total value chain costs come from energy costs. While the debate has focused on energy costs on the farm, we show that off-farm components of the value chain/food system have a higher share of total energy costs.

We showed that the energy costs on the farm and off-farm in the food system are correlated with the degree of "transformation" of the value chain and its segments, such as capital intensification and geographic lengthening. We noted that Asian agrifood value chains (and also those of Latin America, and increasingly, in Africa) are transforming, with capital intensification per segment, with geographic lengthening, and in the more advanced cases, with consolidation and scale increase per segment at least in the off-farm segments. Moreover, de-seasonalization is occurring both in grains and potatoes (with irrigation) and potatoes and other perishables (with cold storage). As these trends continue, reliance on energy along the value chain will be increased. All else equal, that can increase the vulnerability of food supply chains to energy cost shocks – although that can be offset by economies of scale and mitigation measures to save energy along the chain.

While energy costs and food costs are generally correlated in the macro literature, the analysis here allows policymakers to unpack the black box of energy costs in the food sector and ascertain where energy vulnerability challenges are and energy economizing opportunities may best pay off for overall national food security.

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Annex with Survey findings on Energy Costs along the Rice and Potato Value Chains

In this Annex, we proceed by study zone from which issues a rice VC. In each case, we examine energy costs by VC segment, and then in summary over the overall VC. For each segment, we briefly characterize that segment in that case, and then note the roles and shares of energy in that segment.

(a) Energy in the Rice VC in India: from Shahjahanpur (Center-West Uttar Pradesh) to Delhi

General situation of the VC. The Shahjahanpur rice production area is close to its mills and about 5-6 hours, 330km, by road to one of its main consumption markets, Delhi.

Paddy farm segment in Shahjahanpur. (1) Context: Paddy farming in this area is energy-using directly and indirectly. Paddy farming in this area is fertilizer-intensive, as all farmers use chemical fertilizer, which constitutes 11% of farm costs (and thus "second round" energy-using via the use of oil and electricity for the production of fertilizer), and fertilizer energy (80% of the 11%, or 9% is the share of this indirect energy in total costs. Paddy farming there is irrigation-intensive; 96% of the farms are irrigated; 36% own pumps (with a strong bias toward larger farmers owning pumps and selling water to the small farmers). Paddy farming here is machine-intensive; 86% of farmers (without size bias) use tractors; only about a third of the medium and large farms own; the small and the rest of the larger farmers rent. Only 14% of the farmers still use the traditional animal traction. These small/medium farms are commercialized, with a marketed surplus rate of 77, 89, and 94% for the three size strata. But they sell their paddy locally – 40% of their volume is sold right at the farm gate, while 50% is sold at the block level (close by) and only 10% at the district level. Thus farmers are not using much energy to market their paddy. (2) In terms of energy costs: (a) 17% of total farm costs are irrigation costs; by our rough assumption that half of irrigation costs are energy (diesel or electricity), this means about 8% of the farm costs are from irrigation energy; farm machinery is 17% of farm costs; again by rough approximation about half of that is for diesel/energy, hence another 8% of the farm costs are for farm machine energy. Given that most of the paddy is sold at the farm-gate or a few km away at the block wholesale market, we abstract from marketing vehicle energy costs for the farmer.

Off-farm segments of the VC. (1) Trader segment. Transport is by far the largest cost borne by the trader sub-segments, with 80%, 88%, and 82% of the costs of the village traders, rural wholesale market traders, and urban traders from transport alone. As roughly half of that is energy costs, that means about 40% of trader costs are energy (diesel mainly). (2) Mill segment. Major costs of mills include a third of costs for labor, and around 13% for renting trucks. Fully 51% of their costs are for diesel (for trucks and for electrical generators for the mills), and only 1% for electricity directly. Hence about 52% of mill costs are for energy. (3) Retailer segment. About 56% of the small urban retailers use motorized (3 wheeler) transport to fetch the rice they sell, and only 10% of the retail customers get home delivered rice. About 60% of the cost per transaction (to fetch the rice) is from transport, and that is about half their operation costs, about 15% of retailer costs are from energy.

Assessment across the VC segments. Here we use our calculations from the survey data of the share of costs of each segment in the VC, which we first note, and then multiply the energy share in total cost in each segment for a "lower bound" of energy costs in the whole value chain and where they are formed. The shares of segments in the overall costs of the VC (to deliver 1 ton of milled rice to consumers coming to retail points in Delhi) borne by each segment as shares of total VC cost and energy costs per VC segment as shares of total VC costs are as follows:

- farmers have 63% of total VC costs, of which 9% are fertilizer energy, 8% irrigation energy,8% farm machine energy, hence farm-based VC direct energy costs are .16*.63 = 10% of VC total costs; if fertilizer (as second round energy cost) energy costs are added the share is 9%*.63 or 6% more or 16% of VC costs;
- rural traders have 4% of total VC costs, of which 40% are transport energy, hence their share in total VC energy costs is 0.40*0.04 or 2%
- Urban traders have 4% of VC costs, and their energy costs are 2% of VC costs
- Millers have 7% of VC costs, and the share of their energy costs in total VC costs is .07*.52 or 4%;
- Urban traditional retailers have 22% of total VC costs, and their share of energy costs in total VC costs is 0.22*0.15 or 3%.

The upshot is that direct energy costs are 21% of total VC costs in this VC; half of this is from farms, a lower share than their share (63%) in total costs, reflecting the fact that the off-farm segments of the VC are more energy intensive. If indirect energy costs are added only from fertilizer that share goes to 27%.

(b) Energy in the Rice VC in India: from Allahabad (Eastern Uttar Pradesh) to Jabalpur, Madhya Pradesh

General situation of the VC. The Allahabad paddy production area is close to the area's rural mills and about 350-400 km to Jabalpur and 30-70 to the large city of Allahabad.

Paddy farm segment in Allahabad. (1) Context: Paddy farming in this area is moderately energy-using directly and indirectly. Paddy farming in this area is fertilizer-semi-intensive, at 95% of farmers using chemical fertilizer but at half the per hectare rates of western/central Uttar Pradesh (the other paddy study zone in Uttar Pradesh); fertilizer is about 31% of cash costs and 18% of total costs of the farm, hence fertilizer energy is .18*.8=14% of the costs of the farm. Paddy farming there is irrigation-semi-intensive; only one crop of paddy is grown; 88% of the farms are irrigated, but it is mainly by flooding from canals; only 36% own pumps; 84% buy water from other farmers, and 32% from the government, but much of these two sources is from gravity canals not energy-intensive pumping. Paddy farming here is machine-semi-intensive; 10% of the farmers own tractors, and 2% own thresher; but there is an active farm machine rental market for land preparation tractors and threshers; 88% hire tractors (with operators) for land preparation; The larger farmers hire threshing machines. All the harvesting is done by hand. These mainly small farms are commercialized, with a marketed surplus rate of 89, 93, and 94% for the three size strata. But they sell most of their paddy locally – 41% of their volume is sold at the farm gate, and 20% in the district. Thus farmers are not using much energy to market their paddy. (2) In terms of energy costs: (a) 10% of farm cash costs are from irrigation, as are 6% of overall costs (which includes imputed labor costs); again this implies at most 3% of the farm costs are from irrigation energy; farm machinery is 27% of farm cash costs and 16% of overall costs; again by rough approximation, that means (as in western/central UP) about 8% of the farm costs are for farm machine energy. Again as with the Shahjahanpur area, most of the paddy is sold close to the farm so we again abstract from marketing vehicle energy costs for the farmer.

Off-farm segments of the VC. (1) Trader segment. Transport is again the largest cost, with 34% of costs for the rural trader and 60% for the Allahabad wholesaler and the Jabalpur wholesaler, with a rough average of 50%. As roughly half of that is energy costs, that means about 25% of trader costs are energy (diesel mainly). (2) Mill segment. Electricity for the mill is 9% of costs for all mills taken together, but note that that share climbs from 3 to 17% from small to large mills, mainly because the large mills buy electricity and depend less than do the small mills on generating it themselves. Diesel costs for generators are 41, 43, and 36% of costs for the small, medium, and large mills, with an average of 41% of costs. Diesel for mill vehicles averages 3% over mills. Hence, about 53% of mill costs are for energy (approximately as in west-central Uttar Pradesh too). (3) Retailer segment. Retailers in Jabalpur buy all their rice from wholesale markets and use motorized transport for all of it. Transport costs are 38% of their total, and electricity a further 5%, which works out to energy costs being about 25% of retailer costs.

Assessment across the VC segments. The shares of segments in the overall costs of the VC, and energy costs of those segments in the total costs of the VC (to deliver 1 ton of milled rice to consumers coming to retail points in Jabalpur from Allahabad) are as follows.

- Farmers have 69% of total VC costs, of which .18*.8=14% are fertilizer, 3% irrigation energy, 8% farm machine energy, hence farm-based VC direct energy costs are .11*.69 = 8% of VC total costs; if fertilizer (as second round energy cost) energy costs are added the share is 10% (.14*.69) more or a total of 18% of VC costs;
- rural traders have 6% of total VC costs, of which 25% are transport energy, hence their share in total VC energy costs is 0.25*0.06 or 2%
- Urban traders have 3% of VC costs, and their energy costs are 1% of VC costs
- Millers have 19% of VC costs, and the share of their energy costs in total VC costs is .19*.53 or 10%;
- Urban traditional retailers have 3% of total VC costs, and their share of energy costs in total VC costs is 0.03*0.25 or 1%.

The upshot is that direct energy costs are 22% of total VC costs in this VC; 36% of this is from farms, a lower share than their share (69%) in total costs, reflecting the fact that the off-farm segments of the VC are much more energy intensive. If indirect energy costs are added only from fertilizer the total share of energy in the VC goes to 32%.

c) Energy in the Rice VC in Bangladesh: from Naogaon to Dhaka

General situation of the VC. This paddy production and milling zone is about 280km from Dhaka, about five hours by road (similar to Shajahanpur to Delhi). It is a main paddy production area for Dhaka.

Paddy farm segment. (1) Context: Paddy farming in this area is moderately energy-using directly and indirectly. Paddy farming in this area is fertilizer-intensive, all the farmers use chemical fertilizer and like Uttar Pradesh's intensive west-center, about 16% of total costs of the farm, with the energy from fertilizer .16*.80 or 13% of the costs of the farm. Paddy farming there is irrigation-intensive; paddy is grown in three seasons in Bangladesh, with two of the seasons irrigated. All the farms are irrigated; they rely heavily on tubewells. 31% own pumps; as in west/central UP in India, about 77% buy water from other farmers. Paddy farming here is machine-intensive; only 1% of the farmers own tractors, but 93% use tractors or power tillers; the difference between owning and using is due to an active rental market. Only 6% of the farmers still use the traditional animal traction. These mainly small farms are commercialized, with a marketed surplus rate of 57 and 71% over the two size strata. But they sell most of their paddy locally – about half is sold in the same village, and half in the same district. Thus farmers are not using much energy to market their paddy. (2) In terms of energy costs: (a) 4% of farm overall costs are from irrigation; this implies about 2% of the farm costs are from irrigation energy; farm machinery is 15% of overall costs, similar to India's; again by rough approximation, that means about 8% of the farm costs are for farm machine energy. Again as with the Indian studies, most of the paddy is sold close to the farm so we again abstract from marketing vehicle energy costs for the farmer.

Off-farm segments of the VC. (1) Trader segment. Transport constitutes about 36% of costs for all the trader types, so roughly 18% of trader costs are energy (diesel mainly). (2) Mill segment. Electricity for the mill is 11% of costs. Rental trucks dominate as a cost, with an average of 30% (but climbing from 19, to 31, to 44% of mill costs as mills engage more in transport as their size increases), hence a total of 11 plus 15 or 26% of mill costs are for energy. (3) Retailer segment. Retailers in Dhaka buy all their rice from wholesale markets but nearly all use non-motorized transport; transport costs are 53% of the total but given these are non-motorized we do not count them in the energy cost calculation. .

Assessment across the VC segments. The shares of segments in the overall costs of the VC (to deliver 1 ton of milled rice to consumers coming to retail points in Dhaka from Naogaon) and the share of each segment's energy costs in the total VC costs are as follows.

- Farmers have 87% of total VC costs, of which .16*.8=13% are fertilizer energy costs, 2% irrigation energy, 8% farm machine energy, hence farm-based VC direct energy costs are .10*.87 = 9% of VC total costs; if fertilizer (as second round energy cost) energy costs are added the share is 13%*.87=11% more or a total of 20% of VC costs;
- traders have 2% of total VC costs, of which 18% are transport energy, hence their share in total VC energy costs is 0.18*0.02 or 0.5%
- Millers have 3% of VC costs, and the share of their energy costs in total VC costs is .19*.26 or 5%;
- Urban traditional retailers have 8% of total VC costs but use too little energy to count.

The upshot is that direct energy costs are only 15% of total VC costs in this VC; 60% of this is from farms, a lower share than their share (87%) in total costs, reflecting the fact that the off-farm segments of the VC are (only a little) more energy intensive. If indirect energy costs are added only from fertilizer the total share of energy in the VC goes to 26%.

d) Energy in the Rice VC in China: from Jiangxi to Zhejiang cities

General situation of the VC. The paddy farms are located along with rural mills in rural Jiangxi in southern China, about 150-300 km from Zhejiang province and large cities like Hangzhou (the study examined three large cities near Hangzhou).

Paddy farm segment. (1) Context: Paddy farming in this area is very energy-using directly and indirectly. Paddy farming in this area is fertilizer-intensive, 98% use it; it is 19% of cash costs and 14% of total costs of the farm, hence .14*.8=11% of energy costs in total farm costs, similar to the findings in India. Paddy farming there is irrigation-intensive, much more so than in India or Bangladesh; paddy is grown in three seasons with irrigation used in all three (even in the rainy season). 94% of the farms are irrigated. 39% use pumps (with a strong correlation with farm size); the others use canal water in ditches only. Only 19% own an irrigation pump, with uncertain data on the extent to which farmers rent pumps. Paddy farming here is machine-intensive; 27% own tractors (but extremely correlated with farm size, as over the strata the shares are 16, 44, 82% who own); but far more use: over the strata, 76, 76, and 93% use tractors in 2011; hence there is important rental market; the same goes for harvesters: only 3% own a harvester, but an average of 83% use one. 17% use a semi-automatic thresher. These farms are very commercialized, with marketed surplus rates of 73, 93, and 93% over the three size strata. But as in India and Bangladesh they sell most of their paddy locally: 81% at the farmgate, 6% at the village. Thus as in the other two countries farmers are not using much energy to market their paddy. (2) In terms of energy costs: (a) only 4% of farm overall costs are from irrigation; this implies about 2% of the farm costs are from irrigation energy (this may be a slight underestimate because some of the water is brought from nearby lakes and reservoirs by community pump systems); farm machinery is 31% of farm cash costs and 23% of overall costs, nearly twice that of Bangladesh and India samples; by our rough approximation, that means about 12% of the farm costs are for farm machine energy. Again as with the Bangladesh and Indian studies, most of the paddy is sold close to the farm so we again abstract from marketing vehicle energy costs for the farmer.

Off-farm segments of the VC. (1) Trader segment. Transport constitutes about 47% of costs for rural paddy traders who buy and sell in circa 20km from their base; we roughly approximate their mainly-mobile operation as having energy costs of 28% of total costs; for urban rice wholesalers, transport is about 90% of their purchase costs (as they source from on average 1000 km around them, mainly to the north and center) and 65% of their sales costs, so roughly 80% of their variable costs; for their trading base, their electricity bill is about 2% of their fixed monthly costs; diesel for their own transport is another 6%; we roughly approximate their energy costs 45% of their total costs. The rest is mainly labor. (2) Mill segment. For the rural mills, electricity for the mill is 23% of costs (ranging from 20, to 25, to 31% of costs over the three strata of mills). Own and rental truck costs total 30% (the share correlated with s dominate as a cost, with an average of 30%. For the urban mills, electricity is 19% of costs and transport is 43% of costs. Again using our rough assumption that half of transport costs are for energy, the shares of energy costs in total costs of rural and urban mills are 38 and 46% respectively for a simple average of 42%. (3) Retailer segment. Retailers in Hangzhou buy all their rice from wholesale markets and all use motorized transport; 5% of their operational costs are for electricity to light their shop/stall; about 5% of their total costs are transport costs, of which half are energy, so the share of energy in the retailer costs is about 5 plus 3% or 8%.

Assessment across the VC segments. The shares of segments in the overall costs of the VC, and energy costs of those segments in the total costs of the VC (to deliver 1 ton of milled rice to consumers coming to retail points in Hangzhou from Jiangxi) are as follows.

- Farmers have 66% of total VC costs, of which .14*.8=11% are fertilizer energy costs, 2% irrigation energy, 12% farm machine energy, hence farm-based VC direct energy costs are .14*.66 = 9% of VC total costs; if fertilizer (as second round energy cost) energy costs are added the share is 7% (.11*.66) more or a total of 16% of VC costs;
- rural traders have 2% of total VC costs, of which 28% are transport energy, hence their share in total VC energy costs is 0.28*0.02 or 0.5%
- Urban traders have 6% of VC costs, and their energy costs are 0.06*.45 or 3% of VC costs
- Millers have 16% of VC costs, and the share of their energy costs in total VC costs is .16*.42 or 7%;
- Urban traditional retailers have 10% of total VC costs, and their share of energy costs in total VC costs is 0.10*0.08 or 1%.

The upshot is that direct energy costs are 21% of total VC costs in this VC; 43% of this is from farms, a lower share than their share (66%) in total costs, reflecting the fact that the off-farm segments of the VC are more energy intensive. If indirect energy costs are added only from fertilizer the total share of energy in the VC goes to 28%.

e) Energy in the Rice VC in China: from Heilongjiang to Beijing

General situation of the VC. Heilongjiang province has a cluster of paddy farming areas and rice mills, including medium and large mills. They tend to sell direct to wholesale agents in Beijing and other big cities. They are 1400 km from Beijing so the transport costs are large. This is an example of a long supply chain; our work in Zhejiang showed that rice from Heilongjiang is sold as far as Zhejiang (2700km) due to the rapidly increasing popularity of japonica there (displacing indica rice).

Paddy farm segment. (1) Context: Paddy farming in this area is very energy-using directly and indirectly. Paddy farming in this area is fertilizer-intensive, 96% use it and at high rates. It is 14% of total costs just as in Jiangxi; the fertilizer-embodied energy costs are thus .14*.8 or 11% of the overall farm costs. Paddy farming is one season per year, but is irrigation-intensive; 52, 70, and 75% of the three farm strata own irrigation pumps (diesel and electricity); 78% also buy irrigation water from the government. Paddy farming in HLJ is machine-intensive; 40% on average own tractors in 2004, and 56% in 2009 (with very sharp correlation with farm size). But 100% of all farmers use machine traction in 2009; hence the rental market is very active. These farms are fully commercialized, with marketed surplus rates of 100, 94, 92, over the three size strata and 95% on average. Again as in the other study zones almost all is sold locally and thus little transport is incurred (and thus energy expended in that rubric): 29% to the village trader and 64% to the local mill. 78% is sold in the farmer's village. (2) In terms of energy costs: (a) only 7% of farm overall costs are from irrigation; this implies about 3% of the farm costs are from irrigation energy; farm machinery is 23% of overall costs (the same as in Jiangxi even though the latter has smaller farms). That means about 12% of the farm costs are for farm machine energy.

Off-farm segments of the VC. (1) Trader segment. Traders in Beijing getting rice from HLJ have high transport costs (some 95% of their total costs) given the great distance; this makes energy costs of 47% of urban trader costs (similar to the figure in Hangzhou/Jiangxi). (2) Mill segment. Electricity for the mill is 20% of costs for the average mill. Own and rental truck costs total 14%. Again using our rough assumption that half of transport costs are for energy, the share of energy costs in total costs of mills is 27%. (3) Retailer segment. Traditional retailers in Beijing buy all their rice from wholesale markets and use motorized transport; 5% of their operational costs are for electricity and 5% of their total costs are transport costs, of which half are energy, so the share of energy in the traditional retailer costs is 8%.

Assessment across the VC segments. The shares of segments in the overall costs of the VC, and energy costs of those segments in the total costs of the VC (to deliver 1 ton of milled rice to consumers coming to retail points in Beijing from Heilongjiang) are as follows.

- Farmers have 44% of total VC costs, of which 14%*.8=11% are fertilizer energy costs, 3% irrigation energy, 23% farm machine energy, hence farm-based VC direct energy costs are .26*.44 = 11% of VC total costs; if fertilizer (as second round energy cost) energy costs are added the share is 5% (.11*.44) more or a total of 16% of VC costs;
- Traders have 12% of VC costs, and their energy costs are 0.12*.47 or 6% of VC costs
- Millers have 36% of VC costs, and the share of their energy costs in total VC costs is .27*.36 or 10%;
- Urban traditional retailers have 8% of total VC costs, and their share of energy costs in total VC costs is 0.08*0.08 or 1%.

The upshot is that direct energy costs are 28% of total VC costs in this VC; 39% of this is from farms, a lower share than their share (44%) in total costs, but not by much, showing how mechanized and energy using is Heilongjiang agriculture. The relatively low share of farm energy in total energy in the VC comes from the long distance nature of the VC. If indirect energy costs are added only from fertilizer the total share of energy in the VC goes to 33%.

f) Energy in the Rice VC in Vietnam: from the Mekong River Delta (Hau Giang) to Ho Chi Minh City

General situation of the VC. The Mekong River Delta includes several provinces where there is intensive paddy farming serving the domestic market, including the large Ho Chi Minh City (HCMC) market via medium and large mills and a network of traders, as well as (a minority of the rice going to) the export market via large mill/export firms. The study area is only 200km from HCMC. The rice production area and the mills and the city and export markets are connected in the main by traders operating boats on waterways, as well as trucks.

Paddy farm segment. (1) Context: Paddy farming in this area is energy-using directly and especially indirectly. Paddy farming in this area is fertilizer-intensive, 100% use it and at high rates. It is 36% of costs, and fertilizer-energy costs are 29% of farm costs. There are two paddy seasons per year; and extensively irrigated with pumps; 22, 52, 56, and 43% of the three farm strata and overall own irrigation pumps (using diesel and electricity); in 2007 the overall share was only 14% so ownership of pumps tripled in only five years; Paddy farming is machine-intensive, as all farmers use machines for land preparation and harvesting; they are 23% of costs of the farm. These small farms are highly commercialized, with marketed surplus rates of 86% overall (with little difference over the strata). Nearly all the paddy is sold at the farm "gate", which is often near a waterway by which traders move among the farms collecting. (2) In terms of energy costs: (a) only 2% of farm overall costs are from irrigation, hence about 1% of costs are from irrigation energy; farm machinery is 23% and thus about 12% of costs are from farm machine energy. Little is from delivery from farm as the traders come to get the paddy at the farm.

Off-farm segments of the VC. (1) Trader segment. Traders' greatest cost is the diesel for their boats, 52% of their total costs, with direct costs for electricity at 1% of their costs, for total energy costs 53% of trader costs (close to China's). (2) Mill segment. Electricity for the mill is 46% of costs for the average mill. (3) Retailer segment. Traditional retailers in HCMC buy all their rice from wholesale markets and use motorized transport; 5% of their operational costs are for electricity and 5% of their total costs are transport costs, of which half are energy, so the share of energy in the traditional retailer costs is 8%, like in urban China.

Assessment across the VC segments. (1) Shares of segments in the overall costs of the VC (to deliver 1 ton of milled rice to consumers coming to retail points in HCMC from Mekong River Delta) borne by each segment:

Assessment across the VC segments. The shares of segments in the overall costs of the VC, and energy costs of those segments in the total costs of the VC (to deliver 1 ton of milled rice to consumers coming to retail points in Beijing from Heilongjiang) are as follows.

- Farmers have 52% of total VC costs, of which .36*.8= are fertilizer indirect energy, 1% irrigation energy, 12% farm machine energy, hence farm-based VC direct energy costs are .13*.52 = 7% of VC total costs; if fertilizer (as second round energy cost) energy costs are added the share is 15% (.29*.52) more or a total of 22% of VC costs;
- Traders have 26% of VC costs, and their energy costs are 0.26*.53 or 14% of VC costs
- Millers have 11% of VC costs, and the share of their energy costs in total VC costs is .11*.46 or 5%;
- Urban traditional retailers have 12% of total VC costs, and their share of energy costs in total VC costs is 0.12*0.08 or 1%.

The upshot is that direct energy costs are 27% of total VC costs in this VC; 25% of this is from farms, a lower share than their share (52%) in total costs, showing a lower rate of energy intensity cum mechanization than off-farm components. If indirect energy costs are added only from fertilizer energy cost, the total share of energy in the VC goes to 42%.

4. Evidence of Energy Costs in Potato VCs

In this section, we proceed by study zone from which issues a potato VC. In each case, we examine energy costs by VC segment, and then in summary over the overall VC. For each segment, we briefly characterize that segment in that case, and then note the roles and shares of energy in that segment.

4.1. Energy in the Potato VC in India: from Agra (West Uttar Pradesh) to Delhi

General situation of the VC. The Agra area, famous for the Taj Mahal, is close to Delhi (about three hours, 200 km) and supplies the bulk of the potatoes consumed in Delhi, and a quarter of the potatoes produced in India. There is a major highway connecting the potato production area and Delhi. There is a large cluster of cold storage firms (small, medium, and large) in the area that developed mainly in the 2000s, and a medium sized wholesale market in Agra city and a large wholesale market in Delhi. There is a good electricity grid serving the rural area starting in the late 1990s.

Potato farm segment. (1) Context: Potato farming in Agra is very energy-using directly and indirectly. It is fertilizer-intensive, 100% use fertilizer and at high rates. It is 3% of total costs and thus 2% of fertilizer-embodied energy costs in total farm costs. There is one potato season per year, in the dry season; hence it is extensively irrigated with pumps; 8, 31, and 80% of the households in the three farm size strata own pumps, overall 50%; there is a very active water market where mainly large farmers owning pumps sell water to small farmers: 91, 71, and 46% buy water this way, for an average of 64% of the sample; the pumps use diesel or electricity. Potato farming in Agra is very machine-intensive for farming and cold storage. Farm machine use is widespread. 5%, 22%, and 67% of farmers (over the three strata) own tractors, for an average of 41%; again there is an active rental market as 23, 59, and 87% of farmers in the three strata use tractors, with the overall sample at 63%, above the ownership rate of 41%. A traditional view of Indian farming is the image of the bullock pulling the plow: but that has disappeared in this area (and many others); there is no animal traction used in this potato area. Moreover, nearly all the farmers (95%) use cold storage, and by strata, the share of their potato volume that is cold-stored (in refrigerated storage operated by firms) is 67, 76, 64% over strata and 65% overall. These farms, whether small or large, are highly commercialized, with marketed surplus rates of 89, 85, 89% over the three strata. But farmers do not spend much on potato transport: they sell 80% of their potatoes at the nearby cold storages (to traders who congregate at them) and 10% to village traders. (2) In terms of (direct) energy costs: only 3% of farm overall costs are from pump irrigation, hence about 2% of costs are from irrigation energy; farm machinery is 7% and thus about 4% of costs are from farm machine energy. Little is from delivery from the farm as the pickup is done locally. Moreover, because cold storage is done in another segment, we do not ascribe the energy use for that to the farm segment.

Off-farm segments of the VC. (1) Trader segment. There is not sharp seasonality of trading in either rural or urban areas in Agra and Delhi, due to the importance of cold storage that smoothes supply. Traders buy from farmers either at the cold storage or at their farm gate, and then sell half to Delhi and 40% to other states. Only 20% of their costs are from transport as they are relatively near to Delhi. Other major costs are the charges of the cold storages and labor. Thus, energy is about 10% of trader costs. (2) Cold Storage segment. Cold storage activity tends to be seasonal and counter-cyclical to farming. Transport costs are small because farmers or traders bring the potatoes to them and pick up from them. The cold storage firms do little trading themselves. Electricity for the cold storage firm averages 57% and diesel for generators, 14%, of costs, for a total of 71% of energy in total costs. (3) Retailer segment. Traditional retailers of potato in Delhi buy all their potato from wholesale markets; 31% of their costs are transport, so about 15% is the share of energy in retail costs.

Assessment across the VC segments. The shares of segments in the overall costs of the VC, and energy costs of those segments in the total costs of the VC (to deliver 1 ton of potatoes to consumers coming to retail points in Delhi from Agra) are as follows.

- Farmers have 44% of total VC costs, of which 14% are fertilizer, 3% irrigation energy, 23% farm machine energy, hence farm-based VC direct energy costs are .26*.44 = 11% of VC total costs; if fertilizer (as second round energy cost) energy costs are added the share is 3% more or a total of 14% of VC costs;
- Traders have 22% of VC costs, and their energy costs are 0.22*.10 or 2% of VC costs
- Cold storages have 6% of VC costs, and the share of their energy costs in total VC costs is .06*.71 or 4%;
- Urban traditional retailers have 38% of total VC costs, and their share of energy costs in total VC costs is 0.38*0.15 or 6%.

The upshot is that direct energy costs are 23% of total VC costs in this VC; 50% of this is from farms, a lower share than their share (44%) in total costs, but not by much, showing how mechanized and energy using is Agra potato farming. If indirect energy costs are added only from fertilizer the total share of energy in the VC goes to 26%.

4.2. Energy in the Potato VC in Bangladesh: from Bogra to Dhaka

General situation of the VC. The Bogra area is some 200km (about four hours) from Dhaka and a major supplier of potatoes to the city. There is a major highway connecting Bogra to Dhaka. There is a moderate cluster of cold storage firms in Bogra developed, as in Agra, mainly in the 2000s.

Potato farm segment. (1) Context: Potato farming in Bogra is energy-using directly and indirectly. It is fertilizer-intensive, as 98% use fertilizer and at moderate rates. It is 27% of total costs; fertilizer-embodied energy costs are thus .27*.8 or 22% of total farm costs. As in Agra, there is one potato season per year, in the dry season; hence it is extensively irrigated with pumps/tubewells; 14 and 23% (of the two farm size strata) and 18% overall own pumps, but 89% and 86% buy irrigation water from larger farmers with tubewells, as in Agra. The pumps use diesel motors. Potato farming in Bogra, though on smaller farms than in Agra, is machine-intensive for farming and somewhat also for cold storage. As in many of our study zones, farm machine use is widespread but ownership is limited and rental markets are active: only 0 and 4% of the two strata own tractors, and 6 and 12% own small power-tillers; yet an average of 89% of the farms use machine traction, and thus most rent. Animal traction has all but disappeared. Unlike Agra where cold storage has diffused far, but also unlike traditional potato farming in the region, where traditional on-farm storage techniques were nearly the exclusive way of storage, some 22% of farmers in Bogra use energy-intensive cold storage firms to store for seed or sale.

Only 2% use traditional storage techniques; but around 76% sell fresh or dried without storing, much higher to date than in Agra. These farms are mainly marginal or small, yet like Agra are highly commercialized, with marketed surplus rates of 71, 83% over the two strata, and 79% overall. As in Agra, nearly all is sold locally so farmers do not spend much on transport. (2) In terms of (direct) energy costs: only 2% of farm overall costs are from pump irrigation, hence about 1% of costs are from irrigation energy; farm machinery is 3% and thus about 2% of costs are from farm machine energy. Little is from delivery from the farm as the pickup is done locally. Moreover, as noted in the case of Agra, we do not assign cold storage energy here as it belongs in the storage firms segment.

Off-farm segments of the VC. (1) Trader segment. There is a very sharp seasonality of trading in rural areas but less seasonality in urban areas. As noted above, the share of cold storage stored potatoes in total potato supply from Bogra is substantially less than in the Agra case. Traders store a third of their potatoes in cold storages in Bogra but the rest they buy fresh from villages and wholesale markets. Nearly half are sold to Dhaka. The cost of transport is about 64%, hence an energy share of roughly 30% in total trader costs. (2) Cold Storage segment. This tends to be seasonal and counter-cyclical to farming. The cold storage firms do little transporting or trading themselves. Electricity for the cold storage firm averages 52% and diesel for generators, 11%, of costs, for a total of 63% of energy in total costs (just a bit lower than Agra's figures). (3) Retailer segment. Traditional retailers of potato in Delhi buy all their potato from wholesale markets but two thirds are by horse cart or on foot, so much less motorized than the other cases. The share of energy in the total is about 10% similar to the other cases.

Assessment across the VC segments. The shares of segments in the overall costs of the VC, and energy costs of those segments in the total costs of the VC (to deliver 1 ton of potatoes to consumers coming to retail points in Dhaka from Bogra) are as follows.

- Farmers' production constitutes 64% of total VC costs, of which 27% (share of fertilizer in farm costs) is multiplied by .8 to get fertilizer energy costs (21%), 1% irrigation energy, 2% farm machine energy, hence farm-based VC direct energy costs are .64*.03 = 2% of VC total costs; if fertilizer (as second round energy cost) energy costs are added the share is .64*.21 or 13% more or a total of 15% of VC costs;
- Traders have 4% of VC costs, and their energy costs are 0.04*.30 or 1% of VC costs
- Cold storages have 23% of VC costs, and the share of their energy costs in total VC costs is .23*.52 or 12%;
- Urban traditional retailers have 10% of total VC costs, and their share of energy costs in total VC costs is 0.10*0.10 or 1%.

The upshot is that direct energy costs are only 16% of total VC costs in this VC (lower than the others due to lower energy costs on farm, less use of cold storage than Agra, and relatively short distance for transport); only 12% of this is from farms, a far lower share than their share (64%) in total costs, again a sharp difference with Agra. If indirect energy costs are added only from fertilizer the total share of energy in the VC goes to 29%.

4.3. Energy in the Potato VC in China: from Gansu to Beijing

General situation of the VC. The Gansu potato zone is in the mountains and is 1500km from Beijing, about 19 hours by truck. It is thus a similar distance to market as in the case of Heilongjiang and Beijing. These are thus examples of long supply chains highly dependent on energy-using transport. Importantly, Gansu is but one of a number of potato supplying regions for Beijing; that is perhaps why cold storage is less developed in Gansu, as Beijing and other big cities can source across agroclimatic zones north and south and center over the seasons of the year. Moreover, being in the mountains with a cold winter there is less need for energy-using cold storage.

Potato farm segment. (1) Context: Potato farming in Gansu is not directly energy-intensive; it is more traditional. It is fertilizer-using, as 99% bought fertilizer and use it at moderate rates, and it is 17% of costs, and .17*.8 or 14% the energy costs in total farm costs. As in the Indian and Bangladesh potato zones (where rice or wheat is grown in the rainy season but potatoes are grown under irrigation in the off season), in Gansu, there is one season, but it is too cold to grow in the off season. Irrigation is used moderately; some 37% of farmers own pumps, but there is no buying of irrigation water and irrigation costs are minimal. Farming is not very machine intensive compared with the other study zones. 15% of the farms own tractors, and 8% own power tillers. 28% used either of these machines in 2009. 5% of farm costs are from farm machines, versus only 1% for animal traction costs. There is no use by farmers of modern energy-using cold storage firms off-farm; the little they store on farm it is in hand-made caves in the mountains; some traders store but most is sold fresh to the cities and not stored. About 60% is sold near the homes and the most of the rest is at the wholesale market elsewhere in the county near the village. These farms are mainly marginal or small, yet like the potato areas in South Asia, are commercialized, with marketed surplus rates of 69% on average with little variation over the strata. (2) In terms of (direct) energy costs, only 1% of farm overall costs are from pump irrigation, hence negligible; farm machinery is 5% of costs and thus about 2% of costs are from farm machine energy. Again transport costs for the farmer are negligible, as is cold storage.

Off-farm segments of the VC. (1) Trader segment. There is a very sharp seasonality of trading in rural areas but little seasonality in urban areas because the urban traders buy from Gansu (about a quarter), 30% from Inner Mongolia, and 40% from Hebei, as well from southern China. Transport costs for the urban traders are thus very important as by extension is energy. Traders in rural areas have only a storage cellar, and do not use modern (energy using) cold storages). Rural traders transport cost share in total cost is only 13%, and thus energy costs in rural trader total costs are about 7%. By contrast, the share of transport in total costs is 73%, hence about 36% for energy costs in total costs of urban traders. (2) Cold Storage segment. We do not account for this as it is not significant in this VC. (3) Retailer segment. Traditional retailers of potato in Beijing buy all their potato from wholesale markets and nearly all do so by motorized vehicles. The share of energy in the total is about 10% similar to the other urban retailer cases.

Assessment across the VC segments. The shares of segments in the overall costs of the VC, and energy costs of those segments in the total costs of the VC (to deliver 1 ton of potatoes to consumers coming to retail points in Beijing from Gansu) are as follows.

- Farmers' production constitutes 56% of total VC costs, of which 17% is the share of fertilizer in farm costs, and .17*.80=14% the (indirect) energy share in farm costs, 1%

irrigation energy, 2% farm machine energy, hence farm-based VC direct energy costs are .56*.03 = 2% of VC total costs, again quite low given limited mechanization and irrigation costs compared with other zones; if fertilizer (as second round energy cost) energy costs are added the share is .56*.14 or 8% more or a total of 10% of VC costs;

- Traders have 27% of VC costs given the large distance of Gansu from Beijing; and their energy costs are 0.27*.36 or 10% of VC costs
- Cold storages are not counted here because energy-using modern ones not used in this chain.
- Urban traditional retailers have 17% of total VC costs, and their share of energy costs in total VC costs is 0.17*0.10 or 2%.

The upshot is that direct energy costs are only 14% of total VC costs in this VC (among the lowest in the study areas due to lower energy costs on farm, low use of cold storage (compared with the South Asian sites) but a large distance for transport); only 15% of this is from farms, a far lower share than their share (56%) in total costs, again a sharp difference with Agra but similar to Bogra. If indirect energy costs are added only from fertilizer the total share of energy in the VC goes to 22%.