POLICY BRIEF II

DECOUPLING ENERGY AND RESOURCE USE FROM GROWTH IN THE INDIAN CONSTRUCTION SECTOR

A POTENTIAL ANALYSIS STUDY

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ABBREVIATION	FULL FORM
AAC	Autoclaved aerated cement
BAFA	Federal Office for Economic Affairs and Export Control
BAT	Best available technology
BEE	Bureau of Energy Efficiency
BIBB	Federal Institute for Vocational Education and Training
BMUB	Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
BREEAM	Building Research Establishment Environmental Assessment Method
C&D	Construction and demolition
C2C	Cradle to cradle
CAG	Comptroller and Auditor General
CBERD	Center for Building Energy Research and Development
CBRI	Central Building Research Institute
CEPT	Centre for Environmental Planning and Technology
CFL	Compact fluorescent light
CHCP	Combined heating, cooling and power
CSH	Concentrated solar heat
demea	German Material Efficiency Agency
Dena	German Energy Agency
DGB	German Trade Union Confederation
DGNB	German Sustainable Building Council
DMC	Domestic material consumption
DSM	Demand-side management
ECM	Energy conservation measure
EIS	Energy information system
EnEV	Energy Conservation Regulations (German)
EPBD	Energy Performance for Buildings Directive (EU)
EPC	Energy performance certificate
EPI	Energy performance indicator
EPR	Extended producer responsibility
ESCO	Energy service company
EU	European Union
FIT	Feed-in tariff
FSC	Forest Stewardship Council

GDP	Gross domestic product
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GPP	Green public procurement
HQE	High Quality Environmental Standard
HRD	Human resource development
HVAC	Heating, ventilating and air conditioning
IESS	India Energy Security Scenarios
IGEA	Investment grade energy audits
JNNSM	Jawaharlal Nehru National Solar Mission
KfW	KfW Development Bank (KfW Entwicklungsbank)
kgoe	Kilogram oil equivalent
LCOE	Levelised cost of electricity
LED	Light-emitting diode
LEED	Leadership in Energy and Environmental Design
MEPS	Minimum energy performance standard
MNRE	Ministry of New and Renewable Energy
Mtoe	Million Tonnes of oil equivalent
NDC	Nationally Determined Contribution
NEERI	National Environmental Engineering Research Institute
NeMAT	Netzwerken zur Materialeffizienz
NITI Aayog	National Institution for Transforming India
NZEB	Nearly zero-energy buildings
PEF	Primary energy factor
PH	Passive house/Passivhaus
ProgRess	German resource efficiency programme
PV	Solar photovoltaics
RD&D	Research, development and demonstration
REC	Renewable energy certificate
SDA	State Designated Agency
TWh	Terawatt hours
VerMAt	Verbesserung der Materialeffizienz (German programme to promote material efficiency)
VRV	Variable refrigerant volume
VSBK	Vertical shaft brick kilns

THE POLICY BRIEFS

CONTEXT OF THE POLICY BRIEF SERIES

India is currently at a crucial juncture where it is aiming for economic growth to meet the basic needs of its 1.2 billion people. However, so far this growth has resulted in energy shortages and the increasing use of limited resources. This policy brief series is about decoupling, i.e. improving efficiency to reduce the resources and energy needed for this growth and meet the country's increasing development needs.

The construction sector is highly resource and energy intensive; it is therefore imperative that it moves towards a path of environmental sustainability. This transition is likely to be achieved by decoupling both resource and energy use from the sector's growth. Decision-makers in the sector will play a crucial role in achieving this. The aim of this policy brief series is to inform decision-makers in India at central government and state level about the current status of research, policy and institutions in the Indian construction sector and to identify key drivers and barriers. Finally, practical recommendations will be made for decision-makers about how to promote decoupling of resource and energy use from growth in the construction sector.

The series comprises three policy briefs:

Policy brief 1 focuses on the baseline for decoupling in the Indian construction sector. The study draws attention to the existing scenario in terms of key policies, research and institutions linked to resources and energy in the sector.

Policy brief 2 focuses on analysing the potential for decoupling in the Indian buildings and construction sector. Primary and secondary research was conducted to identify the factors that influence decoupling. Subsequently, a framework was established to make it possible to measure the nature and extent of decoupling that is possible within the existing policy environment. Furthermore, gaps, drivers and barriers have been identified which could enable a potential analysis study on decoupling to be carried out. In addition, examples of good practice from Germany and other European countries have been studied with a view to learning lessons that can help to bridge the current gaps in India.

Policy brief 3 focuses on recommendations both at national and state level on the possible interventions that could result in resource and energy use being decoupled from growth in the Indian construction sector. Lack of a comprehensive policy on resource efficiency and the possibility of using secondary raw materials to obtain resource and impact decoupling continue to be the key issues that India will have to grapple with in the years to come.

The policy briefs are a follow-up of the Policy Paper "Decoupling Economic Growth from Resource Consumption. A Transformation Strategy with Manifold Socio-Economic Benefits for India and Germany" by Peter Hennicke and Ashok Khosla with contributions from Chitrangna Dewan, Kriti Negrath, Zeenat Niazi, Meghan O'Brien, Mandira Singh Thakur, Henning Witts, published in November 2014. The Policy Paper was elaborated by members of the Indo-German Expert Group on Green and Inclusive Economy. The group is supported by the German Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) and facilitated by the GIZ Environmental Policy Programme in Berlin and the Indo-German Environment Partnership in Delhi.

KEY MESSAGES

POLICY BRIEF 2 – A POTENTIAL ANALYSIS STUDY

DECOUPLING ENERGY AND RESOURCE USE FROM GROWTH IN THE INDIAN CONSTRUCTION SECTOR

→ A weak decoupling trend has been observed at world level, while strong decoupling can be seen among OECD countries, especially in Germany. Signs of relative decoupling have been observed in India. Some lessons can be learnt from the European/German experience and could be used to improve policies in the buildings and construction sector; not only the success stories but also the development process holds valuable learning potential.

→ Green and resource-efficient building design, use of alternative building materials, passive design techniques and technology interventions – classified into non-disruptive (e.g. bricks from efficient kilns, star-rated fans and ACs) and disruptive (e.g. fly ash brick, M-sand, CHCP and solar PV) categories – have the potential to achieve impact and resource decoupling in India. However, there is only limited adoption of these options and approaches because of gaps and barriers in existing policies.

→ The potential cooling generation from disruptive technologies can meet only a miniscule percentage of space cooling energy demand in India. Moreover, it is very difficult to integrate these technologies into existing buildings.

→ Despite capital subsidy programmes and central and state government policies on feed-in tariffs for renewable energy, factors such as lack of guidelines of reference for net metering by the Ministry of New and Renewable Energy (although 19 states and union territories have formulated their own net metering policy) and provision of batteryless systems as part of different schemes have discouraged domestic users from taking advantage of the full benefits of the schemes. Solar rooftop programmes in government office buildings usually take an inordinate time to be installed after being sanctioned on paper and suffer from a lack of maintenance after installation.

KEY MESSAGES

- Barring solar photovoltaic and, to a certain extent, solar thermal, promising technologies that could increase the share of onsite renewable energy in buildings are still confined to pilot projects and await large-scale deployment.

- Regulatory policies appear to be the front-runner when it comes to resources, followed by transparency and information, target-setting and planning, and infrastructure and funding. RD&D and BAT promotion and capacity building (including scaling-up measures, involvement of SMEs and skills development initiatives) appear to be severely underrepresented in current policies.

- To be able to develop long-term policies on decoupling, it is important to identify the technical feasibility in various building sub-sectors and make recommendations that target realisation of their full potential.

- Incentives and financial instruments lead the charge for energy-efficient technological interventions policies, followed by regulation, and transparency and information policies in this segment. There is a need for more policies that promote Research, Development and Demonstration (RD&D) and best available technologies (BAT) to increase the use of low-impact building materials.

- The majority of green building projects are commercial and office buildings, whereas those in the residential sector comprise large developments or government-sponsored housing projects. However, the majority of residential projects are still constructed by small builders, developers and local masons who are not highly literate and are not yet aware of green buildings.

- It is crucial that energy (cost) savings derived from dedicated energy conservation measures (ECMs), demand-side management (DSM) programmes and energy service company (ESCO) contracts translate into long-term bonds and are not converted into short-term monetary savings, which are then lost in the rebound effects.

- It is unclear at this stage whether a decrease in resource use results in economic growth shrinking and whether switching to efficient resources results in sustained growth. Only once a set of reliable indicators has been established can decoupling act as a yardstick for policy implementation. A national resource policy is needed to understand, highlight and rank the severity of impact due to the use of various resources.

1 FRAMEWORK FOR ASSESSING THE POTENTIAL FOR DECOUPLING IN THE INDIAN BUILDINGS AND CONSTRUCTION SECTOR

Over the years, many resource-synergetic options and approaches in the buildings and construction industry have been developed. They include resource substitution, multiple uses, and use of secondary raw materials during the construction phase. Energy efficiency and increasing renewable energy in the buildings' energy mix or total energy mix are primary instruments that can advance decoupling in the operational phase of a building. These measures ensure that the pressure on natural resources is mitigated by decoupling growth from energy and resource use. Yet there is only limited spontaneous adoption of these options and approaches beyond a handful of isolated oases of good practice. It is often argued that energy efficiency has multiple benefits for the economy, such as stimulating growth in new technologies, creating new jobs etc., and that it therefore helps to promote a green economy. Various studies have analysed the barriers to and drivers of uptake of resource and energy-efficient technologies and highlight the interventions needed in the policy sphere. The main aim of all these policies is to decrease virgin material consumption and increase efficiency by promoting alternative materials and technologies. However, it is vital to critically enquire whether the alternatives being proposed achieve the following objectives in the buildings and construction sector:

- augment the growth of the green economy as envisaged?
- act in a coordinated manner to deliver the intended energy and resource savings?
- achieve decoupling of growth from energy and resource use (both impact and resource decoupling)?

On a macro-economic scale, the consulting company ECON has studied the effects of decoupling energy and greenhouse gas intensity on the gross domestic product (GDP) of various OECD and non-OECD countries. The potential drivers of decoupling include energy efficiency, increasing the share of renewables in the total energy mix, and structural changes in the economy.[1] Decoupling has been defined in terms of weak (relative) decoupling and strong (absolute) decoupling. GDP growth with declining energy intensity indicates weak decoupling, whereas GDP growth with declining energy consumption indicates strong decoupling. The study concluded that a weak decoupling trend has been observed at world level. Strong decoupling has been observed among OECD countries, with especially strong decoupling in Germany. China show weak decoupling with the potential to turn that into strong decoupling in future (ECON, 2015). From the baseline study of energy and resource use in the indian construction sector, some signs of relative decoupling have been observed in India.

1 That is, by replacing high energy intensive sectors with low energy intensive sectors

Multiple studies have researched the extent of decoupling in different sectors of the economy by applying decomposition analysis. Decomposition analysis uses various mathematical models to help quantify the relative contribution of predefined factors to the change in overall energy and resource consumption (Heinen, 2013). A number of such studies by Mulder & de Groot (2004), Diakoulaki & Mandaraka (2007), and Andreoni & Galmarini (2012) have been summarised (see *Table 10* and *Table 11* in the Annex) to understand the key factors that influence decoupling.

Decoupling exclusively in the buildings and construction sector has not yet been analysed in previous studies. However, conceptual parallels can be drawn from the literature to conduct a theoretical potential analysis. It is vital to identify the key factors (see *Table 1*) that influence decoupling, the alternative materials and technologies being proposed, and the indicators against which decoupling in the buildings and construction sector can be assessed.

Table 1: Influencing factors and indicators of decoupling

Influencing factors	Relevance to decoupling in the buildings and construction sector
Total primary energy consumption	This specifies the total primary energy consumed in the life cycle of a building. For effective decoupling, fossil fuel-based primary energy consumption has to decrease.
Utility fuel mix	Utility fuel mix describes the share of various renewable and non-renewable energy sources supplied by utilities. For effective decoupling, the renewable energy in the utility fuel mix has to increase.
Building fuel mix	Building fuel mix describes the share of various renewable and non-renewable energy sources used by an individual building (by generating onsite renewable energy etc.). For effective decoupling, the renewable energy in the fuel mix of individual buildings has to increase.
Primary resource consumption	This is the total primary resource consumption in the life cycle of a building. For effective decoupling, primary resource consumption has to decrease.
Environmental impact	This is the cumulative environmental impact caused by building construction. For effective decupling, the environmental impact caused by resource and energy consumption has to decrease.
Growth and productivity	This specifies the economic growth and productivity resulting from building construction activities. For effective decoupling, the economic growth and productivity in the building sector and subsectors have to increase.
Labour productivity and human resource development (HRD)	This is the labour productivity and HRD resulting from building construction activities. For effective decoupling, it is crucial to increase and diversify employment opportunities, and use human resources effectively.

Alternative materials and technology interventions	
Non-disruptive materials and technologies	Improving the efficiency of production and operation of existing construction practices and technologies. For example, using more efficient air conditioners, lighting and appliances in the place of old and inefficient ones, or using bricks produced from vertical shaft brick kilns (VSKB), which are more efficient than conventional kilns.
Disruptive materials and technologies	Replacing existing construction practices and technologies with new and efficient ones. For example, replacing burnt mud bricks with fly ash and autoclaved aerated concrete (AAC) blocks, using construction and demolition (C&D) waste-based aggregates in place of natural aggregates, replacing single-glazed wooden frame windows with polyurethane double-glazed windows, using solar cooling technologies in place of conventional air conditioning etc.
Indicators of decoupling	
Resource decoupling	This means reducing the rate of use of (primary) resources and the energy per unit of economic activity. This understanding of 'dematerialization' is based on the concept of using less material, energy, water and land to achieve the same economic output, resulting in more efficient use of resources. This is also sometimes referred to as absolute/strong decoupling.
Impact decoupling	This means raising economic output while reducing the negative environmental impacts that arise from the extraction of resources (degradation of rivers and land caused by extracting sand and soil respectively), production (land degradation, waste and emissions), use of commodities (transport resulting in CO_2 emissions), and in the post-consumption phase (waste and emissions). This is also referred to as relative/weak decoupling.

Source: Authors' analysis

2 THEORETICAL POTENTIAL FOR DECOUPLING

This chapter discusses all the factors integral to India and their relevance to decoupling. For the sake of brevity and understanding the decoupling concept, only key information is presented here. The following theoretical model (see *Figure 1*) shows the steps involved in evaluating the potential for decoupling in various sub-sectors of the buildings and construction sector using various resource and technological interventions. In the course of this study, we discovered that quantifying decoupling needs more reliable data and verifiable indicators, which are unavailable at the moment. Therefore, only a qualitative analysis has been presented in this section that focuses more on developing a methodology to quantify decoupling, identifying key factors, required data, and reliable indicators.

Figure 1: Steps to evaluate the theoretical potential for decoupling in buildings and construction sector

STEP 1

Phase-wise resource and energy usage:

Segregate resources and energy as per their usage into operational and construction phase

Design and construction phase

Operation and maintenance phase

STEP 2

Alternative materials and technology interventions:

Identify alternatives to the existing inefficent technologies and materials and classify them into the following two categories:

- Disruptive
- Non-disruptive

STEP 3

Sub sectors:

Group technologies and meterials as they are applicable to each of the sectors described below in various scenarios:

- Residential
- Institutional and office
- Retail
- Hospitality
- Medical facilities
- Transport terminals

STEP 4

Factors:

For each of the scenarios identified above analyse all the relevant factors described below

Total primary energy consumption

Fuel mix at utility level

Fuel miy at building level

Primary resource consumption

Environmental impact

Growth and productivity

Labour productivity and HRD

Source: Authors' analysis

2.1 PHASE-WISE RESOURCES AND ENERGY USAGE IN BUILDINGS

Resource and energy consumption in buildings can be broadly divided into two phases: the design and construction phase, and the operation and maintenance phase. The design and construction of buildings results in the consumption of primary resources, which can be expressed by weight or volume, while energy required for transport and processing primary resources results in embodied energy of these resources. Soil and sand are amongst the primary resources used for construction. The operation and maintenance phase consists of energy consumption for the day-to-day functioning of the buildings, which is also called specific or final energy consumption. Total primary energy consumption includes both embodied and final energy consumption. Although the life cycle of a building also includes a demolition phase, its share is negligible compared to the construction and operational phase and hence has not been discussed in detail here.

2.2 ALTERNATIVE MATERIALS AND TECHNOLOGY INTERVENTIONS

Various alternative materials and techniques have been developed in order to reduce environmental impact and increase energy and resource efficiency. The ease of adaptability and potential impact of these alternatives differ depending on various factors. They can be classified into two categories: non-disruptive and disruptive. *Table 2* below shows a few examples of the most commonly used alternative building materials and technologies. The nature of the merits and the challenges associated with various alternatives for each of the materials and technologies is discussed later.

Table 2: Examples of alternative materials and technology interventions

Measure	Business as usual	Non-disruptive	Disruptive
Construction phase			
Replacing sand with other alternatives	Sand	–	Manufactured sand
Replacing brick with other alternatives	Burnt mud bricks	Burnt mud bricks from efficient kilns	Autoclaved aerated concrete (AAC) and fly ash brick
Operational phase			
Efficient technical systems reduce energy consumption	Window/split air conditioners	High efficiency split air conditioners/variable refrigerant volume (VRV) systems	Solar air conditioners and combined heating, cooling and power (CHCP)
Efficient lighting systems reduce energy consumption	Incandescent	Compact fluorescent light bulbs (CFL) and light-emitting diodes (LED)	–
Using renewable technologies	None	Solar photovoltaics (PV) and solar thermal	High efficiency building-integrated solar PV, CHCP

Source: Authors' analysis

2.2.1 EXAMPLE ANALYSIS OF BRICK AND ALTERNATIVES

The use of clay bricks for construction has been a common practice in India. According to the Ministry of Mines, Government of India, brick earth accounted for 5.2 % of total minor minerals extracted in the year 2014–15. The extraction of brick earth involves removing topsoil, which is valuable for its high level of fertility and has high opportunity costs because of its use in agricultural production. In the year 2014–15, 184.14 million tonnes of fly ash were generated by 145 thermal power plants (Central Electricity Authority, 2015). Disposal of this material has been a major problem in India, but it has started to be incorporated into a variety of masonry units in the construction sector. It is used both as a stabilizer and as a main component in bricks. Since it is a by-product, the energy used and carbon dioxide emitted in its production are attributed to the intended product and not to the production of fly ash. Thus, the utilization of fly ash in brick-making results in impact decoupling, since not only is the extraction of topsoil reduced, thereby reducing the environmental impact of extraction, but also the energy required to produce these bricks is lowered. As per estimates by the Fly Ash Bricks and Blocks Manufacturers' Federation (FABMAFED), about 20 billion cubic feet (0.566 billion cubic metres) of topsoil could be saved annually if the existing 140,000 red brick kilns in the country switched to using fly ash. Over the last two decades, the production of fly ash-based bricks/blocks/tiles has increased from 0.70 million tonnes in 1998–99 to 12.02 million tonnes in 2014–15, which constitutes 11.72 % of total fly ash utilized in that year (Central

Table 3: Comparison of properties of various alternative masonry materials

Parameters	Clay bricks	Autoclaved aerated concrete (AAC)	Fly ash bricks
CO_2 emissions (kg CO_2/kg of brick)	0.2[e]	0.3[e]	0.04[b]
Embodied energy (MJ/kg of brick)	3[e]	3.5[e]	0.52[b]
Thermal conductivity (K value) W/m-K	0.7[e]	0.12[a]	0.6–0.8[c]
Soil consumption	1 kg/kg of brick[d]	0 kg/kg of brick (Uses fly ash, which is a waste product from thermal power plants and thus involves no consumption of topsoil)	0 kg/kg of brick (Uses fly ash, which is a waste product from thermal power plants and thus involves no consumption of topsoil)

[a] Satyanarayan, 2014
[b] Flyashbricksdelhi, 2009. Weight of fly ash bricks considered to be 2.5 kg per brick
[c] Based on expert consultation
[d] Based on expert consultation
[e] Kumar, Buddhi, & Chauhan, 2012

Electricity Authority, 2015). Existing green building rating systems in the country mandate the use of fly ash in construction. However, fly ash availability and supply varies from region to region. A regional approach based on fly ash availability may be a more prudent way to mandate its use in construction.

2.2.2 EXAMPLE ANALYSIS OF SAND AND ALTERNATIVES

Sand continues to be a critical resource for construction; it contributed 16.5 % to the value of minor minerals in 2014–15 (Ministry of Mines, 2015). The demand for sand as a construction aggregate accounted for 29 % of the total aggregate demand in 2010. According to a study by the Freedonia Group, the total demand for sand is expected to increase from 630 million metric tonnes in 2010 to 1430 million metric tonnes in 2020 (Aggregates Business Europe, 2013). Sand mining has adverse impacts on the environment, which include degradation of land, disturbance to the water table resulting in topological disorder/erosion, changes in biotic and abiotic systems, severe ecological imbalance etc. (O.C. & Ramzan, 2016). In this context, viable alternatives have been developed with stable physical and chemical properties making it stronger than natural sand. One of the alternatives used in building construction is manufactured sand (M-sand). In India, particularly in the state of Karnataka, M-sand has been included in the Schedule of Rates for public works with close to 100 M-sand manufacturing facilities located in the state (The Hindu, 2015). Increasing the supply and use of M-Sand in construction is expected to bring about a reduction in ecological destruction on the riverbeds where the sand is extracted, which will result in impact decoupling.

2.2.3 EXAMPLE ANALYSIS OF AIR CONDITIONING TECHNOLOGIES

Sales of air conditioners (ACs) are expected to increase significantly in the coming years due to the current low market penetration of ACs (approximately 4 %) in Indian households and due to the increase in built footprint in the coming years. This implies that the market, associated revenue, and energy usage for air conditioners will continue to increase. It is safe to assume that the majority of the green building projects use non-disruptive and efficient cooling technologies. Non-disruptive technologies – such as Bureau of Energy Efficiency (BEE) star-rated ACs, fans, Building Energy Code compliant chillers etc. – increase the overall system and operational efficiency of the heating, ventilating and air conditioning (HVAC) equipment and thereby reduce the cooling energy consumption.

On the other hand, there are non-conventional and renewable HVAC technologies, such as solar cooling, and combined heating, cooling and power (CHCP), which can be considered as disruptive technologies. The total area occupied by collectors for concentrated solar heating technologies under the UNDP-GEF project on concentrated solar heat (CSH) was 16,373 square metres, of which 11,247 square metres (69 %) were used for process heat or cooling[2] (MNRE, 2014). If the potential were fully utilised, 5 million square metres of collector area for solar cooling with 25,000 TR (0.088 GW) could be achieved by 2022 (Signal, 2014). Applications of CHCP in building cooling are not very widespread compared to its industrial applications. As per an estimate by Deutsche Gesell-

2 Includes both heating and cooling. Exact estimates of space cooling are not available.

schaft für Internationale Zusammenarbeit (GIZ), the potential for building-integrated gas-based CHCP systems is approximately 6 GW (Pales & West, 2014).

The potential cooling generation from alternative technologies can meet only a miniscule percentage of space cooling energy demand. Moreover, it is very difficult to integrate these technologies into existing buildings. Despite their attractive payback periods, the use of disruptive cooling technologies is still confined to flagship projects and a few green building projects, owing to factors such as the scale of the project, cooling and heating schedule and demand, technical feasibility and expertise, capital cost etc. (Pales & West, 2014). Cooling energy demand itself can be reduced by adopting passive cooling techniques and by maximising natural ventilation potential. However, a wide range of reasons such as air pollution, noise, building usage patterns, user behaviour etc. limit the adoption of most simple passive building techniques. Active integration of passive and active cooling systems to work in a mixed-mode/hybrid system is also still limited to demonstration/experimental buildings and still needs validation and adoption.

2.2.4 EXAMPLE ANALYSIS OF LIGHTING TECHNOLOGIES

Lighting has always been a low-hanging fruit for achieving energy efficiency and the transformation from inefficient incandescent to compact fluorescent lights (CFL) and then to light-emitting diodes (LEDs) has been rapid, owing to several pro-active policies such as Bachat Lamp Yojana and the Domestic Efficient Lighting Programme (BEE, 2015; MoP, 2016). Rural areas that have not yet been electrified are being served by solar lamps in the interim (NABARD, 2016). These policies are a combination of subsidies, bulk procurement, energy services schemes etc. In the light of these policy interventions and easy access to and deployment of energy efficient lighting technologies such as LEDs, the potential for further efficiency in lighting could be fully exploited in the coming decades. While LED lighting imports increased by up to 2.7 times from 2012–15, LED exports shrank by up to 0.7 times in the same period (ElectronicsB2B, 2015).

2.2.5 EXAMPLE ANALYSIS OF RENEWABLE ENERGY TECHNOLOGIES

Building-integrated renewable energy has the highest potential for reducing fossil fuel-based total primary energy consumption in the buildings sector when compared to the combined effect of designing efficient building envelopes and using efficient cooling and lighting technologies (Talakonukula, Prakash, & Shukla, 2013). The proliferation of building-integrated solar photovoltaics has been especially encouraging, although not phenomenal. Out of the total 525 MW of solar rooftop systems installed, residential accounts for 143 MW, commercial for 172 MW, and the remaining 210MW is on industrial rooftops. Solar rooftop systems certainly hold immense unfulfilled potential given the solar radiation levels in the country and the amount of roof space available. Despite capital subsidies and feed-in tariff policies by state governments, the Comptroller and Auditor General of India's report on renewable energy found that factors such as lack of net metering and provision of batteryless systems within the schemes discouraged domestic users from taking advantage of their full benefits. In addition, the report also highlights several instances of installed rooftops not operating to their full potential due to a lack of maintenance and technical challenges to grid connectivity (CAG, 2015).

Similar to rooftop solar photovoltaic technology, rooftop solar water heaters (SWH) also represent considerable unfulfilled potential. Only a minute fraction of energy consumption for thermal applications – about 0.25 % (0.6 Mtoe out of a total of 240 Mtoe) – comes from solar thermal. Looking on the bright side, buildings accounted for about 82 % of installed capacity of solar water heaters in the country. The market for SWH in buildings is expected to grow tenfold between 2014 and 2032 and is expected to be equivalent to the annual electricity generated from approximately 64 GWp of solar PV installations. Capital costs and performance risks, equitable distribution in high-rise buildings, inadequate quality standards, lack of labelling, and inclusion of a mandatory requirement in local building by-laws to provide SHW technologies have been cited as challenges to the expansion of SWH in residential buildings (Greentech Knowledge Solutions Pvt. Ltd, 2015).

2.3 SUBSECTORS

The core construction practices in the buildings and construction sector in India appear to be similar across different subsectors such as residential, offices, retail, hospitality, medical facilities, educational and transport terminals. However, the resource and energy consumption patterns in each of them vary considerably. In addition, many efficient construction and energy technologies that are suited for a particular type of building might not be suitable for other sectors. For example, CHCP technologies are mostly suited for hospitality and medical facilities, where there is a simultaneous cooling and heating demand, and are less suited in residential applications.

2.4 FACTORS

The following factors have been identified from the literature as the key factors that affect decoupling. The list of factors is neither exhaustive nor conclusive, but strives to provide enough information to analyse decoupling on a macro scale. Quantification metrics, sources of information and gaps have been discussed for each of the factors.

2.4.1 OPERATIONAL ENERGY

Of the total energy consumption in the country during the year 2013–2014, 22.5 % was consumed by the residential sector and 8.7 % by the commercial sector, taking the total consumption by building-related uses to approximately 31 % (CSO, 2015). *Table 4* shows a comparison of energy consumption profiles, baseline and best practice energy consumption patterns in the country, and projection scenarios for the residential and commercial sector. An energy performance indicator (EPI) typically serves as an indicator of specific energy intensity in buildings and is expressed in kWh/m2/year. The EPI should be treated with caution as the procedure for calculating energy consumption and floor area is at the discretion of the rating system in question. There is no methodology for calculating EPIs that has nationwide acceptance (CSE, 2014).

Residential sector: A study conducted in sample urban residential buildings in two climatic regions of India – composite climate (Delhi-NCR) and warm humid climate (Chennai) – calculated the mean final energy consumption as 48 kWh/m2/year and 43 kWh/m2/year respectively (Kanagaraj et al., 2014). Another study published in 2014 by the Global Buildings Performance Network (GBPN) reported that the average EPI in 1–4 bedroom residential units ranges from 35–46 kWh/m2/year in four cities representing four different climate zones. The energy consumption depends on the number of air conditioners and peaks during the summer months. The studies also found out that absolute energy consumption increases with the growth in the number of air conditioners (AC) per dwelling unit. *Table 4* below shows a comparison of average energy consumption (based on the two studies mentioned above) versus baseline energy consumption (based on different rating systems and regulations in India and Germany) in the residential sector.

Although observed EPIs for the majority of the buildings in both studies by Kanagaraj et al. (2014) and GBPN (2014) fall below the GRIHA EPI baseline and the Passivhaus standard, they are still marred with inefficiencies in design, technologies deployed and usage. Hence, they hold immense potential for further lowering their energy consumption. In addition, average energy consumption is only a gross approximation considering the diversity in the data. There also appears to be a need to correlate and revise the EPI baselines in India to reflect the values based on latest measured consumption data, usage and available best practices.

Table 4: Energy consumption scenario in residential buildings

	Average energy consumption		Baseline consumption			
	Kanagaraj et al., 2014	GBPN, 2014	GRIHA green building rating (voluntary standard)		Passivhaus, Germany (voluntary standard)	Energy Conservation Regulations, (EnEV) Germany (mandatory)
Climate zones	Composite & warm and humid	Composite, hot and humid, hot and dry, moderate	Moderate	Composite, hot and humid, hot and dry, cold	All (a few exceptions exist for hot and humid climates)	–
EPI value (kWh/m^2/year)	40–50 (average)	35–46 (average)	<50	<70	Space heating/cooling energy <15 Specific energy demand < 46.1	Energy consumption for heating and hot water < 60–70 kWh/m^2 of heated indoor area/year

Source: Authors' analysis

As per GBPN (2014), annual energy consumption in the residential sector in India is projected to increase from 650 kWh in 2012 to 2,750 kWh by 2050 in a business-as-usual scenario and could be cut down to 1,170 kWh in a very aggressive efficiency scenario. Energy use in the residential sector is projected to reach around 2,250 TWh in a moderate efficiency scenario and 1,200 TWh in an aggressive efficiency scenario by 2047 (NITI Aayog, 2015). Each scenario includes assumed different levels of efficient lighting and appliance penetration for a given growth in the residential building sector within the timeframe.

Commercial sector: Preliminary results from a benchmarking study on commercial buildings in India show that energy consumption in typical office buildings ranges from about 100 kWh/m2/year to about 500 kWh/m2/year, depending on the type of building, climate zone and period of usage (USAID ECO-III Project, 2010). *Table 5* shows a comparison of baseline energy consumption versus best-practice energy consumption in the non-residential sector.

Energy use in the commercial sector is projected to reach around 795 TWh in a moderate efficiency scenario and 671.5 TWh in an aggressive efficiency

Table 5: Energy consumption scenario in non-residential buildings

	Average energy consumption (kWh/m^2/year)	Baseline energy consumption (kWh/m^2/year)		
Sector	USAID ECO-III Project, 2010	USAID ECO-III Project, 2010	GRIHA	BEE star rating
Typical day time operated office building	115	141	< 75 (moderate climate) < 90 kWh/m^2/year (all other climate zones except moderate)	65–85 (for buildings that have < 50 % air conditioned area)
Office buildings operating three shifts	349		< 225 (moderate climate) < 300 kWh/m^2/year (all other climate zones except moderate)	115–200 (for buildings that have > 50 % air conditioned area)
Secondary government hospitals	88	–	–	–
Multi-speciality hospitals	378	–	–	–
Luxury hotels	279	–	–	–

Source: Authors' analysis

scenario by 2047 (NITI Aayog, 2015). Each scenario includes different assumed levels of efficiency for the building envelope, lighting and appliance penetration for a given growth in the residential building sector within the timeframe.

2.4.2 EMBODIED ENERGY

Embodied energy is the total energy that is required for the extraction, processing, manufacture and delivery of building materials to the building sites. It is thus the indicator for the overall environmental impact of building materials and their production processes. Talakonukula, Prakash, & Shukla (2013) calculated that embodied energy in air-conditioned residential buildings in India is approximately 10–20 % per cent of operational energy. Their study of a 4-storey concrete-framed block of flats comprising 44 units revealed that the embodied energy of the building was about 11 % of the operating energy, with the predominant materials being steel, cement and bricks. Steel accounted for 34 % of the initial embodied energy followed by cement (25 %) and bricks (24 %). However, another study by Praseeda, Venkatarama Reddy, & Mani (2016) observed that the embodied energy can further increase up to 50 % in non-air-conditioned buildings, indicating that air conditioning plays a critical role in total primary energy consumption (Praseeda, Venkatarama Reddy, & Mani, 2016).

The use of alternative materials and technologies can significantly reduce embodied energy. For example, vertical shaft brick kilns are an energy-efficient technology for fired clay brick production. The technology saves 30–50 % on fuel as compared to other brick-firing technologies, thus reducing the embodied energy of brick production considerably. Similarly, Fal-G bricks are manufactured from a mix of fly ash (industrial waste), lime and calcined gypsum (a by-product of phosphogypsum or natural gypsum). The mix capitalizes on the strength of fly ash/lime mixtures in the presence of gypsum. These fly ash bricks reduce the embodied energy because they use waste material and are manufactured by mechanically compressing the raw material and thus do not need firing (Khanna, 2011). Thus, reducing embodied energy through design and choice of building material can significantly reduce the environmental impacts.

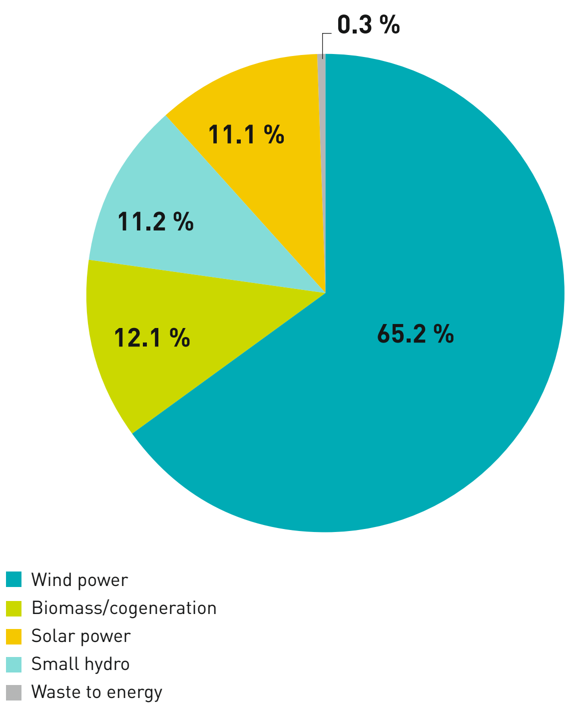
Embodied energy is measured in MJ or GJ in absolute terms and MJ/m2 or GJ/m2 in specific terms.

2.4.3 UTILITY FUEL MIX (SUPPLY GRID ENERGY MIX)

The total installed electricity capacity in the country as at August 2015 was 276,783 MW, which comprised 60.8 % coal, 8.4 % gas, 0.4 % diesel, 2.1 % nuclear, 15.2 % hydro and 13.17 % renewable energy. Of the total capacity of 36,471 MW of renewable energy, 11.2 % was from small-scale hydro projects, 65.2 % from wind power, 12.1 % from biomass/cogeneration, 0.3 % from waste to energy, and 11.1 % from solar power (see *Figure 2*) (CEA, 2015). The anticipated figures for total electrical energy available in the country for the period 2014–15 are 995,157 MU of available energy at a peak demand of 144,788 MW against a requirement of 1,048,672 MU at a peak demand of 147,815 MW, leaving a shortage of 5.1 % and 2 % respectively (CEA, 2014). This implies an increase in the electricity shortage and results in load shedding. The utility mix provides an easy opportunity to move towards a transition to clean energy. Options that are available for consumers in this direction include switching to a cleaner utility provider or purchasing renewable energy certificates. India has a renewable energy potential of 245,880 MW (estimated) and its market is growing at an average annual rate of 15 % (IGEP, 2013). Despite the high demand for the input materials needed for wind energy, the potential resource savings of using it instead of coal-based power plants are still much higher – saving up to 350 million tonnes of primary raw materials by 2030 (IGEP, 2013).

The primary energy factor (PEF) indicates the efficiency of converting a primary source of energy such as coal, gas, solar etc. into usable electricity. PEF typically takes into account all inherent conversion and transmission losses and serves as an appropriate indicator for individual fuels or fuel mix. A lower PEF indicates higher efficiency of production and vice versa. *Table 6* shows PEF values from the European Union (EU) (Fritsche & Greß, 2015). The comparative values for India are not readily available, but values from older sources show a PEF value of around 3.4.

Figure 2: Breakdown of renewable energy generation as of August 2015 in MW (Total 36,470)



Source: CEA, 2015

Table 6: Primary energy factors in the EU

PEF (kWhprim/kWhel)	PEF total	PEF non-renewable	PEF renewable	PEF other*
EU (2013)	2.46	2.18	0.36	0.04

*= includes waste heat, and non-renewable wastes
Source: Fritsche & Greß, 2015

2.4.4 BUILDING FUEL MIX (ON-SITE ENERGY GENERATION AND CONSUMPTION)

Technologies that influence fuel mix at an individual building level include solar photovoltaic, solar thermal, ground-source heat pumps, and co-generation (CHCP) technologies etc. However, except for solar photovoltaic and to a certain extent solar thermal, the remaining technologies are still confined to pilot projects and await large-scale deployment. The total installed rooftop capacity at the end of 2015 is estimated to be 525 MW, which represents around 11 % of total solar PV installed capacity, which also includes utility-scale solar PV (PTI, 2015). As a part of the Jawaharlal Nehru National Solar Mission (JNNSM), the target for installed capacity of solar rooftops is 40 GW by 2022.

The potential for using conventional and alternative sources of energy varies across building sectors and depends on several factors. For the formulation of long-term policies on decoupling, it is important to identify the technical feasibility in various building sectors and make recommendations that target the achievement of their full potential. For example, single-family and multi-family houses have more roof surface area to install solar renewable technologies, but apartment buildings have limited area. Similarly, cogeneration techniques are useful only in buildings with simultaneous heating and cooling demand. Therefore, a blanket policy recommendation to increase the use of various renewable technologies in the buildings sector will not yield the expected results unless the nuances in technology use and deployment are understood.

The building fuel mix is considered in terms of energy generated or saved and therefore subtracted from the building's specific energy consumption. Typically, the EPI for low-energy and net zero-energy buildings is expressed after factoring in the energy generated from renewable sources of energy.

2.4.5 PRIMARY MATERIAL CONSUMPTION

Resource efficiency is considered to be an effective means of reducing environmental burdens and simultaneously strengthening India's economy by contributing to the decoupling of resource consumption from economic growth. India's construction sector has been growing at an average annual growth rate of 10 % since 2000 and it is still growing rapidly, which means that India's housing stock is estimated to increase from 330 million housing units in 2011 to 770 million in 2030. This increases energy use and significant raw material footprints, including the consumption of minerals (sand, gravel), cement, steel, bricks, aggregates, and diminishes natural reserves. It uses 40–45 % of India's steel, 85 % of its paint production, 65–70 % of its glass; furthermore, a significant percentage of the output from the automotive, mining and excavation equipment industries are used in the construction industry (Planning Commission, 2012).

Resource-efficient measures hold significant material-saving potential of more than 40 %. About 50 billion tonnes of materials could be saved if all the housing demand were constructed using resource-efficient options by 2030 (IGEP, 2013). It is important to note that the two crucial resources sand and soil often operate outside of the formal economy. Hence, even though the resource use and environmental impact related to their usage is very real, the value addition arising from the use of these resources in the formal economy is debatable.

2.4.6 ENVIRONMENTAL IMPACT

As mentioned earlier, both the construction as well as the operational phase contributes to primary resource consumption, which include aspects related to the mining of construction ores and minerals. The environmental impacts of these activities lead to erosion of topsoil, air and ground water pollution etc. For a more holistic understanding of primary resource and energy consumption of buildings it is critical to analyse resource and energy consumption through the life cycle perspective of the building. The life cycle energy and resource analysis is an approach that includes the direct energy inputs during construction, operation and demolition of a building, and indirect energy inputs through production of components and materials used in construction, i.e. embodied energy (Talakonukula, Prakash, & Shukla, 2013). Besides the obvious environmental impacts, primary energy consumption also results in drain on the economy as most of the fossil fuels are imported in India. *Table 7* gives a brief overview of the life cycle stages of a building and the possible environmental impacts.

Table 7: Environmental impacts through the life cycle of a building

Life cycle stages of buildings	Activities	Environmental impacts
Construction (initial embodied energy)	• Raw material extraction (sand, soil) • Transportation • Building material production process	• Biodiversity loss • Soil erosion and land instability • Lowering of ground water table • Water contamination • Air pollution
Operation/maintenance	• Electrical energy for cooling, heating, ventilation, lighting, water supply	• Depletion of fossil fuels • Biodiversity loss • Air pollution (CO_2, NO_x, SO_x)
Building demolition	• Operation of demolition machinery • Transportation of waste materials to landfill site	• Air pollution (CO_2, NO_x, SO_x, particulate matter)

Source: Authors' analysis

2.4.7 GROWTH AND PRODUCTIVITY

Buildings in India are divided into the residential and the service sector. According to 2015 estimates, the service sector (54.4 %) is the single largest contributor to India's GDP, compared to agriculture (16.1 %) and industry (29.5 %) (CIA, 2016). Energy consumption is thus crucial to productivity in service sector buildings such as IT, finance and hospitality etc. India's service sector is the second fastest growing in the world (Bhargava, 2014). Increasing its productivity while consuming the least energy possible is therefore crucial.

Unlike in the service sector, growth in the residential sector cannot be directly quantified into productivity and economic growth. Significant reasons for lowering energy consumption in the residential sector include the fact that it would reduce the financial losses accumulated by the distribution companies because of the heavily subsidized electricity prices, reduce peak demand, and lower the capital and operational expenses for the distribution companies. Making energy accessible and affordable for residential consumers and enabling them to save electricity will lower their monthly expenditure on electricity and give households more disposable income. The increase in GDP due to the spur in the real estate sector also has to be taken into account.

Data on economic growth in the commercial sector is easily available and can be measured directly in terms of GDP and employment generation. However, growth in the residential sector should take into account a combination of qualitative measures of human wellbeing, reduction in revenue loss for the generation and distribution companies, and economic activity in the construction and real estate sector. This data is not readily available and appropriate metrics to measure growth and productivity across the various subsectors of the buildings and construction sector need to be developed.

2.4.8 LABOUR PRODUCTIVITY AND HUMAN RESOURCE DEVELOPMENT

The construction sector is India's second largest employer after agriculture. The employment rate is increasing, with about 41 million people employed in the sector in 2011, which is almost four times as many as in 2005. The bulk of construction work takes place in the metros and cities. The workforce chiefly comprises unskilled workers – more than 80 % – who are predominantly seasonal migrant workers from rural areas (Planning Commission, 2013). The shortage of skilled workers is exacerbated by a lack of capacity in public and private training institutions (Darko et al., 2013). This data is not readily available and appropriate metrics to measure labour productivity across the various subsectors of the buildings and construction sector need to be developed.

2.5 CONCLUSION: TYPE AND NATURE OF DECOUPLING

Viewed individually, alternative technologies and materials have differing potential to contribute to decoupling. However, it would only be possible to measure their cumulative impact if they were used comprehensively and in a particular building sector. This is because a certain alternative might individually have a high impact compared to another low-impact alternative. However, the use of such a high-impact alternative might be very limited in terms of quantity, volume or net savings achieved compared to another low-impact alternative. Furthermore, cost, payback, and certain other factors, as discussed for each of the alternatives described, might inhibit their use.

For example, it is becoming increasingly clearer that there is a great deal of untapped potential in the rooftop solar photovoltaic sector. Ambitious targets have already been set, the technology and roof space is available, and there is no dearth of solar radiation in the country, so all it would take to tap the full potential is technology integration and policy leapfrogging.

Similarly, projections such as the India Energy Security Scenarios 2047 (IESS 2047) show that there is immense potential for achieving relative decoupling in individual sectors. For example, relative decoupling is possible in the residential and commercial building sector under certain scenarios. In a developing economy such as India, it is not feasible to achieve absolute decoupling in any sector. However, absolute decoupling – both in terms of technology and material – should be made a priority for critical resources. For example, it is very important to reduce the overall use of sand.

Table 8 analyses drivers and barriers to achieving absolute and relative decoupling in both the residential and non-residential sectors for the various factors listed above.

Table 8: Analysis of decoupling

Impact decoupling	
Drivers	Barriers
Construction phase – residential and non-residential: • Given the lack of awareness of the adverse impact of CO2 emission and NDCs at regional and grassroots levels, the problem should be translated and interpreted in terms of environmental and air pollution which are immediately felt and easily understood by people. • Increase in employment opportunities and commercial viability of construction materials and SMEs. **Construction phase – residential and non-residential:** • Non-disruptive technologies have the potential to reduce environmental impact. **Operational phase – residential:** • Building fuel mix, incorporating solar rooftop for example, has the highest potential to reduce dependence on fossil fuel-based grid electricity. • Elimination of load shedding due to solar back up. • Monetary benefits. • Energy cost savings – encourage conversion of energy (cost) savings into long-term bonds. • Competitive feed-in tariff (FIT) and levelised cost of electricity (LCOE) regime.	**Construction phase – residential and non-residential:** • Mass production and commercial viability of some alternative building materials. • Lack of awareness and monitoring at city/municipal level. • Informal nature of the building materials supply chain. • Labour intensive cum exploitative nature of building materials manufacturing industry. **Operational phase – residential and non-residential:** • Functional issues in deploying renewable technologies in individual buildings. **Operational phase – residential:** • Greater proliferation of home appliances, especially appliances which are not within the regulatory ambit. • Lack of credibility measures to encourage renewable energy certificate (REC) purchase schemes. • Energy subsidy not in line with demand in higher consumption slabs.
Resource decoupling	
Construction phase – residential and non-residential: • Increased economic opportunities in rural areas **Construction phase – residential and non-residential:** • Non-disruptive technologies have the potential to reduce primary resource consumption. • Increase in local manufacturing in appropriate disruptive technologies. • REC purchase obligations for buildings that exceeds specific consumption level.	**Construction phase – residential and non-residential:** • Demand for construction activity due to increase in population growth. • Lack of regulatory framework for the flow of building construction materials. • The nature of and need for increased economic growth that is dependent on the consumption of energy and resources. **Operational phase – residential:** • Lack of leapfrogging in uptake of disruptive technologies.

Source: Authors' analysis

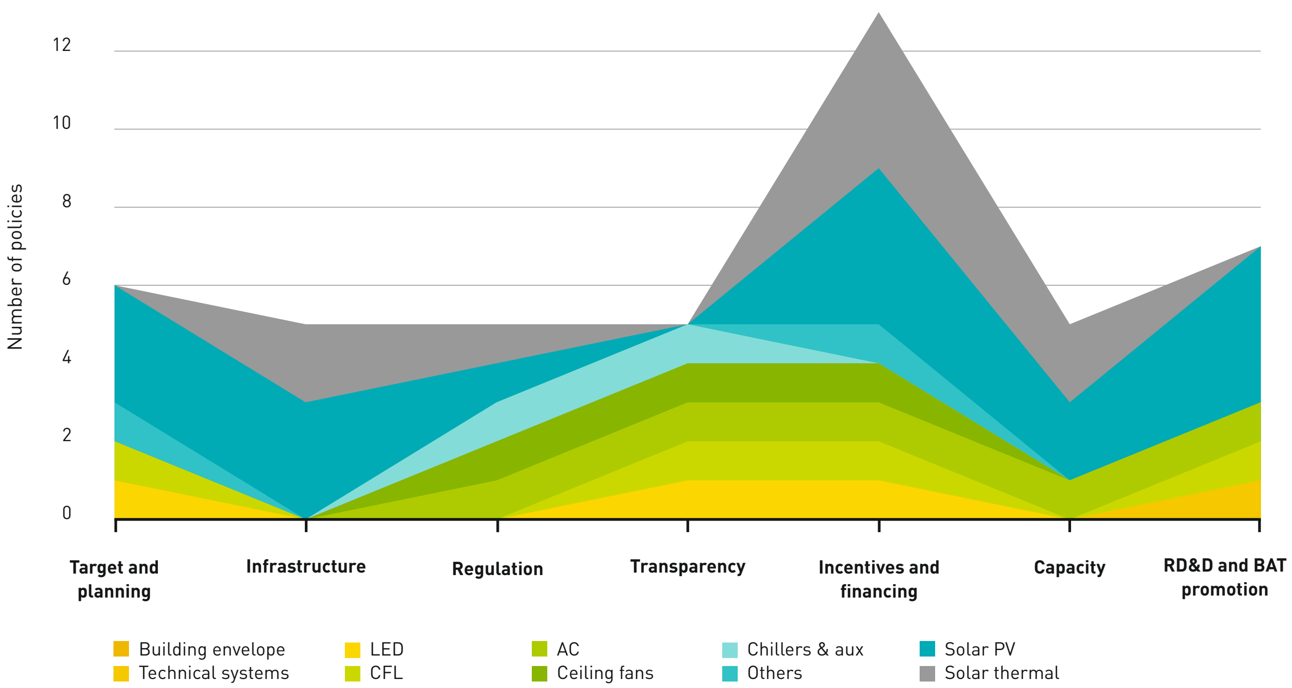
3 ANALYSIS OF THE CURRENT POLICY SCENARIO

3.1 CURRENT POLICY SITUATION

Numerous policies at central, state and local levels, along with popular green building rating systems, are key to minimising the environmental impact and resource consumption caused by the construction and operation of buildings. They encourage the use of materials with low embodied energy and the reuse of industrial by-products in construction, and the use of energy-efficient and renewable energy technologies during the operational phase. A number of key non-disruptive and disruptive technologies and resources being used in India have been identified from the literature, along with examples of good practice and green building standards (refer to policy brief 1 for details). The policies have been classified for the purpose of analysis using the bigEE.net policy package (Wuppertal Institute, 2016). The technologies pertain, for example, to the building envelope, air conditioners, solar thermal, solar photovoltaic, fans, LED and CFL lighting, and chillers. Resources include sand, cement, steel, brick and others. These technologies and resources have then been categorized into different policy headings as identified in policy brief 1 to identify the trigger points and gaps.

Firstly, technological interventions that have been recognized as crucial to facilitating decoupling in the buildings and construction sector were analysed (see *Figure 3*). It can be seen that incentives and financing has been one of the popular policy instruments across different technologies, followed by capacity building and research, development and demonstration (RD&D) and promoting best available technology (BAT). One observation while making the classification was that most policies aim to minimise

Figure 3: Policies that impact on operational energy usage through various technologies



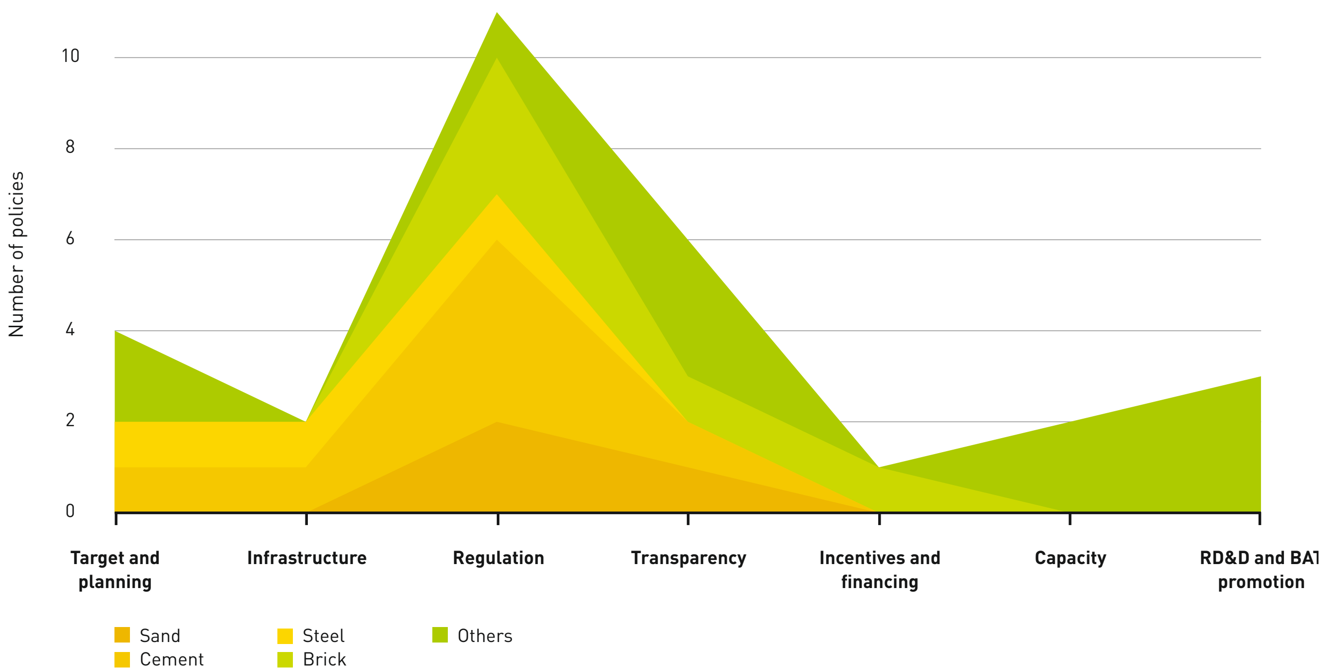
Source: own illustration

the total building energy consumption instead of focusing on a particular efficient technology option. Most of the time, generic terms such as 'green building' or 'energy-efficient' building are used. This runs the risk of introducing trade-offs between different technology and resource groups, leaving some efficient options out of the race for various reasons such as high capital cost, lack of technical knowledge etc.

Secondly, resource interventions that have been recognized as crucial to enabling decoupling in the buildings and construction sector were analysed (see *Figure 4*). Regulatory policies appear to be the front-runner when it comes to resources, followed by transparency and information, target-setting and planning, and infrastructure and funding. Research, Development and Demonstration (RD&D) and best available technology (BAT) promotion and capacity building appear to be severely under-represented in polices. Although the four resource options are covered by regulatory oversight, implementation is possible only in formal sectors such as cement and steel. Sand and soil (brick) run the risk of slipping through the net. Capacity building and R&D policies should be encouraged.

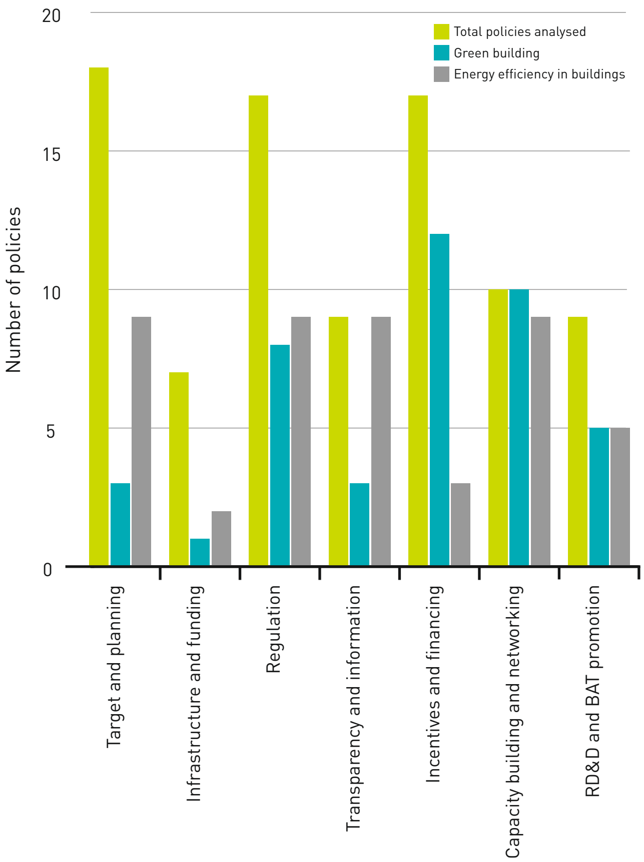
Thirdly, policies were categorised according to whether they address the construction or operational phase (see *Figure 5*). Here, the green building category comprises policies on building materials used during the construction phase and the energy efficiency category comprises policies that emphasise reducing energy use during the operational phase. Often, green building is used as an umbrella term for both green and energy-efficient buildings. Only a

Figure 4: Policies that use various measures to impact resource usage



Source: own illustration

Figure 5: Breakdown of polices dealing with construction and operational phases



Source: own illustration

few policies explicitly emphasise energy efficiency. It can be seen that there are strikingly fewer policies that define targets and address designing green buildings than those dealing with energy efficiency in buildings. Most often, the success and prevalence of green buildings is measured in terms of built footprint or number of buildings certified. However, to better formulate and measure targets, green building policies should include metrics to represent resource consumption and environmental impact, along with water use, energy consumption and operational CO_2 saved.

3.2 WEAK LINKS AND MISSING POLICY ELEMENTS

1. Renewable energy technologies, including both solar PV and solar thermal, have been consistently addressed by almost all the policy instruments within an integrated package. What is also of merit is to analyse each of these implemented policies in conjunction with the Comptroller and Auditor General's (CAG) report on renewable energy (especially rooftop installations) in India, focusing on outcomes and gaps in implementation. There is currently no similar monitoring, verification and evaluation report for other policies implemented in the buildings and construction sector. A small effort, however, can be seen in the LED lighting programme (DELP), where progress is tracked and displayed in real time on a web platform (MoP, 2016). It is therefore essential to develop a reliable measurement and verification protocol for evaluating the impact of various policies on decoupling. Some of the measurement and verification of energy savings can be derived from these studies:

- Energy service companies (ESCOs) working with investment grade energy audits to select suitable buildings for retrofitting.
- The Ministry of Statistics and Programme Implementation and BEE at central level or state designated agencies (SDAs) at state level should also be named as nodal agencies to track, monitor and display information and savings achieved on all buildings approved under investment grade energy audits (IGEA).

2. Incentives and financial instruments lead the charge for technological intervention policies. However, there is a clear lack of regulation and policies on transparency and information in this segment. Although there are some minimum energy performance standards (MEPS) and labelling policies in the lighting and appliances sector, most of them are still in the changeover stage from being voluntary to binding.

3. Of the total energy consumption in the country during the year 2013–2014, 22.5 % was accounted for by the residential sector and 8.7 % by the commercial sector (CSO, 2015). By 2030, the highest growth in building construction is expected in the residential sector (67 %) followed by the service sector (37 %) (Climate Works Foundation, 2010). This indicates that both resource and energy consumption will be highest in the residential sector. Although exact estimates for sub-sectors are not available, LEED reports that the housing sector occupies about 40 % of the green building footprint (Mutu Krishnan, 2012). Besides, it is likely that GRIHA certified buildings are mainly government-owned, while LEED-certified buildings range from large corporate to office spaces, factories and hotels (Darko et al., 2013). Given the existing footprint of residential buildings and the projected growth in the residential sector, it is not surprising that the majority of green construction should happen in the residential sector. However, the majority of the green building projects in the service sector are commercial and office buildings, whereas projects in the residential sector are large-scale developments or government-sponsored housing projects. The majority of the residential projects are still constructed by small builders, developers and local masons who are not highly literate and not yet aware of green buildings.

4. Targets and planning policy measures during the construction phase lag behind those for the operational phase. One quite possible reason for this is that the latter is easy to measure. The construction phase has more impact on environment and resource consumption, both of which are comparatively difficult to account for, given their diverse nature and use patterns. In order to deal with resource-efficiency challenges and explore related options that India will face in the years ahead, more comprehensive qualitative and quantitative data are required, from which future scenarios and trends can be predicted (IGEP, 2013).

5. Although regulatory measures appear to dominate in resource policies, a closer look at particular polices gives a different view. Cement and steel production have already reached considerable efficiency both in terms of resources and embodied energy. However, the national policy on sand has recently been formulated and regulatory oversight on both sand and brick production is extremely difficult given the very nature of their procurement and manufacturing. There is a clear lack of incentives and finance to promote alternative materials, although there are considerable RD&D and BAT promotion policies. An integrated policy package should ensure mass production and a closed supply chain for alternative materials.

4 EUROPEAN/GERMAN POLICY EXPERIENCE IS ENCOURAGING FOR DECOUPLING

Efforts to achieve absolute decoupling can be seen in European countries, e.g. Germany, where there is innovation in efficient technologies and a stringent and supportive policy environment. Although the German economy doubled in size between 1970 and 2011, CO_2 emissions have decreased and energy use stabilised (see *Figure 6*). The gap between GDP growth and GHG emissions reduction is widening and a 1 % GDP increase has coincided with a 0.9 % decrease in carbon emissions (PWC, 2013). Likewise, the economy of the United Kingdom grew by 27 % while emissions fell by 20 % between 2000 and 2014 (Aden, 2016). Decoupling in other countries can be seen in *Table 12* in the Annex. The increase in energy and resource efficiency, and a growth in renewable energy are the main factors of decoupling in Europe. Renewables, including wind power, solar power (thermal, photovoltaic and concentrated), hydroelectric, tidal power, geothermal energy, biomass and waste to energy, have huge potential to stimulate employment and create jobs in new green technologies in the EU (Eurostat, 2016). Besides that, studies show that factors playing a role in decoupling in Europe are deindustrialisation and growing imports from developing countries.

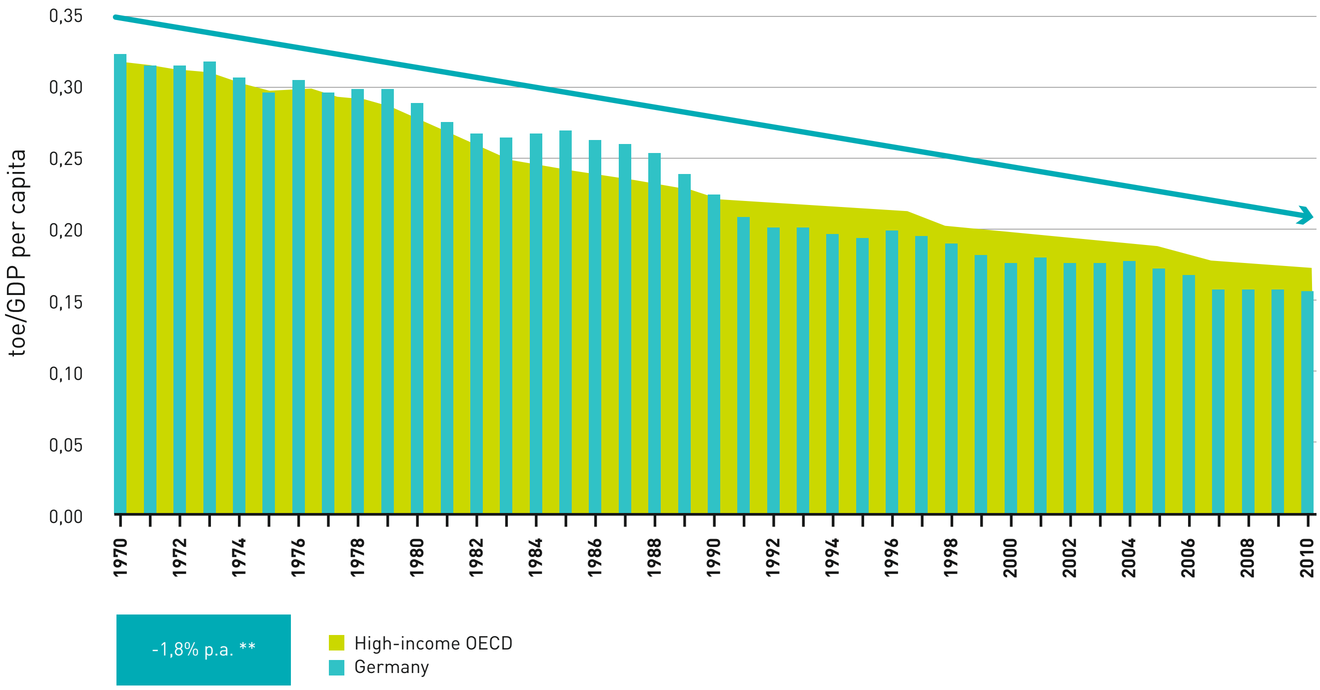
Technological development and stringent policies on energy and material efficiency have played a vital role in decoupling energy and resource use from growth in the European/German construction sector. A number of lessons can be learnt from the European experience, which are discussed below.

4.1 ENERGY EFFICIENCY IN THE EUROPEAN/ GERMAN BUILDINGS AND CONSTRUCTION SECTOR

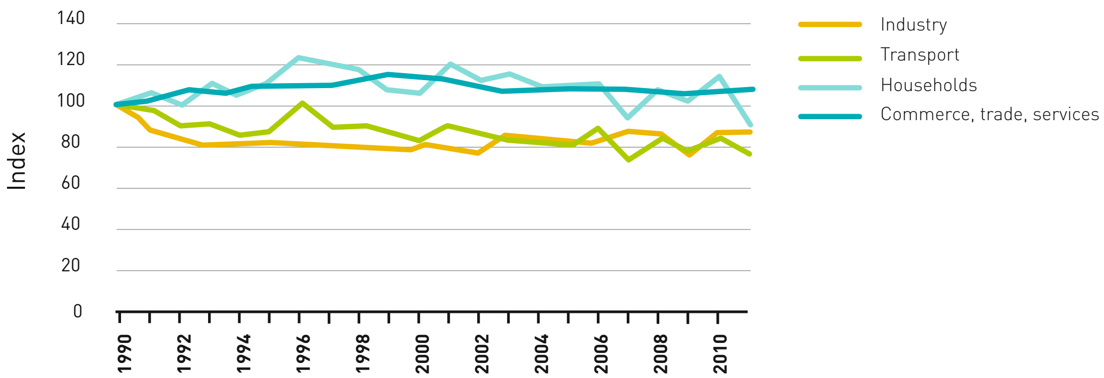
At European level, the Energy Performance for Buildings Directive (EPBD), a mandatory framework directive, obliges member states to set minimum energy performance standards (MEPS) to achieve significant reductions in the energy consumption of buildings. The Directive was recast in 2010 (EPBD recast, 2010/31/EU), making its goals more ambitious – including moving towards nearly zero-energy buildings (NZEB) for new public buildings by 2018 and all new residential and commercial buildings by 2020. Germany's Energy Conservation Regulations (Energieeinsparverordnung, EnEV) stipulate minimum energy performance for new buildings and substantial retrofitting. They cover heating, cooling, domestic hot water and, for non-residential buildings only, lighting and ventilation. The energy standards are stringent and mandatory, and have been tightened regularly. The regulations have been updated from EnEV 2007 to EnEV 2009 in order achieve around 30 % energy savings. The latest revision which is EnEV 2016 calls for increased energy efficiency compared to all the previous editions bigEE 2014). In terms of other governance frameworks, Germany has no energy subsidies but energy-intensive industries are exempted from energy taxes to avoid increasing their electricity costs (bigEE 2014). Besides offering the choice of using clean (renewable) energy in buildings, Germany provides feed-in tariffs to promote renewable energy. It offers compensation to renewable energy producing buildings and also provides guaranteed grid access,

Figure 6: Energy intensity of the German economy

Energy intensity (toe/GDP thousand USD)*, 1970–2010



Energy consumption per sector ****



* The energy intensity includes the transport sector
** Change in primary energy intensity; Final energy use intensity decreased by -3.1% annually (1990–2011)
*** Transport sector is excluded form the scope of this study
**** Due to the reunicication, sector data is only available from 1990

Source: PWC, 2013

long-term contracts (15–20 years) for the electricity produced and purchase prices based on the cost of generation (UNEP, 2014).

In EU member countries, voluntary energy performance certificates (EPC) provide information about a building's energy consumption and give advice about energy-saving potential. It is a legal obligation for a building to have an EPC before being let or sold. Likewise, a building built to the Passive House (PH) standard provides an opportunity for energy savings of at least 80–90 % compared with conventional buildings. It enables high energy efficiency/performance in a building by using appropriate insulation, an airtight construction and efficient mechanical ventilation. These voluntary labels incentivise owners and investors to accept higher building costs and at the same time tenants benefit from lower energy costs and long-term social benefits. The German Energy Agency (Deutsche Energie-Agentur, Dena) has been responsible for and active in demonstrating higher energy-efficient buildings. It monitors, documents and evaluates buildings, incentivising people to save energy and resources, and enjoy economic and social gains.

Likewise, innovation and the use of highly energy-efficient technologies in buildings, such as double and triple glazing, efficient lighting (LED), energy-efficient appliances and insulation have contributed to significant energy reductions. The availability and cost effectiveness of these technologies, supported by incentives, have boosted their extensive use. Financial incentives are available in Europe for both residential and commercial buildings. The most common ones are grants/subsidies, loans and tax incentives. KfW Development Bank (KfW Entwicklungsbank) funding in Germany provides low-interest loans to individuals and municipalities to improve building energy performance, under the rules of which the more the efficient the building the higher the subsidy level. Besides that, various German energy advice services have specially trained energy advisors, providing information about the options for energy saving before and during construction. Estimated savings through this programme amount to 1 to 2 TWh in primary energy and 0.3 to 0.6 million tonnes of CO_2 emissions (bigEE.net, 2014).

4.2 RESOURCE EFFICIENCY IN THE GERMAN BUILDINGS AND CONSTRUCTION SECTOR

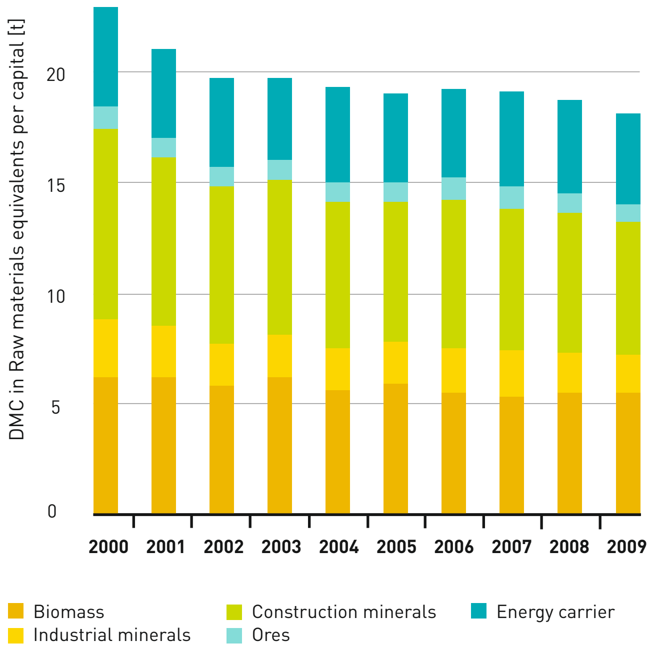
Buildings in the EU account for 42 % of its energy consumption, 35 % of its greenhouse gas emissions and 50 % of its extracted materials (EC, 2011 in PE International, 2013). The European Commission's 'Roadmap to a Resource Efficient Europe' is a core part of the Europe 2020 strategy, which is aiming to achieve high resource efficiency levels for the renovation and construction of buildings and infrastructure by 2020. It uses a life-cycle approach, in which all new buildings will be nearly zero energy and highly material efficient. Furthermore, policies for renovating existing buildings will be in place to ensure cost-efficient refurbishing at a rate of 2 % per year and also targeting recycling 70 % of non-hazardous construction and demolition waste (PE International, 2013). Likewise, the EU's Ecodesign Directive provides consistent EU-wide rules for improving the environmental performance and energy efficiency of building appliances. It helps to eliminate the inefficient products from the market, contributing to the EU's 2020 energy efficiency objective. It also supports industrial competitiveness and innovation by promoting energy-efficient products (EC, 2016).

The German government adopted the Resource Efficiency programme (ProgRess) in 2012 to promote the protection and sustainable use of the country's natural resources (Bundesregierung, 2012) and support resource efficiency goals. Data on domestic material consumption (DMC) in raw material per capita is available for Germany for every year since 2000, and Eurostat is implementing the indicator for the EU27 (BMUB, 2015). DMC in *Figure 7* shows the diminishing rate of material consumption per capita in Germany. Likewise, *Figure 8* shows the decoupling relationship between raw material productivity, extraction and imports on the one hand and GDP on the other.

The Swiss vision of '2000 Watt per capita society' combines energy efficiency with material efficiency and implies a factor 4 to 5 increase in energy efficiency. Research and development activities have been carried out for this Europe-wide with the aim of increasing economic growth using low carbon technologies.

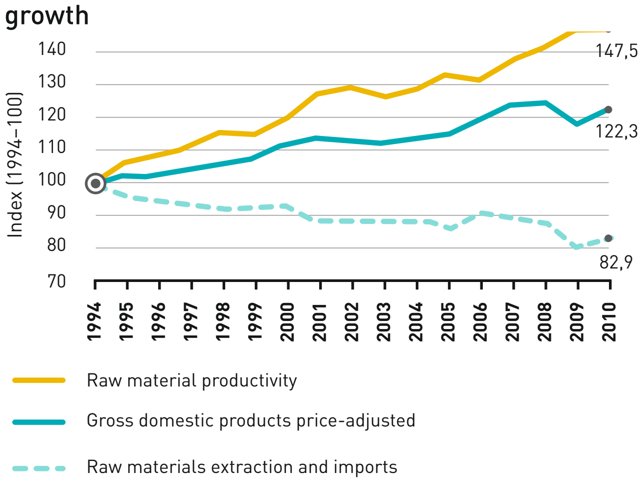
A number of voluntary green building certification schemes promote green buildings. They include the German Sustainable Building Council (DGNB), the UK's Building Research Establishment Environmental Assessment Method (BREEAM), the High Quality Environmental standard (HQE) in France, and Leadership in Energy and Environmental Design (LEED) from the USA, each of which has been developed and modified to suit the needs of the country in question. Building energy and resource efficiency in Europe and Germany could become more effective if these schemes were mandatory instead of voluntary.

Figure 7: DMC per capita (in raw material equivalents)



Source: Federal Statistical Office

Figure 8: Raw material productivity and economic growth



Source: Federal Statistical Office, Wiesbaden 2011

In terms of material production, Germany supports the circular economy concept for material waste reduction. In this concept, resources and products are sustainably sourced, designed to be reused, remanufactured and recycled so that waste becomes a resource and less primary raw material needs to be used (IGEP, 2013). The German construction industry has demonstrated that of the 13.0 million tonnes construction waste, 0.3 million tonnes were recycled (2.3 %), 12.3 million tonnes (94.6 %) were sold on for a different use, and only 0.4 million tonnes (3.1 %) were disposed of in landfills (Kreislaufwirtschaft Bau, 2013). The European Commission has also obliged all member states to develop national waste prevention programmes and describe in detail how the generation of waste can be decoupled from economic development.

As an innovative alternative building material to reduce energy and resources, Germany produces eco-cement that uses industrial waste materials such as blast furnace slag and fly ash, and reduces the embodied carbon of the average structure by 25 % (ecocem n.d.). Likewise, metal (e.g. aluminium) recycling is carried out intensively in Germany. Various certification schemes – Cradle to Cradle (C2C), Forest Stewardship Council (FSC), Natureplus, European Ecolabel and the Blue Angel – are used in Europe to provide information on and certify green products.

KfW has also made funds available for green buildings that are similar to its financial incentives for energy-efficient building. The range of energy and resource efficiency policies and technologies in Europe/Germany illustrates the efforts towards decoupling economic growth from energy and resource use in the construction sector.

4.3 IMPACT OF VARIOUS POLICY INTERVENTIONS ON DECOUPLING

Based on a policy paper on decoupling economic growth from resource consumption by Hennicke et al. (2014), the key activities for the decoupling process, which can be driven by policies and measures, are listed in *Table 9*. The Table also illustrates how they might be further adapted and developed in the context of the buildings and construction sector in India, detailing their barriers, key actors involved, and how they are dealt with in Europe/Germany.

The Table shows that supportive policies do exist in India, but that they are either voluntary or limited to specific sectors or building types (see policy brief 1 for more detail on policies in India). The barriers listed are some of the underlying reasons or they are the ones that hinder the success of policy implementation. Key actors and stakeholders have also been identified. Comparing Indian and European/German experience for the same activities, it can be seen that the latter's policies are stronger, address a wider scope and take a long-term planning approach. Some lessons can be learnt from the experience and used to improve policies in the buildings and construction sector; not only the success stories but also the development process holds valuable learning potential. In Europe, some of the EU Member States are still struggling to achieve the stringent targets set. Refurbishing existing buildings to nearly zero-energy buildings (NZEB) as per the target of the Energy Performance for Buildings Directive (EPBD) is still a challenge due to the issue of cost efficiency. The EPC database is available but access to it (e.g. in Germany and Austria) is only allowed for experts who are directly involved and occasionally for policy-makers and researchers working on specific projects. This limits transparency and the efforts to create energy efficiency awareness (ADENE, 2015). *Table 9* shows gaps in decoupling in the buildings and construction sector in India and some international examples of good practice that address those gaps.

Table 9: Decoupling gaps and international lessons

Setting realistic targets and developing indicators Long term targets, indicators monitor progress and the distance to targets	
Existing policies and initiatives in India	Key stakeholders
• National Action Plan on Climate Change, 12th five-year plan (2012–2017) • Energy Conservation Action Plan • National Electricity Policy • ECO III – Municipal Energy Efficiency Programme • National Mission on Sustainable Habitat (NMSH) • Appliance MEPS and labelling programme	• Central and state ministries • Municipal authorities
Gaps	
• Lack of cohesive national policy/directive on energy consumption in buildings	
European/German experience	
• EU's Energy Performance Building Directive (EPBD) as a tool to transition to nearly zero-energy buildings (NZEBs) within a specified time limit • EU's Ecodesign Directive (MEPS) designed to increase efficiency of appliances • Germany's Energy Conservation Regulations (EnEV) make it mandatory for every new residential and non-residential building to adhere to specified energy consumption limits and possess an energy performance certificate indicating its energy consumption • Germany's Resource Efficiency programme (ProgRess), adopted by the Federal Environment Ministry (BMUB) in 2012, to make the extraction and use of natural resources more sustainable and reduce associated environmental pollution as far as possible.	

Scenario analysis on the macroeconomic impacts of decoupling in buildings	
Existing policies and initiatives in India	Key stakeholders
• A handful of studies on the energy-saving potential of energy-efficient and green buildings • NITI Aayog's India Energy Security Scenarios 2047, for example	• Research institutes such as policy think tanks, centres for development studies etc. • Ministry of Statistics And Programme Implementation • NITI Aayog • MoP, MNRE, MoUD, etc.
Gaps	
• No comprehensive studies/scenario analysis considering the impacts of decoupling, due to lack of data availability, specific targets and indicators	
European/German experience	

• Macroeconomic modelling on resource efficincy in Europe
• The following factors are being considered while conducting the macroeconomic research in Europe:
  ◦ various studies on rebound effect exists
  ◦ spillover effects of reducing material inputs
  ◦ technology and resource prices and their substitution
  ◦ lifestyle changes	

Development and use of indicators showing energy and resource-efficient economy Indicators – energy use in various buildings, resource and material use along the production chain and carbon, land and water footprint	
Existing policies and initiatives in India	Key stakeholders
• Voluntary measurement and recording • Post-occupancy evaluation of buildings certified under schemes such as GRIHA and LEED	• Research institutes such as National Environmental Engineering Research Institute (NEERI), Central Building Research Institute (CBRI) • Statistical and economic institutes • Green building rating bodies
Gaps	
• Lack of priority indicators in terms of resource criticality and pollutants • No comprehensive qualitative and quantitative directory on buildings, construction materials • Not enough detailed studies on by how much building construction stimulates the economy	
European/German experience	
• Energy performance certificate database (EPC), for example, providing information on use of energy by buildings (but this involves a data protection issue) • TABULA-EPSICOPE database provides chronological building typologies and energy consumption of buildings across Europe in the last century. Such a database helps map consumption and develop reliable efficiency scenarios. • ODYSSEE MURE project supported by Intelligent Energy Europe provides comprehensive monitoring of energy consumption and efficiency trends as well as an evaluation of energy efficiency policy measures by sector for EU countries and Norway. • EUROSTAT, provider of statistics at European level, consolidates the data and ensures they are comparable, using harmonized methodology. Eurostat does not collect data. This is done in Member States by their statistical authorities. • Energy Efficiency Watch 3 project (EEW3) facilitates implementation of the Energy Efficiency Directive (EED) across the EU and provides a constant feedback loop on the implementation of European and national energy efficiency policies.	

Establishing an institutional setting for RD&D	
Existing policies and initiatives in India	Key stakeholders
• R&D on alternative building materials by the Building Materials and Technology Promotion Council (BMTPC), CBRI etc. • Department of Science and Technology, Government of India, under the Clean Energy Research Initiative (CERI), plans to initiate a programme to support research and development in the area of habitat energy efficiency. • IIT Delhi, Madras and Bombay working on low-emission and resource-efficient cement	• Ministry of Science and Technology • Ministry of Environment • MoP, MNRE • International organizations • SMEs • Highly skilled workforce
Gaps	
• There is a very little connection between innovation and incubation, i.e. the research does not always translate into market scale-up	
European/German experience	
• R&D at universities, demonstration of ultra-low energy buildings and Plus Energy house • Building envelope specifications for new and refurbished buildings have been scaled up and adopted as benchmarks • Wide reach of Passivhaus standard • Intelligent Energy Europe has offered a helping hand to organizations willing to improve energy sustainability	

Getting the prices right and phasing out environmentally harmful subsidies Internalisation of external environmental costs	
Existing policies and initiatives in India	Key stakeholders
• Administered pricing mechanism (APM) in April 2002 – 12th FYP • Environmental tax-12th FYP • Renewable energy is growing but coal is still a major source of energy	• Ministry of Environment and Forests • Ministry of Power
Gaps	
• Unfulfilled potential and limited adoption of renewables and good practices	
European/German experience	
• There are no energy subsidies, except up to some thresholds for some energy-intensive industries. • Average monthly household power bill in Germany is 0.34 EUR/kWh, which is higher than in the U.S.A. (0.12EUR/KWh) but total monthly electricity bills are similar. This indicates that higher tariffs encourage customers to use less energy.	

High-impact policies on recycling and use of secondary raw materials Ensure strong regulatory mechanisms for internalising principles of reduce, reuse, recycle	
Existing policies and initiatives in India	Key stakeholders
• Construction and Demolition Waste Management Rules, 2016 • Fly Ash Notification, 1999 and amendments	• Component manufacturers • Construction companies • Civil society • Owners
Gaps	
• Lack of information and skills • Most recycling takes place in the informal sector • No provision on deconstruction in the C&D waste rules • Limited buying and selling of energy-efficient technologies and environmentally friendly products • Weak incentives for efficient alternatives • Voluntary nature of these certifications attracts the attention of very few builders	
European/German experience	
• Support for the circular economy concept and focus on waste as a resource (remanufacturing, re-use, repair, and waste to energy) • Extended producer responsibility (EPR)	

Promoting new energy and resource-efficient business models Brings about a change from a linear-economy approach (business models focused on selling high quantities) to a circular-economy approach (business models focusing on interactions between producers and customers)	
Existing policies and initiatives in India	Key stakeholders
• Linear economy • Limited buying and selling of energy-efficient technologies and environmentally friendly products • Energy-efficient and green building certifications – Energy Star, GRIHA, LEED	• Property development companies • Component manufacturers • Investors and owners
Gaps	
• Less connection between innovation and incubation, i.e. the research does not always translate into market scale-up • Weak incentives for efficient alternatives • Voluntary nature of these certifications attracts the attention of very few builders	
European/German experience	
• Higher energy costs encourage customers to buy energy-efficient products • Feed-in tariffs in Germany • Take-back schemes for the products. Incentives to compensate upfront costs. • DGNB, LEED, HQE etc. Financial incentives encourage investors and owners to build energy-efficient and green buildings	

Delivering a stronger and more coherent implementation of green public procurement (GPP) Provide support to engage in GPP by establishing a network to exchange good practices, standardised approaches and the use of labels	
Existing policies and initiatives in India	Key stakeholders
• CFL procurement for BLY (Bachat Lamp Yojana) programme • LED procurement for DELP (Domestic Efficient Lighting Programme)	• Ministry of Trade And Commerce (clearing legal bottlenecks) • Manufacturers • ESCOs • Utility companies • End users
Gaps	
• Lack of directive on preferential procurement guidelines for efficient technologies and materials • Trust-building activities should be developed for manufacturers, retailers and end users	
European/German experience	
• GPP as a voluntary instrument has been adopted in National Action Plans by 23 EU member states, including Germany. • Buy Smart+ (a project that establishes green procurement helpdesks on energy related technologies in 15 European countries)	

Developing instruments for SMEs	
Existing policies and initiatives in India	Key stakeholders
• SMEs for PV, LEDs, fly ash brick manufacture etc.	• Ministry of Trade and Commerce • Ministry of Micro Small and Medium Enterprises • Construction companies • SMEs
Gaps	
• Lack of capacity, skills and access to finance • Potential clash with free trade polices (for example, case against India in WTO for mandating locally manufactured content in solar PV panels)	
European/German experience	
• Programmes to improve material efficiency (Verbesserung der Materialeffizienz, VerMAt), material efficiency networks (Netzwerken zur Materialeffizienz, NeMAT), initiated by the German Material Efficiency Agency (demea) to support SMEs	

Supporting employment and skills on the ground – institutional framework and capacities to implement building regulations and regulations related to SMEs manufacturing building materials	
Existing policies and initiatives in India	Key stakeholders
• Construction Skills Development Council provides training • Industrial training institutes (ITIs) • Polytechnics	• MHRD • Property development companies • Workers • Local governments
Gaps	
• Skilled labour deficit plagues virtually every major economic sector in India • Lack of capacity building activities for construction workers and technicians who actually build and operate buildings, training them on using and working with efficient technologies and materials	
European/German experience	
• The Federal Institute for Vocational Education and Training (BIBB) • The German Trade Union Confederation (DGB) and the German Employers' Organisation for Vocational Training • The construction workforce is trained to understand and handle efficient building technologies such as installation of thermal insulation, thermal bridging, renewable technologies, highly efficient heating and cooling systems etc.	

Guiding the financial sector to enable the transition	
Existing policies and initiatives in India	Key stakeholders
• Financial incentives for certified buildings – but the focus is on large-scale construction, for example KfW Development Bank's refinancing programme and the National Housing Bank's (NHB) programme on energy-efficient residences • Financial incentives leveraging international agreements such as Bachat Lamp Yojana	• Government ministries such as MoHUD, MNRE, etc. • Non-banking financial corporations such as National Housing Bank • Banks • Investors and owners • Financial regulators
Gaps	
• More incentives needed for small players	
European/German experience	
• KfW, a state-owned bank, provides capital at low interest rates to building investors who wish to increase their building's energy performance. • Federal Office for Economic Affairs and Export Control (BAFA) • Energy Efficiency Fund	

Source: Authors' analysis

5 CONCLUSIONS

Despite persistent demand and short supply of energy, and the high reliance on coal-based thermal power plants, the overall energy intensity in India has been declining gradually over the years and is estimated to be 0.62 kgoe /US$ in 2011 compared to 1.09 kgoe/US$ in 1981. This is partly due to the fact that renewables' share has increased, production efficiency has been stepped up and the country has seen sustained GDP growth (Planning Commission, 2013). However, absolute resource and energy consumption, as well as the environmental impacts associated with that, are on the rise. Various bottom-up analyses show that reducing primary resource and energy consumption in buildings is possible using alternative materials and technologies and renewable energy technologies. However, it has been noticed that only a few policies have well-defined targets. Most often policies are only seen as catalysts for change instead of as a process that guides the entire reaction. An effective policy evaluation mechanism needs to be developed for every policy measure.

The idea of weak (relative) decoupling argues for decreasing the share of fossil fuel and nuclear-based energy and increasing the share of renewables in the primary energy mix. However, in the case of India, both shares are set to keep on increasing for at least the next two decades. To enable decoupling in the buildings and construction sector in the operational phase, it is vital to increase the share of renewable energy technologies at individual building (neighbourhood or community) level in the short term, which is a bottom-up approach. However, the country appears to be giving equal priority to increasing the share of renewables in the utility mix, which is a top-down approach.

It is absolutely crucial that energy (cost) savings derived from dedicated energy conservation measures (ECMs), demand-side management (DSM) programmes and ESCO contracts translate into long-term bonds and are not converted into short-term monetary savings, which are lost in the rebound effects. Analogous to 'cess' collected, energy savings that result from various dedicated energy efficiency programmes should be accounted for and used to provide better and equitable energy services.

In the short term, it is essential that alternative materials be deployed on a large scale as soon as possible during the construction phase. This requires scaling-up measures, involvement of SMEs and skills development initiatives. In the long run, construction activity should become less dependent on virgin resources and should focus on recycling technologies.

It should be noted that the various policy initiatives that have had a high impact in one target sector have not necessarily produced the same results in other target sectors. For example, regulation has been very effective in the lighting and AC sector, while it has done precious little in the sand and soil sector. There are a wide variety of reasons for this. For example, regulation in the AC industry is strongly supported by a cohesive transparency and information campaign, incentives and BAT promotion. Such a vigorous approach is clearly absent when it comes to promoting alternatives for sand and brick. This can be clearly attributed to the visibility of the indicators against which the impacts are measured. While the former affects energy consumption, which is clearly visible, the effects of the latter are varied and cannot be directly accounted for. The environmental impact of construction activity should be made more accountable by developing appropriate indicators similar to those for energy consumption. It is unclear at this stage whether a decrease in resource use results in shrinking growth and whether switching to efficient resources results in sustained growth. Only once sets of reliable indicators have been established, will decoupling be able to act as a yardstick for policy implementation.

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ANNEX

Table 10: Comparison of decoupling studies from the literature

Study	Mulder and de Groot	Andreoni and Galmarini	Diakoulaki and Mandaraka
Investigation	The extent to which technology-driven improvements in energy and labour productivity performance contribute to decoupling of economic growth from environmental pressure	To assess trends in decoupling between economic growth from CO_2 emissions	To assess the progress in decoupling industrial growth from CO_2 emissions
Area of study	14 OECD countries	Italy	European Union
Sectors	10 manufacturing sectors	5 main economic sectors	Key manufacturing sectors
Period of study	1970–1997	1998–2006	1990–2003
Data sources	Energy data published by IEA Economic data from by ISDB and STAN published by OECD	Italian National Institute of Statistics (ISTAT) and Eurostat National energy accounts	OECD Energy Balances (IEA, 2005) Average IEA emission factors Groningen Growth and Development Centre Database
Factors	Technology productivity Labour productivity	Emission intensity Energy intensity Overall economic activity Sectoral share in overall economic activity	Industrial output Energy intensity Structure Fuel mix Utility mix
Growth indicator	Gross domestic product (GDP)	Gross domestic product (GDP)	Total value added from manufacturing
Intensity indicators	CO_2	CO_2	Energy-related CO_2
Conclusions and observations	Technology-driven productivity growth stimulates decoupling Increase in energy productivity leads to increase in labour productivity	No improvement in energy intensity Improvement in CO_2 emission intensity This improvement has been attributed to the increasing number of energy policies intended to promote the use of renewable energy and abatement technologies.	Strong decoupling linked to a reduction in the manufacturing energy intensity and a shift towards other less energy intensive economic sectors. Fuel shifts in the utility mix have strongly contributed to decoupling compared to fuel shifts in the industry energy mix.

Table 11: Absolute decoupling metrics in 21 countries

	Change in CO_2 (2000–2014) %	Change in CO_2 (2000–2014) Mt	Change in real GDP (2000–2014)	Change in industry's share in GDP (2000–2013)
Austria	-3 %	-2	21 %	-3 %
Belgium	-12 %	-20	21 %	-6 %
Bulgaria	-5 %	-2	62 %	2 %
Czech Republic	-14 %	-18	40 %	-0.3 %
Denmark	-30 %	-17	8 %	-5 %
Finland	-18 %	-11	18 %	-9 %
France	-19 %	-83	16 %	-4 %
Germany	-12 %	-106	16 %	-1 %
Hungary	-24 %	-14	29 %	-2 %
Ireland	-16 %	-7	47 %	-9 %
Netherlands	-8 %	-19	15 %	-3 %
Portugal	-23 %	-16	1 %	-6%
Romania	-22 %	-21	65 %	-1 %
Slovakia	-22 %	-9	75 %	-3 %
Spain	-14 %	-48	20 %	-8 %
Sweden	-8 %	-5	31 %	-4 %
Switzerland	-10 %	-4	28 %	-0.3 %
Ukraine	-29 %	-99	49 %	-10 %
United Kingdom	-20 %	-120	27 %	-6 %
United States	-6 %	-382	28 %	-3 %
Uzbekistan	-2 %	-2	28 %	10 %

RESEARCH TEAM

THE SOCIETY FOR TECHNOLOGY AND ACTION FOR RURAL ADVANCEMENT (TARA)

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Development Alternatives

ABOUT DEVELOPMENT ALTERNATIVES GROUP

Development Alternatives (DA), the world's first social enterprise dedicated to sustainable development, is a research and action organisation striving to deliver socially equitable, environmentally sound and economically scalable development outcomes. Established in 1982 and headquartered in New Delhi, the DA Group pioneered the concept of business-like approaches to eradicating poverty and conserving the natural resource base on which human development depends. The Society for Technology & Action for Rural Advancement (TARA) is a social enterprise set up in the year 1985 at New Delhi, India. It is an "incubation engine" of the Development Alternatives Group which has been providing development solutions in India and elsewhere.

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ABOUT WUPPERTAL INSTITUTE

The Wuppertal Institute undertakes research and develops models, strategies and instruments for transitions to sustainable development at local, national and international level. Sustainability research at the Wuppertal Institute focuses on the challenges connected with resources, climate and energy and their relation to economy and society. Special emphasis is put on analysing and stimulating innovations that decouple economic growth and wealth from natural resource use.

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