MODULE 4

Economic Assessment

NAMAs in the refrigeration, air conditioning and foam sectors. A technical handbook.

Deutsche Gesellschaft
für Internationale
Zusammenarbeit (GIZ) GmbH

On behalf of:

Federal Ministry
for the Environment, Nature Conservation,
Building and Nuclear Safety

of the Federal Republic of Germany

Imprint

As a federally owned enterprise, GIZ supports the German Government in achieving its objectives in the field of international cooperation for sustainable development.

Published by
Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH

Registered offices
Bonn and Eschborn,
Germany

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Layout
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Place and date of publication
Eschborn, April 2014

Serial number
G-S01-2013-en-01

Proklima

Proklima is a programme of the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. Since 2008 Proklima has been working successfully on behalf of the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) under its International Climate Initiative (IKI) to promote ozone-and climate friendly technologies.

Proklima provides technical assistance for developing countries since 1996, commissioned by the German Federal Ministry for Economic Cooperation and Development (BMZ) to implement the provisions of the Montreal Protocol on substances that deplete the Ozone Layer.

This publication has been compiled in the project "Development of NAMAs in the refrigeration, air conditioning and foam manufacturing sectors" funded by the BMUB International Climate Initiative.

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The International Climate Initiative

Since 2008, the International Climate Initiative (IKI) of the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) has been financing climate and biodiversity projects in developing and newly industrialising countries, as well as in countries in transition. Based on a decision taken by the German parliament (Bundestag), a sum of at least 120 million euros is available for use by the initiative annually. For the first few years the IKI was financed through the auctioning of emission allowances, but it is now funded from the budget of the BMUB. The IKI is a key element of Germany's climate financing and the funding commitments in the framework of the Convention on Biological Diversity. The Initiative places clear emphasis on climate change mitigation, adaption to the impacts of climate change and the protection of biological diversity. These efforts provide various co-benefits, particularly the improvement of living conditions in partner countries.

The IKI focuses on four areas: mitigating greenhouse gas emissions, adapting to the impacts of climate change, conserving natural carbon sinks with a focus on reducing emissions from deforestation and forest degradation (REDD+), as well as conserving biological diversity. New projects are primarily selected through a two-stage procedure that takes place once a year. Priority is given to activities that support creating an international climate protection architecture, to transparency, and to innovative and transferable solutions that have an impact beyond the individual project. The IKI cooperates closely with partner countries and supports consensus building for a comprehensive international climate agreement and the implementation of the Convention on Biological Diversity. Moreover, it is the goal of the IKI to create as many synergies as possible between climate protection and biodiversity conservation.

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Executive Summary

This module aids countries to carry out an economic assessment for introducing technical options in the refrigeration, air conditioning and foam (RAC&F) subsectors. Technical options might be selected according to the reduction of emissions and the respective costs. The first part of this module gives a detailed description of cost quantification.

It is important to establish baseline costs, to which the conversion costs can be compared. Baseline costs will be based on a conventional technology, as used in the business-as-usual (BAU) scenario.

The costs for introducing a technical option usually arise from barriers that have to be overcome by interventions. The related costs can be assigned to several cost groups, which include e.g. the market introduction costs, prices for refrigerants and other components, training, legislation, awareness raising or research and development (R&D) costs.

In the foam sector, there is no natural unit size, so one tonne of blowing agent replaced is considered as a "unit". When changing the blowing agent as a technical option, an important aspect to consider is the reduced insulation characteristics of the foam product, which might be compensated by increased thickness. The most important cost component is the incremental operating cost for the manufacturing of the foam products, which is primarily driven by the cost for the blowing agent. Furthermore, the plant type and size, enterprise capacity and other parameters of the foam production have to be considered. Further costs include the incremental capital costs, which are related to the conversion of the production equipment and the costs for training and trials.

Finally, this module provides an introduction to marginal abatement cost curves (MACCs) and how these can be developed. MACCs show the cost-effectiveness of technical options, by providing the marginal costs per tonne of reduced CO_2eq specific to each technical options.

MACCs are a valuable tool for selecting suitable technical options in the various subsectors, but also to support the selection of a focus subsector. Thus, MACCs can support policy-makers when selecting technical options and subsectors for a NAMA (Nationally Appropriate Mitigation Action). However, MACCs do not take co-benefits and co-costs into consideration.

1. Introduction

Economic assessments allow estimating the costs of technical options with MACCs. They allow the comparison between alternative systems (technical options, cf. module 3) and conventional systems (BAU) in RAC&F sectors. The marginal abatement costs approach includes both costs and emission reductions specific to a technical option (TO). The costs that incur with the introduction of TOs to reduce emissions are a key aspect to consider when preparing a NAMA. This will also influence the type of NAMA to be selected (supported or domestic NAMA, cf. module 8.2).

The purpose of quantifying costs for implementation of a certain alternative technology is to enable an estimation of the difference in costs of alternative systems which include technical options and the BAU systems. More specifically, it is important to establish a baseline cost for a standardised RAC&F system in the different subsectors; the various costs associated with implementing a given technical option can then be compared against it.

The same holds true for the emissions. Firstly we have to define standardised RAC&F systems. The associated emissions are quantified and the emission patterns are defined as the baseline. Secondly, various technical options are defined and the appropriate emissions of the technical options have to be quantified analogously to the BAU technology (cf. module 1). The difference between the baseline emissions and the emissions that arise after the introduction of technical options is the reduction potential, also referred to as effect.

The consideration of both additional costs and the associated emission reductions are the basis for cost-effect balances that can be summarised in MACCs. These have been demonstrated as valuable tools in economic assessments and allow an estimate whether it is worthwhile to introduce a certain technology or not. Thus, MACCs can support policy makers regarding the choice of alternative technology.

This module focuses on:
- Quantification of costs for implementation of technology (chapter 2.1 and 2.2),
- Development of MACCs (chapter 2.3).

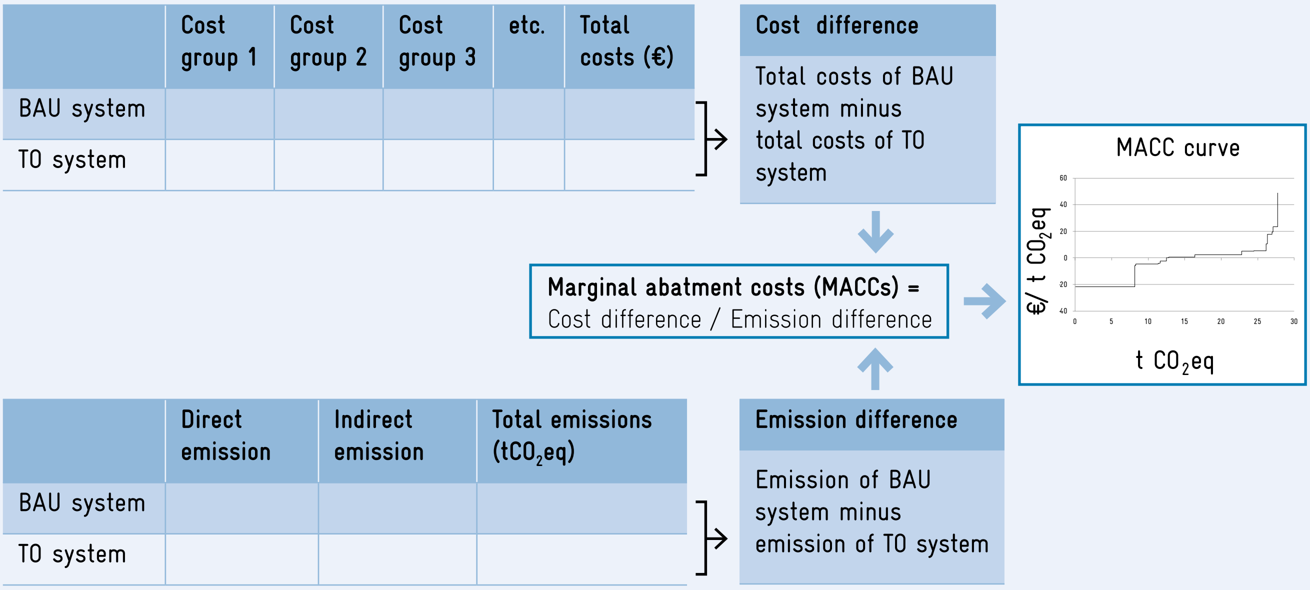
As mentioned above the quantification of emission reductions represents an integral part of the MACCs. The detailed calculation steps for the quantification of emissions and mitigation potential are given in annex 1 to module 1.

Figure 1 visualises the principal of determining the cost-efficiency of technical options using marginal abatement cost curves. First, the total costs of a BAU and an alternative (TO) system are derived by summing up different cost groups (Figure 1, top part). Second, the total emissions of BAU and TO systems, which consist of direct and indirect emissions, are quantified (Figure 1, bottom part); the difference will yield to the emission reduction potential. Now, the cost and the emission differences are combined to estimate the cost-efficiency (cf. MACCs, chapter 2.3).

2. Methodology: Costs for introducing technical options

This chapter introduces the different RAC&F subsectors. It discusses the most important technical options for introducing climate friendly technologies. Finally it describes the barriers that stand in the way to introducing these technical options and possible ways to overcome them as well as market penetration rates.

FIGURE 1
Determining cost-efficiency of technical options



2.1 Quantification of costs in the RAC sector

In this section, a general methodology for quantifying the costs for implementing technical options is provided. In addition, some reference cost data are listed.

Costs can be divided into direct product and economic costs. Direct product costs refer to costs that affect the price of the product and will be paid by the consumer depending on the price elasticity of the demand. Economic costs are costs that occur in the wider economy (so-called external costs) and are not included in the price. This module focuses on the cost elements referring directly to product cost.

Economic benefits and co-benefits in a wider context are not subject in this module. Co-benefits include environmental, social or health benefits which can not easily be quantified and allocated to a specific technical option. Module 10 specifically deals with co-benefits and includes an extensive analysis of the co-benefits of introducing technical alternatives to the RAC&F sectors.

Establishing baseline costs

It is important to establish baseline costs, to which costs for the technical option are compared. The cost difference may be positive, i.e. additional costs, or negative, i.e. savings.The baseline costs are based on the BAU technology currently in use or anticipated to be in use for the specific system types.

In order to assist with this, an "average" BAU system has to be formulated (Table 1). The charge size, refrigerant cooling capacity and coefficient of performance (COP) are chosen to represent an average type, design and construction of a given system. It is considered to cover the majority of the systems within a subsector.
Unless mentioned specifically, all refrigeration systems described are vapour compression type.

All subsectors and refrigerating systems are listed in Table 1. Systems are grouped, for example, where the majority of technical implications are similar (cf. module 1).

TABLE 1
Average design of the BAU system

Parameter	Unitary air conditioning							Chillers		Transport air conditioning		Domestic refrigeration	Commercial refrigeration			Industrial (cold storage and food processing)			Transport refrigera-tion
	Self-contained	Split residential	Split commercial	Duct split residential	Commercial ducted splits	Rooftop ducted	Multi-splits	Air conditioning chillers	Process chillers	Car air conditioning	Large vehicle air conditioning	Fridge/Freezers	Stand-alone	Condensing units	Centralised systems for supermarkets	Stand-alone	Condensing units	Centralised systems	Refrigerated trucks/trailers
Charge size (kg)	0.8	1.25	1.8	5	10	10	15	35	35	0.6	8	0.175	0.4	4	230	0.5	5	500	6.5
BAU refrigerant	R410A	R410A	R410A	R410A	R410A	R410A	R410A	R134a	R404A	R134a	R134a	R134a	R404A	R404A	R404A	R404A	R404A	R404A	R404A
Cooling capacity (kW)	3	3.5	4.5	20	30	30	27	100	100	5	25	0.2	0.5	5	100	1	10	270	8
Rated average COP	3	3.2	3.2	3.2	3	3	3	3.5	2.5	2.5	2.5	1.5	2	2	2.5	2	2	2.5	2
Made on production line?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
Portion made in production line ‡	All	All	IDU, ODU	IDU, ODU	IDU, ODU	All	IDU, ODU	All	All	All	All	All	All	Cond U, cases	Packs, cases	All	Cond U, evaps	None	All
Entire system charged in production line?	Y	N	N	N	N	Y	N	N	N	Y	Y	Y	Y	N	N	Y	N	N	N
Production run p.a. *	100k	100k	100k	50k	10k	10k	10k	10k	5k	100k	10k	100k	100k	10k	1000	10k	10k	1000	10k
Baseline product cost (EUR)†	320	430	680	1500	3000	2800	3300	9500	9600	430	2100	90	150	650	170000	200	1200	35000	1200

*Assuming one or two lines
† Nominal product costs based on internet searches and BSRIA Marketplace Intelligence reports; it is recognised that even within a single region, almost identical products of similar size can be seen to vary price by ±50%
‡ IDU = Indoor unit, ODU = outdoor unit

The costs for BAU systems with a HFC reference refrigerant are displayed in Table 2.

TABLE 2
Average cost per unit including energy consumption over lifetime

Appliance System	Reference refrigerant	Cost (in Euro)
Self-contained air conditioners	HFC-410A	4,645
Split residential air conditioners	HFC-410A	5,143
Split commercial air conditioners	HFC-410A	11,514
Duct split residential air conditioners	HFC-410A	27,347
Commercial ducted splits	HFC-410A	50,822
Rooftop ducted	HFC-410A	96,839
Multi-splits	HFC-410A	96,839
Air conditioning chillers	HFC-134a	617,157
Process chillers	HFC-404A	692,698
Car air conditioning	HFC-134a	4,563
Large vehicle air conditioning	HFC-134a	99,251
Domestic refrigeration	HFC-134a	3,094
Stand-alone equipment	HFC-404A	4,381
Condensing units	HFC-404A	54,729
Centralised systems for supermarkets	HFC-404A	907,622
Integral	HFC-404A	8,449
Condensing units	HFC-404A	109,868
Centralised systems	HFC-404A	3,574,262
Refrigerated trucks/trailers	HFC-404A	41,312

Barriers and cost groups

A number of barriers normally exist which have resulted in the technical options not already being applied, or at least not on a wide scale (cf. module 3). These barriers can be overcome through interventions. Costs will usually incur for implementing these interventions and various cost components are related to the removal of barriers.

In some cases, the cost elements or indeed overall costs could be negative as well as positive. For example, for technical options such as charge size reduction, leak reduction or use of indirect system, the amount of refrigerant consumed throughout the lifetime may be much less than the BAU case. Thus, the impact will be a significant reduction of refrigerant cost over the lifetime of the system.

Table 3 provides a list of the various barriers and a cost group categorisation for each; a cost group is a general group of cost elements that can be addressed together.

In many cases, the same or similar intervention and thus cost are required for several different barriers. Similarly, same or similar barriers and interventions may apply to different technical options and different system categories.

Therefore, in order to simplify the task of quantifying the costs for a given intervention, the costs are consolidated into cost groups, as summarised in Table 3.

TABLE 3
Barriers to implementing technical options (TO) and corresponding cost groups

Barrier	Reason	Interventions	Cost implications	Cost group
No refrigerant availability	No demand	Local supplier makes refrigerant available	• Purchase of refrigerant • Set up import/ distribution • Conformity to relevant rules • Different material costs	• Refrigerant price
Refrigerant has high price	• Small demand • Price of conventional products do not internalise external economic costs	Additional resources to make products available	• Market introduction cost	• Market introduction cost
No suitable compressor available	No demand	Compressor manufacturer makes compressor available	• R&D of new compressors • Conversation of existing compressor production line • Awareness raising of new compressor • Different material costs	• Product/system parts (system components)
Suitable compressor too high price	Small demand	Additional resources to make products available	• Market introduction cost	• Market introduction cost
Suitable system components not available	No demand	Additional resources to make products available	• Market introduction cost	• Product/system parts (system components) Market introduction cost
Suitable ancillary components too high price	Small demand	Additional resources to make products available	• Market introduction cost	• Market introduction cost
Additional components increase cost	Not needed for conventional system	n/a	• Purchase of additional components • Different material costs	• Product/system parts (system components) • Product/system parts (ancillary components)
Additional ancillary/safety components increase cost	Not needed for conventional system	n/a	• Purchase of additional components/ material costs • Development of safety mechanisms	• Product/system parts (ancillary components)

TABLE 3
Barriers to implementing technical options (TO) and corresponding cost groups

Barrier	Reason	Interventions	Cost implications	Cost group
Technicians need additional tools/ equipment	To handle different characteristics of TOs	Provide with necessary tools/ equipment	• Purchase of additional tools/ equipment	• Technician tools
Design engineers lack knowledge	No need to work on TO before	Educate engineers	• Provide dedicated training • Disseminate technical information	• R&D • Awareness raising
Current rules/ regulations have general prohibition	No previous concern	Modify existing rules/regulations	• Assessment of existing regulations	• Regulations
Charge size limits restrictive	Conservative standards	New standards; Develop low charge systems	• Develop new/ revised rules • Carry out R&D	• Legislation • R&D costs
Installation rules are restrictive	Conservative standards	New standards; Develop new safety systems	• Develop new/ revised rules • Carry out R&D	• Regulations • R&D
Consumers not interested in technology option	Consumers ignorant of issues	Make consumers aware	• Introduce • marketing • schemes	• Awareness raising
Retails not interested in technology option	Retailers ignorant of issues	Make retailers aware	• Introduce marketing schemes	• Awareness raising
High production costs	New, more expensive production line equipment	Provide new production line equipment	• Purchase of equipment • Internal training • Infrastructure changes, • disruption	• Production line equipment
Installation srestrictions	Strict or undeveloped rules	Improve rules, standards, etc	• Time/resources for developing new rules • R&D type activities	• Standards (restrictions)
Longer installation time	Longer time, more complex	n/a	• Different type of piping, components, etc • Different processes • Different working procedures	• Installation time
High installation material costs	Different piping, more complex	n/a	• Different type of piping, components • Additional parts, materials	• Installation materials
Higher service and maintenance costs	Longer working procedures Higher cost of materials	n/a	• Time to carry out additional procedures • Cost of components/parts not normally used	• Installation time • Product/system parts (system components) • Refrigerant price

From this assessment, these common cost groups are identified:

- Product/system parts (system components, ancillary components),
- Installation of systems (installation time, installation materials),
- Technician assessment, certification and registration,
- Research and development (R&D),
- Production line equipment,
- Regulations, standards, (restrictions),
- Technician training,
- Engineer training,
- Technician tools/equipment,
- Refrigerant price,
- Awareness raising,
- Market introduction cost.

These can then be used for individual cost quantifications for specific equipment type/technical option combinations. Except for market introduction costs, each cost group will be described below. The description comprises a short explanation of what cost elements are involved and a qualitative explanation of how they can be determined. Additional details for their quantification are provided in the annex to this module.

RAC costs groups

Cost group: Product/system parts (system components, ancillary components)

The cost group for system parts is extensive and covers the following two sub-groups:

- Additional and/or different parts and components for refrigeration system (compressors, heat exchangers, valves, etc.),
- Additional and/or different ancillary parts associated with the system (such as safety devices and electrical equipment, etc.).

Refrigerant is not included in this section.

Furthermore, there are three different categories for consideration of the parts and components:

(i) Limited changes to system implying same (or similar) system construction,
(ii) Change of refrigerant implying same (or similar) system construction,
(iii) Change of system (and refrigerant) implying different system construction.

In the case of (i), this may involve a simple change of one or more system components for similar items, or using virtually identical ones that have been, for example, subject to improved tightness testing. Thus changes are minor. The differences in costs are established by comparing the costs for the new and the old components.

In the case of (ii), the system construction remains more or less the same but alternative components may be used to suit the characteristics of the new refrigerant. Again, the differences in costs are identified by comparing the costs of the new and old parts. Furthermore, additional ancillary components may be needed (such as for safety reasons) and therefore the costs are determined by identifying the costs of those new parts.

For the case (iii), the situation is considerably more complex. In principle, due to a change in the entire system, none of the original parts are likely to be used within the technical option. Therefore the difference in costs must be established through quantifying the entire cost for the parts for the original and then for the new system. This also should take account of further ancillary parts deemed necessary due to the characteristics of the new refrigerant (such as safety devices to handle flammability or higher pressures).

TABLE 4
Examples of the parts and components that may be needed to be changed/required additionally

	Technical options	Refrigeration system parts and components	Ancillary parts and components
(i) Limited changes to system	• Leak reduction (design/ const) • Charge size reduction	• Evaporator • Condenser • Piping • Valves	not needed
(ii) Change of refrigerant	• R-600a • HC-290/ HC-1270 • R-717 • R-744 • unsat-HFC • HFC/unsat	• Compressors • Intermediate heat exchangers (two-stage/ cascade cycle) • Joints (brazed, press, flares) • Gas coolers (R-744) • Ejectors (R-744) • Condenser • Evaporator • Compressor oil • Piping • Valves	• Ex-rated or safe electrics • Gas detection systems • Scrubbers • Extract ventilation • Charge/gas detection system
(iii) Change of system	• Low-GWP + liquid secondary • Low-GWP + evap secondary • Low-GWP + cascade • Distributed water-cooled • District heating/cooling	• Compressors • Intermediate heat exchangers (two-stage/ cascade cycle) • Joints (brazed, press, flares) • Gas coolers (R-744) • Ejectors (R-744) • Condenser • Evaporator • Compressor oil • Piping • Valves	• Pumps • Pressurisation kit • Secondary valves and controls • Secondary piping • Ex-rated or safe electrics • Gas detection systems • Scrubbers • Extract ventilation • Charge/gas detection system

Cost group: Installation of systems (installation time; installation materials)
This cost group covers the costs associated with the differences in time and materials (consumables) associated with site-installation of a particular technical option. It is assumed that any part of the system or components associated with the system are accounted for the cost group for system parts.

Consistent with the system parts, there are three different categories for consideration of the installation:
(i) Limited changes to system implying the same (or similar) installation time and materials,
(ii) Change of refrigerant implying the same (or similar) installation time and materials,
(iii) Change of system (and refrigerant) implying different installation time and materials.

In the case of (i), since there is only a simple change of one or more system components, the difference in installation requirement should be negligible. However, where improved system tightness is required, additional time will be needed for testing.

In the case of (ii), the system construction again remains similar to the baseline, although alternative components may be applied. Thus differences in installation time are assumed to be minor. The aspects that would demand additional time and materials – albeit minimal – are:

- More thorough procedures for leak checking and brazing procedures when handling flammable, more toxic or high pressure substances;
- Installation of additional ancillary components such as gas detectors, extract ventilations, etc.

For the case (iii), the entire system is being changed. For example, different pieces of equipment are being positioned, different lengths, size and types of pipework and installation, different controls, instrumentation and joining methods, etc. Therefore the difference in costs must be established through quantifying the entire cost for the installation time and materials of the original and then for the new system.

Cost group: Technician assessment, certification and registration scheme

When a technical option is introduced, technicians may face a new refrigerant or a relatively novel system concept. The new refrigerant may possess significantly different characteristics than the BAU refrigerant, such as flammability, higher toxicity or higher pressure. Novel system concepts may include evaporating secondary systems, district cooling, etc. Both cases, new refrigerants and novel system concept, demand specialist technician expertise and it is often desirable to adopt a competence scheme. This involves assessing technicians, providing certification and subsequently registration of a technician and/or the enterprise they work for. This therefore provides a means of achieving quality control.

For this and the following cost groups, additional details, cost approximations and calculation steps for estimating additional costs are provided in the annex to this module.

Cost group: Research and development

When an enterprise introduces a selected technical option, it is necessary to determine modification to system designs, including selection of components, heat exchanger circuit design and system balancing. In terms of system performance, greater investment in development, alongside charge reduction, can lead to efficiency benefits and reduced material and refrigerant costs. In the case of flammable substances, it may involve additional safety testing and development of safety mechanisms. An overview of the main areas of R&D for technical options with the indication of their relevance is given in Table 5.

TABLE 5
Main areas of R&D for technical options, indicating high (H) and low (L) importance

	Operation – system design	Operation – reliability	Circuit – charge reduction	Circuit – leak tightness	Energy – Heat exchanger	Energy – circuit design	Energy – controls	Energy – parasitic losses	Safety – pressure	Safety – flammability	Safety – toxicity
Leak reduction (design/const)				H							
Leak reduction (maintenance)											
Charge size reduction			H	L							
Recovery and recycling											
R-600a			H	L	L					H	
HC-290/ HC-1270			H	L						H	
R-717		L	H	L						L	H
R-744	H			L	H	H			H		
unsat-HFC		L	L	L	H	H				L	
HFC/unsat-HFC blends		L	L	L	L					L	
Low-GWP + liquid sec (central)						H	H	H	As with R-600a, HC-290/HC-1270, R-717, R-744, unsat-HFC		
Low-GWP + evap sec (central)						H	H	H			
Low-GWP + cascade (central)						H	H	H			
Low-GWP + liquid sec (discrete)	H	L			H	H	H	H			
Low-GWP + distrib w-c (central)						H	H	H			
Low-GWP + district cooling						H	H	H			

NOTE: Empty boxes typically not applicable

Rather than an enterprise initiating a product redevelopment programme for implementation of a new refrigerant, it may instead opt for purchasing of licences, etc., for a particular technology. It is noted that the costs associated with this are difficult to evaluate. This may be considered as an entire or partial alternative to the product development.

Cost group: Production line equipment
Depending on the technical option adopted by a system producer, various changes to the production area or production line will be necessary. Table 6 summarises the main considerations for various technical options. For the generic low-GWP technical options, the implications will depend upon which particular technical option is chosen.

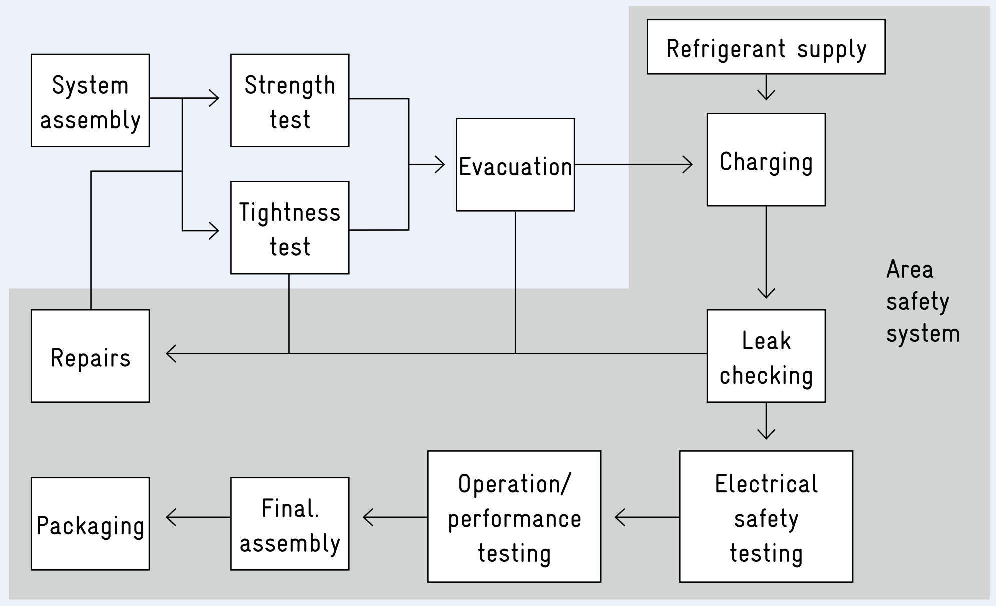
The requirement for non-standard equipment arises from the need to handle flammability and/or toxicity characteristics of the refrigerant, higher pressures, improved leak tightness testing and certain more sensitive compatibility aspects of the refrigerants.

TABLE 6
Main considerations for production changes for different technical options

Technical option	Main considerations for production changes
Leak reduction (design/construction)	Improved leak tightness checking
Leak reduction (maintenance)	None
Charge size reduction	None
Recovery and recycling	None
R-600a	New refrigerant supply, new charging equipment, safety systems
HC-290/ HC-1270	New refrigerant supply, new charging equipment, safety systems
R-717	Facilities for working with steel piping, safety systems
R-744	Facilities for working with steel piping
unsaturated-HFC	New refrigerant supply, new charging equipment, safety systems
HFC/unsaturated-HFC blends	New refrigerant supply, new charging equipment
Low-GWP + liquid secondary (centralised)	As with R-600a, HC-290/HC-1270, R-717, R-744, unsat-HFC
Low-GWP + evap secondary (centralised)	
Low-GWP + cascade (centralised)	
Low-GWP + liquid secondary (discrete)	
Low-GWP + distributed water-cooled (central)	
Low-GWP + district cooling	

Figure 2 shows a generic production line sequence with cost-critical steps that may be affected by the introduction of a technical option.

FIGURE 2
Generic production line layout. The boxes indicate cost-critical steps within the production line that might be affected by the introduction of technical options.



The requirement for non-standard equipment arises from the need to handle flammability and/or toxicity characteristics of the refrigerant, higher pressures, improved leak tightness testing and certain more sensitive compatibility aspects of the refrigerants.

Table 7 identifies the parts of the production line or production area that would typically require specific equipment to address each of the technical options under consideration. Technical options that are based on system concept changes are not included in the table as it is assumed that the sub-systems are obtained from existing sources. However, depending on the low-GWP refrigerant chosen for the sub-systems that make up the alternative system concept, the corresponding changes to the third-party production lines may apply.

TABLE 7
Necessary production line equipment for different technical options

	Refrigerant storage	Refrigerant feed system	Charging machines	Leak check/ gas detectors	Tightness test equipment	Repair area equipment	Evacuation lines	Safety detect/ alarm/vent	Electrical safety test	Performance test	Ultrasonic welding	Heat exchanger tool	Facilities for steel piping
Leak reduction (design/const)				Y	Y							Y	
Leak reduction (maintenance)													
Charge size reduction				Y								Y	
Recovery and recycling													
R-600a	Y	Y	Y	Y	Y	Y		Y	Y		Y		
HC-290/ HC-1270	Y	Y	Y	Y		Y		Y	Y		Y	Y	
R-717	Y	Y	Y	Y	Y	Y		Y					Y
R-744	Y	Y	Y	Y	Y							Y	Y
unsat-HFC	Y	Y	Y	Y		Y		Y				Y	
HFC/unsat-HFC blends	Y	Y	Y	Y		Y		Y					

NOTE: "Y" indicates new equipment is required

Cost group: Regulations, standards (restrictions)
With the introduction of many of the technical options, it is necessary to have appropriate regulations, standards and/or technical guidelines available for the industry to help implementation.

The purpose of the rules is to cover a range of aspects including mandating the use of certain technologies or performance criteria, specifying how different substances should be integrated into systems and giving general information on good practice. The specific requirements vary according to the subsector/technical option combination.

In many cases, corresponding rules are published and thus available in other countries and regions; in these cases it may be able to copy them directly. Similarly, it is anticipated that the rules for a specific technical option will cover all of the relevant subsectors.

Table 8 indicates the general purpose of the regulation, standard and technical guidelines as well as whether or not comparable rules already exist in other countries.

TABLE 8
Types and availability of regulations, standards and technical guidelines for different technical options

Technical option	Regulation		Standard Guidelines		Mobile AC	
	Purpose	Exist elsewhere	Purpose	Exist elsewhere	Purpose	Exist elsewhere
Leak reduction (design/const)	n/a		LTD	Y	LTD	Y
Leak reduction (maintenance)	SP	Y	n/a		BGOO	
Charge size reduction	MCS		n/a	Y	LCD	Y
Recovery and recycling	SP	Y	n/a		BGOO	
R-600a	n/a		SDI	Y	PDI	Y
HC-290/ HC-1270	n/a		SDI	Y	PDI	Y
R-717	n/a		SDI	Y	PDI	Y
R-744	n/a		SDI	Y	PDI	Y
unsat-HFC	n/a		SDI	Y	PDI	Y
HFC/unsat-HFC blends	n/a		SDI	Y	PDI	Y
Low-GWP + liquid sec (central)	SWTU		SDI	Y	PDI	
Low-GWP + evap sec (central)	SWTU		SDI	Y	PDI	
Low-GWP + cascade (central)	SWTU		SDI	Y	PDI	
Low-GWP + liquid sec (discrete)	SWTU		SDI	Y	PDI	
Low-GWP + distrib w/c (central)	SWTU		SDI	Y	PDI	
Low-GWP + district cooling	SWTU		SDI	Y	PDI	
Minimum efficiency rules	SME	Y	PT	Y	ESD	

SP: Specify the required practice
MCS: Specify the maximum (specific) charge sizes
SWTU: Specify when the technical option must be used
SME: Specify minimum efficiency of systems
LTD: Requirements on leak tightness and design of components and systems
SDI: Requirements for safe design and installation on systems
PT: Requirements for system performance testing
BGOO: Guidelines on behaviour or technicians and operators obligations
PDI: Guidelines on practical design and associated information
LCD: Guidelines on low charge design
ESD: Guidelines on efficient system design

Cost group: Technician training
If technicians are working on a particular technical option, they need to be sufficiently trained to be able to competently carry out these activities. The primary activities field technicians are required to carry out are:

- Installation of systems,
- Routine maintenance,
- Servicing,
- Dismantling at end-of-life products.

Different technical options would require expertise and thus training in different topics, which affects the amount of time a single technician would need to be trained for. The amount of training is similarly linked to the complexity of the system that is under consideration. The results are sensitive to how reliable specific products are, how well they have been designed for easy installation, how many parts are subject to regular maintenance, etc.

Cost group: Engineer training
In order for engineers to be able to develop, design and plan systems and installations of technical options, they must have received some extent of training. Depending on the particular technical option, the required training includes one or more of the following:

- Component selection,
- Circuit design,
- Special software,
- Standards,
- Safety,
- Cycle concepts.

The amount of time engineers need to spend receiving the training can be assumed to be proportional to the size (cooling capacity) and the number of the systems under consideration as well as the complexity of the assembly.

For example, when an enterprise produces a small number of very large systems and the complexity is high, a high level of knowledge would be required. On the other hand, if a small number of small and basic systems are produced, the level of knowledge would not necessarily have to be high, so the amount of training would be less.

Cost group: Technician tools and equipment
For technicians to suitably install and service equipment related technical options, there is sometimes a need to procure new tools and equipment. Differences in choice of tools and equipment occur due to the following:

- Handling of flammable substances,
- Handling higher pressure,
- Improved refrigerant conservation,
- Accessing unusual machinery.

After systematically evaluating each of these items with regards to their suitability for the use with the various technical option refrigerants, possible cost implications can be estimated.

Some of the alternatives are more susceptible to system contaminants than others, so it could be argued that the importance of using a vacuum pump and vacuum gauge is heightened in some cases. Similarly, because of the comparatively smaller charge sizes for certain options, there may be a need for more accurate electronic charging balances.

Cost group: Refrigerant price
The price of a given refrigerant varies widely according to country, particular distributor, size of cylinder, etc. In particular, refrigerants which are sold in smaller cylinders, as for example, to the service sector, tend to retail at higher prices, whereas purchase of refrigerants in bulk quantities, as for manufacturers, tend to have lower prices per unit mass of refrigerant.

Refrigerants that are distributed within smaller, more isolated countries often have higher prices because of the relatively necessary infrastructure and higher operating costs and the comparatively small volume. The refrigerant market in larger and more accessible countries, which is subject to greater competition, tends to lower refrigerant prices.

Costs that suppliers preparing to set-up a supply of a new refrigerant are likely to incur costs for the purchase of cylinders/containers, storage facilities, provision of customer/technical support, hazardous area protection (when applicable) and possibly initial slow turnover of product.

Table 9 provides refrigerant price information for each of the standard refrigerants and technical option refrigerants, for cylinders/service sector and for bulk/manufacturing. The prices are provided as a range, where the lower value may represent larger containers in larger and more accessible countries, whereas the higher value may represent smaller containers and less accessible countries.

TABLE 9
Refrigerant price ranges per kg of refrigerant

Refrigerant	Price range (manufacture) (in Euro/kg)	Price range (service) (in Euro/kg)
HCFC-22	1.5 – 3	1.5 – 15
HFC-152a	2 – 3	[2 – 15]
HFC-161	2 – 3	[2 – 15]
HC-290	1.5 – 5	5 – 15
HC-1270	1.5 – 4	2 – 15
R-600a	1.5 – 5	5 – 15
R-717	0.5 – 1.5	1 – 3
R-744	0.5 – 1.5	4 – 5
HFC-1234yf	[35 – 50]	[35 – 60]
HFC-1234ze	[20 – 40]	[20 – 50]
HFC-134a	5 – 7	3 – 20
R-404A	6 – 8	5 – 26
R-410A	6 – 8	6 – 35
R-407C	6 – 8	6 – 35
HFC/unsat HFC blend	[15 – 30]	[20 – 40]

NOTE: Values in parentheses [ ] are estimated. Some refrigerants which are particularly new, such as HFC-1234yf and HFC-1234ze, are not in wide commercial use so the typical retail prices are estimates. Further, for some refrigerants, the final composition is not known, so only vague approximation of the cost is currently available.
A report from UNEP[1] provided a survey of refrigerant prices globally for 2009, but mainly comprised data for common CFCs, HCFCs and HFCs. Where appropriate, price data has been used. A range of prices has also been obtained following consultation with various refrigerant suppliers.

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[1] UNEP/OzL.Pro/ExCom/61/6, 9th June 2010

Cost group: Awareness-raising
Awareness-raising is primarily focused towards three target groups:

- Technicians involved in installation, service, maintenance and disposal of systems,
- (Potential) retailers or sellers of systems,
- End users or consumers.

Technicians must be provided with some basic information, so that when they come upon a particular technical option, they can recognise what it is and be able to make a decision as to whether they can appropriately work on it or whether they should pass it onto someone else.

The potential retailers or sellers of systems must be aware of what the technical options are and the general circumstances under which they can and cannot be applied. Depending on the complexity of the technical option, they may need to know very little or a significant amount about them. At the least, they need to know that a particular product has a low climate impact associated with it. In other cases, they may need an intimate knowledge of many implications associated with not only climate impact but other technical matters.

End users or consumers of a system should be informed at least about the importance of climate issues and the corresponding benefits associated with a particular technical option. At a more basic level, this may apply to a householder in terms of which is a more suitable appliance to purchase due to its lower energy consumption and/or lower greenhouse gas emissions. At a more comprehensive level, this may apply to a building operator who should become aware of the particular issues associated with larger, complex systems.

Table 10 summarises the most relevant cost groups for the various technical options.

TABLE 10
Cost groups applicable to technical options

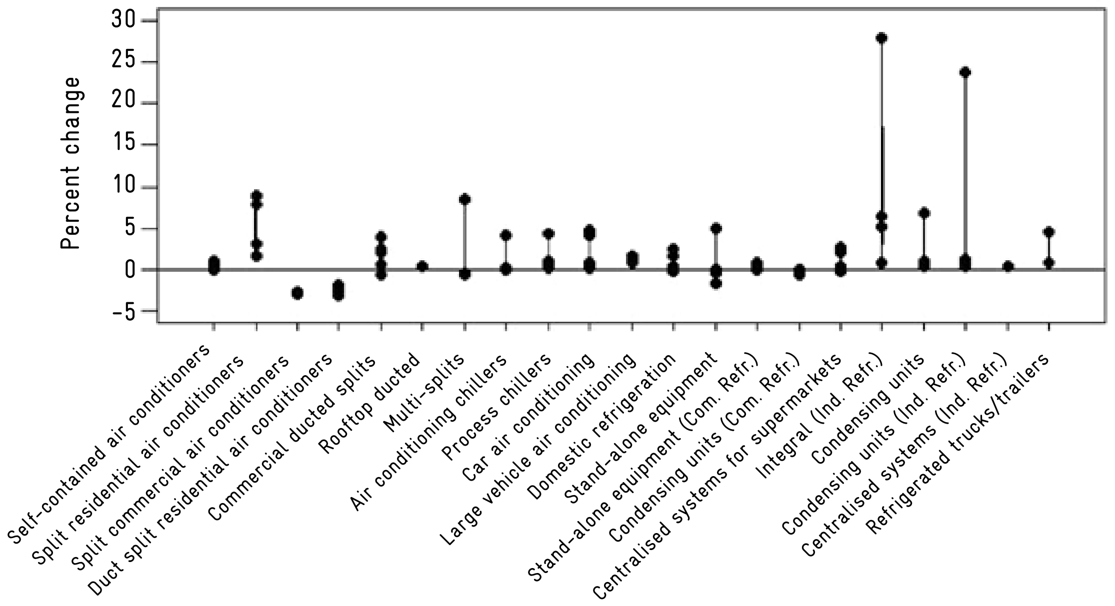
Technical option	Cost groups														
	Market introduction	**Refrigerant price**	**Product parts (system)**	**Product parts (ancillary)**	**Technician tools/ equipment**	**Technician training**	**Engineer training**	**Techn assess., cert., registr.**	**Regulations**	**Standards (restrictions)**	**Awareness raising**	**Research and development**	**Production line**	**Installation time**	**Installation materials**
Leak reduction (design/const)			X				X				X	X	X	X	X
Leak reduction (maintenance)					X	X		X			X				
Charge size reduction			X				X				X	X			
Recovery and recycling					X	X		X			X				
HC R-600a				X	X	X	X	X	X		X		X	X	X
HC-290/ HC-1270	X	X	X	X	X	X	X	X	X	X	X		X	X	X
R-717	X				X	X	X	X	X	X	X		X	X	X
R-744	X	X	X	X	X	X	X	X			X	X	X	X	X
unsat-HFC	X	X	X	X	X	X	X	X	X		X			X	X
HFC/unsat-HFC blends	X	X	X		X	X	X		X						
Low-GWP + liquid secondary	X	X	X								X			X	X
Low-GWP + evap secondary	X	X	X			X	X				X	X		X	X
Low-GWP + cascade	X	X	X								X			X	X
Distributed water-cooled	X	X	X			X	X				X			X	X
Low-GWP + liquid sec (discrete)	X	X	X			X					X	X		X	X
District heating/ cooling						X	X			X	X		X	X	X

Incremental costs

Figure 3 shows the resulting relative costs of technical options for the most relevant application systems relative to the BAU references case. The vertical lines indicate the range of cost changes with the dots showing cost for specific technical options. In most cases, the introduction of technical options will result in additional costs in the range of 0 to 10 %. The cost increases are due to changes in the system design. Potential energy savings are not yet considered. This will be the case at least during initial years until a full replacement of the BAU reference system with the technical options has taken place at full production scale.

FIGURE 3

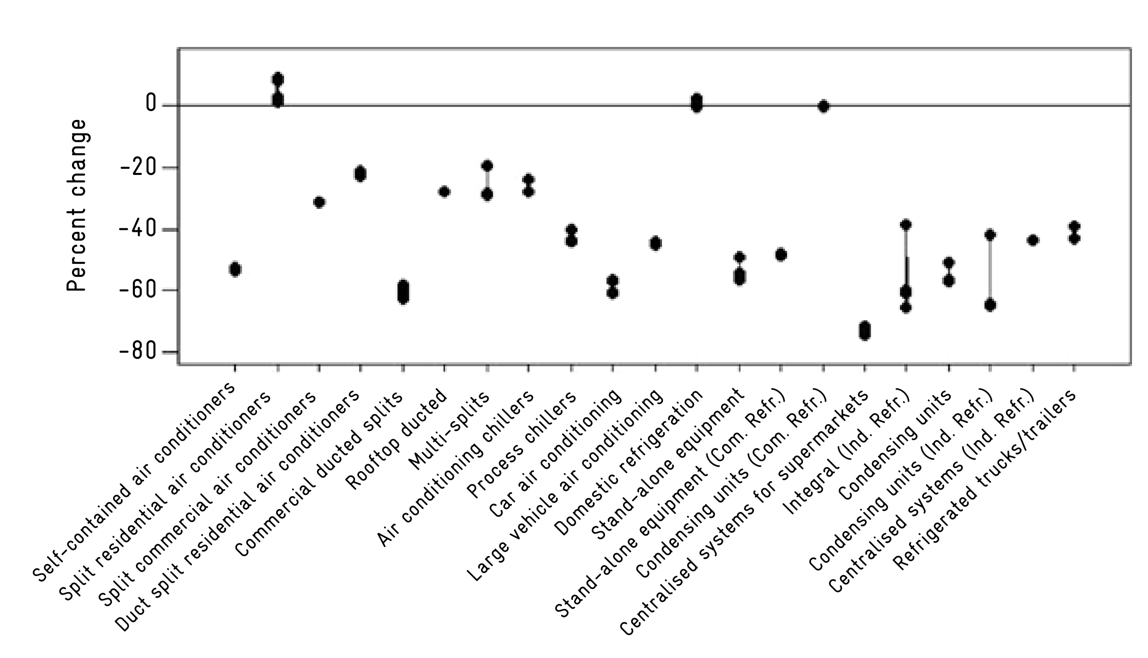
Costs of selected technical options for each appliance system relative to the BAU (assuming no changes in the energy consumption).



In many cases energy savings during the operation of the systems can be achieved with the introduction of technical options. This is due to several reasons including e.g. the thermodynamic advantages of alternative refrigerants like hydrocarbons (HC). Relative costs of technical options are 20 to 60 % lower considering energy savings during operations (Figure 4).

FIGURE 4

Costs of selected technical options for each appliances system relative to the BAU reference system (assuming lower energy consumption)



BOX 1

Incremental costs and marginal costs

Incremental costs are the additional costs of a low emission technical option compared to the conventional technology.

Marginal costs or marginal abatement costs are the costs which have to be paid additionally for one (the last) unit of a given amount of avoided greenhouse gases compared to the conventional technology.

2.2 Quantification of costs in the foam sector

Since there is no natural unit size in foam production as in the other sectors (e.g. one refrigerator), incremental costs of technical options in the foam sector are calculated on the basis of the incremental costs needed to replace one tonne of blowing agent, i.e. a replaced ton of blowing agent serves as “unit”.

As mentioned in module 3, insulation quality decreases when HCFC blowing agents are replaced with HFCs and when HFC blowing agents are replaced with HCs, respectively. In order to compensate for the loss in insulation properties, thicker insulation needs to be installed. This allows an energy neutral conversion which is an asset. However, the cost for the increased thickness of the insulation material must be considered. A detailed overview of the technical options costs can be found in annex of this module.

Cost group: Blowing agent and raw material

The largest portion of the technical costs can be attributed to the incremental operating costs (IOC) which are driven by the blowing agents. The cheapest blowing agents are HCs and HCFCs. HFCs are approximately 3 to 5 times more expensive than HCs. Unsaturated HFCs are even more expensive. That is the reason why the use of HCs results in negative incremental operating costs and compensates for higher capital costs.

Unsaturated HFCs as blowing agents in the foam sector

Low-GWP alternatives to HFCs, the unsaturated HFCs, are under development. Interviews with producers have resulted in the assumption that these will be available around 2015. Costs for these unsaturated HFCs will be considerably higher than for HFCs or HCs and therefore they are not a very practicable alternative, especially for developing countries. In developed countries, unsaturated HFCs may be introduced when specific properties are given, such as when insulation properties are achieved with a threshold thickness.

As a technical option in developing countries, synthetic unsaturated HFCs, are still lacking economies of scale, prove of significant advantageous product properties, in particular with regard to insulation. It has not been demonstrated that unsaturated HFCs with low GWP can be supplied in sufficient quantities. In addition, unsaturated HFCs need to be considered as hazardous waste at their end of life status with the need for special, cost intensive waste management.

Estimation of the amount of blowing agent required

To determine the amount of blowing agent required for a product, a standardised estimate is provided below. The amount of blowing agent is derived form the amount of produced foam. Table 11 provides standard production amounts of foam for typical foam industries.

TABLE 11
Standard production amounts for typical foam industries[2]

Foam sector	gg/piece	Density [kg/m³]	Surface [m³]	Thick-ness [mm]	Prod. quantity/ year [m²]
PU					
Insulation foams for the construction sectors					
Sandwich panels with metal facings, continuous (CME)	4.00	40	2	50	960,000
Sandwich panels with metal facings, discontinuous (DIP)	45.00	50	9	100	11,520
Sandwich panels with flexible facings, board stock (CFF)	4.00	40	2	50	960,000
Spray foam (SPR)	4.80	60	1	80	48,000
Insulation for refrigeration applications					
Domestic refrigeration (DOR)	4.00	35	3.81	30	138,240
Commercial refrigeration (COR)	4.00	40	2	50	34,560
Refrigerated trucks, reefer containers (RTRU)	150.00	50	30	100	11,520
Integral foam for automotive, furniture sectors					
Integral foams (INT)	0.60	400	0.03	50	134,400
XPS					
Insulation foam boards (XPS)	1.26	35.00	0.72	50.00	2,073,600

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[2] The abbreviations within the brackets will be used for the technical options descriptions later on

Cost group: Production line equipment
Due to the flammability of HC blowing agents, the production lines need to be adapted to ensure the safe use of flammable blowing agents. That means that foaming equipment, mixing, storage and foaming fixtures have to be modified or exchanged completely. Costs for this conversion range from EUR 250,000 to 500,000. In comparison, the conversion to non-flammable blowing agents would be in the range of EUR 10,000 to 50,000. Costs for training and trials, as well as for product certification, are also considered as they sometimes make up a significant cost component.

Costs of technical options in the foam sector

The costs for technical options in the foam sector that are described in this chapter focus on the change of blowing agent.

To allow the comparison between conventional foam products and technical options, the costs for the raw materials are assumed to remain the same. Also, concerning the use of co-blowing-agents, not all options are included here: Mixtures which cannot be readily bought, but have to be prepared by the producer, are excluded.

The approach used here relies on equivalent molecular weight. In the case of unsaturated HFCs, several types that are under development have a considerably higher molecular weight than HCs. Therefore, the impact on the incremental costs of the blowing agent is largest.

Table 12 shows relevant applications with abbreviations (cf. DIS tool, module 1). The costs for technical options for these applications will be described below and quantified in the annex to this module.

Table 13 shows the classification of technical options for the respective BAU systems.

Table 14 introduces the different cost groups that have to be taken into account when calculating the costs for the introduction of technical options in the foam sector.

TABLE 12
Abbreviations used for description of technical options and the industry sector

Abbreviation	Description	Application
RFTRU	Refrigerated truck	Appliance
COR	Commercial refrigeration	Appliance
DOR	Domestic refrigeration	Appliance
INT	Integral	Automotive, Shoe
SPRAY	Spray foam	Construction
DIP	Discontinuous sandwich panel	Construction
CME	Continuous sandwich panel with metal faces	Construction
CFF	Continuous sandwich panel with flexible faces	Construction
XPS	Polystyrene boards	Construction

TABLE 13
Selected technical options (TO) for different applications

	BAU	TO	
TO Code	Blowing agent conversion from	Blowing agent conversion TO	Application
2.x	HFC-245fa	HC, H_2O	PU
3.x	HFC-365mfc/227ea	HC, H_2O, HFO (unsat-HFC)	PU
4.x	HFC-141b	HC, H_2O	PU
5.x	HFC-134a	HC, HFO	XPS
6.x	HFC-152a	HC, HFO	XPS
7.x	HCFC-142b	HC	XPS
8.x	HCFC-22	HC	XPS

NOTE: Certain existing but not very relevant technical options have not been considered:
- TO 2.x: unsaturated-HFCs have not been selected as the option 3.x is very similar and can be used for it
- TO 4.x: following the MLF and the additional funding for low-GWP substances the shift to HFCs is not expected. Also the shift to unsaturated HFCs due to their higher costs is unlikely
- O 7.x and 8.x: often the combination of HCFC-142b and HCFC-22 is used. Considering the costs of a blowing agent the companies will look for the less expensive solution therefore unsaturated HFCs have not been selected

TABLE 14
Overview of cost groups in the foam sector (BLA = blowing agent)

Cost group		Explanation
Incremental Operating Cost (IOC)	Incremental cost blowing agent [EUR/tBLA]	Additional costs for replacing 1 ton of blowing agent with the substitution
	Incremental cost raw material [EUR/tBLA]	Additional costs for other raw materials
	Cost for thickness increase for stable R value [€/tBLA]	For foams with insulation properties, construction, appliance, the additional costs for increase of material thickness and neutral energy consumption
Incremental Capital Cost (ICC)	[EUR/tBLA]	Costs for modification of equipment
Cost for technology conversion	[EUR/tBLA]	Costs for trials and training

Incremental operating costs: Incremental operating costs have a direct effect on the costs for foam. For sandwich panels with metal compounds the cost impact is about 40% of the total product cost. The impact is largest when the alternative blowing agent requires a higher quantity and is more expensive. This is the case for HFCs and unsaturated HFCs, whereas HCs are generally cheaper.

Incremental capital costs: Incremental capital costs (ICC) for the introduction of technical options have an average payback period of 5 to 10 years. ICC tend to be relatively higher for flammable blowing agents as technical options. They are minimal for waterblown alternatives.

Costs for technology conversion: In larger companies where training takes place continuously, additional costs for training are of minor importance. Test runs have a direct impact in the first year. Certification costs are one-time costs.

Recycling and recovery costs: Recycling and recovery of blowing agents are fairly easy for refrigerators and small electrical domestic appliances and the associated costs can be handled. This is not the case with large PU sandwich panels or XPS boards. The PU panels can easily be dismantled and the PU and steel recovered, but transport and recycling will be expensive. For sea containers made with thick steel, a recovery without releasing blowing agent is practically impossible. Similar for XPS or PU used for construction purposes, where the boards are built into walls and covered by cement or synthetic materials. The recovery of the boards are a challenge and blowing agent losses will occur during this process. This module does not consider this cost group as the focus is on the costs for alternative blowing agents.

Table 15 quantifies detailed costs for converting one tonne of conventionally used blowing agents in XPS foam. The table uses the TO codes introduced in Table 13 and refers to the cost groups described above.

TABLE 15
Detailed cost quantification for XPS

		XPS					
	TO Code	5.1	6.1	6.2	5.3	7.1	8.1
	BAU blowing agent	HFC 134a	HFC 152a	HFC 152a	HFC 134a	HFC 142b	HFC 22
	TO blowing agent	HC	HC	HFO	HFO	HC	HC
Incremental operating cost	Incremental cost Blowing agent [EUR/tBLA]	-4'413	-3'540	13'060	12'060	-2'626	-2'686
	Incremental cost raw material [EUR/tBLA]	788	600	1'575	1'575	475	386
	Cost for thickness increase for stable R value [EUR/tBLA]	1,078	-	-1,015	-	688	-
Incremental Capital Cost	[EUR/tBLA]	660	517	660	660	421	353
Cost for technology conversion	[EUR/tBLA]	35	28	35	35	22	19

Several additional tables for detailed costs of other selected foam applications are attached in the annex of this module.

2.3 Marginal abatement cost curves (MACCs)

Marginal abatement cost curves (MACCs) have been demonstrated as a valuable tool in economic assessments. Essentially, these curves represent a standardised concept for presenting the emission reduction versus cost effectiveness of a particular technical option used as an alternative to the previous, conventional technology. Moreover, MACCs can be given at the country level which allows quick assessment with regard to a country's entire CO_2eq reduction potential in the various RAC&F subsectors and the associated costs.

The x-axis of the MACCs shows the amount of tCO_2eq abated, while the y-axis shows the associated costs in Euro/tCO_2eq that must be afforded in order to achieve this level of abatement.

Most often, there is reduction potential at negative costs, i.e. below the zero Euro/tCO_2eq line. These mitigation options are also referred to as no-regret options and represent a net welfare gain from an overall economy viewpoint. No-regret abatement options should preferentially be followed, however, often they have not been implemented due to various, sometimes non-monetary, barriers (cf.module 3).

Each subsector may be dominated by one technical option or by a combination of different technical options, depending on the penetration rates. The share of different technical options in a particular subsector could be calculated by a cost-optimisation procedure. Then, the key parameter to be considered is the marginal cost in relation to the reduced emissions (in Euro/tCO_2eq), caused by the introduction of a particular technical option:

$$€/tCO_2eq\ reduced = \frac{Cost_{TO} - Cost_{BAU}}{E_{BAU} - E_{TO}}$$

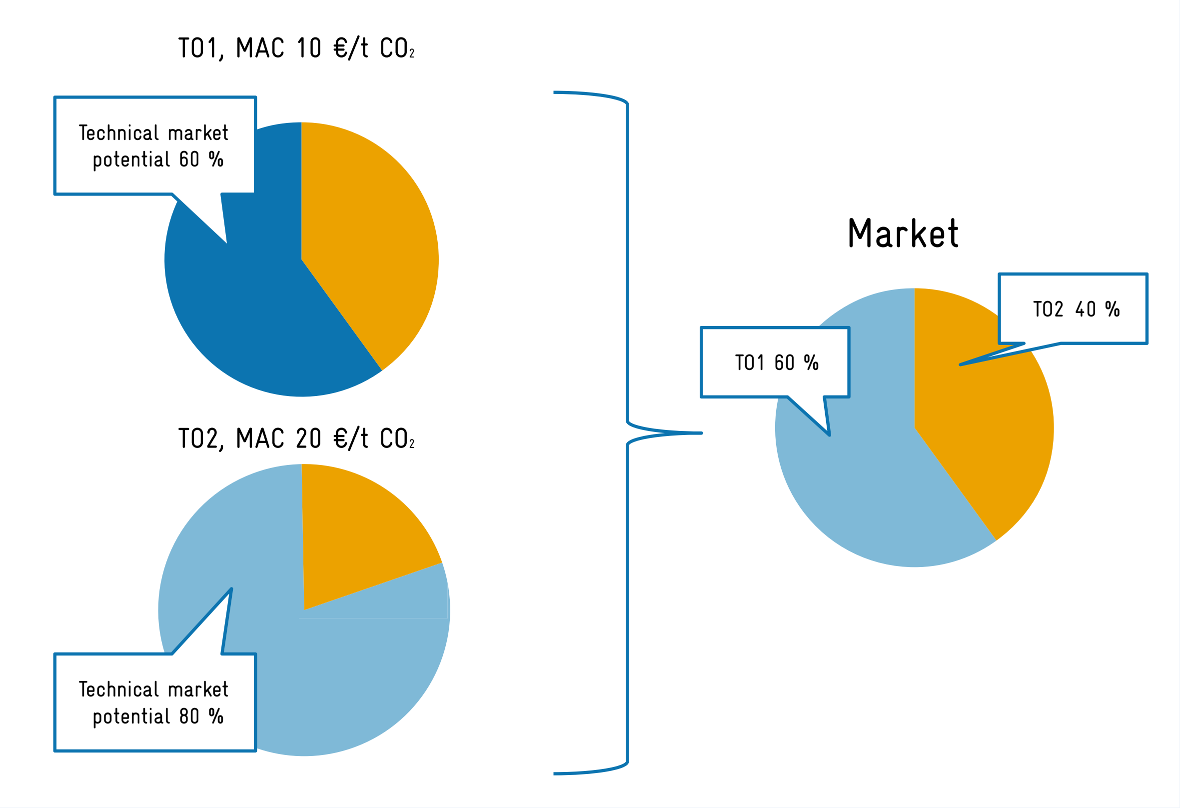
where

$Cost_{TO}$ = Costs of an appliance system with a particular technical option
$Cost_{BAU}$ = Costs of an appliance system with business-as-usual technology
E_{TO} = Emissions of an appliance system over lifetime with a particular technical option
E_{BAU} = Emissions of a business-as-usual appliance system over lifetime

The cost quantification of a standardised appliance system was explained in the first sub-chapter of this module, the quantification of emissions is explained in annex 1 to module 1. Note that for foam, the costs refer to one tonne of blowing agent instead of a RAC appliance system.

Technical options that reveal low costs per reduced tonne of CO_2eq are preferentially used and thus introduced to the market as cost-optimisation procedures as illustrated in Figure 5.

FIGURE 5
Illustration of market filling up by technical option (TO) up to their technical penetration potential



The most cost-effective technical option will penetrate the market according to its maximum technical penetration rate. In the example provided in Figure 5 this is TO1 with marginal abatement costs (MAC) of 10 EUR/tCO_2. If this rate is less than 100 % (i.e. technical option will not entirely penetrate the market), the market might continuously be filled up with other technical options following a cost-optimisation procedure. This fill up-process might continue until a 100 % saturation of the market is achieved. Consequently the second technical option (TO2) to fill up the market might reveal a penetration rate lower than its maximum technical penetration rate. In the example, the maximum technical penetration rate is 80 %. However, this option will only fill up the market up to 40 %, because the cheaper TO1 will be considered first until the full technical market potential of TO1 has been reached. The reduced penetration rate is referred to as adjusted penetration rate. In order to derive the total costs per tonne of reduced CO_2eq for a subsector, the costs per tonne of reduced CO_2eq for each technical option are then weighted according to the adjusted penetration rates of the technical options. This describes a theoretical, mathematical procedure to estimate the cost-effectiveness. In reality, preference might be given to a specific preselected technical option.

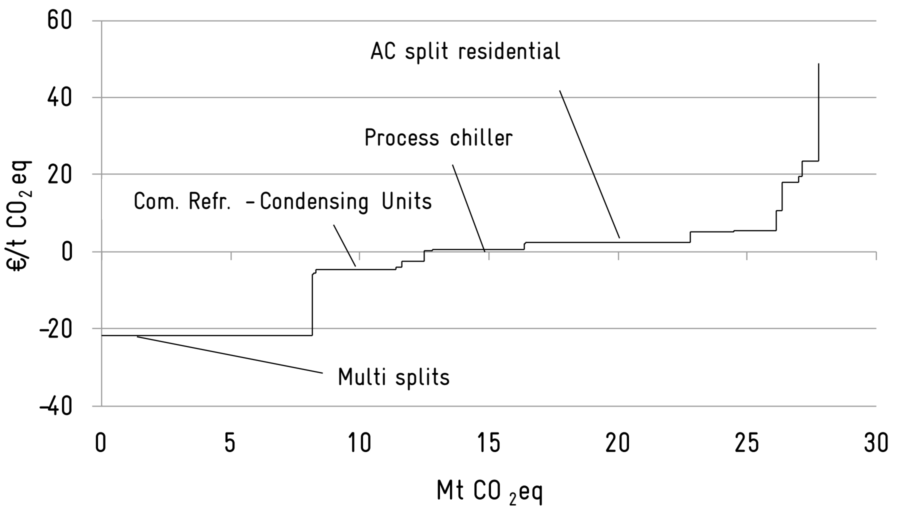
In MACCs, the costs per tonne of reduced CO_2eq on the y-axis are plotted against the subsector's total emissions that are reduced when introducing new technical option or a combination of technical options. The resulting MACCs appear as a step function rather than a smooth transition. Each step reflects the potential reduction amount for a single technical option or a specific combination of technical options per subsector.

Emissions either consider total emissions, i.e. direct and indirect emissions, or direct emissions only. For the latter, about 50 % of the emissions can typically be reduced at negative costs .

Exemplary MACCs

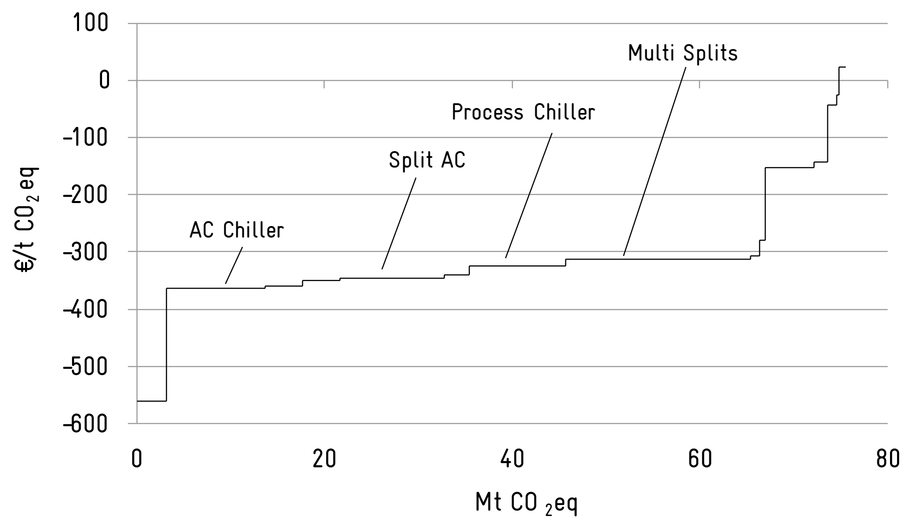
Two MACCs are exemplarily shown below. They are based on artificial data for an exemplary country. These data were adjusted so as to reflect the situation in an Asian country in 2030 with an export oriented economy. Figure 6 refers to direct emissions (cf. DER scenario, annex 1 to module 1 and module 5) while Figure 7 refers to total emissions (cf. DEREE scenario). Energy costs and savings are included as a cost component in both scenarios. The two figures show considerable differences at both axes. Firstly, the magnitude of emission reductions is much higher in Figure 7, i.e. when additionally considering indirect emission reductions. These additional indirect emission reductions stem from the improved energy efficiency of the appliance systems as suggested under the DEREE scenario. Secondly, the costs to reduce a tonne of CO_2eq are much lower in Figure 7, i.e. when additionally improving the energy efficiency. This is because the operating costs (mainly energy consumption) are lower.

FIGURE 6
MACC for direct emission reductions across all subsectors of the RAC sectors.



NOTE: Only subsectors with large emission reduction potential are labeled.

FIGURE 7
MACC for possible total (direct and indirect) emission reductions across all subsectors of the RAC sectors.

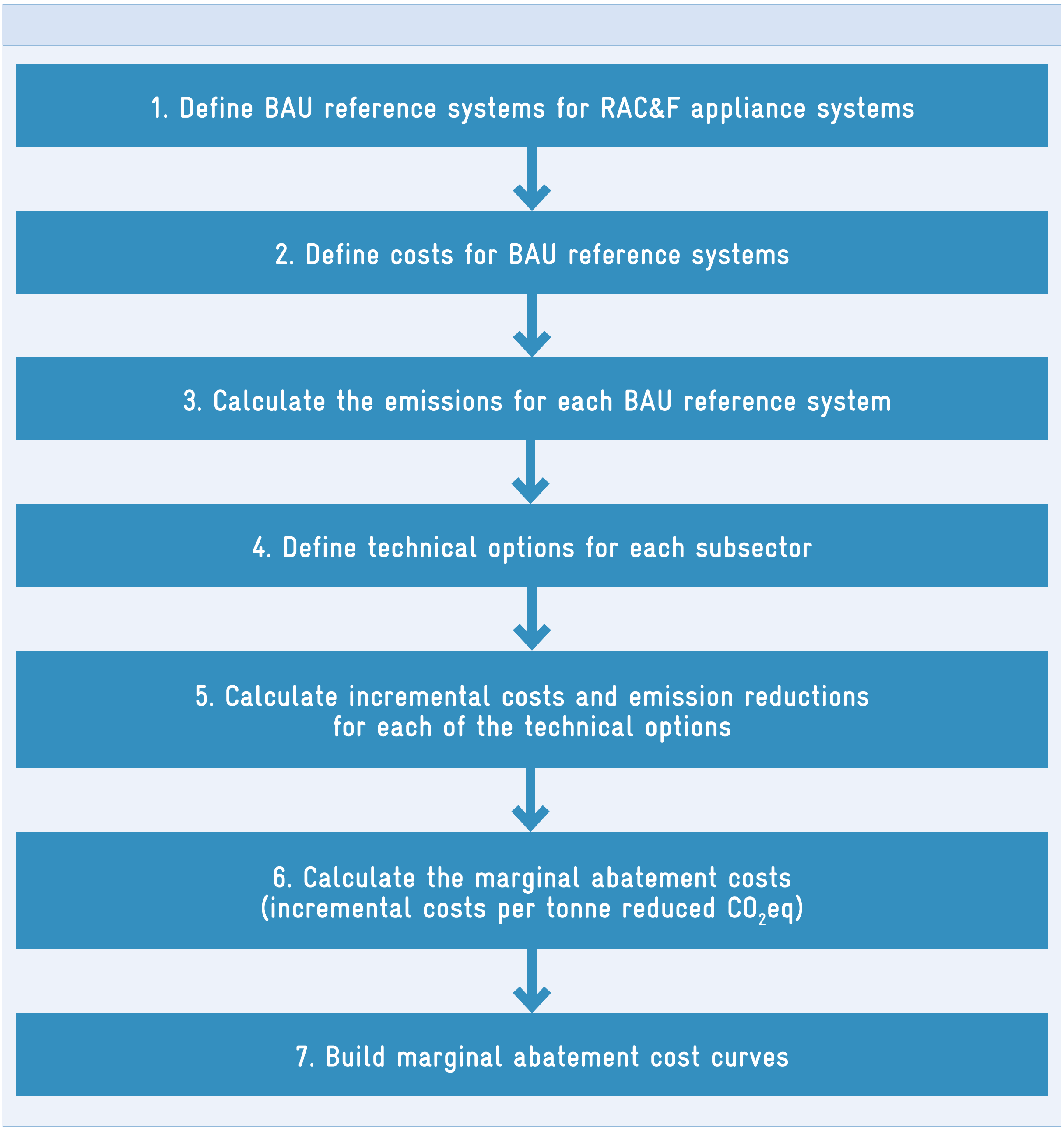


NOTE: Only subsectors with large emission reduction potential are labeled.

3. Practical application

The illustration below provides a step-by-step guide to identify the most suitable technical options in terms of cost efficiency. This is done by calculating incremental costs and emission reductions of technical options for RAC&F appliance systems in comparison to the BAU reference systems. You can then identify optimal subsectors in the resulting marginal abatement cost curves (MACCs).

Steps to identify the most suitable technical options:



1. Define BAU reference systems for RAC&F appliance systems
2. Define costs for BAU reference systems
3. Calculate the emissions for each BAU reference system
4. Define technical options for each subsector
5. Calculate incremental costs and emission reductions for each of the technical options
6. Calculate the marginal abatement costs (incremental costs per tonne reduced CO_2eq)
7. Build marginal abatement cost curves

Step 1: Define BAU reference systems for RAC&F appliance systems

Define the design of standardised appliance systems or foam products in each subsector. These should represent the types of equipment typically used in the country. You can get this information from:

- Industry representatives
- RAC&F associations
- Ministry of Industry
- Inventory

Define key parameters of the standardised systems such as:

- Initial charge (kg) and the dominant refrigerant
- Dominant blowing agent in PU/PS foams
- Emission factors (%)
- Average cooling capacity (kW)
- Average coefficient of performance (COP)
- Runtime ratio of the systems (describing annual runtime hours)
- Emission factor for electricity and motor gasoline, respectively (t CO_2/MWh)

When the inventory is completed (module 1), use the values from the DIS-Tool in the sheet 'Technical data RAC' and 'Technical data Foam'. These values are country-specific averages and thus represent the standardised systems.

Step 2: Define costs for BAU reference systems

Ask experts from RAC&F industry for the final cost of a standardised reference system. Alternatively, you can ask various experts for the different cost components that make up the final price. If you do not have access to unit prices, estimate the following cost components that influence the final costs:

- Product/system parts (system components, ancillary components)
- Installation of systems (installation time, installation materials)
- Technician assessment, certification and registration
- Research and development (R&D)
- Production line equipment
- Regulations, Standards, (restrictions)
- Technician training
- Engineer training
- Technician tools/equipment
- Refrigerant price
- Awareness raising
- Market introduction cost

For the foam sector estimate the following major cost components:

- Blowing agent and raw material per produced reference unit of foam
- Production line equipment
- Costs for training

Use the formulas in the annex to this module to calculate the different cost components.

Step 3: Calculate the emissions for each BAU reference system

Calculate direct and indirect emissions that result from the standardised BAU systems that were defined in step 1.

Direct emissions

Direct emissions are calculated on an annual basis, as the sum of manufacture emissions, in-use emissions and disposal emissions:

$$E_{CO2,dir,j} = E_{CO2,manuf,j} + E_{CO2,in\text{-}use,j} + E_{CO2,disp,j}$$

Where

$E_{CO2,dir,j}$ = direct emissions (CO_2eq) of units j

$E_{CO2,manuf,j}$ = manufacture emissions (CO_2eq) of produced units j

$E_{CO2,in\text{-}use,j}$ = in-use emissions (CO_2eq) of stock units j

$E_{CO2,disp,j}$ = disposal emissions (CO_2eq) of scrapped units j

Indirect emissions

The indirect emissions stem from the energy consumption of the units in use (stock). The annual indirect emissions are given by:

$$E_{CO2,ind,j} = n_{stock,j} \cdot \frac{CP_j}{COP_j} \cdot RT_j \cdot EF_{electr}$$

Where

$E_{CO2,ind,j}$ = indirect emissions (CO_2eq) of units j
$n_{stock,j}$ = stock of units j
CP_j = cooling capacity of units j
COP_j = coefficient of performance of units j
RT_j = average annual runtime hours of units j
EF_{electr} = emission factor of electricity

Additional details for these calculations are given in annex 1 to module 1.

Step 4: Define technical options for each subsector

Select a set of technical options per subsector (cf. module 3). Define the design of these technical options analogously to step 1.

Step 5: Calculate incremental costs and emission reductions for each of the technical options

Calculate the incremental costs per unit and the appropriate emissions that arise from the technical option systems, analogously to step 2 and 3.

The example below illustrates this step for a split air conditioning system, whereby total emissions refer to the system lifetime. The achieved emission reductions in this example result from the replacement of an HFC refrigerant with propane. The reduced emissions and the incremental costs are simply derived by extracting the difference between total emissions (column 1) and system costs (column 2).

TABLE 16

Example of calculating the incremental costs and emissions that arise from the technical option systems

	Total emissions (tonnes CO_2eq)	System costs including operational costs (Euro)	Emission reduction (tonnes CO_2eq)	Incremental costs (Euro)
BAU system (HFC-410A)	23	5,143	6	16
TO system (R-290)	17	5,159		

Step 6: Calculate the marginal abatement costs (incremental costs per tonne reduced CO_2eq)

For each technical option derive the marginal abatement costs using the following equation:

$$€/tCO_2eq\ reduced = \frac{Cost_{TO} - Cost_{BAU}}{E_{BAU} - E_{TO}}$$

Where

$Cost_{TO}$ = Costs of an appliance system with a particular technical option
$Cost_{BAU}$ = Costs of an appliance system with BAU technology
E_{TO} = Emissions of an appliance system over its lifetime with a particular technical option
E_{BAU} = Emissions of a BAU appliance system over its lifetime

The marginal abatement costs are given by the ratio of incremental costs, i.e. additional costs, to the emissions reduced. In the example above this results in 2.7 Euro per tonne CO_2eq reduced (16 Euro/6 tonnes CO_2eq reduced). Having calculated the marginal abatement costs for the selected technical options, compare the results and identify the “low hanging fruits”, i.e. the technical options with low or negative abatement costs. These technical options are the ones you should consider for implementation.

You can also use the Mitigation and Cost Tool to compare the marginal abatement costs from different technical options.

Step 7: Build marginal abatement cost curves

To build marginal abatement cost curves (MACCs), you need the marginal abatement costs from step 6 and the emission reduction potential that can be achieved by introducing the corresponding technical option per subsector.

To calculate the mitigation potential per subsector, you need the emission reduction per system and lifetime (from step 5) and the expected future sales figures in the country. Use the formulas that are given in annex 1 to module 1. Alternatively, GIZ Proklima can assist you with these calculations.

Finally, plot the marginal abatement costs (from step 6) for a selected technical option against the mitigation potential per subsectors to derive the marginal abatement cost curves. Examples of MACCs are show in chapter 2.3 of this module. Alternatively, use the Mitigation and Cost Tool to extract these parameters.

Compare the different subsectors in the MACC plot to identify the most promising subsectors in terms of cost-efficiency. Optimal subsectors for a NAMA are those with high mitigation potential and low or negative marginal abatement costs.

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